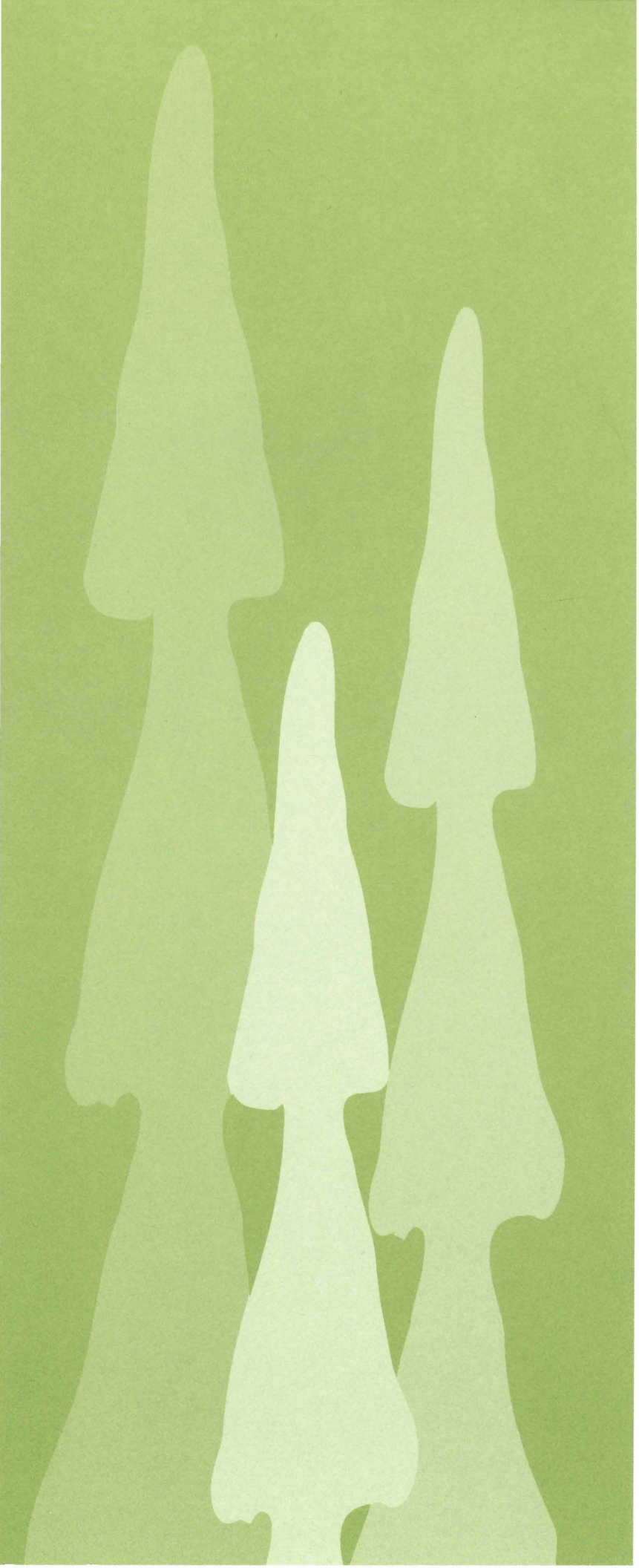

GENERIC ENVIRONMENTAL IMPACT
STATEMENT ON ANIMAL AGRICULTURE

A Summary of the Literature

Related to the Social, Environmental, Economic and Health Effects

VOLUME 2

Prepared for the
Minnesota Environmental Quality Board
by the
University of Minnesota

ENVIRONMENTAL
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SEPTEMBER 1999

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To Interested Minnesotans:

The GEIS on Animal Agriculture is a statewide study authorized and funded by the 1998 Minnesota Legislature and ordered by the EQB. The Legislature directs the EQB to "...examine the long-term effects of the livestock industry as it exists and as it is changing on the economy, environment and way of life of Minnesota and its citizens."

The intent of the GEIS is twofold: 1) to provide balanced, objective information on the effects of animal agriculture to future policymakers; and 2) to provide recommendations on future options for animal agriculture in the state. The success of the GEIS on Animal Agriculture will be measured by how well it educates and informs government officials, project proposers, and the public on animal agriculture, and the extent to which the information is reflected in future decisions and policy initiatives, made or enacted by Minnesota state and local governments.

The GEIS consists of three phases during the period summer 1998 through summer 2001: scoping the study; studying and analyzing the 12 scoped topics; and drafting and finalizing the GEIS. The EQB has established a 24-member Advisory Committee to provide advise to EQB during all phases of the GEIS. The scoping phase of the GEIS was completed in December of 1998.

This literature summary is the first step in the second phase aimed at study and analysis of the 12 key topics. This summary is intended to inform the Environmental Quality Board (EQB) members, EQB staff, and the Advisory Committee on the "Feedlot GEIS" scoping questions and research needed for adequate completion of the GEIS. The EQB would like to acknowledge the time and effort of the Advisory Committee members who provided invaluable input in the development of this "tool" for use throughout the GEIS process.

The literature summary is formatted to address the 12 topics of concern and 56 study questions outlined in the Feedlot GEIS Scoping Document (www.mnplan.state.mn.us). Any conclusions or inferences contained in this report are those of the authors and do not necessarily reflect the positions of the EQB or the Feedlot GEIS Advisory Committee.

The EQB would like to make this literature summary available to others interested in the effects of animal agriculture. Copies of this literature summary will be available for use in the Minnesota Planning/EQB Library, 300 Centennial Building, 658 Cedar Street, St. Paul. The Library will also house copies of the key literature review articles and the searchable database compiled as part of this literature review. A limited number of copies of this literature summary will be printed for distribution at cost.

For further information on the GEIS or this literature summary please contact the EQB at 651-296-9535.

Sincerely,

Gene Hugoson, Commissioner, Minnesota Department of Agriculture and
Chair, Minnesota Environmental Quality Board

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Topics

This *Summary of the Literature* has been prepared for the Environmental Quality Board by the University of Minnesota and its partners to inform GEIS decisionmaking. Any conclusions and inferences contained in the report are those of the authors and do not necessarily reflect the positions or policies of the EQB or the Advisory Committee convened to advise the EQB on the GEIS.

H *Air Quality*

I *Soils*

J *Manure and Crop Nutrients*

K *Human Health*

L *Animal Health*

Air Quality / Odor

H

Generic Environmental Impact Statement on Animal Agriculture:
A Summary of the Literature Related to Air Quality and Odor (H)

Prepared for the Minnesota Environmental Quality Board

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EXECUTIVE SUMMARY

Animal agriculture can be a source of numerous airborne contaminants including gases, odor, dust, microbes, and insects that are produced or emitted inside and near animal production facilities and when waste products are land-applied. Numerous gaseous compounds and living organisms are generated from livestock and poultry manure decomposition shortly after it is produced or during storage prior to use as a fertilizer on cropland. Particulate matter and dust come primarily from the feed and the animals. The rate of generation of these gases, organisms, and particulates varies with time, species, housing, manure handling system, feed type, and management system used, thus making prediction of contaminant presence and concentrations extremely difficult.

Research has shown some animal production systems have reduced contaminant generation rates compared to other production systems. Numerous control strategies are being investigated to reduce contaminant generation. These strategies include the use of vegetable oil (in the feed or directly sprinkled in the barn) to lower airborne dust and other particulate emissions or the use of a biomass cover on a manure storage basin to reduce odor and gases emissions from stored manure. Even when using best management systems and/or mitigation techniques, some airborne contaminants may be generated. The contaminants may build up concentrations inside livestock and poultry buildings that result in animal and human health concerns. Most of these concerns are associated with chronic or long-term exposure. Some human and animal health concerns or safety hazards can result from acute or short-term exposures, like those expected during the pumping of liquid manure from a pit inside a slatted floor livestock building.

Once these contaminants are generated they can be emitted from the sources (building, manure storage unit, or cropland) through the barn's ventilation system or by natural (weather) forces. Again emission rates are dependent on many factors—time of year and day, temperature, humidity, and other weather conditions, ventilation rates or wind forces, housing type, manure properties or characteristics, and animal species.

Determination of emission rates for gases and odor, dust, microorganisms, and insects is an active area of research in the US and Europe. Emission rates from point sources (buildings) and area sources (manure storage units and manure applied on cropland) are difficult to accurately determine because collection techniques have not been standardized, the large number of contaminants to measure, and the many factors and conditions at sites that affect them. Emission rates of only a few of the many gas compounds identified have been investigated. Ammonia is the most common gas studied and measured because of the negative environmental impact it can have on ecological systems. There is very little emission data for other contaminants such as odor, dust and microorganisms. The environmental and health effects of these ambient air contaminants on people, animals, and the environment surrounding animal production sites is only beginning to be investigated. In some areas some or all of the emission contaminants have created environmental or health concerns, but long term impacts on ecological systems and people are not known.

There are management systems and control technologies that can reduce the contaminant emission rates. These systems can reduce generation or they can collect or capture the

contaminants as they leave a source. An example would be the use of a biofilter, which reduces odor and gas emissions in the ventilating exhaust air from a livestock building. Windbreak walls are another example. They can capture dust released from animal buildings, which can also carry odors and microorganisms. Successful technologies that find widespread application must be both effective in reducing contaminant emission rates and economical for use in the animal industry.

Finally, after these materials are emitted and become airborne they are transported downwind. Travel distance can vary greatly due to size of particles, weather conditions, and surrounding topography and vegetation. Odor is the most common contaminant of concern downwind of some animal sites, although certain gases like hydrogen sulfide and even flies can be of concern to neighbors living and working near these production units.

Computer prediction models are being used to estimate the movement and concentration of these contaminants downwind for animal production sites. The models being adopted were used to model emissions from other smokestack industries, which generally have a more constant and standard (one or two specific compounds) emission rate. Evaluation of these models is needed to verify that they accurately predict contaminant levels around animal facilities. It is anticipated that these models will be used to assist in local decision making on setback requirements and other land use issues.

Contaminant emissions rates from animal production systems are beginning to be categorized, even though their measurement and identification are difficult and highly variable. The impact of the contaminants on the environment and their health effects on humans and animals are not fully known. Research continues to find mitigation and control strategies that not only reduce the generation and emission rates of these contaminants into the buildings and to the ambient air but also does it in an economical and manageable way that will be compatible with animal production systems.

OVERVIEW/CRITIQUE OF STUDY QUESTIONS

The University of Minnesota team that was assembled to address the GEIS scoping document questions under topic III. H.—**air quality and odor**—decided to regroup the questions from five to a total of four. The original question 3, which asked how the impacts discussed in questions 1 and 2 were affected by animal species, size, management and systems types, was incorporated into the first two questions. Contributors to this topic were assigned to one or more of these four questions. The questions and a list of contributors for this section of the GEIS are listed below:

Questions 1 & 3—Quantify emissions and environmental impacts as function of species, size, and management, etc?

Contributors—Charles Clanton, Richard Nicolai, Jun Zhu, Sally Noll, Kevin Janni, and Roger Moon

Questions 2 & 3—Health risks/impacts as function of species, size, & management, etc.

Contributors—Philip Goodrich, Carlos Pijoan, Jill Bruns, Thomas Blaha, Larry Jacobson, Sally Noll

Question 4—Mitigation and emission control technologies

Contributors—Jose Bicudo, Richard Nicolai, Jerry Shurson, Lisa Brosseau, Sally Noll, Larry Jacobson

Question 5— Monitoring, measuring, and modeling emissions

Contributors—David Schmidt, Richard Nicolai, Kevin Janni, Chuck McGinley

This is the final draft of the document that is being forwarded to the Environmental Quality Board (EQB). Changes have been made since the first and second drafts as a result of comments from Citizens Advisory Committee (CAC)/EQB members and designated reviewers as well as additions made by the authors during the final draft preparation. The document is a review of the information sources (literature summary) found addressing the above four questions.

The reader will see from the table of contents that the above four groupings of questions are not listed in numerical order. The authors decided to begin with question 5, Monitoring, measuring, and modeling emissions, followed by the questions as listed above (1 & 3, 2 & 3, and 4). The reason for this change was the belief of the authors that it was more logical to first describe how emissions are measured, then list specific contaminate concentrations and emission rates, followed by their environment and health impacts, and finally procedures for their mitigation and control.

The authors believe this is a comprehensive review of the air quality and odor topic concerning animal production in Minnesota. It is longer than most originally envisioned because we found more material than anticipated, and also as a response to comments received from the CAC and other reviewers. We have attempted to avoid duplication of materials both within this document and between other GEIS topic reports. There are references to other reports listed in the document. Some materials are repeated intentionally where appropriate to certain sections or reports. Some materials will probably be duplicated, especially between different topic reports, since there simply was not time to coordinate fully with the other topic report authors.

MONITORING, MEASURING, AND MODELING EMISSIONS (QUESTION 5)

INTRODUCTION

Quantifying air emissions from animal agriculture is a complex process. The complexity arises from the multitude and variety of individual sources responsible for these emissions, the extreme variability of these emissions, and the variety of components being emitted. Emission sources include barns, manure storages, silage piles, dead animal compost structures and a variety of other smaller emissions sources. Each of these sources will have a different emission profile, i.e., different gases, dusts, and microbes emitted, and these emissions will fluctuate throughout the day and throughout the year. Therefore, quantifying these emissions and their impact on the surrounding environment is extremely difficult. The following information documents various measurement, monitoring, and modeling techniques and standards that could be used to detect and regulate these air emissions.

The American Society for Testing and Materials and the United States Environmental Protection Agency have led the way in defining standards and methods for measuring both emissions and ambient concentrations of specific gases and particulates from industrial sources. These EPA standards were developed as a result of rules promulgated from the Federal Clean Air Act. Therefore, methods to measure those pollutants listed as a "Criteria Air Pollutant" or a "Hazardous Air Pollutant" in the Clean Air Act are fairly well defined. Unfortunately, the majority of emissions from animal agriculture do not appear on these EPA priority pollutant lists. Because of this, very few standard methods and monitoring techniques are available to measure the emissions from agricultural sources. However, these methods and protocols are useful in the development of new standards and protocols for the measurement of air pollutants of interest emitted from animal agriculture.

Part 50 of Title 40 in the Code of Federal Regulations—National Primary and Secondary Ambient Air Quality Standards (EPA 1998c)defines ambient concentrations for the six Criteria Pollutants: sulfur dioxide, suspended particulate matter, carbon monoxide, ozone, lead, and nitrogen dioxide. Measurement and monitoring methods for these pollutants are defined by 40CFR53—Ambient Air Monitoring Reference and Equivalent Methods (EPA 1998a) and 40CFR58—Ambient Air Quality Surveillance (EPA 1998b). Other Parts of Title 40 may also be a source of information when developing standard measurement methods.

The American Society for Testing and Materials has standard methods available for measuring ambient concentrations of some of the USEPA "Criteria pollutants" and some general standards for sampling and analysis of ambient air and source emissions (ASTM 1997; ASTM 1998).

This review will focus on measurement and modeling of some of the most common aerial pollutants from agriculture, typically dust, ammonia, methane, volatile organic compounds, hydrogen sulfide, and odors. This document is broken into three distinct sections—the first dealing with measurement techniques and standards, the second addressing computer modeling approaches to predict ambient concentrations of these emissions and the third, a summary of state ambient standards for hydrogen sulfide and odor.

MEASUREMENT AND MONITORING TECHNIQUES

Measurement and Monitoring of Particulate and Gas Emissions

Emission is the amount of a particular compound of concern released per time. This emission rate is most often calculated by measuring the concentration of the gas or particulate in the exhaust air stream and multiplying by the ventilating rates of the same exhaust streams. As such,

both concentrations and ventilation rates must be known for each emitting source. Concentrations are measured in terms of mass of compound per volume of air or volume of compound per volume of air. Unfortunately, most of the research in agriculture has focused on the concentration of specific gasses and particulates inside buildings or ventilation rates of buildings and has not combined the two. This combined measurement is critical because ventilating rate could affects concentration measurements.

Methods for measuring and monitoring either emissions or ambient air quality must be designed and developed to meet the demands of the research or regulatory program. This criteria most likely includes accuracy and precision of the method, but may also consider a variety of other criteria such as economics, data acquisition parameters, automatic operation, maintenance, calibration, average concentrations versus continuous measurement and a variety of other factors. Therefore, in order to define or develop standard measurement techniques the goals of the measurement must be well established.

The measurement technique or standard must also include protocols for sampling methods. Sampling methods, especially from sources where emissions are extremely variable, can drastically affect the outcome of any measurement or monitoring outcome. Sampling methods are defined by the type of emitting source, e.g., area source or point source, the variability of the emissions, and the goal of the measurement, e.g., average or maximum.

Most of the emission research from animal agriculture has focused on laboratory scale emission measurement. For purposes of regulation and field monitoring of full scale facilities, laboratory methods are not typically applicable. Some field research has been conducted to measure emissions in the field. These research projects have employed several different techniques. These techniques are specific to the type of air pollutant monitored and the goal of the project.

A recent European project was designed to measure emission rates of ammonia, inhalable and respirable dust, and endotoxins from livestock and poultry buildings (Phillips and others 1998). The goal of the study was to standardize instrumentation and methods for physical, chemical, and microbiological characterization of aerial pollutants; quantify emissions as a function of animal species, management system and external climate; and verify mathematical models for predicting emissions. This study represents one of the largest air pollutant emissions studies from animal agriculture. **Table 1** indicates the methods used to measure these aerial emissions (Wathes and others 1998). The measurement methods used in this research have not been designated as standard methods, however, most of the research currently being conducted in Europe uses these methods (van't Klooster and others 1996).

One of the most rigorous ammonia emissions research programs is taking place in The Netherlands. In response to concerns of soil acidification, regulators have implemented a program to reduce ammonia emissions from animal agricultural production. These regulations have encouraged the development of low ammonia emission systems. In order to qualify as a low emission system, the facilities are monitored for ammonia emissions according to a strict measurement protocol (Verdoes and others 1996). Ammonia measurements for this work, and for most other ammonia research in Europe, use Chemiluminescence NO_x analyzer and an upstream thermal ammonia converter as described by Scholtens (Scholtens 1993).

Table 1. Measurement techniques for aerial pollutants in livestock buildings (Wathes, Phillips and others 1998)

Variable	Technique	Location	Frequency
Ammonia concentration	Chemiluminescence NOx analyzer	3 @ animal height 3 @ human height 1 @ outlet 1 @ ambient	Hourly
Carbon dioxide concentration	Infra-red analyzer	As above	Hourly
Ventilation rate	Indirect mass balance of CO2	As above	12 h
Airborne dust concentration	gravimetric filtration mass oscillator	As above but not ambient	12 h
Airborne endotoxin concentration	Gravimetric filtration	As above but sample pooled	12 h
Air temperature	Platinum resistance	As above	6 min
Relative humidity	Capacitance sensor	As above	6 min
Airborne microorganisms concentration	Impaction	Single	12 hr
Wind speed	Cup anemometer	1 @ ambient	6 min
Wind direction	Wind vane	1 @ ambient	6 min

Unfortunately, measurement of building emissions has received more attention than measuring emissions from area sources, e.g., open manure storages or outdoor feedlots. Harper (Harper and Sharpe 1998) measured ammonia emission from manure lagoons in North Carolina using micrometeorological techniques. Air samples were collected at several locations above the surface of the lagoon and drawn through gas washing bottles. Sampling time of four hours corresponded to micrometeorological data collection. A total of twenty measurements were made throughout three measurement seasons (winter, spring and summer) to determine annual emission rates. Similar micrometeorological techniques to measure gas and odor emissions have been used by other researchers (Phillips and others 1997; Smith and Kelly 1996).

Fourier-Transform Infrared (FTIR) measurement methods have been used recently to measure gas emission rates from livestock facilities. This method has the capability of simultaneously measuring the concentrations of a variety of gases including ammonia, nitrous oxide, carbon dioxide, and methane. These concentrations are combined with micrometeorological data to determine emissions of these gases from both point and area sources (Schafer and others 1997).(Depta and others 1997)

Zahn et. al. (Zahn and others 1997) attempted to develop a method to measured emissions of volatile organic compounds in the exhaust air from swine facilities. This study was designed to develop methods to quantify specific chemical compounds thought to be responsible for odor emissions from swine facilities. In this methodology, gas samples were collected with thermal desorption tubes and analyzed using a gas chromatograph and mass spectrometer. Unfortunately, this research did not measure emission rates but was limited to concentrations. ASTM D-5466-95 is a standard method that has been developed for measuring volatile organic compounds. However, this method is only applicable to volatile organic chemicals that remain stable in pressurized or sub-atmospheric pressure canisters.

Very few research institutes are engaged in measuring emissions of hydrogen sulfide from livestock facilities. The University of Minnesota currently is measuring concentrations of hydrogen sulfide using a Jerome® Meter (Jacobson and others 1997) and will soon be combining this data with ventilation rate measurements using the carbon balance method and fan ventilation rates to determine hydrogen sulfide emission rates. The Jerome® meter measures concentrations of total reduced sulfur in the ppb range comparable to the an EPA approved total reduced sulfur measurement (EPA) and a reflectance measurement technique (ASTM 1984) using an MDA Scientific Chemcassette® Model 7100 (Minnesota Pollution Control Agency 1999). The EPA does have a measurement method defined for continuos emissions of hydrogen sulfide (Test Method 15 (EPA)). This method uses the GC/MS and is limited to concentrations between 0.5 and 10 ppm.

Measurement and Monitoring of Particulates, Gasses, and Odors in Ambient Air

Health and environmental consequences of ambient air quality are not only a function of emissions but of the combined factors of emission and the dispersion, deposition, and degradation of these compounds in the downwind plume. For example, larger dust particles that settle quickly after leaving a barn have little impact on the ambient air quality at any substantial distance downwind from the emitting source. More information on predicting the movement of these compounds downwind will be discussed in the following section on air emission modeling. Ambient air quality monitoring and measurement reflect both source emissions and these other processes taking place downstream of the emitting source.

Ambient air is defined as that portion of the atmosphere, external to buildings, to which the general public has access (EPA 1998c). Ambient monitoring typically reflects an average concentration of a particular compound over some period of time. Once again, standard ambient measurement protocols have been developed for EPA Criteria Air Pollutants and some Hazardous Air Pollutants but methods for measuring other compounds are limited. Ambient air quality measurements are much more difficult than emission measurements because often concentrations of the compounds being measured are very low and below the detection threshold of most equipment.

Ammonia

Several methods and equipment are available to measure ambient concentrations of ammonia. A few studies have compared these methods and equipment. One such study has been conducted by Mennen et. al, (Mennen and others 1996). This research evaluated six automated ammonia analyzers in the field for their suitability for the Netherlands National Air Quality Monitoring Network. The instruments studied were a continuous flow denuder, a WO_3–coated thermodenuder, a V_2O_5-coated thermodenuder, a commercial Differential Optical Absorption Spectroscopy system, a photoacoustic monitor, and a chemiluminescence NO_x monitor with an upstream NH_3 thermal converter. Results from this study indicate that several of the devices might be suitable for ambient monitoring with the continuous flow denuder meeting all of the criteria set out in this study. Other more economical ambient ammonia monitors include a variety of passive diffusion samplers (van't Klooster and others 1996).

Hydrogen Sulfide

The Minnesota Pollution Control Agency currently has an extensive program documenting ambient hydrogen sulfide concentrations around livestock facilities (Minnesota Pollution Control

Agency 1999). Ambient monitoring employs use of a Jerome® meter for prescreening, an MDA Scientific Chemcassette® Model 7100 and a TRS monitor (EPA Test Method 15A (EPA)) for compliance monitoring.

Dust and Particulates

Suspended dust is a designated EPA Criteria Air Pollutants. As such, EPA standard methods have been developed to measure concentrations in ambient air. These standards are outlined in EPA National National Primary and Secondary Ambient Air Quality Standards Appendix L (EPA 1998c) and elsewhere in EPA documents citing promulgated test methods.

Odor Measurement Technologies and Methods

Many of the gases released from animal production are odorous, meaning they can be detected by the human olfactory system. As such, odors can be measured in one of two ways. Measurements can be made by measuring the concentration of odorous gases and correlating these concentrations to human olfactory sensations, or the human nose can be "calibrated" to measure odors. Both of these measurement methods have significant drawbacks. The techniques and methods to measure odor using gas concentrations or the human olfactory system will be explained in the following sections.

Gas Measurement as a Method of Odor Quantification

An odor consists of a complex mixture of many odorous compounds. There are at least 168 different gases that contribute to swine odor (O'Neill and Phillips 1992). As such, analytical monitoring of individual chemical compounds present in such odors is typically not practical (ASCE 1995). However, it has been proposed that some of the gases found in livestock odors could be used as a "indicator gases." (A good indicator gas would be one whose concentration would correlate well with the human olfactory system, e.g., a high concentration of an indicator gas would result in a high concentration of odor.) The advantage of using an indicator gas is that it would be easier to measure than odor.

Spoelstra (Spoelstra 1980) concluded that hydrogen sulfide, ammonia, and phenols would not be good indicators of odor but rather p-cresol and volatile fatty acids may be suitable. Jacobson (Jacobson and others 1997) documented the lack of correlation between hydrogen sulfide and livestock odor. Pain (Pain and Misselbrook 1990) showed little correlation between ammonia concentrations and odor. Zahn (Zahn and others 1997; Zahn 1999) attempted to correlate a suite of volatile organic compounds to odor.

The "electronic nose" is an attempt to correlate an odorous air sample to odor by evaluating the concentrations of several gases in the sample air. Gas sensing methods include metal oxide semi-conductor capacitors; chemically modified field-effect transistors; optical devices, and peizo-electronic quartz crystal devices (Mackay-Sim 1992). Misselbrook (Misselbrook and others 1997b) did one of the most recent studies that evaluated this equipment. This research developed a relationship between the output pattern of the electronic noses tested and the human sensory system using olfactometry for land application of cattle slurry to cropland. The research indicates that there may be some possibility for this type of technology to be used in the future to evaluate agricultural odors.

Ostojic (Ostojic and O'Brien 1996) reviewed attempts to correlate odor to gas. His review indicates that measurements of specific gases to correlate to odors are limited by the odor

threshold information, the complex interactions between odor sensation and multiple gas composition, and the detection limits of the olfactory system, far exceeding the detection limits of gas sensing equipment.

Sensory Methods to Quantify Odors

There are five parameters that provide a fairly complete description of an odor. Quantification of these parameters provides a sensory measurement tool for odor quantification.

Concentration of odors are measured as the amount of clean air needed to dilute a sample of odorous air to the point where it can be either detected or recognized. The detection threshold is the minimum amount of an odorous air that can be mixed with clean air and still be detected by a human nose. Recognition threshold is the minimum amount of odorous air that can be mixed with clean air and that people are able to describe the odor by applying a character descriptor to. The odor concentration is expressed as a volume ratio of clean air to odorous air. The two most used methods to quantify this ratio are discussed below.

Intensity describes the strength of an odor and is measured at concentrations above the detection threshold (ASCE 1995). Intensity changes with concentration and can be measured at full strength or after dilution with clean air. Intensity measurements are most often based on the intensity of a reference gas. This gas is most often n-butanol.

Persistence is a parameter that describes the relationship between odor concentration and perceived intensity. It is a calculated value based on the intensity at full and the intensity of diluted samples. Odors with high persistence include livestock manure and smoke.

Character descriptors are used to describe what an odor "smells like." Some terms used are sweet, sour, pungent, mint, citrus, and earthy. Character descriptors are used at or above the threshold.

Hedonic Tone measures the pleasantness or unpleasantness of an odor (ASCE 1995). This is typically recorded in a scale of -10 to +10 with neutral odors being recorded as zero. Unpleasantness usually increases with odor intensity. Pleasant odors may increase in pleasantness with odor intensity when the intensity is low, but become less pleasant and eventually unpleasant at relatively high intensities.

Odor concentration and odor intensity are the two most common parameters used for odor quantification. The other three odor parameters—persistence, character descriptors, and hedonic tone—are commonly viewed as more subjective parameters not lending themselves to science or regulatory purposes.

Olfactometry

Two techniques are used most commonly to measure odor concentration or dilution threshold. Dynamic forced-choice olfactometry is a method where the odor samples are captured in bags and evaluated by trained human panelists. The scentometer is a dilution device used in the field.

Dynamic forced-choice olfactometry is the most common method for determining odor concentration (dilution threshold). Dynamic forced-choice olfactometry is widely used to evaluate livestock odors (Hobbs and others 1999; Watts and others 1994; Ogink and others 1997). The American Society for Testing and Materials has developed a standard practice for olfactometry (ASTM 1991) which is the method most commonly used in the United States. In this method odorous air samples are diluted with clean air. Panelists are asked to smell three

samples, two clean air samples and one odorous sample mixed with clean air, and determine which of the samples is different from the other two. The detection threshold is determined when the panelist correctly identifies the odorous air sample. The ratio of clean air to odorous air in that sample is then determined to be the detection threshold for that sample. The ratio of clean air to odor sample of the mixture is reported as odor units (ou). An olfactometer is the equipment used to dilute the odorous sample and deliver the diluted odorous sample, and the two clean samples, to the panelist. Several styles of olfactometers are available. Olfactometers differ primarily in how they achieve dilution ratios, how samples are presented to the panelists, and the airflow rate at which the samples are delivered.

Dynamic forced-choice olfactometry is reproducible, statistically reliable and is widely used in Europe to evaluate livestock odors (Dravnieks and Jarke 1980). A standard method for this type of olfactometry has been standardized for use in European odor laboratories (Thomas and Skoda). This method is an excellent tool for research in a laboratory setting; however, it is not a good tool for regulatory purposes since it is not very portable, requires a number of trained panelist, and is expensive.

The Scentometer is another piece of equipment designed to determine odor concentration or dilution threshold. The Barnebey and Sutcliffe Corporation developed the Scentometer in the late 1950s, specifically for field evaluation of ambient odors (Barnebey-Cheney 1973). It is a rectangular, clear plastic box with two nasal ports, and two chambers of activated carbon with four to six air inlets. By covering some of the inlets, various odorous air concentrations can be sniffed through the nasal ports to determine the detection threshold. Each inlet has a known threshold (odor unit) number. Portability to the field and relative low cost are some advantages of the instrument (Barnebey-Cheney 1987). The Scentometer is not known for high accuracy (Jones 1992), requires a sufficient number of panelists, and subjects the panelist to odor fatigue by not isolating them from the ambient odorous air.

Sweeten (Sweeten 1995) provides a detailed review of the use of dynamic olfactometers scentometers.

Intensity Measurements

An intensity measurement involves ranking an odor to a known scale. The scales are either descriptive (e.g., no odor, faint odor, strong odor, etc.), or numerical (e.g., zero to ten scale). Although these scales can be somewhat subjective, a standard scale can be developed using specific gas concentrations. ASTM standard E 544-88, Referencing Suprathreshold Odor Intensity (ASTM 1988), defines concentrations of n-butanol to correlate with an odor intensity measurement. This intensity measurement can be used in the laboratory with odor samples collected in bags directly from the odor source or in the field in the odor plume.

Field measurements of odor using intensity measurements have been used by several researchers and communities to monitor odor emissions and odor plume transmission (Nicell and St. Pierre 1996; MacKenzie and Mann 1996; McGinley 1996; Hartung and Jungbluth 1997; Zhu and others 1998). In all cases, community members or trained field monitors determined odor intensity on some predetermined scale. These results were then used to evaluate odor control technologies, odor dispersion models, or quantify odor emissions.

Fly Monitoring and Measurement

Methods for monitoring breeding of house flies and stable flies have been developed for use in integrated pest management (IPM) programs on livestock and poultry premises (Lysyk and Moon 1994). Some of the methods are used routinely at progressive livestock and poultry operations in Minnesota or elsewhere, to improve on-site fly management and thereby prevent annoyance and health problems for animals, workers and neighbors. Scouting is used routinely to monitor fly breeding at some beef and dairy feedlots in Nebraska. Premises are inspected at weekly intervals to detect, map and eliminate fly breeding sites before they turn into problems.

In a similar manner, adult insects can be monitored with spot cards and sticky tapes inside egg layer barns and dairies. The resulting counts are being used at some facilities in California, North Carolina and California to evaluate need for additional fly suppression measures. Sticky fiberglass traps have been used to monitor outdoor abundance of stable flies and house flies in the context of field research in Florida, Nebraska, Kansas and elsewhere. Despite existence of these monitoring methods, procedures for scouting and trapping indoors and outdoors are not standardized, and are not used widely to monitor insect abundance—either on animal premises or in surrounding residential environments.

At present, insect abundance in residential neighborhoods is monitored passively, through logging of complaints about excessive numbers of insects from citizens to public health and environmental quality authorities in Minnesota and other states. These complaints are recorded, and some have prompted action from authorities, but no active monitoring system is in use anywhere. It is not clear that all complaints are directly related to actual insect abundance. Research projects in Ohio (Winpisinger-Slay and Berry unpubl.) and Minnesota (Moon R. 1999) have been initiated to calibrate catch rates on traps with matching levels of human annoyance at residences in rural settings. The results may provide public health authorities with a tool for setting and enforcing community fly nuisance standards.

It should be generally understood that house flies and other animal-related insects have always been a common part of rural life in the Upper Midwest. These insects winter in freeze-protected environments, and then disperse and reproduce in ephemeral deposits of organic media that are scattered on the landscape during the summer months. Fly populations grow exponentially until cold weather freezes out the outdoor populations.

A critical question that cannot be answered with available knowledge is whether an industry with large concentrations of animals at few premises would contribute more or fewer flies to the overall landscape than an industry with fewer animals at a greater number of premises. One approach to studying this question might be through simulation modeling, where biologically based models of on-farm fly populations were coupled with difusion models to evaluate patterns of abundance on landscapes surrounding modeled premises of different sizes. On-farm population models have been developed for house fly (Wilhoit and others 1991), stable fly (Lysyk 1999), and face fly (Moon 1986), but those models remain to be evaluated through comparison with empirical field data. Furthermore, knowledge about dispersal by adults of both species is insufficient to develop realistic models of diffusion by adults in different kinds of landscapes.

Table 2 Elements of Dispersion Modeling.

INPUT	Source	What is generating the pollution?
	Chemical	What type of pollution?
	Emission Rate	How much pollution?
	Location	Where is the Source?
	Meteorology	What are the atmospheric conditions?
MODEL	Selection	Which model fits the "needs" ?
OUTPUT	Receptors	Who and what will be affected?
	Distances	Where are the receptors?
	Time	What are the temporal considerations? ... when and how often?
EVALUATION	Critiques	Is the model valid? ... accuracy and precision

AIR DISPERSION MODELING

Efforts to model air pollution began after 1917. However, the science of "atmospheric dispersion modeling" is recognized to have started in the 1950s. The Clean Air Act Amendments (CAAA) of 1977 first required the Environmental Protection Agency (EPA) to use air quality simulation models. The EPA held its first conference on air quality modeling in December, 1977. The Air Pollution Control Association (APCA) presented a Critical Review on "Atmospheric Dispersion Modeling" at the 1979 Annual Meeting and subsequently published a critical review as an APCA Reprint Series (Volume 10) in March, 1980. The APCA Reprint Series contains "A Critical Review" by D. Bruce Turner—with critical review comments and thirteen papers published between March, 1977, and September, 1979. This APCA Reprint Series, "Atmospheric Dispersion Modeling," is a good starting point for the body of literature encompassing "air quality simulation models."

Turner (1979) defines a *dispersion model* as "a mathematical expression of the effects of the atmosphere upon air pollution. This includes the effects of advection (transport) and dispersion (including dilution by the wind and dispersal due to turbulence) and may also include considerations of plume rise, wind shear, and chemical and physical transformations (including removal mechanisms)."

Air dispersion modeling consists of four major elements: (1) Input, (2) The Model, (3) Output, and (4) Evaluation; as outlined in **Table 2** (Turner 1979).

A failure to properly research the Input elements for modeling is the equivalent to the popular adage for computers: "Garbage In–Garbage Out." Further, the selection and usage of an inappropriate model will yield erroneous output results. If the Evaluation element can be implemented, the modeling process may be validated or corrected. However, without the Evaluation element, the modeling process can simply yield misleading results and the ramifications of subsequent decision making.

What is, therefore, an "ideal" model? (Lamb 1984; Benarie MM 1987; Zannetti 1990). Zannetti (Zannetti 1990) cautions that complex models do not necessarily perform better than simpler models. The model selection must be based not on its complexity but rather on its applicability.

The application of air dispersion models (air quality simulations) to "Animal Agriculture" includes the following pollutant types:

1. "Air Toxics" (non-regulated and regulated gases)
2. Odor (common nuisance and health impacting)

3. Particulate (non-pathogen and pathogen)

Further, the application of air dispersion models (air quality simulations) to "Animal Agriculture" addresses the following air pollution phenomena:

1. Near-field phenomena (<1 km from the source, < ½ mile)
2. Short-term transport (<10 km from the source, < 6 miles)

"Animal Agriculture" encompasses a unique set of air pollution cases that differ in many respects from industrial and urban air pollution cases. The modeling parameters that require special treatment for "Animal Agriculture" cases include:

1. Rural meteorology (throughout the day and night).
2. Facility design and features (i.e. natural and forced ventilated structures and open manure storage basins).
3. Pollutants generation from animals (compared to processes in industry).
4. Pollutants generation from biological activity in manure storage basins.
5. Pollutant release from manure storage basins (large area sources).
6. Receptor (population) density surrounding facilities.
7. Receptor "sensitivity" and "tolerance" to selected pollutants (i.e. air toxics, odor, and pathogens).

Given the uniqueness of emissions from animal agriculture, what then is the appropriate air dispersion model to apply? The mathematics of air dispersion modeling includes three categories (Zannetti 1990):

- Eulerian Dispersion Models,
- Gaussian Models, and
- Lagrangian Dispersion Models

One model type and method will not be necessarily suitable for all livestock facilities and manure storages or combinations of facilities and storages. Gases, odor, and particulate behave differently and are generated differently from buildings and from basins.

Models recognized and approved by the EPA and the Minnesota Pollution Control Agency (MPCA) are called "Regulatory Models." Regulatory Models have been formalized for the purpose of meeting specific federal requirements of the Clean Air Act (Stern 1976; Zannetti 1990), i.e. New Source Review (NSR) and Prevention of Significant Deterioration (PSD). The most widely recognized and used regulatory model is the Industrial Source Complex (ISC) Model. The ISC model is a steady-state Gaussian plume model suitable for a wide range of "industrial" applications and special cases. Variations of the standard ISC model include the Industrial Source Complex Short Term (ISCST) and the SCREEN[3] model. However, there are many other "non-regulatory" models available commercially and as public domain software that have specific applicability to animal agriculture. One important consideration for these regulatory models is the fact that they do not include provisions for the degradation and deposition of gases in transport downwind from the source.

The Minnesota Pollution Control Agency recently used the ISCST model to evaluate ambient concentrations of ammonia and hydrogen sulfide resulting from the cumulative effect of 60 feedlots located in a region in West-Central Minnesota (Pratt 1998). The model predicted exceedences of the state's 30 ppb half hour average up to 4.9 kilometers from the source with the

highest emissions. Predicted ammonia concentrations exceeded the states proposed Health Risk Values of 1000 $\mu g/m^3$ at distances up to 1.6 miles from the highest emitting source. The author reported several problems with the modeling results including: 1) no provisions for chemical transformations; 2) no provisions for wet or dry deposition; 3) hourly ammonia emission were estimated from annual ammonia emissions data; 4) emission data for hydrogen sulfide were based on unvalidated prediction model; 5) one hour steady state conditions were used; 6) the model ignored calm conditions.

Atmospheric (Air) dispersion modeling is an evolving science as practiced for regulatory purposes and general land use planning purposes. EPA began such a process when the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) met in 1999 to introduce state-of-the art modeling concepts into EPA's

Table 3 Comparison of the various state standards for hydrogen sulfide (State of Minnesota R. 7009-0080)

State	Concentration (ppm)	Averaging Time
Alabama	20	30 minute
Alaska	0.035	30 minute
Arizona	0.08 0.13	24 hour 60 minute
California	0.03	60 minute
Colorado	0.10	60 minute
Delaware	0.06 0.03	3 minute 60 minute
Georgia	15	OSHA PEL guidance only
Hawaii	0.025	60 minute
Idaho	0.05	
Illinois	0.01	8 hour
Michigan	0.0045 0.0007	10 minutes 24 hour
Minnesota	0.05 0.03	30 minutes, twice per year 30 minutes, twice per 5 day
Montana	0.05	60 minute
Nebraska	10.0 (TRS) 0.1 (TRS) 0.01 (TRS) 0.005 (TRS)	1 minute 30 minute 30 day 30 day
Nevada	0.08	60 minute
New Hampshire	0.03	24 hour
New Mexico	0.01	60 minute
New York	0.01 0.0007	60 minute 1 year
North Carolina	1.5	15 minutes
North Dakota	10 0.2 0.1 0.02	instantaneous 60 minute 24 hour 90 day
Oklahoma	0.1	30 minute
Pennsylvania	0.1 0.005	60 minute 24 hour
South Carolina	0.1	24 hour
Tennessee	20	12 hour
Texas	0.08	screening level
Vermont	0.02	24 hour
Wyoming	0.05 0.03	30 minute 30 minute

air quality models. The new AERMIC Dispersion Model, known as AERMOD, will be phased in during the year 2000 as a replacement for the ISC standard regulator model. One special feature of AERMOD that may have particular applicability to modeling emissions from animal agriculture is its ability to include the air boundary layer above surface releases, ie., manure storage basins.

Odor Modeling

Odor is a significant issue for animal agriculture (Heber 1998). Land use planning and determination of setback distances is a difficult and complex issue. Air dispersion modeling is a tool which will assist in setting setbacks and siting facilities (Heber 1998; Smith 1993).

Regulatory models (i.e. ISCST and SCREEN3) are unsuitable and not recommended for modeling odors (Duffee 1992). Several odor-specific models have been developed and tested by researchers (Hogstom 1972; Murray and others 1978; Smith and Hancock 1992; Duffee 1992). These "odor-specific" models predict odor dispersion and dilution using modified "fluctuating plume, puff" modeling methods and claim to predict odor impacts 30 times greater than "standard regulatory models" (Duffee 1992). Field evaluation methods have been used to validate air dispersion models for odor (McFarland 1996; Smith 1993; Li and others 1994; Zhu and others 1998) with little success to date. The most significant problem with validation of any odor model is the ability to quantify odors in ambient air.

Specific new research is needed to evaluate and judge the validity of current air dispersion models for gas, odor, and particulate emissions from agricultural sources. New additional research is needed to address the unique set of air pollution cases of animal agriculture, ie., natural ventilated structures, manure storage basins, calm/near calm meteorology, and cumulative effects of multiple sources and activities in the rural community.

ODOR AND HYDROGEN SULFIDE STATE STANDARDS

Federal, state and some local governments regulate ambient concentrations of specific gases and dust. Although the USEPA has set ambient standards for Criteria Pollutants, several states have implemented standards for hydrogen sulfide and odor. **Table 3** is a summary of the various state hydrogen sulfide standards (State of Minnesota). **Table 4** is a summary of odor regulations compiled by the North Dakota Office of Attorney General (Attorney General of the State of North Dakota 1999).

Table 4. A summary of odor regulations (Attorney General of the State of North Dakota 1999).

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
Arizona	Yes (Water)	Arizona has a rule that restricts "odor in drinking water." Arizona does not have a specific rule or statute restricting odor in the air other than their general pollution and nuisance laws. AZAC § R18-11-108(A)(3)		http://www.adeq.state.az.us/air/assess/index.htm
Colorado	Yes	AQCC Reg. 2 - Residential or commercial - viol. If odors are detected after the air has been diluted with 7 or more volumes of odor free air. All other land use areas - 15 or more vols. EXCEPT- if source is mfg. or agricultural operation, no viol. if "best practical control methods" are used. Exception doesn't apply if, after air has been diluted with 127 or more vols. of odor free air and odors are detected.	Barnebey-Cheney Scentometer or any other instrument, device or technique.	http://www.state.co.us/gov_dir/cdphe_dir/ap/aphom.html
Connecticut	Yes	No person shall cause or permit the emission of any substance or combination of substances which creates or contributes to an odor, in the ambient air, that constitutes a nuisance. § 22a-174-23(a). It constitutes a nuisance if a rep. of the comm. or at least 50% of any group of reps. of the comm. determines, based upon at least 3 samples or observations in a 1 hour period, that after a dilution of 7 parts clean air to 1 part sampled air, the odor is equal to or greater than the odor detection threshold. The owner or operator of the source of the burden to rebut the presumption of a nuisance. § 22a-174-23(b). A table sets out the concentration levels. § 22a-173-23(c). The comm. may reasonable suspect that a source has caused or contributed to a violation based upon 1 or more of the following: 1) citizen complaints; 2) comparisons of odors upwind and downwind of the source; 3) material handling and storage practices; 4) methods of operation; 5) site inspections; 6) surveys; 7) info. gathered from any other source; or 8) actual or estimated stack emissions, fugitive emissions or ambient pollutant concentrations. § 22a-174-23(e). An agr. or farming operation shall be exempt to the extent provided by §19a-341. § 22a-174-23(j). The provisions of this section shall not apply to mobile sources or structures which are occupied solely as a dwelling and contain six or fewer dwelling units. § 22a-174-23(k).	Comm. may use air quality modeling tech. To calculate ambient pollutant concentrations. It cannot be the sole basis for finding a violation unless the comm. has received 10 or more written complaints. §22a-174-23(f).	http://dep.state.ct.us/lawreg/lawhome.htm
Delaware	Yes	Reg. 19 - No limit, just "significantly effect the citizens...outside the boundaries of the air contaminant source."	Scentometer, air quality monitoring and affidavits	http://www.dnrec.state.de.us/
Florida	Yes	62-296.320(2) - No person shall cause, suffer, allow or permit the discharge of air pollutants which cause or contribute to an objectionable odor.		http://www.dep.state.fl.us/ogc/documents/rules/air/62-296.doc
Kentucky	Yes	Secondary standard for odor shall be applicable only when the cabinet receives a complaint with respect to odors from a source. 401 KAR 53:005 § 2(2). Odor means the property of an air contaminant that can be detered by the sense of smell. § 3(12). The ambient air quality standards are listed on Appendix A to 401 KAR 53:010.		http//www.state.ky.us/directory/agencyn.htm

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
Louisiana	Yes	Title 33, Part III, Ch. 29 § 2901(A) establishes ambient air standards for odors. There is an "odor dilution ratio" and "perceived odor intensity" is the intensity of an odor sensation that is independent of the knowledge of the odorant concentration. § 2901(c). Exemptions are provided for 1) single family dwellings; 2) restaurants; 3) other establishments for the purpose of preparing food for human consumption; 4) materials odorized for safety purposes; 5) materials possessing strong odors for reasons of public health and welfare where not suitable substitute is available and where best modern practices are employed; 6) agricultural, fiber, timber, poultry, seafood or fisheries production, unless such odors are detected in concentrations or intensities above that normally detected from these processes or by products when using applicable air pollution control devices; and 7) emission points regulated under the Total Reduced Sulfur (TRS) emission standard. § 2901(E).	Odor test methods: 1) Butanol odor evaluation procedure; 2) Butanol referencing techniques for quantifying odors in terms of intensity; 3) Problems/Backflows. (All of the above are described in technical detail at § 2901(G))	http://www.deq.state.la.us/olae/irdd/title33/p03c2901.pdf
Maine	Yes	06-096(4) provides for adequate provisions for the control of odors under the solid waste laws. The board may establish terms or conditions of approval, reasonable requirements to control odors.		http//www.state.me.us/dep/mdep_reg.htm
Maryland	Yes	A person may not cause or permit the discharge into the atmosphere of gases, vapors, or odors beyond the property line in such a manner that a nuisance or air pollution is created. § 26.11.06.09. Also use nuisance section at 26.11.06.08		http://www.dnr.state.md.us/
Massachusetts	Yes	No person having control of any dust or odor generating operations...shall permit emissions therefrom which cause or contribute to a condition of air pollution. 310 CMR § 7.09. Air pollution means the presence in the ambient air space of one or more air contaminants or combinations thereof in such concentrations and of such duration as to: a) cause a nuisance; b) be injurious, or be on the basis of current information, potentially injurious to human or animal life, to vegetation, or to property; or c) unreasonably interfere with the comfortable enjoyment of life and property or the conduct of business. 310 CMR § 7.00.		http://www.magnet.state.ma.us/dep/dephome.htm
Michigan	Yes	Odor is included in the definition of "air contaminant." Emissions of air contaminants are prohibited if the cause either of the following: a) Injurious effect to human health or safety, animal life, plant life of significant economic value, or property. b) Unreasonable interference with the comfortable enjoyment of life and property. Pt.9, R.336.1901. Rule 901.	No rule concerning the method and just use general reasonableness, frequency, duration, intensity etc.An old court case lists some of these.	http://www.deq.state.mi.us/aqd/
Minnesota	Yes	While they do not have a general restriction on odors (this is left up to the locals), Minnesota does have a state statute, § 116.061(1)(a)(3), which requires notification of excessive emissions that cause obnoxious odors constituting a public nuisance. Also, in their ambient air quality standards, they limit Hydrogen Sulfide to 0.05 ppm by volume (70.0 micrograms per cubic meter); 1/2 hour average not to be exceeded over 2 times per		http://www.dnr.state.mn.us/

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
		year. See Rule 7009.0080.		
Mississippi	Yes	Rendering plants or other similar operations which may cause odors must be at least 1500 feet from the nearest residential, recreational, or light commercial area and be located in compliance with Miss. Code Ann. §41-51-19. APC-S-2(15). There shall be no odorous substances in the ambient air in concentrations sufficient to adversely and unreasonable: 1) affect human health and well being; 2) interfere with the use or enjoyment of property; or 3) affect plant or animal life. APC-S-4.	Factors to consider include: 1) the number of complaints or petitioners; 2) the frequency of occurrence; and 3) the land use of the affected area.	http://www.deq.state.ms.us/domino/deqweb.nsf
Missouri	Yes	10CSR 10-2.070 restricts emissions of odors when the odor can be perceived when 1 volume of odorous air is diluted with 7 volumes of odor-free air for 2 separate trials not less than 15 minutes apart within the period of 1 hour. Missouri actually has four separate standards which are closely related to the above. See attached. One for Kansas City metro area, Springfield, Greene County and St. Louis metro area. 10-5.160 provides a separate standard for objectionable odors when 30% or more of a sample of the people exposed to it believe it to be objectionable in usual places of occupancy, the sample size to be at least 20 people or 75% of those exposed if fewer than 20 people are exposed. The agricultural exemption still applies to this section. See 10.5-160(2). 10 CSR 10-2.070(3) provides an exception for odors from the raising and harvesting of crops or feeding, breeding and management of livestock or domestic animals or fowl (Class 1A CAFOs). However, the commission will vote next month on whether to take out the agriculture exemption. See the attached proposed amendment (which may be subject to change prior to the vote).	Barnebey-Cheney Scentometer or by similar technique that will give equivalent results. as agreed to at the source operator and the staff director.	
Montana	Yes	No person shall cause, suffer, or allow any emissions of gases, vapors, or odors beyond his property line in such a manner as to create a public nuisance. § 17.8.315. Also limits business and equipment operation, storage, gases, dust and incineration among others as to odors. Id. Waste generating noxious odors may not be open burned. § 17.8.604.		http://www.deq.state.mt.us/
Nebraska	Yes	No specific odor reg. as such, but have total reduced sulfur (TRS) regs. and H_2S like MN. TRS 10.0 parts per million (10.0 ppm) maximum 1 minute average concentration. 0.10 parts per million (0.10 ppm) maximum 30-minute rolling average. See Title 129, Ch. 4 §§ 007 et seq. Neb. said they did have an agr. exemption, got sued (because Iowa Beef said they were discriminated against). The Iowa case was decided and Neb. then took out the ag. exemption and the suit was dropped about 2 weeks ago.	TRS thermal converter in conjunction with an SO2 monitor.	http://www.deq.state.ne.us/
Nevada	Yes	No person may discharge or cause to be discharged from any stationary source, any material or regulated air pollutant which is or tends to be offensive to the senses, injurious or detrimental to health and safety, or which in any way interferes with or prevents the comfortable enjoyment of life or property. NAC 445B.393(1).	The director shall deem the odor to be a violation if he is able to make two odor measurements within a 1-	http://www.state.nv.us/cnr_menu.htm

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
		Investigation shall occur when 30% or more of a sample of the people exposed to it believe it to be objectionable in usual places of occupancy. The sample must be at least 20 people or 75% of those exposed if fewer than 20 people are exposed. NAC 445B.393(2).	hour period. These measurements must be separated by at least 15 minutes. An odor measurement consists of a detectable odor after the odorous air has been diluted with eight or more volumes of odor free air. NAC 445B.393(3)	
New Jersey	Yes	When I spoke with New Jersey, they said they had odor provisions. However, when I received their fax of the regs. it appears that they limit "air pollution" and include odors within that although odors are not specifically mentioned in the definition. They also sent copy of their penalties for emissions. See attached NJCA § 7:2705.1 and NJSA § 26:2C-19		http://www.state.nj.us/dep/
New York	Yes	No person shall cause or allow emissions of air contaminants to the outdoor atmosphere of such quantity, characteristic or duration which are injurious to human, plant or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life or property. Notwithstanding the existence of specific air quality standards or emission limits, this prohibition applies, but is not limited to any particulate, fume, gas, mist, odor, smoke vapor, pollen, toxic or deleterious emission, either alone or in combination with others. §211.2 Notwithstanding the existence of specific standards, emissions of odorous, toxic, or deleterious substance in concentrations or of such duration that will affect human health or well-being, or unreasonably interfere with the enjoyment of property, or unreasonably and adversely affect plant or animal life shall not be permitted. §257-1.4(b)		http://unix2.nysed.gov/ils/executive/encon/encon.htm
North Carolina	Yes	15A NCAC §2D.0522. A person shall not cause, allow, or permit any plant to be operated without employing suitable measures for the control of odorous emissions including wet scrubbers, incinerators, or other devices approved by the commission. NC also adopted temporary odor rules for animal operations. Public hearing will be summer or 1999 and effective July 1, 2000. Temp. rule specifies "applicable management practices for the control of odors" 15A NCAC 2D.1802(c) and requires a "best management plan for animal operations" 15A NCAC 2D.1803. Exemptions are provided for at 2D.0102.	May consider: 1) nature, intensity, frequency, pervasiveness..., and duration; 2) potential to emit known odor causing compounds... 3) any epidemiological studies... 4) any other evidence, including complaints...	http://www.ehnr.state.nc.us/EHNR
North Dakota	Yes	No person may discharge into the ambient air any objectionable odorous air contaminant	Barnebey-Cheney	http://www.health.state.

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
		which is in excess of 2 odor concentration units. N.D. Admin. Code §33-15-16-02. H2S is restricted re: objectionable odors. Two samples with concentrations greater than 0.05 part per million (50 parts per billion)sampled at least fifteen minutes apart within a sixty minute period the measured in accordance with section 33-15-16-04 constitute a violation. § 33-15-15-02.1.	Scentometer or other instrumental method as approve by the Dept. An odor is objectionable when a Dept. certified inspector or at least 30% of a random group of people, or an odor panel deem it objectionable if the odor were present in their place of residence.	nd.us/ndhd/environ/ee/index.htm
Oregon	Yes	They have several sections concerning odor regs. Wastes req. special management/agric. waste--must be disposed of so as not to create odors...§ 340-093-0190(1)(a). Incidental control practices for CAFO's--app. of manure...should be done when air movements is least likely to carry objectionable odors to residential or recreational areas § 340-051-0075. Solid waste, storage and collection §340-093-0210(5)(b). Several others sections define "air contaminant" as including "odor," §§304-028-0110- Stationary source air poll. and 340-021-0005--gen. emission standards for particulate matter.		http://www.deq.state.or.us/od/rules/statrule.htm
Pennsylvania	Yes	25 §123.31 - Malodorous air contaminants cannot be detectable outside the property... Emissions shall be incinerated at a minimum of 1200°F for at least 0.3 second prior to their emission into the outdoor atmosphere. Techniques other than incineration may be used if they are equivalent or better and are approved in writing by the Dept. § 123.31(c) provides an ag. exemption: The prohibition in subsection (b) does not apply to odor emissions arising from the production of agricultural commodities in their unmanufactured state on the premises of the farm operation. § 123.41 - A person may not permit the emission ... in such a manner that the opacity of the emission is either of the following: 1) Equal to or greater than 20% for a period or period aggregating more than 3 minutes in any 1 hour. 2) Equal to or greater than 60% at any time. The proposed amendments have received public comment and changes are being made to the draft. However, revised draft is still an internal documents and not available to the public yet.	Olfactory sense of dept. personnel. They have proposed amendments to change certain things such as not having to prove public nuisance, changing some definitions, make it more tech. based, i.e. if a co. has implemented current tech. to control odor they have a 5-year grace period before being review/asked to do more.	http://www.dep.state.pa.us/
Rhode Island	Yes	No person shall emit or cause to be emitted into the atmosphere any air contaminant or combination of air contaminants which creates an objectionable odor beyond the property line of said person. Rule 17.	A staff member of Div. of Air Res. shall determine by personnel observation if an odor is objectionable, taking into account its nature, concentration,	http://www.health.state.ri.us/yhd08.htm

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
			location, duration and source.	
Texas	Yes	Texas said they do have an odor reg. but what they faxed was a nuisance reg. which provides: No person shall discharge from any source whatsoever one or more air contaminants or combinations thereof, in such concentration and of such duration as are or may tend to be injurious to or to adversely affect human health or welfare, animal life, vegetation or property, or as to interfere with the normal use and enjoyment of animal life, vegetation, or property. § 101.4. Under their location standards for domestic wastewater treatment facilities they define "nuisance odor prevention" as: the reduction, treatment, and disposal of potential odor conditions that interfere with another's use and enjoyment of property that are caused by or generated from a wastewater treatment plant unit, which conditions cannot be prevented by normal operation and maintenance procedures of the wastewater treatment unit. § 309.11(6). Texas also adopted new "CAFO" rules in Aug. 1998. The buffer zone was increased to at least one-half mile from any occupied residence, business, school, public park, or church, unless the intervening landowner gives approval. In the alternative, new operations can be sited with at least a quarter-mile buffer if the owner develops and implements an odor control plan to minimize air contaminants. See 8-19-98 press release.		http://www.sos.state.tx.us/tac/30/1/index.html
Vermont	Yes	A person shall not discharge, cause, suffer, allow, or permit any emissions of objectionable odors beyond the property line of a premises. Subchapter II § 5-241(3). Vermont also has regs. for control of odor from industrial processes at Subchapter II § 5-241(3).	Vermont does not have rules concerning method. After a complaint, they go out and if there is an odor, they will try to determine the source and work it out.	http://www.anr.state.vt.us/dec/air/
Virginia	Yes	The rule applies to each facility that emits odor but does not apply to accidental or other infrequent emissions of odors. Pt. IV, Rule 4-2, § 120-04-0201. The board directs an investigation and the board may, at its discretion, hold a public hearing to hear complaints. Upon violation, the board approves measures for the economically and technologically feasible control of odorous emissions. § 120-04-0204	The investigation may include the use of an odor panel survey and/or other methods approved by the board.	http://legis.state.va.us/codecomm/codhome.htm
Washington	Yes	Under Washington's General Standards for Maximum Emissions there is an Odor section: Any person who shall cause or allow the generation of any odor from any source which may unreasonably interfere with any other property owner's use and enjoyment of his property must use recognized good practice and procedures to reduce these odors to a reasonable minimum. WAC § 173-400-040(4).		http://www.wa.gov/dnr/
West Virginia	Yes	No person shall cause, suffer, allow or permit the discharge of air pollutants that cause or contribute to an objectionable odor at any location occupied by the public. § 45-4-3(3.1). "Odor" means a sensation resulting from stimulation of the human sense of smell, § 45-	Barnebey-Cheney Scentomoeter or any other instrument, device, or	http://www.wvweb.com/www/travel recreation/fishing/fishin

STATE	ODOR REG. YES/NO	LEVEL	METHOD	WEBSITE
		4-2(2.5). Variance--An acceptable control program shall be developed and presented to the Director... After approval, but the issuance of a variance, the person responsible... shall not be considered to be in violation of this rule. § 45-4-6(6.1). There is also a section on emergency circumstances - § 45-4-6(6.2) and exemptions for "internal combustion engines" and ag. operations - §45-4-7. West Virginia also has a draft of proposed amendments that they won't release just yet. It has a little more teeth, more options re: monitoring and enforcement but industry had input into it so not as tough as they would have liked to seen.	technique designated by the Director.	g.html
Wisconsin	Yes	No person may cause, allow or permit emission into the ambient air of any substance or combination of substances in such quantities that an objectionable odor is determined to result unless preventative measures satisfactory to the department are taken to abate or control such emission. NR 429.03(1). Tests: Decision resulting from investigation by the department, based upon the nature, intensity, frequency, and duration of the odor as well as the type of area involved and other pertinent factors OR when 60% of a random sample of persons exposed to the odor in their place of residence or employment, other than employment at the odor source, claim it to be objectionable and the nature, intensity, frequency and duration of the odor are considered. Wisconsin also sent a copy of a survey they use entitled: "Odors in Your Community."	An odor shall be deemed objectionable when either or both of two tests are met. (See description to the left.)	http://www.dnr.state.wi.us/
Wyoming	Yes	Odor emission at the property line is limited being undetectable at 7 dilutions with odor free air. Two measurements shall be taken within a 1 hour period, separated by at least 15 minutes. Reduction of animal matter gases etc. shall be incinerated at a temp. of not less than 1200°F for a period not less than 0.3 second, or processed by condensation or such manner as determined by the Division. Also regulates how odor producing materials are stored, transported, and handled. Section 16.	Barnebey-Cheney Scentometer or any other instrument, device, or technique designated by the Division as producing equivalent results.	http://www.dnr.state.wi.us/

QUANTIFY EMISSIONS AND ENVIRONMENTAL IMPACTS AS FUNCTION OF SPECIES, SIZE, AND MANAGEMENT (QUESTIONS 1 AND 3)

INTRODUCTION

Airborne emissions from animal production sytems can be defined as gases, dust, and microbes, which are released into the ambient air surrounding the facility over some period of time. The quantity and mix of compounds emitted is a function of several factors but primarily animal species and facility design. Emission values are reported in terms of the amount of compound emitted per time on a per animal or per area basis. Unfortunately, most of the research to date has focused on the concentrations of compounds within buildings due to health concerns for both animals and those working in the barns. Considerably less effort has been devoted to quantifying these emissions and measuring concentrations of these same compounds in ambient air. The following section will present information in the following areas:

- management factors that affect gas, odor, and dust emissions
- detection and emission of gases from livestock buildings or manure storages
- dust and bioaerosol emissions
- fly and insect populations

EFFECT OF FACILITIES DESIGN AND MANAGEMENT ON EMISSIONS

Animal production and waste handling and treatment facilities should be planned as an integral system that reduces environmental impacts while promoting animal health and performance and worker safety. It is well known that direction of prevailing winds, the number and species of animals, the type and size of manure storage, the type of feed used, the distance to neighbors and farm residence, topography and presence of natural windbreaks, affect what is emitted or how these emissions impact the surrounding area.

It has been shown that odor and gaseous emissions from buildings are increased if the walls and floors are constantly covered with layers of feces and urine (e.g. (Voermans and others 1995; Aarnink and others 1997)). Voermans et al. (Voermans and others 1995) described the effect of pen design and climate control on the emissions of ammonia from pig houses. Design modifications are based on lowering the emitting surfaces, frequent removal of slurry from the houses, movement of slurry through slats, temperature control and ventilation rates. Emitting surfaces under the slats are reduced by sloped plates, gutters and narrow channels. Reductions in ammonia emission from new buildings varied from 30 to 70% as compared to conventional buildings. As stated by Verdoes and Ogink (Verdoes and Ogink 1997), more research is needed in order to identify how different factors (environmental conditions, feed, pen design, manure handling and management) influence both odor and gaseous emissions from barns.

In the United States, hoop structures with straw bedding are being considered as an alternative to large-scale confinement structures for swine production (Brumm and others 1997). On deep litter systems (15 lb straw/pig-day), ammonia emission is comparable with emission from a fully slatted floor barn (Valli and others 1994). Emissions can be kept at low levels by increasing the amount of straw or by allowing partial urine drainage. However, emissions of air polluting nitrogen gases in deep litter systems tend to be higher due to the formation of N_2O which contributes to the greenhouse effect and affects the ozone layer (Voorburg 1994; Groenestein and Faassen 1996).

The first measurements of odor and ammonia emissions in housing systems for layers were carried out by Dutch researchers in 1985 (Klarenbeek 1985). They concluded that odor emission from systems with dried manure was between 20 and 35% of the odor emission when manure was stored as slurry.

Ammonia emissions from housing systems for laying hens with litter were four times higher than with battery cages

Flooring design has been shown to significantly affect the airborne dust levels; solid floors have much higher levels than open-mesh floors (Carpenter and Fryer 1990; Dawson 1990). The latter allow feces and soiled bedding to fall below the floor level and minimize dust generated by animal activities.

Summary

The effect of animal facility design and management can have a major impact on all types of emissions. Specific research that has investigated these factors has generally determined large variations in airborne emissions of contaminants like ammonia or dust. Unfortunately, all of the management factors contributing to these changes in emissions are not well understood or documented.

GASEOUS EMISSIONS

Animal housing and manure handling systems generate a variety of gases. Most of the research conducted to date has not quantified these emission but rather documented the generation of these gases. Kreis (Kreis 1978) developed one of the earliest lists of volatile compounds associated with decomposition of cattle, poultry, and swine wastes. He listed 32 compounds reported to have come from cattle wastes, 17 from poultry wastes, and more than 50 compounds from swine wastes (Kreis 1978). O'Neill and Phillips (O'Neill and Phillips 1992) compiled a list of 168 different compounds identified in swine and poultry wastes (**Table 5**). Unfortunately, without emission data it is difficult to determine the real impact these gases have on human health or the environment since it is both the dose and duration of these chemicals that can cause the problems.

Only three of these gases have been studied in detail, quantifying emissions and documenting environmental concerns or human health problems. These include hydrogen sulfide, ammonia, and methane. Other gases, such as oxides of nitrogen and volatile fatty acids, are currently being studied in greater detail because of their potential impact on global warming or their contribution to odor.

Table 5. Listing of volatile organic compounds and gases identified in livestock wastes. Adapted from (O'Neill and Phillips 1992).

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	Carboxylic Acids					
1	formic acid methanoic acid	2-640	2	1	0	0
2	acetic acid ethanoic acid	0.025-10	13	4	0	0
3	propionic acid propanoic acid	0.003-0.89	13	4	0	0
4	n-butyric acid butanoic acid	0.0004-42	12	3	0	0
5	i-butyric acid 2-methylpropanoic acid	0.005-0.33	12	3	0	0
6	n-valeric acid pentanoic acid	0.0008-0.12	9	3	0	0
7	i-valeric acid 3-methylbutanoic acid	0.0002-0.0069	8	0	0	0
8	2-methylbutanoic acid	0.02	1	0	0	0
9	2-methyl-2-butenoic acid (angelic acid)	-	1	0	0	0
10	n-caproic acid hexanoic acid	0.02-0.52	5	0	0	0
11	i-caproic acid 4-methylpentanoic acid	0.037	5	0	0	0
12	2-methylpentanoic acid	-	1	0	0	0
13	oenanthic acid heptanoic acid	0.022-0.033	5	0	0	0
14	caprylic acid octanoic acid	0.0003^r-0.6	4	0	0	0
15	pelargonic acid nonanoic acid	0.0016^r-0.12	4	0	0	0
16	capric acid decanoic acid	0.05	1	0	0	0
17	hendecanoic acid undecanoic acid	-	1	0	0	0
18	lauric acid dodecanoic acid	0.004^r-0.005^r	2	0	0	0
19	tredecanoic acid	-	1	0	0	0
20	myristic acid tetradecanoic acid	-	1	0	0	0
21	benzoic acid	-	5	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	benzenecarboxylic acid					
22	penylacetic acid phenylethanoic acid α-toluic acid	0.00003	4	0	0	0
23	3-phenylpropionic acid 3-phenylpropanoic acid hydrocinnamic acid	-	4	0	0	0
	Alcohols					
24	methanol methylalcohol	4-7,800	3	0	0	0
25	ethanol ethyl alcohol	0.64-1,350	4	0	0	0
26	n-propyl alcohol 1-propanol	0.075-140	4	0	0	0
27	i-propyl alcohol 2-propanol	3.9-5,400	4	0	0	0
28	n-butyl alcohol 1-butanol	0.158-42	5	0	0	0
29	sec-butyl alcohol 2-butanol	0.4-80	1	0	0	0
30	isobutyl alcohol 2-methyl-1-propanol	0.036-500	4	0	0	0
31	pentanol n-amyl alcohol	0.4-35	2	0	0	0
32	i-pentanol 3-methylbutanol iso-amyl alcohol	0.08-0.1	4	0	0	0
33	1-hexanol n-hexyl alcohol	0.04-1.93	1	1	0	0
34	hex-3-ene-1-ol	-	0	1	0	0
35	2-methyl-2-pentanol, demethyl-n-propyl-carbinol	-	1	0	0	0
36	1-heptanol	0.05-2.4	1	1	0	0
37	iso-heptanol	-	1	0	0	0
38	3-octanol amylethyl alcohol	-	1	0	0	0
39	2-ethylhexanol	0.4	1	0	0	0
40	2-methoxyethanol methyl cellosolve methyl glycol	0.3-190	1	0	0	0
41	2-ethoxy-1-propanol	-	3	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
42	2,3-butanediol	-	2	0	0	0
43	benzyl alcohol α-hydroxytoluene	-	0	1	0	0
44	α-methylbenzyl alcohol	-	0	1	0	0
45	4-methylcyclohexanol	-	1	0	0	0
46	2-penylethanol	0.00035	1	0	0	0
	Phenolics					
47	penol carbolic acid benzenol hydroxybenzene	0.022-4	14	3	0	0
48	p-cresol 4-hydroxytoluene 4-methylphenol	0.00005-0.024	16	4	0	0
49	m-cresol 3-hydroxytoluene 3-methylphenol	0.00022-0.035[a]	2	1	0	0
50	o-cresol 2-hydroxytoluene 2-mthylphenol	0.0004	1	0	0	0
51	p-methoxyphenol 4-methoxyphenol hydroquinone mono-methylether	-	1	0	0	0
52	o-methoxyphenol 2-methoxyphenol guaiacol	0.0037-0.64	1	0	0	0
53	p-ethylphenol 4-ethylphenol 1-ethyl-4-hydroxybenzene	-	9	1	0	0
54	m-ethylphenol 3-ethylphenol 1-ethyl-3-hydroxybenzene	-	1	0	0	0
55	o-ethylphenol 2-ethylphenol 1-ethyl-2-hydroxybenzene phlorol	-	1	0	0	0
56	2,6-dimethyl phenol 1,3-diethyl- 2-hydroxybenzene	0.0002	0	1	0	0
57	3,4-dimethylphenol 1,3-dimethyl- 5-hydroxybenzene	0.003	0	1	0	0
58	3-hydroxy-2-methyl- 4-pyrone lanxinic acid maltol	-	0	1	0	0
	Aldehydes					

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
59	formaldehyde methanal	0.033[r]-12,000	3	0	0	0
60	acetaldehyde ethanal	0.0027-1	4	1	0	0
61	propionaldehyde propanal	0.0036-0.69	4	0	0	0
62	acrolein 2-propenal acrylaldehyde	0.069	2	1	0	0
63	butyraldehyde butanal	0.00084-0.2	2	1	0	0
64	iso-butyraldehyde 2-methyl propanal	0.015-0.14	5	1	0	0
65	crotonaldehyde 2-butenal	1.7	1	1	0	0
66	valeraldehyde pentanal	0.0025-0.034	4	1	0	0
67	iso-valeraldehyde 3-methylbutanal	0.0016	0	1	0	0
68	2-pentenal	-	1	0	0	0
69	caproaldehyde hexanal	0.028-0.067	7	0	0	0
70	2-hexenal	0.034[a]-0.63	1	0	0	0
71	oenanthaldehyde heptanal	0.006-0.26	5	0	0	0
72	2-heptenal	0.034[a]-0.25	2	0	0	0
73	2,3-heptadienal	-	2	0	0	0
74	caprylaldehyde octanal	0.0078	3	0	0	0
75	pelargonaldehyde nonanal	0.0003[a]-0.045	2	0	0	0
76	2-nonenal	0.0005[a]-0.0036	1	0	0	0
77	2,4-nonadienal	0.00025[a]-0.0004	2	0	0	0
78	capraldehyde decanal decylaldehyde	0.00025[a]	3	0	0	0
79	2,4-decadienal	0.00018[a]	2	0	0	0
80	benzaldehyde benzenecarbonal	0.18-3,400	5	0	0	0
81	acetone dimethylketone	0.94[a]-1,550	4	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	(2-)propanone					
82	diacetyl dimethylglyoxal 2,3-butanedione	0.000007-0.005	4	1	0	0
83	(2-)butanone methylethylketone	0.75[a]-250	4	0	1	0
84	acetoin 3-hydroxy-2-butanone	-	4	1	0	0
85	3-pentanone diethylketone propione	3-33	4	0	0	0
86	cyclopentanone adipic ketone	31-1120	1	0	0	0
87	2-methyl cyclopentanone	-	0	1	0	0
88	2-octanone hexylmethylketone	0.06[r]-0.78	4	1	0	0
89	amylvinylketone 1-octene-3-one	0.0001[a]	3	0	0	0
90	acetophenone acetylbenzene methylphenylketone	0.01[a]-1.5	4	0	0	0
	Esters					
91	methylformate formic acid methyl ester	165[r]-5,000	1	0	0	0
92	methylacetate acetic acid methyl ester	0.5[a]-550	2	0	0	0
93	elthylformate formic acid ethyl ester	54[r]-61[r]	1	0	0	0
94	ethyl acetate acetic acid ethyl ester	0.6[a]-180	1	0	0	0
95	propylacetate acetic acid propyl ester	0.2-70	2	0	0	0
96	i-propylacetate acetic acid isopropyl ester	1.9-140	1	0	0	0
97	butylacetate acetic acid butyl ester	0.03-1750	2	0	0	0
98	i-butylacetate	1.7-17	1	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	acetic acid isobutyl ester					
99	i-propylpropionate propanoic acid iso-propyl ester	-	1	0	0	0
	Nitrogen heterocycles					
100	indole 1-benzopyrrole	0.0006-0.0071	11	4	0	0
101	skatole 3-methylindole	0.00035-0.00078	13	4	0	0
102	pyridine azine	0.04-40	1	0	0	0
103	3-aminopyridine	-	2	0	0	0
104	(2)-methylpyrazine	-	1	0	0	0
105	methylpyrazine	-	1	0	0	0
106	trimethylpyrazine	-	1	0	0	0
107	tetramethylpyrazine	-	1	0	0	0
	Amines		1	1	0	0
108	methylamine aminomethane	0.0012-6.1	3	0	0	0
109	ethylamine aminoethane	0.05-0.5	3	0	0	0
110	n-propylamine aminopropane	0.022[a]	1	0	0	0
111	i-propylamine amino iso-propane	0.5	2	0	0	0
112	pentylamine 1-aminopentane amylamine	-	1	0	0	0
113	trimethylamine	0.00026-2.1	3	0	0	0
114	triethylamine	0.33[a]	4	0	0	0
	Sulphides		1	1	0	0
115	carbon disulphinde	0.05[a]-0.1	0	0	2	0
116	carbonylsulphide carbon oxysulphide	0.25[a]	2	0	2	0
117	dimethylsulphide methylthiomethane	0.0003-0.16	7	3	2	1
118	diethylsulphide ethylthioethane	0.0014-0.0045	2	0	1	0
119	dimethyldisulphide	0.0011-0.046	6	2	2	1

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	methyldithiomethane					
120	dimethltrisulphide methyldithiomethane 2,3,4-trithiapentane	0.0073[r]	4	1	1	0
121	diethyldisulphide ethyldithioethane	0.0003	1	0	0	0
122	dipropyldisulphide propyldithiopropane	0.13	1	0	0	0
123	methylpropyldisulphide methyldithiopropane	-	0	0	1	0
124	propylporop-1-enyl disulphide	-	1	0	0	0
125	diphenylsulphide phenylthiobenzene	0.0026[a]	1	1	0	0
126	3,5-dimethyl-1,2,4-trithiolane	-	0	1	0	0
127	3-methyl-5-propyl-1,2,4- trithiolane	-	0	1	0	0
128	3,6-dimethyltetra-thiane	-	0	1	0	0
129	2,6-dimethylthi- 3-inc-carbonaldehyde	-	0	1	0	0
	Thiols (mercaptans)		2	0	0	0
130	methanethiol methyl mercaptan	0.0000003-0.038	7	2	2	1
131	ethanethiol ethylmercaptan	0.000043-0.00033	3	0	0	0
132	propanethiol n-propylmercaptan	0.0016[a]	1	1	1	0
133	2-propanethiol isopropylmercaptan	0.0000025-0.00002	0	1	0	0
134	2-propene-1-thiol allylmercaptan	0.000005-0.00004	1	0	0	0
135	butanethiol n-butylmercaptan	0.0015-0.003	1	0	0	0
136	2-butene-1-thiol crotylmercaptan	0.00043-0.0014	1	0	0	0
137	benzenethiol thiophenol	0.00014	1	0	0	0
138	α-toluenethiol benzylmercaptan	0.013[a]	1	0	0	0
	Unclassified					

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
139	carbon dioxide	odourless	5	1	0	0
140	hydrogen sulphide	0.0001-0.27	11	3	1	1
141	ammonia	0.03[a]-37.8	12	3	0	0
142	sulphur dioxide	0.87[a]-10	1	0	0	0
143	methane	odourless	3	0	0	0
144	pentane	350[a]	0	0	1	0
145	2-methylpentane	-	0	0	1	0
146	hexane	230[a]	1	0	1	0
147	hexene	-	0	0	1	0
148	heptane	750-930	0	0	1	0
149	octane	71[a]-710	0	0	1	0
150	octene	0.33[a]	1	0	0	0
151	undecene hendecene	-	0	0	1	0
152	dodecane	37[a]-50	0	1	1	0
153	benzene	1.5-380	1	0	1	0
154	toluene	0.08[a]-140	4	0	1	0
155	xylene dimethylbenzene (isomer not specified)	0.35-86	3	0	0	0
156	indane hydrindene	-	3	0	0	0
157	naphthalene	0.2	1	0	0	0
158	methylnaphthalene	-	3	0	0	0
159	chloroform trichloromethane	3-3,000	1	0	0	0
160	tetrachloroethane perchloroethylene	12-320	0	1	0	0
161	hydrazine	3.9-5.2[a]	1	0	0	0
162	2-methylfuran sylvan	-	1	0	0	0
163	2-pentylfuran	-	1	0	0	0
164	2-methylthiophene 2-methylthiofuran	-	1	0	0	0
165	2,4-dimethylthiophene 2,4-thioxene	-	1	0	0	0
166	diethylether	0.75-35	1	0	0	0

	Compound (names)	Odour detection threshold (mg/m^3) (from van Gemert et al.[32])	References(# of citations) Pigs	Poultry	Cattle	Sheep
	ether ethoxyethane					
167	limonene citrene carvene	0.01[a]	0	1	0	0
168	ocimene	-	0	0	1	0

Note r: value for recognition threshold is given when there is a published value of it lower than the published detection threshold.

Note a: tables do not specify whether the value is for detection or recognition.

Hydrogen Sulfide (H_2S)

H_2S gas is colorless, heavier than air, highly soluble in water and has the characteristic odor of rotten eggs. However, the odor of H_2S can be deceiving. The odor is first detected by most people at concentrations below 1 ppm by volume. Above 6 ppm, the odor will only increase slightly although the concentration of H_2S increases significantly; at 150 ppm, the gas can have a deadening effect on the sense of smell making detection difficult. Taiganides and White (Taiganides and White 1969) determined that H_2S was produced from the putrefaction of pig manure and found that the minimum concentration for identifiable H_2S odor was 0.7 ppm. High concentrations of H_2S are toxic to humans and animals (Hartung 1988). A concentration of 50 ppm can cause dizziness, irritation of the respiratory tract, nausea, and headache. Death from respiratory paralysis can occur with little or no warning in concentrations exceeding 1,000 ppm (Field 1980). No environmental problems associated with hydrogen sulfide emissions have been documented.

H_2S is usually very low in animal houses compared with NH_3 and CO_2. It was measured at 90 ppb in a normally ventilated confinement building and 280 ppb after the ventilation was shut off for six hours (Muehling 1970). Avery (Avery and others 1975) found that the H_2S production in swine confinement units was highly correlated with several factors, i.e., the average outside air temperature, the ratio of pit area to building volume, the air retention time for the building, and the daily sulfur intake. Shurson (Shurson and others 1998) showed a reduction in hydrogen sulfide emissions from nursery pigs fed a low sulfur diet as compared to a traditional diet. Donham (Donham 1985) documented a positive, but not significant, correlation between water sulfate levels (in the drinking and cleaning water) and the sulfide content in swine manure. Also noted was a slightly positive relationship between total sulfides in manure and the hydrogen sulfide concentration in the building exhaust air. Research by Jacobson (Jacobson and others 1997) could not determine a correlation between hydrogen sulfide concentrations in the air immediately above manure storages to total sulfur content of feed or water sulfate levels. Since the process of converting elemental sulfur or sulfate to sulfide is a biological process, hydrogen sulfide production will most likely be more dependent on manure slurry temperature, pH, and storage time.

Clark and McQuitty (Clark and McQuitty 1987) investigated air quality in six Alberta commercial free-stall dairy barns. They measured H_2S in four of the six barns and concluded that the concentrations of H_2S were low (the maximum recorded value was only 145 ppb), and the possibility of detecting more than trace concentration of H_2S was remote where manure was removed from free-stall dairy units with solid passageways. With respect to poultry layer facilities, McQuitty et al. (McQuitty and others 1985) conducted an air quality survey in three commercial poultry laying barns under winter conditions. They reported that there were no detectable traces of H_2S found in two of the three barns at any time during the study, while the maximum ambient concentration of H_2S in the third barn was 30 ppb.

Significant quantities of hydrogen sulfide can be released during agitation of stored liquid manure. The most extensive documentation of this well known phenomenon is presented by Patni et al. (Patni and Clarke 1991). This research measured peak hydrogen sulfide concentrations near the floor of a dairy barn during agitation at 70 ppm. Peak hydrogen sulfide

Table 6. Variation in hydrogen sulfide emissions over a 12 hour measurement period

Time of day	Emissions µg/s/m2						
	dairy freestall N.V.	swine finishing M.V.	swine ges. M.V.	swine farrowing M.V.	swine finishing N.V.	swine nursery M.V.	poultry broiler M.V.
7am	0.4	5.6	0.4	8.8	5.1	20.7	0.1
9am	0.5	8.6	0.9	6.2	8.0	139.5	0.2
11am	0.3	4.9	0.7	7.1	6.2	41.4	0.2
1pm	0.2	8.0	0.8	5.8	9.8	27.6	0.2
3pm	0.9	7.1	0.7	3.9	13.0	27.5	0.1
5pm	0.3	8.9	0.9	3.6	5.9	34.4	0.1
7pm	0.6	6.4	0.7	3.1	5.6	29.0	0.3
Average	0.4	7.1	0.7	5.5	7.7	45.7	0.2

M.V. Mechanically ventilated
N.V. Naturally ventilated

concentrations in a deep pitted swine barn were 100 ppm and concentrations as high as 220 ppm were documented in the exhaust air from the pit fan.

The emission rate of H_2S from animal buildings has not been extensively studied by past researchers. Heber et al. (Heber and others 1997) reported that a mean emission rate of 0.00033 lb/day/pig place was observed from a 1000-head naturally ventilated swine-finishing house while Hobbs et al. (Hobbs and others 1999) showed documented H_2S emission rate from the open surface of liquid manure storage facilities was about 0.02 lb/ft^2/day (a deep pitted finishing barn has about 8 ft^2 per pig indicating H_2S emissions of 0.16 lb/day/pig place). Ni, et al. (1998) found that during 3 months (June to Sept.) a deep-pitted swine finishing barn emitted about 0.0015 lb/day/pig place. Zhu (Zhu and others 1998) reported hydrogen sulfide emissions from seven different facilities over a 12 hour period (**Table 6**). Emissions comparisons can be made for swine finishing buildings if a area per pig place is assumed. Using a value of 8 ft^2 per pig place for a finishing building, the average hydrogen sulfide emissions for the swine finishing facility is 0.00013 lb/day/pig place. This compares well to the field measurements made by Heber (Heber and others 1997).

In 1998, the Minnesota Pollution Control Agency measured ambient hydrogen sulfide concentrations at the property line of 138 different livestock facilities using a Jerome® Meter (Minnesota Pollution Control Agency 1999). Of the 500, 30-minute average, samples taken, 24 farms had at least one measurement exceeding the 30 ppb regulatory threshold. Four of these 24 farms were monitored continuously for several weeks using a Total Reduced Sulfur (TRS) monitor. During the period of continuous monitoring, only one of the facilities exceeded the 30 ppb standard.

Ammonia (NH_3)

Urine is the primary source of ammonia (NH_3) and is released during manure storage and decomposition. NH_3 gas is an irritant, colorless, lighter than air, and highly water soluble. It has a sharp pungent odor becoming detectable at levels as low as 5 ppm. Typical NH_3 levels in well ventilated confinement buildings are 5 to 10 ppm with liquid manure systems and 10 to 20 ppm where manure and urine are deposited on solid floors, especially poultry units. Levels can exceed 25 ppm with lower winter ventilation rates and reach 40 ppm in poorly ventilated buildings. Very high levels of NH_3 concentrations, such as 2500 ppm may even be fatal. In many countries, the

threshold limit is 25 ppm (time weighted) for an eight hour working day for staff and for the living environment for livestock.

Large quantities of NH_3 emit from animal production facilities each year. Agricultural sources, and livestock farming in particular, are the largest contributors to NH_3 emissions (Groot Koerkamp and others 1998). For example, about 85% of the total NH_3 emission in The Netherlands originates from livestock farming. NH_3 from livestock husbandry emanates from buildings, slurry and manure stores, pastures (grazing), and during manure application, e.g., slurry spreading. Among these sources, livestock housing and manure storage tanks contributed about 40 to 60% of the total emissions.

Meyer and Bundy (1991) surveyed 200 swine-farrowing houses and found the average NH_3 concentration was 11.4 ppm from December to February and 6.9 ppm from March to May. Collins (1990) observed a 1000-sow swine complex to determine atmospheric NH_3 levels. He found the total annual discharge of the NH_3 was about 67,500 kg (144,400 lb), or about 0.40 lb/sow place/day. Ni et al. (1998) measured NH3 emissions from a 1000 pig finishing barn from June to September (3 months) and found an average rate of 0.028 lb/pig place/day. Clark and McQuitty (1987) studied the air quality in six Alberta commercial free-stall dairy barns and found that the NH_3 was present in all six barns and the overall mean values ranged from 7 to 20 ppm. The overall mean NH_3 production rates ranged from 1.7 to 4.4 L/(hour-cow (500 kg)). According to the research conducted by McQuitty et al. (1985) in three commercial poultry laying barns under winter conditions, the daily average of NH_3 in the exhaust air was 33 ppm.

Table 7. Influence of housing type on ammonia emissions.

Species	Management	Ammonia	Units	Author
Pig	not specified	1.5	kg/pig/yr	Clark and McQuitty (1987)
	Fully slatted	24.0	lb/1000 lbwt/yr	Hartung (1994)
	partly slatted	43.4	lb/1000 lbwt/yr	Hartung (1994)
	Liquid	15.0	lb/1000 lbwt/yr	Hartung (1994)
	Bedding	3.4	lb/1000 lbwt/yr	Hartung (1994)
	fully slatted	13	lb/1000 pigs/day	Heber (1997)
	lagoon	10.5, 6.2, 4.9	kg/ha/day	Harper (1998)
	sows, litter	744-3248	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	sows, slats	1049-1701	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	weaners, slats	649-1562	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	finish, litter	1429-3751	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	finish, litter	2076-2592	mg/500 kg/hr	Groot Koerkamp et al. (1998)
Layer	layer, deep litter	7392-10892	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	layer, battery	602-9316	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	Battery cages, basement storage	83	g/bird/yr	Hartung (1994)
	Battery cages, belts	34	g/bird/yr	Hartung (1994)
	Battery cages, belts and drying	31	g/bird/yr	Hartung (1994)
Broiler	broiler	2208-8294	mg/500 kg/hr	Groot Koerkamp et al. (1998)
Cattle	litter	371-900	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	slats	346-686	mg/500 kg/hr	Groot Koerkamp et al. (1998)
Dairy	Freestall	7-13	g/LU/day	Junbluth (1997)
	litter	260-890	mg/500 kg/hr	Groot Koerkamp et al. (1998)
	cubicles	843-1769	mg/500 kg/hr	Groot Koerkamp et al. (1998)

Table 7 lists various ammonia emissions from several researchers. Unfortunately most of the research has been conducted in Europe where the facility design and management are different from that found in the United States.

NH_3 is attributed to the effects of acidification on the environment. NH_3 and chemical combinations (NH_x) are important components responsible for acidification in addition to sulfur compounds (SO_x), nitrogen oxides, and volatile organic components (Groot Koerkamp 1994).

NH_3 may cause several ecological problems in the environment. First, the inputs of nitrogen may lead to considerable changes in plant communities with the result that plants which prefer low nitrogen soils disappear and there is an increase in nitrogen indicator plants (Ellenberg 1988). Second, acidification of soil with low buffer capacity may occur after nitrification of the nitrogen added. A falling pH leads to the dissolution of toxic soil constituents such as aluminum ions, and to the leaching of nutrients and aluminum into the groundwater (Van Breemen and others 1982; Roelofs and others 1985; Speirs and Frost 1987). Third, the natural capability of forest soil to take up methane (CH_4) decreases by NH_3 deposition, thus increasing the concentration of the greenhouse gas in the atmosphere (Steudler and others 1989). Fourth, surface waters may be affected by eutrophication and acidification (Dillon and Molot 1989). Finally, NH_3 depositions on buildings will promote bacterial growth, which contributes substantially to weathering and corrosion damage of the buildings (Spiek and others 1990).

A European study shows the annual maximum amounts of nitrogen that can be taken up by natural habitats without any signs of adverse effects (called "critical loads"). These critical loads are 4.5 to 17.8 lb/acre for deciduous forest, 2.7 to 13.4 lb/acre for coniferous forest, 2.7 to 4.5 lb/acre for low vegetation, 2.7 to 8.9 lb/acre for grassland, and 2.7 to 4.5 lb/acre for moorland (Schneider and Bresser 1988). Therefore, the consequences of NH_3 emission are primarily of an ecological nature and must be considered on a long-term basis in terms of minimizing the environmental damage caused by NH_3 emission from agricultural production.

Methane (CH_4)

Methane is a nontoxic and odorless gas. Methane is very effective at absorbing infrared radiation, approximately 70 times as much as carbon dioxide. As such, methane's contribution to global warming is believed to be second only to carbon dioxide (Safley and Casada 1992). Methane is emitted from both natural and man-made sources, including animal agriculture. Safley (Safley and Casada 1992) estimates a global emission rates of methane at 540×10^9 kilograms per year with 5% of the emissions resulting from the anaerobic decomposition of animal manure and another 15% coming from the gut of ruminant animals. **Table 8** lists the estimated contribution per animal from cattle, pigs and poultry. These estimates were made on manure production and management practices on a global scale, and are therefore, only crude estimates of production per animal.

Limited research is available on the actual emission rates of methane. The methane emission estimates used by Safley were based on standard methane conversion factors (MCF). These MCF's are based on manure handling method, temperature and the amount of volatile solids excreted by the animal. Steed and Hashimoto (Steed and Hashimoto 1994) conducted a laboratory experiment to verify the estimated MCF values used by Safley for dairy cows (**Table 9**). This research gives some indication of the effect of manure management on methane

production. As was expected, the MCF was less for the dryer, more aerobic systems, e.g. feedlots and pasture, than for both solid and liquid manure storage systems.

Table 8. Estimated methane emissions from livestock and poultry waste (Safley and Casada 1992)

Animal Type	Methane Emissions (kg/year per animal)
Cattle in feedlots	23
Dairy	70
Swine	20
Caged Layer	0.3
Broiler	0.09
Turkey and ducks	0.16

Table 9. Measured methane emission factors (MCF) for dairy cows.

System Type	MCF estimates by Safley (1992)	MCF measured at 20°C Steed (1994)
Pasture/Feedlot	10	0.3
Liquid slurry	20-90	55.3
Solid	10	45.7

Summary

The emissions from animal production systems include an extensive list (168) of gaseous compounds. The three most researched gases are hydrogen sulfide, ammonia, and methane. H_2S poses the largest safety risk in confined spaces (indoor) and is of concern in the ambient air (outdoor) mainly because of the Minnesota state ambient air standard for this gas. It seems that swine facilities and manure storage units produce the largest concentrations and emissions of H_2S. Ammonia, also is produced by animal production systems, especially poultry facilities. Indoor concentrations of NH_3, poses some health concerns inside buildings but emissions may contribute to ecological damage to the environment. Finally, methane emissions, which are more of a problem with cattle than other animal species, contributes to global warming concerns.

DUST, ENDOTOXINS, AND AIRBORNE MICROORGANISMS

Dust—Composition and Sources

Dusts in and around animal facilities include bits of feed, dried skin, hair or feathers, dried feces, bacteria, fungi, and endotoxins (cell wall of gram-negative bacteria) (Koon and others 1963; Anderson and others 1966; Curtis and others 1975a; Heber and others 1988). Feed was found to be the primary component of the dust (Curtis and others 1975b; Heber and others 1988). Open unpaved feedlots can also be a dust source, which will include soil particles (Alegro and others 1972; Sweeten and others 1998; Sweeten and others 1988). Dust comes from the animals themselves, feed storage and processing sites, floors, manure storage and handling equipment, open lots, compost sites, and other elements of animal agriculture systems.

Table 10. Mean inhalable and respirable dust emission rates from English, Dutch, Danish, and German livestock buildings.

	Mean inhalable dust emission rate (mg/h 500 kg liveweight)	Mean respirable dust emission rate (mg/h 500 kg liveweight)
Cattle Buildings (dairy and beef)		
England	97	31
The Netherlands	143	35
Denmark	128	12
Germany	184	20
Overall mean	145	24
Pig Buildings		
England	633	93
The Netherlands	674	74
Denmark	1102	117
Germany	651	53
Overall mean	762	85
Poultry Buildings		
England	3138	373
The Netherlands	3640	721
Denmark	3509	618
Germany	2118	248
Overall mean	3186	504

Environmental Impact of Agricultural Dust Emissions

Little information is available on the environmental impact of animal agricultural dust emissions. Most dust research deals with human and animal health effects due to indoor dust exposure (Donham and Gustafson 1982; Donham and Leininger 1984; Mulhausen and others 1987; Donham 1990; Nicolai and Janni 1998a). The human and animal health impacts are discussed in the Animal Health and Human Health sections.

Dust emissions contribute to nutrient deposition. Accumulated dust may also affect cleanliness and aesthetics. Dust particles adsorb odorous gases, which can assist odor transport and dispersion (Day and others 1965; Hammond and others 1979). Research also indicates that indoor dust increases equipment deterioration (Gupta and others 1988).

Facility Dust Emissions

There is little research on dust emissions from animal agriculture facilities and their environmental impact in Minnesota or the upper Midwest. Most of the dust information available gives dust concentrations within swine and poultry facilities rather than emissions. The focus of these projects was indoor air quality, dust characterization, and its impact on both human and animal occupants inside the building. Little information is available on dust concentrations in dairy or horse facilities.

Takai et al. (Takai and others 1998) provides the first inhalable and respirable dust emission estimates from various cattle, swine, and poultry facilities in Europe. They reported on an extensive four-country study on aerial emissions from livestock housing facilities. **Table 10** summarizes the estimated dust emissions. Emissions were estimated using mean daily dust concentrations near an air outlet and the daily mean ventilating rate (Takai and others 1998).

Inhalable dust was collected using an IOM (Institute of Occupational Medicine, Edinburgh) dust sampler, which represents the dust inhaled through a human's nose and mouth (Mark and Vincent 1986). Respirable dust was measured using a cyclone in series with a filter. The cyclone removes most of the particles with an aerodynamic diameter of 5 microns or more. The remaining respirable dust captured on the filter represents the dust that can penetrate deeply into the respiratory tract and the lungs of humans. Both samplers are commonly used in personal dust sampling.

Statistical analysis indicated that both country and housing type were significantly different for inhalable dust emissions. Inhalable dust emissions from cattle buildings were not affected by season. There were significant seasonal effects on inhalable dust emissions from both the pig and poultry buildings. Percheries (laying hen facilities with litter flooring and perches) in The Netherlands and Denmark and broiler houses in England and The Netherlands had the highest dust emission rates. Animal activity level, stocking density, spilled feed, bedding material selection, and humidity levels affect dust emissions (Takai and others 1998). The significance of country, season and other factors suggests that these results may not accurately describe dust emissions from animal buildings in Minnesota.

Published data on dust emissions from unpaved outdoor cattle feedlots is available from California (Alegro and others 1972) and Texas (Sweeten and others 1988). Emissions depend on soil texture, rainfall, feedlot surface moisture content, wind speed, season, and other factors. The climate and production practices in Minnesota differ from these regions, which means that their emission rates need to be modified for use in Minnesota.

Grain Handling and Processing Dust

There is little data on the everyday emissions of dust from grain handling and processing. Most of the testing is done during peak harvest times to develop worst case design criteria for dust collection devices (Muleski and Garman 1996) or to determine the potential to emit for Federal EPA regulations (Kenkel 1996). Research conducted in Oklahoma (Kenkel 1996) on country elevators determined that emissions were 15 to 35 times lower than EPA published material. Kenkel and Noyes determined an emission rate of 0.0191 lb/ton for the hopper bottom truck and 0.0388 lb/ton for the end-dump truck. They concluded that grain elevators were unlikely to be major sources of air pollution.

Dust from feed is also a concern at the producer level, ranging from a small tub grinder up to the larger feedmills. The dust emissions from these sites are constant throughout the year as the feed is handled and processed on a regular basis. Dust arises from grinding, flaking, mixing, and pelleting of the feed. No substantial research is available documenting emission from these sites.

Vehicle and Traffic Dust

Since the majority of the service and township roads are gravel, dust generated from vehicles traveling over these roads can be considerable. Currently, calcium chloride is spread on these roads in short strips where dust is considered a problem such as, in front of a residence or around animals that could continuously breath the dust.

Microbial and Endotoxin Emissions

Reported airborne concentrations of microbial and endotoxins can be somewhat misleading because of the wide ranges that are reported. For instance, three papers on egg layer housing reported the following airborne microbial concentrations for layers in cages: range of 360 to 3781 Colony Forming Units (CFU's) per liter of air (Hartung 1994); range of 17 to 5860 CFU's per liter of air (Muller 1987); and, range of total bacteria of 290 to 680 CFU's per liter (Clark and Rylander 1983). It is unclear at this time if the actual concentrations are varying that much or the variation is due to the sampling and measurement methods.

Table 11. Mean emission rates of inhalable and respirable endotoxins over 24 h from different animal housing.

Species	Mean inhalable endotoxin emission rate (µg/h per 500 kg liveweight)	Mean respirable endotoxin emission rate (µg/h per 500 kg liveweight)
Cows	2.9	0.3
Beef	3.7	0.6
Calves	21.4	2.7
Sows	37.4	3.7
Weaners (growing pigs)	66.6	8.9
Fattening pigs	49.8	5.2
Layers	538.3	38.7
Broilers	817.4	46.7

µg = micro grams

The most recent research estimated microbial (bacteria and fungi) and endotoxin emissions from cattle, swine and poultry barns in four countries in Europe (Seedorf and others 1998). The emission rates were estimated by using the ventilation rate and the indoor concentration.

In this study total airborne microorganism emissions rates were reported as the logarithm base 10 log of the number of colony forming units (cfu) per hour per 500 kg of live-weight animals housed in the building. The average total airborne microorganism emission rates were approximately 7 log cfu/h * 500 kg live-weight, ranging from 9.5 log cfu/h * 500 kg live-weight from broiler houses to approximately 6.5 log cfu/h * 500 kg live-weight from beef and cow housing (Seedorf and others 1998).

The emission rates of Enterobacteriaceace were much lower. Layers had the highest emission rate at 7.1 log cfu/h * 500 kg live-weight, sows had the lowest emission rate at 6.1 log cfu/h * 500 kg live-weight. Fungi emissions ranged from 7.7 log cfu/h * 500 kg live-weight for broilers to 5.8 log cfu/h * 500 kg for weaners (i.e., grower pigs) (Seedorf and others 1998).

Seedorf et al. (Seedorf and others 1998) noted that data on the biological half-life period of viable microorganisms under varying environmental conditions was needed in order to predict their dispersion and estimate the risk of airborne disease transmission. Local topography, weather, and ventilation system design also affect potential contaminant transmission.

Estimated endotoxin emission rates in the inhalable and respirable dust fractions from different livestock are summarized in **Table 11** (Seedorf and others 1998). The data indicates that poultry had the highest endotoxin emission rates while cattle had the lowest, with pigs in between. Seedorf et al. (Seedorf and others 1998) concluded that it was not known whether outdoor human exposure to such endotoxin emissions was hazardous to health.

Summary

Dust and other particulates, like microorganisms and endotoxins, are a real indoor air quality concern for both animals and humans. The emissions of these contaminants from animal production units are much less of a concern although only a limited amount of research has been done to document emissions levels and their impact on the environment and people near these areas. Particulates can transport odor and thus cause some nuisance concerns. It does seem from existing data that poultry units emit the highest levels of dust and endotoxins followed by swine units and cattle facilities in that order.

ODOR EMISSIONS

Odor emissions from an animal production site originate from three primary sources: manure storage units, animal housing, and land application of manure.

Most of the odorous gases that make up livestock odors are by-products of anaerobic decomposition / transformation of livestock wastes by microorganisms. Livestock wastes include manure (feces and urine), spilled feed and water, bedding materials (i.e., straw, sunflower hulls, wood shavings), wash water, and other wastes. This highly organic mixture includes carbohydrates, fats, proteins, and other nutrients that are readily degradable by microorganisms under a wide variety of suitable environments. The by-products of microbial transformations depends, in a major part, on whether the transformation is done aerobically (i.e., with oxygen) or anaerobically (i.e., without oxygen). Microbial transformations occurring under aerobic conditions generally produce fewer odorous by-products than those occurring under anaerobic conditions. Moisture content and temperature affect the rate of microbial decomposition.

After generation, the volatile compounds accumulate in the wastes. At exposed surfaces or when the wastes are agitated, the compounds can escape and be emitted into the air. Once in the air, they diffuse through and are transported along air currents and disperse into the atmosphere. Some compounds adsorb onto airborne particles and other surfaces.

There has been limited research on quantifying odor emissions from livestock facilities and manure storages. Most research on odors measures concentrations. It is important to understand the difference between emission and concentration. Odor concentration is measured as a dilution-to-threshold. Dilution to threshold is the ratio of the amount of clean air needed to dilute a sample of odorous air to the point where a human panelist cannot detect the odor. Odor emissions are calculated by multiplying the odor concentration by the air flow rate from which the sample is taken. For example, an air sample is taken from a 1000 cubic feet per minute exhaust ventilation fan on a livestock building. The odor concentration of the air sample was 350 odor units as measured with an olfactometer. Assuming the fan to be the only exhaust for a 100 pig finishing barn, the odor emission from that fan is calculated to be 3500 ou/min/pp (odor units per minute per pig). It is more meaningful sometimes to report emission based on area rather then the number of animals. In this case, odor emissions would be reported as ou/min/area.

Verdoes and Ogink (Verdoes and Ogink 1997) measured odor from "low ammonia emitting pig barns" in The Netherlands (**Table 12**). Research from Minnesota reports odor emission rates of 3.4 to 14.8 ou/s-m^2 for swine finishing barns (Zhu and others unpubl.; Heber and others 1998) determined an average odor emissions rate from four 1,000 head pig finishing barns to be 3.0 o.u./sec/pig place. The only attempt to quantify odor emissions from deep litter system was made

Table 12. Odor emissions for different pig categories (Verdoes and Ogink 1997)

Category	Period	Odor Concentration (ou./m^3)	Odor Emission (ou./s/pp*)
Dry Sows	Summer	434	12.18
	Winter	619	9.79
Farrowing Sows	Summer	836	39.56
	Winter	876	31.44
Weaned Piglets	Summer	2856	7.7
	Winter	1557	3.18
Fatteners - low pH ration	Summer	892	16.62
	Winter	1019	12.15
Fatteners - multiphase feeding	Summer	1245	18.57
	Winter	854	5.5

* pig place

by Schmidt (Schmidt 1999). An average emission rate of 2.6 o.u./s-m^2 was obtained from air samples taken in a single hoop barn. Although there does seem to be some reduction in odor emission with the deep bedded systems, there is clearly a need for more research in this area.

Zhu (Zhu and others 1998) measured daily variations in odor emissions from a swine, dairy, and poultry systems (**Figure 1**). Dairy and broiler buildings showed the most consistent and lowest odor emission rates. Odor levels in all facilities increased slightly in the afternoons. The nursery building had the highest odor emissions for all the sampling times during the day. Peak emissions recorded at 9 am corresponded to the feeding time for the animals.

Watts et.al. (Watts and others 1994) found that emission rates from a cattle feedlot measured over the period of one week showed considerable variation with time of day, surface

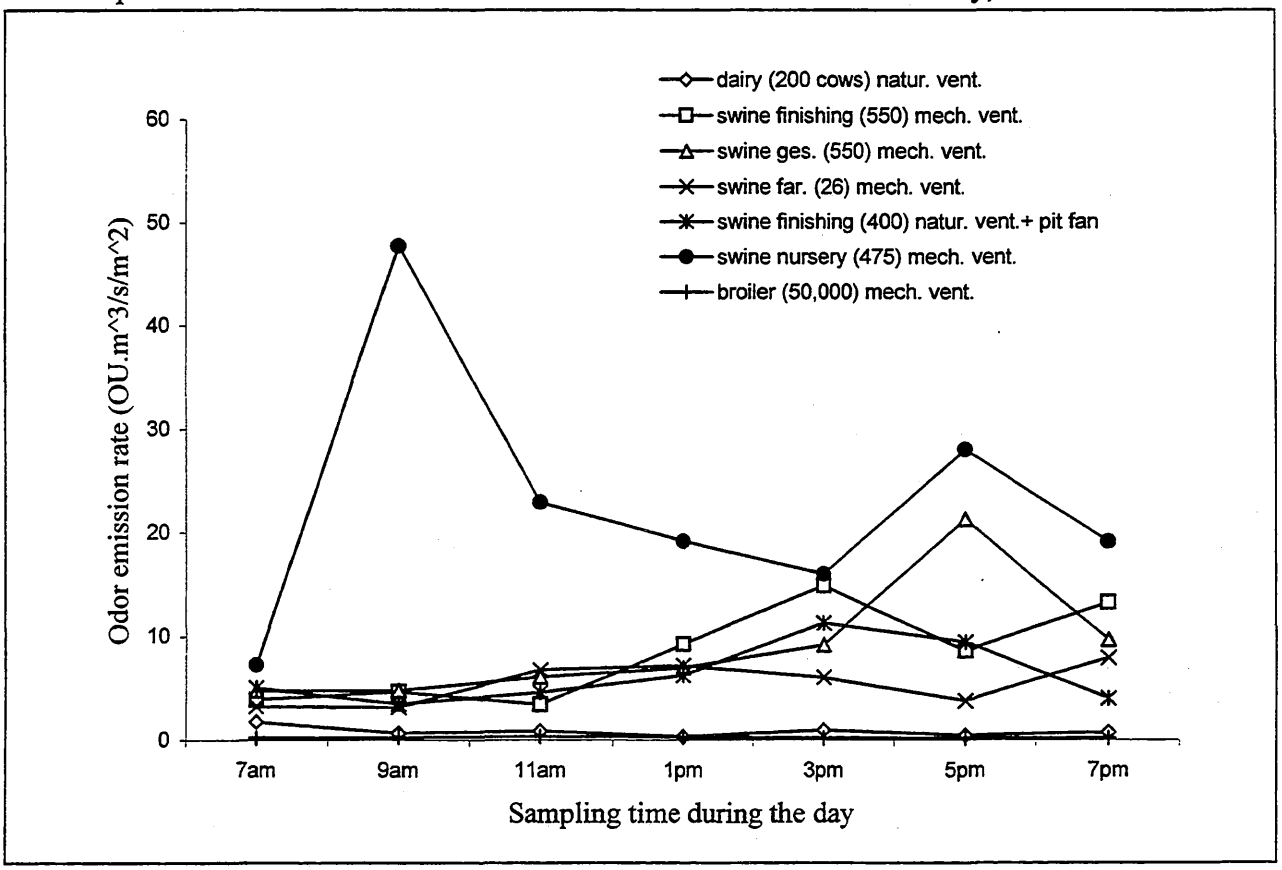

Figure 1. Daily variation in odor emissions for different animal buildings

temperature, moisture content, and time since wetting. Mean daily emissions ranged from 20 to 300 ou/s/m^2. Measured odor emissions from the wet feedlot pad were up to 60 times more intense than the odors emitted from the dry pad, and the peak in odor emission occurred approximately 48 hours after wetting the pad. It is difficult to compare odor measurements because of the non standard methods used in odor measurement.

Summary

Odor emissions from various animal production sites are beginning to be reported for animal production sites in the United States and Europe. Large ranges of values have been reported due to diurnal (24 hour) variations and difficulty in collecting and analyzing odor samples. Certain housing and manure handling systems seem to produce more odors than others systems for pigs, poultry and cattle. Pigs may have more concerns but dairy and poultry units also are capable of producing odors which can have a negative impact on neighbors.

CUMULATIVE IMPACT OF EMISSIONS

The cumulative impact of airborne emissions from animal agriculture is largely undocumented. This is partially because of the complexity of the process with individual gases, particulates, and bioaeresols all responding differently to various environmental conditions and the limited amount of information available on actual emissions from most of these compounds. It is well known that methane emissions from animal agriculture, or any other source, contribute to global warming (Hogan 1993). As such, methane and other greenhouse gas emissions from animal agriculture have an impact far beyond the immediate location of their source. Other gas emissions such as volatile organic compounds and hydrogen sulfide are thought to have a more localized impact since they are oxidized rapidly in the environment. Zahn (Zahn and others 1997) showed evidence of this in a recent study measuring the concentrations of various volatile organic compounds at the source and at 100 meters from the source. Just how localized these impacts are has not been well defined. However, it is common knowledge that since odors are sometimes detected several miles from their source, leading to the obvious conclusion that these odorous gasses and possibly others have impacts beyond the source property line.

The transport of any airborne emissions is affected by dispersion, settling, and chemical reactions in the atmosphere. Unfortunately, these relationships have not been well defined in literature for most compounds.

One gas whose fate has been studied intensively is ammonia. This research involves the transport and deposition of ammonia in the environment and the conversion of ammonia to other nitrogen species. Ammonia has received special attention because of its role in nitrogen enrichment and acidification of the environment. The fate of ammonia is quite complicated involving direct deposition, diffusion into the atmosphere where it reacts with many acidic species to form a variety of ammonium aeresols (Apsimon and Kruse-Plass 1991). The amount of ammonia deposited locally is shown to be quite dependent on downwind land-cover with transport and deposition being quite variable across the landscape (Sutton and others 1998). Other research has shown that local deposition is concentrated in the first 500 meters from the source (Fowler and others 1998; Pitcairn and others 1998; Nihlgard 1985).

The fate of these airborne compounds is directly related to the accumulation of these compounds in the ambient air. If the compounds quickly disperse, react, or are deposited within 500 meters

of the source, then the accumulated impact is limited. If, however, these compounds persist, then there is some potential for increasing ambient concentrations in areas with several emission sources. At this time, information to predict these cumulative impacts is limited.

INSECTS

Seven types of insects (**Table 13**) can become abundant enough during summer to affect air quality and human comfort in and around animal enterprises. These insects develop in larval breeding sites that occur around animals and other places, and then disperse as adults into the surrounding landscape. Depending on the type of insect, their presence can lead to a variety of problems. House flies and blow flies can reach annoying densities and pose a threat to public

Table 13. Different types of insects emanating from breeding substrates at livestock and poultry production facilities in the Upper Midwest, by animal species and facility type. "+" indicates likely presence, "-" scarcity or absence.

		Types of insects around agricultural animals (and principal breeding substrates*)						
Animal species	Facility type	House fly (F,B,M)	Stable fly (F,B,M)	Fruit flies (F)	Manure gnats (M)	Blow flies (C,M)	Darkling beetles (L)	Face fly (D)
Swine	Pasture	+	+	-	-	-	-	-
	Open front	+	+	-	+	-	-	-
	Slat floor	+	-	+	+	-	-	-
	Crate	+	-	+	+	-	-	-
Dairy	Pasture	+	+	-	-	-	-	+
	Tie- or free-stall	+	+	-	+	-	-	-
	Drylot	+	+	-	+	-	-	-
	Slat floor	+	+	+	+	-	-	-
Beef	Pasture	+	+	-	-	-	-	+
	Drylot	+	+	-	-	-	-	-
Sheep	Pasture	+	+	-	-	-	-	-
	Drylot	+	+	-	-	-	-	-
Horse	Pasture	+	+	-	-	-	-	-
	Stable	+	+	-	-	-	-	-
Egg layer	High- or low-rise	+	-	-	+	+	-	-
Broiler	Pasture	-	-	-	-	+	-	-
	Litter barn	+	-	-	-	+	+	-
Turkey	Pasture	-	-	-	-	+	-	-
	Litter barn	+	-	-	-	+	+	-
Substrates: F = rotting feed, B = soiled bedding, M = manure (old feces), C = carcasses, L = poultry litter and manure, D = cow dung pats. Compiled from various sources.								

health. Adults of stable flies have painful bites that irritate cattle, dogs, horses and people. Other types of insects are small enough to be inhaled, and swarms can interfere with human comfort in the workplace.

No scientific surveys have been conducted to assess insect abundance at different kinds of livestock and poultry enterprises in Minnesota or elsewhere, so comparisons among animal species and housing styles lack an objective basis. Available evidence suggests that abundance of the principal types of insects (**Table 13**) varies with kind of insect, with supply of breeding medium, and with distance from source (Greenberg 1971; Greenberg 1973; Thomas and Skoda 1992; Thomas and Skoda). Size of animal facility, per se, is not as important as how potential breeding media are managed in a given kind of facility.

House flies (*Musca domestica*) are common wherever livestock and poulty are housed (Thomas and Skoda). This insect can reach extraordinary densities if feedstuffs and manure are handled improperly, in much the same way that mishandled household garbage can create summer fly outbreaks in urban environments. House flies lay eggs in fermenting organic media that are 40-80% water. Larvae (maggots) can survive and develop to maturity in the same substrates if they remain within 30-80% water. Fermenting grain meal, soiled livestock bedding and accumulated wet manure are ideal substrates for house fly reproduction. It takes less than a thimble of wet manure to produce one fly, and time from egg to adult can be as little as 12 days. Studies in Ohio (Winpisinger-Slay and Berry unpubl.) and Maryland (Pickens and others 1967) indicated that density of dispersing house flies decreased exponentially with distance from animal facilities; densities declined to less than 10% at distances beyond 1.0 mile.

Similarly, abundance of stable flies (*Stomoxys calcitrans*) is governed by substrate supply and moisture, although in comparison to house flies, there tends to be more stable flies in fiberous media such as wet hay, wet grass clippings, soiled straw bedding, and older, drier manure (Meyer and Shultz 1990). Consequently, stable flies tend to be more abundant around cattle, sheep and horses than around swine and poultry. The dispersal distances of stable flies appear to be somewhat less to those of house flies (Stein 1986).

Relatively less is known about the remaining types of flies and beetles (**Table 13**) that are common around livestock and poultry in the Upper Midwest. Several species of fruit flies (Drosophilidae) breed in fermenting, grain based feeds, and can reach annoying densities around swine, dairies and caged layers if wet, spilled feed is allowed to accumulate (Harrington and Axtell 1994). Manure gnats (Sphaeroceridae) (Marshall and Richards 1987) will colonize and reproduce in liquid manure storage systems wherever manure solids collect at or above the water surface. Swarms of fruit flies and manure gnats if inhaled can interfere with human comfort in the workplace (Harrington and Axtell 1994). Dispersal distances of these two types of insects from animal facilities have not been studied, but absence of complaints from citizens living near livestock and poultry facilities suggests these flies are more sedentary than house flies.

Blow flies (Calliphoridae) develop as larvae in decaying wild or domesticated animal carcasses and other nitrogen-rich organic substrates (Broce 1985; Hall 1948). Blow flies will become abundant wherever animal carcasses or slaughterhouse offal are not promptly buried, composted or rendered. Blow flies can also reach excessive densities if broken eggs are allowed to contaminate manure under caged laying hens. Adults of these shiny, metallic flies can disperse more than a mile from point of origin (Greenberg 1973).

Darkling beetles (*Alphitobius diaperinus*) breed successfully in dry manure under caged laying hens and in broiler and turkey house litter. Larvae of these beetles (a form of wireworm) are known to damage insulation in certain styles of poultry barns (Despins and others 1989), and dispersing adults have annoyed residents adjacent to agricultural fields where infested poultry manure and litter had been spread (Anonymous 1997).

Finally, the face fly (*Musca autumnalis*) is often noticed as a household nuisance when adults aggregate in buildings in autumn and again when they exit in spring (Krafsur and Moon 1997). This type of fly reproduces exclusively in cattle dung pats in pastures, so face fly nuisance problems are traceable to grazing cattle, and not to feedlots and barns where animals are confined.

Effects of all seven types of insects (**Table 13**) on the environment are difficult to evaluate. All types can be considered beneficial in the sense that they are scavengers that aid in the natural decomposition and recycling of organic matter. Furthermore, all serve as food for other insect eating animals, including other insects, spiders, amphibians and birds.

On the negative side, people can become annoyed and suffer a reduced quality of life if their yards and homes are populated with extraordinary numbers of any of the seven insect types. It does not take many insects to interfere with human comfort (Thomas and Skoda). Beyond annoyance, stable flies are known to bite and suck blood from a wide variety of animals, including dogs and people, and stable flies are known to reduce the comfort and economic productivity of dairy and beef cattle (Thomas and Skoda 1992). Finally, house flies and blow flies are a potential health risk to humans and animals, because these manure and carcass breeding species have the potential to transport microbes from their breeding media to human foods (Greenberg 1971). These connections with human and animal health will be reviewed in greater detail under GEIS topic K on human health and topic L on animal health.

Summary

Flies and other insects that are produced on animal production sites can have an impact on nearby communities and neighbors if there numbers are of sufficient size. It seems that the manure management system or presence of insect breeding areas is more predictive of an insect problem than physical size of the animal operation. Insects that are commonly seen on animal production farms are mostly a nuisance concern, but certain fly varieties can poses a human and animal health concern.

HEALTH RISKS AND IMPACTS AS FUNCTION OF SPECIES, SIZE, AND MANAGEMENT (QUESTIONS 2 AND 3)

INTRODUCTION

Airborne contaminants within and emissions from animal facilities include gases, odors, particulates or dust, pathogens (bacteria, viruses, bacterial toxins, fungi and mites) and a host of microbial byproducts including endotoxins and glucans. Individually and combined they have potential direct and indirect impacts on human and animal health.

The potential **direct** impact on human health can be:

- physical impairment of the biological/mechanical defense mechanisms by dust and irritant gases such as ammonia and hydrogen sulfide (e.g. damage to the respiratory epithelium of the airways, including dysfunction of the cilia that transport mucus and foreign bodies out of the upper respiratory tract) and damage to the goblet cells changing the functional capacity of the mucus that normally flows on the surface of the airways to trap and transport out foreign material,
- chemical irritation of the upper respiratory tract lining by gases (e.g. damage of the epithelial barriers to inflammatory substances, respiratory bacterial or viral pathogens; decreased cilia function and increased inflammation of the airways involving increased cellular infiltration and release of inflammatory mediators),
- immunological sensitizing to allergens (e.g. organic dust particles such as feed ingredients, fungi, animal epidermal scales, and mites), and
- infection with bacteria or viruses that have a pathogenic potential for the human respiratory tract (e.g. Influenza-A-Virus, Streptococcus, Staphylococcus, Pasteurella, Salmonella, Leptospirosis, Cryptosporidiasis, Giardia, and Haemophilus) and toxins from the organism pfiesteria.

The potential **indirect** impact on human health can be:

- gaseous emissions such as NH_3, washed down by precipitation, can contribute to the nitrogen content of ground and surface waters that are used for drinking water,
- zoonotic bacteria emitted from livestock and poultry facilities may contribute to an increased population of these same microorganisms in the ecosystem (such dust-borne, non-respiratory, bacteria pose hardly any direct risk to human health, even to passers-by near animal houses),
- bacteria from animal excretions (emitted via exhaust air) that contain genetic determinants for antimicrobial resistance can contribute to an increase of bacterial resistance in the ecosystem but the risk is unknown and needs further study.

The potential **direct** impact on animal health can be:

- physical impairment of the biological / mechanical defense mechanisms by dust (e.g. damage to the respiratory epithelium of the airways, including dysfunction of the cilia that transport mucus and foreign bodies out of the upper respiratory tract),
- chemical irritation of the membranous lining of the respiratory tract by gases (e.g. damage of the epithelial barriers to inflammatory substances, respiratory bacterial or viral pathogens;

decreased cilia function and increased inflammation of the airways involving increased cellular infiltration and release of inflammatory mediators),

- infection with bacteria or viruses that have a pathogenic potential for the animal respiratory tract (e.g. Influenza-A-Virus, Streptococcus, Staphylococcus, Pasteurella, Salmonella, Leptospirosis, Cryptosporidiasis, Giardia, and Haemophilus). These may be spread from animal to animal or from animal unit to animals in other units by transference.

HEALTH RISKS OF ANIMAL AGRICULTURAL EMISSIONS ON FACILITY WORKERS

The health of people working in animal housing facilities, especially in swine and poultry units, has become a concern to the producers, health officials, and researchers. Chronic respiratory problems for workers in these environments are common including symptoms such as cough, sputum production, chest tightness, shortness of breath, and wheezing due to the airborne dust, gases, and other particulates (Donham 1989). Acute worker health and safety concerns also exist during short-term events like manure pit agitation that can result in large emissions of toxic gases like hydrogen sulfide. Seven fatalities have been reported since 1992 in Minnesota from exposure to these gases during the agitation and transfer of manure in or near storage tanks or pits.

A number of studies have found workers in intensive animal facilities with a high prevalence of respiratory health problems (Patni and Clarke 1991; Iversen and Takai 1990; Hellickson and others 1989; Zejda and others 1994). Most of these studies were done in pig barns but several (Hellickson and others 1989; Nicolai and Janni 1998a) were carried out in poultry (turkey) facilities. Assessment was done by measuring the reduction in lung function of animal facility workers (Iversen and Takai 1990). (Patni and Clarke 1991) compared to non-exposed people. Lung function also decreased as workers aged (Hellickson and others 1989).

Several studies compared the health or respiratory function between workers in pig facilities and those on farms without swine and workers not associated with farms. A number of studies reported a higher frequency of respiratory symptoms, more colds, wheezing, coughing, and pneumonia in swine workers than in other farm workers not exposed to pig barn environments (Donham and others 1984; Holness and others 1987; Vohlonen and others 1987; Dosman and others 1987; Wilhelmson and others 1989).

Dust

Airborne dust is suspected as the major cause of chronic worker health symptoms (Rylander and others 1989). Dusts in and around animal facilities include bits of feed, dried skin, hair or feathers, dried feces, and soil particles (Koon and others 1963; Anderson and others 1966; Curtis and others 1975a; Alegro and others 1972; Sweeten and others 1998; Sweeten and others 1998). Feed was found to be the primary component of the dust (Curtis and others 1975b; Heber and others 1988). Airborne biogenic particles include bacteria, viruses, fungi spores, amoebae, algae, pollen, plant parts, insect parts and wastes, endotoxins and mycotoxins. Endotoxins are naturally occurring substances in the cell walls of gram negative bacteria that are released when the microogranisms die. Mycotoxins are toxins produced by fungi.

Numerous studies have reported dust concentrations in animal buildings. Mean inhalable dust levels in various catttle, swine, and poultry buildings in Europe ranged from 0.22 to 4.58 mg/m3

(Takai and others 1998). Inhalable dust represents the dust inhaled through a human's nose and mouth (Mark and Vincent 1986). Mean respirable dust concentrations ranged from 0.09 to 0.64 mg/m3 (Takai and others 1998). Respirable dust represents the dust that can penetrate deeply into the respiratory tract and lungs.

Total dust concentrations in turkey barns in Minnesota ranged from 0.4 to 13.8 mg/m^3 across two studies (Mulhausen and others 1987; Reynolds and others 1994). Concentrations were highest in the winter. Respirable dust concentrations ranged from 0.1 to 2.6 mg/m^3 (Reynolds and others 1994).

Total dust concentrations in broiler barns in North Carolina ranged from 0.02 to 11 mg/m^3 (Jones and others 1984). Respirable dust levels ranged from 0.02 to 0.62 mg/m^3. Bird age, litter age, and animal activity were factors (Jones and others 1984).

Total dust concentrations in an Italian horse stable ranged from 0.26 to 10.82 mg/m^3 with a mean concentration of 1.95 mg/m^3. Respirable dust concentrations ranged from 0.03 to 1.46 mg/m^3 with a mean of 0.38 mg/m^3 (Navarotto and others 1994).

Total and respirable dust concentrations in caged layer barns in Sweden were comparable or less than those in barns without cages (alternative housing) (Martensson 1995). Total dust concentrations in the conventional caged layer barns ranged from 1.3 to 2.7 mg/m^3 while respirable dust concentrations ranged from 0.08 to 1.04 mg/m3. Corresponding total and respirable dust concentrations in the alternative barns ranged from 2.6 to 4.1 mg/m^3 and 0.08 to 1.13 mg/m^3, respectively.

Research in swine buildings indicates that total dust concentrations are higher in finishing barns than either nursery or gestation barns. Donham, Scallon, et al. (Donham and others 1986) reported mean total mass dust concentrations to be 3.2 mg/m^3 in farrowing units, 5.2 mg/m^3 in nursery units, and 15.3 mg/m^3 in finishing buildings. The respirable fractions were 20%, 13.4%, and 12.4% of the total dust in the farrowing, nursery, and finishing buildings, respectively. Maghirang, Puma, et al. (Maghirang and others 1997) reported a mean total dust concentration of 0.72 mg/m^3, ranging from 0.12 to 2.14 mg/m^3 in a test swine nursery. The respirable fraction ranged from 2 to 30% of the total dust, with an overall mean of 11%.

Time-weighted average (TWA) total and respirable dust exposure thresholds of 2.4 mg/m^3 and 0.16 mg/m^3, respectively for workers in livestock and poultry facilities have been suggested (Donham and others 1989; Donham K. and others 1995; Reynolds and others 1996; Donham and Cumro 1999a). Time-weighted average threshold limits are based on eight-hour work days and a 40-hour work weeks.

Worker health can be mitigated using dust respirators or masks. Studies report reduced incidence of common respiratory symptoms and substantial respiratory protection (Iversen and Takai 1990; Hellickson and others 1989; Barber and others 1999; Senthilselvan and others 1999).

Summary

Dust concentrations in animal facilities can vary widely. Sampling techniques (i.e., aerial versus personal) and building conditions vary widely making direct comparison very difficult. They depend on many management and animal factors. Aerial and personal sampling techniques differ and will give different results. The results indicate that animal buildings can be quite dusty and

generally depend on numerous factors including ventilating rate, humidity level, litter use and condition, animal density and activity level, feed form and content, feeding system, amount of cleaning, and other management practices. Dust in animal facilities can be a major contributor to worker health symptoms. Researchers have suggested time weighted average limits for total and respirable dust for workers in livestock and poultry. Respirators and masks can provide substantial respiratory protection.

Gases

In addition to the dust there are irritating gases in the environment of animal facilities which can have an additive or synergistic effect (Reynolds and others 1994; Donham and Cumro 1999b). Groot-Koerkamp et al. (Groot Koerkamp and others 1998) reported mean and maximum ammonia concentrations in cattle, pig, and poultry houses in northern Europe. Mean ammonia concentrations ranged from 0.3 to 30 parts per million (ppm). The maximum concentrations ranged from 1.7 to 73 ppm. The data indicates that health risks would be greater due to ammonia in the pig and poultry buildings than in the cattle buildings.

Ammonia concentrations in pig buildings in Minnesota were less than 30 ppm averaging only 10-15 ppm (Jacobson and others 1996).

Ammonia levels in turkey grower barns in Minnesota were higher in the fall and winter season compared to the spring and summer (Mulhausen and others 1987). Seasonal average values ranged from 10 to 35 ppm. Mean ammonia concentrations in turkey buildings ranged from 1.9 ppm in brooder barns in the summer to 46.2 ppm in grower barns with hens in the winter (Reynolds and others 1994).

Concentrations of carbon monoxide, hydrogen sulfide, nitrogen dixoxide, and methane in turkey grower barns were below detectable levels (Mulhausen and others 1987). Mean sulfur dioxide concentrations in turkey barns ranged from 0.13 to 0.36 ppm (Reynolds and others 1994).

Ammonia concentrations in three broiler barns in North Carolina had average concentrations around 25 ppm ranging from 6 to 75 ppm. Carbon dioxide concentrations ranged from 500 to 1,000 ppm. Carbon monoxide, hydrogen sulfide, nitrogen dioxide, oxides of nitrogen (NOx), methane, mercaptan, formaldehyde, and hydrocarbons concentrations were all below the detection limits of the detector tubes used (Jones and others 1984).

MidWest Plan Service (MidWest Plan Service 1990) lists TWA concentrations for NH_3 at 25 ppm and for H_2S at 10 ppm. However, Donham and Cumro (Donham and Cumro 1999a; Donham and Cumro 1999b)have shown synergistic effects between ammonia and dust and suggest an ammonia TWA threshold limit of 7 ppm inside livestock and poultry facilities. Other gases like carbon dioxide (CO_2) and carbon monoxide (CO) have TWA levels of 5,000 ppm and 50 ppm, respectively. Methane (CH_4) has a safety consideration because of possible explosiveness at 30,000 ppm (MidWest Plan Service 1990).

Summary

Ammonia and hydrogen sulfide were the most commonly monitored gases in animal buildings. Concentrations varied widely and depend on animal species, housing, and manure handling. Research evidence strongly suggests that ammonia and dust have synergistic effects. Researchers

are suggesting TWA threshold limits for workers in livestock and poultry facilities. Most other gases have not been found at levels of concern.

Biogenic Particles

Researchers have reported biogenic concentrations for bacteria, fungi and endotoxins in animal buildings. Microbial sources include the animals, bedding, feed, manure or exterior (outside) sources.

Airborne endotoxin concentrations were measured in cattle, pig, and poultry buildings in Europe (Seedorf and others 1998). Mean inhalable endotoxin concentrations ranged from 11.8 to 786 nanograms/m^3 (ng/m^3). Mean respirable endotoxin concentrations ranged from 0.6 to 72 ng/m^3. In general both inhalable and respirable concentrations were higher in poultry buildings than pig buildings and lowest in cattle buildings. Generally daytime concentrations were higher than nighttime concentrations.

Seedorf et al. (Seedorf and others 1998) measured airborne microorganism concentrations in animal buildings, mostly in Germany. The highest mean bacterial concentrations were measured in broiler buildings where the mean concentration was 6.43 logrithim of colony-forming-units per cubic meter of air (log cfu/m^3). Mean bacterial concentrations in layer and pig houses ranged from 4 to slightly over 5 log cfu/m^3. Mean bacterial concentrations in cattle barns were generally slightly over 4 log cfu/m^3. Mean daytime Enterobacteriaceae concentrations ranged from 3.2 to 4.5 log cfu/m^3. Mean daytime fungi concentrations were 3.8 for cattle, 3.7 for pigs, and 4.0 for poultry log cfu/m^3, respectively with similar values for nighttime (Seedorf and others 1998).

Hartung (Hartung 1994) noted some generalities in a review regarding airborne microbes in poultry buildings. Airborne microorganisms found in poultry buildings, as in most livestock facilities include: staphylococci, streptococci, pseudomonas, E. coli/Enterobacter, fungi, molds and yeasts. Of the fungi, several different species were found – some of which considered to be allergenic (Penicillium, Aspergillus, Cladosporium, and Alternaria) (Hartung 1994).

Airborne bacteria concentrations in three broiler barns in North Carolina were around 150,000 cfu/m^3 (Jones and others 1984). Fungi concentrations were 10,000 cfu/m^3. Endotoxin concentrations ranged from 0.77 to 61 ng/m^3 in the total dust samples and from 0.71 to 15 ng/m^3 in the respirable dust.

Because methods of microbial determination (i.e., bacteria and/or fungi) and differentiation (i.e., fungi species), sampling times and sites differed between studies, there may be limited value in reported quantities of airborne particulates as absolute values. For instance, three papers reported widely varying airborne microbial concentrations in egg layer houses for layers in cages: range of 360 to 3781 cfu's per liter of air (Hartung 1994); range of 17 to 5860 cfu's per liter of air (Muller 1987); and, range of total bacteria of 290,000 to 680,000 cfu's per cubic meter (Clark and Rylander 1983).

The effects of independent variables can be assessed when measurements are taken using the same standard procedures for specific comparison purposes. For instance, the type of poultry and housing shows an effect on airborne microorganism concentrations. (Hartung 1994) indicated that airborne microorganisms in houses with chicken layers on litter (bedding) had

approximately 5 times the concentrations compared to chicken layers in cages, perhaps reflecting the difference in hen activity and contributions of the litter material.

In the Midwest, season had a significant affect on airborne microorganisms in turkey houses. (Mulhausen and others 1987) found that airborne Aspergillus concentrations in a turkey barn in Minnesota never exceeded 73 cfu/m^3, which was less than background levels found in two ambient air studies (Calvo and others 1980; Jones BL and Cookson JT 1983). Reynolds et al. (Reynolds and others 1994) found that mean bacteria concentrations in turkey barns ranged from 300,000 to 38,700,000 cfu/m^3. Higher levels of bacteria, approximately 5 fold, (Debey and others 1995) and higher levels of Aspergillus, approximately 3.5 fold (Janni and others 1985) were found in rearing facilities in the winter compared to summer. The large difference is most likely due to ventilation rates targeted toward keeping barns warm in the winter and heat removal in the summer time.

There is limited research information on microbial populations as affected by feed type, animal activity, bedding type and management, manure handling system, stocking density, air temperature, and relative humidity. Bedding provides environmental conditions appropriate for bacterial growth and fungal spores (Beran 1991). Populations change with bedding use. Fungi populations in fresh and used litter in broiler houses had different specie populations. Aspergillus spp. and Scopulariopsis brevicaulis were predominant in the litter after one cycle of birds (Dennis and Gee 1973). Research reported by Jones et al. (Jones and others 1984) for broiler farms in North Carolina indicated airborne fungal counts were an order of magnitude higher in a house with fresh litter compared to a flock housed on old litter (same age birds).

Some researchers have noticed episodes of organic dust toxic syndrome (ODTS) in animal facilities workers (33% of workers), mainly during high dust exposure times like sorting or moving animals and during power washing of the building interior. These situations may be related to inhaling endotoxins from aerosolized gram negative bacteria (Rylander and others 1989). Donham et al. (Donham and others 1988) found endotoxin levels to be significantly related to the one-second forced expiratory volume (FEV1) and the forced expiratory phase at 25-75% lung volume (FEV25-50) of swine workers in a dose dependent way. Donham & Cumro (Donham and Cumro 1999a) suggest TWA threshold concentrations of 614 EU/m^3 for total endotoxin and 0.35 EU/m^3 for respirable endotoxin.

Summary

Biogenic particles are a broad class of organic particulates including bacteria, fungi, and endotoxins. Concentrations differ depending on animal species, manure system and management, bedding use, feed form and quality, feeding system, animal activity, and management. Measurement techniques vary making direct comparison between studies very difficult. Endotoxins can reduce respiratory capacity and researchers have suggested threshold limits for workers in livestock and poultry facilities.

COMMUNITY HEALTH EFFECTS OF ANIMAL AGRICULTURAL EMISSIONS (PARTICLES, GASES/ODORS, PATHOGENS)

The Association of Health Effects with Exposure to Particles

There is little research on the health effects of ambient dust concentrations downwind of animal facilities and their impact on human health. Ambient dust is regulated by the U.S. Environmental Protection Agency (EPA) under the National Ambient Air Quality Standard (NAAQS) (EPA 1998c).

Dust from animal facilities and feed mills can contribute to the ambient dust levels. Emissions from large beef cattle feedlots in Texas and California are regulated (Sweeten and others 1998). Dust mitigation methods are used to reduce emissions from these sources. No research was found reporting on the health effects of ambient dust from animal facilities in the Midwest or Minnesota. This might be a topic for future research.

Human Health Effects with Exposures to Gases and Odors

Several studies investigated the health effect of ambient odors downwind of industrial and agricultural sources. Shukla (Shukla 1991) stated that the immediate physiological stresses produced by odors can cause loss of appetite and food rejections, low water consumption, poor respiration, nausea, and even vomiting and mental perturbations. In extreme cases, offensive odors can lead to deterioration of personal and community well-being, interfere with human relations, deter population growth, and lower its socio-economic status (Shukla 1991).

Shusterman et al. (Shusterman and others 1991) reported on three studies which were conducted in California regarding odor and health complaints. The odorants identified in each of the studies were reduced sulfur gases and compounds with odor thresholds three to four times lower than thresholds that cause respiratory irritation or systemic toxicity. These studies found great variability at when different people in the community could detect odors. Females were more sensitive, while elderly and smokers were less sensitive to smells. The study notes that these differences are important when the community responds to odor abatement measures. It also found that repeated exposure to an odor resulted in enhanced odor recognition and detection. Most symptoms reported by individuals were acute in onset, self-limiting in duration, and subjective, making it difficult or impossible to substantiate objectively (Shusterman and others 1991).

Shim and Williams (Shim and Williams 1986) reported that many patients complain that some odors worsen their asthma. Perfume and cologne are two of the most frequently mentioned offenders. Four patients with a history of worsening asthma on exposure to cologne underwent challenge with cologne, and their pulmonary function was tested before, during, and after the exposure. Forced expiratory volume in one-second declined 18 to 58 percent below the baseline period during the 10-minute exposure and gradually increased in the next 20 minutes. Saline placebo pretreatment did not affect the response to subsequent challenge. A survey of 60 asthmatic patients revealed a history of respiratory symptoms in 57 of them on exposure to one or more common odors. Odors are an important cause of worsening of asthma. From a practical standpoint, sensitive asthmatic patients should be advised to eliminate odors from their environment as much as possible (Shim and Williams 1986).

Shusterman et al. (Shusterman and others 1991) also presented theories as to why the body may respond to odor. He sets them out in various categories.

- Relationship between Odor Detection and Acute Toxicity: Acute odor-related symptoms could and do occur without toxic exposures. For example, symptoms reporting of sulfur gases begin at levels that barely exceed their odor threshold.
- Innate Odor Aversion: A built-in mechanism for all people to react to pleasant and unpleasant odors. Even babies respond predictably.
- Innate Pheromonal Phenomena: Odors trigger some hormonal responses in animals. Still under study with humans.
- Odor-related Exacerbation of Underlying Conditions: One pre-existing medical condition that may coincide the hyper susceptibility to odors is bronchial asthma. Pre-existing psychological conditions might cause some individuals to respond more to odors.
- Odor-related Aversive Conditioning: After a traumatic exposure, some people report symptoms in response to low-level exposures. While initial symptoms occurred with traumatic exposure, subsequent attacks and symptoms occurred both with and without odor triggers.
- Odor-related, Stress-induced Illness: Persons who believe the odor source is a toxic risk have more symptoms and psychological distress when exposed to odors. This was shown to be the most important variable in people's response to odor.
- Mass Psychogenic Illness: Clusters of people experience similar symptoms. Odors frequently play an important role in causing alarm. Not usually seen in a community setting.
- Recall Bias: This can occur when an adverse health outcome, the publicity surrounding an environmental issue or odor perception, affects the accuracy of recall for a particular symptom.

Knasko (Knasko 1993) reported on the effects of intermittent bursts of pleasant, unpleasant, and no odor on human task performance, mood and perceived health. Odors did not influence any of these measures; however, subjects who had been exposed to the malodors reported retrospectively that they thought the odors had a negative effect on all of these factors (Knasko 1993).

Retrospective symptom prevalence data, collected from over 2000 adult respondents living near three different hazardous waste sites, were analyzed with respect to both self-reported environmental worry and frequency of perceiving environmental (particularly petrochemical) odors (Shusterman and others 1991). Significant positive relationships were observed between the prevalence of several symptoms (headache, nausea, eye and throat irritation) and both frequency of odor perception and degree of worry. Headaches for example, showed a prevalence odds ratio of 5.0 comparing respondents who reported noticing no such odors and 10.8 comparing those who described themselves as very worried versus not worried about environmental conditions in their neighborhood. Potential explanations for these observations are presented, including the possibility that odors serve as a sensory cue for the manifestation of

stress-related illness (or heightened awareness of the underlying symptoms) among individuals concerned about the quality of their neighborhood environment.

Cavalini (Cavalini 1994) noted that with regard to general health complaints, it was found that when exposed to (industrial) odorant concentrations, some people are annoyed and of these people, only some report general health complaints. Exposure in itself does not directly cause general health complaints. Annoyance is the intervening variable between exposure and general health complaints. A possible explanation for the relation between annoyance by malodor and general health complaints might be found in the personality and attitudes of the exposed individual. Caralini (Cavalini 1994) found confirmation for the appraisal hypothesis, i.e., the extent to which individuals regard malodor as threatening is positively related to odor annoyance.

In a Terre Haute Indiana study (U.S. Public Health Service 1964), concentrations of hydrogen sulfide ranged from 22 to 300 ppb and were sufficient to cause public complaints and discomfort and paint blackening of lead-based paint. While Terre Haute, Indiana, had many potential sources of odorous air pollutants, the most probable source, which caused the public complaints and discomfort, was a 35-acre lagoon used for the biodegradation of organic industrial waste. Many public complaints were generated about odors, health effects, and property damage. Main symptoms reported were nausea, loss of sleep and abrupt awakening, shortness of breath, and headache. Few citizens sought medical attention. In the opinion of the medical observers, the hydrogen sulfide and other odorous materials were the likely cause of the symptoms.

Odors have also been reported to affect cognitive performance (Lorig 1992; Ludvigson and Rottman 1989) and physiological responses including heart rate and electroencephalographic patterns (Lorig 1989; Lorig and others 1991; Lorig and Robers 1990; Lorig and others 1993; Lorig and Schwartz 1988; Manley 1993). Learning (via conditioning) may also play a role in the psychological and physical effects from odors. Conditioned aversions to odors are documented in the scientific literature (Dyck and others 1990; Goodwin and others 1992; Hunt and others 1993; Meachum and Bernstein 1992; Murua and Molina 1990; von Kluge and Brush 1992).

Animal Odor Sources

Odor complaints have been reported to be most frequent among new, large, or recently expanded animal facilities that are located near existing residences or shopping areas (Miner 1980; Sweeten and Miner 1993).

Odorant molecules contained in emissions from hog farms may cause nasal and respiratory irritation (Bundy 1992; Cometto-Muniz and Cain 1991; Donham 1990; Miner 1980; Blaha 1999). Nasal irritation has been shown to elevate adrenaline (Allison and Powis 1976) which may contribute to feelings of anger and tension. The volatile organic compounds (VOCs) responsible for odors may also be absorbed directly by the body (into the bloodstream and fat stores) via gas exchange in the lungs. Many VOCs that are inhaled into the lungs are known to reach blood and adipose tissue. Persons who have absorbed odorants through the lungs can sometimes smell the odor for hours after exposure due to slow release of the odorants from the bloodstream into expired air activating the olfactory receptors. Volatile organic compounds are well known to be eliminated in breath after exposure (Raymer and others 1991; Wallace and

others 1991), and methods for measuring VOCs in breath have been described as abnormal smell functioning.

A Michigan study (Warner and others 1990) was designed to assess the impact of a 50,000 animal swine-growing facility as an odor source and potential health problem. In parallel with the measurement of odor intensity, the Michigan Department of Public Health conducted a health survey to obtain information regarding the pervasiveness of the odor in the community and its possible health implications. Citizen's complaints reported included physical symptoms such as breathing difficulties, burning sensations in the nose and throat, nausea and vomiting, and headaches. A survey of residents within 0.5 miles of the center of the facility (58 households / 89 persons) and those between 0.5 and 1.25 miles away (176 households / 225 persons) resulted in response rates of 55% and 49%, respectively. The authors concluded the following: "These responses contained complaints of symptoms attributable to the swine facility. As with any population, symptoms as general as those which relate to complaints as noted are difficult to correlate to specific health problems. However, the clear excess of complaints stands as a fact of record. Perhaps further study is needed to surface a better understanding of individual health effects and symptoms as these relate to perception of odor. "Information is not provided on the type of complaints nor was there any report on frequency of symptoms or whether they differed by proximity to the farm" (Warner and others 1990).

From 1984 to the mid-90s, a large scale and long-term epidemiological study on the frequency of respiratory disease in children comparing rural and urban areas was conducted in Germany by the German Medical Association. The results showed that in the rural areas a non-significant higher proportion of allergic disease in children was recorded, however, no conclusions on any causal relation to livestock operations could be drawn, since there were too many confounding factors (Blaha 1999).

Schiffman et al. (Schiffman and others 1995) evaluated forty-four individuals living near hog operations and forty-four control subjects in North Carolina. These two groups were matched on the basis of age, gender, race, and educational level. Compared to controls, the experimental group had statistically significant increases in tension, depression, anger, fatigue, and confusion scores from the standardized Profile of Moods State Questionnaire. Schiffman deemed these findings consistent with other previous studies where odors of varying hedonic properties have been found to affect mood (Baron 1990; Ehrlichman and Bastone 1992; Rotton 1983; Schiffman and others 1994a; Schiffman and others 1994b; Blaha 1999; Winneke and Kastka 1977). Schiffman states that the mood alteration could be caused by "a) the unpleasantness of the sensory quality of the odor; b) the intermittent nature of the stimulus; c) learned (via conditioning) aversions to the odor, and are well documented in the scientific literature; d) potential neural stimulation of immune responses via detect neural connections between odor centers in the brain and lymphoid tissue; e) direct physical effects from molecules in the plume including nasal and respiratory irritation; f) possible chemosensory disorders; and g) unpleasant thoughts associated with the odor."

Thu et al. (Thu and others 1997) reported on the association of health effects with exposures to environmental odors from animal operations. The study collected mental and physical health information by personal interviews from a small random sample of 18 residents living within two miles of a 4,000-sow operation in Iowa. Data was compared to that collected from a

demographically comparable sample of 18 rural residents living in an area with minimal livestock production. The results of the comparison indicated that "neighbors of the large-scale swine operation reported experiencing significantly higher rates than the controls of four clusters of symptoms that are known to represent toxic or inflammatory effects on the respiratory tract. These clusters of symptoms have been well documented among swine confinement workers." The specific symptoms reported are quite similar to the list of symptoms reported by hog farm workers: cough, increased sputum production, shortness of breath, chest tightness, wheezing, nausea, dizziness, headaches, runny nose, scratchy throat, burning eyes, muscle aches and pains, skin rash, and fever. Among the control group in this study, symptoms of skin rash, muscle aches, and fever were more frequently reported. There was no difference in the frequency of reported symptoms and distance from the swine facility. This study found that neighbors did not suffer higher rates of psychological health effects, such as depression or anxiety, when compared to controls. Thu et. al. (Thu and others 1997) also states that all responders felt the owner of the farm was creating social and class divisions within that community.

A recent study (Wing and Wolf 1999) was prompted by the rapid expansion of intensive hog productions in North Carolina. Residents of three rural communities were surveyed, one community in the vicinity of a 6000-head hog operation, one community in the vicinity of two intensive cattle operations, and a third rural agricultural community where residents lived at least two miles from livestock operations that use liquid waste management systems. The average number of episodes of most symptoms was similar in the three communities with the exception of respiratory, gastrointestinal, and mucous membrane problems. The study found "a number of symptoms that have previously been reported to be elevated among persons occupationally exposed in swine confinement houses were elevated among residents of the hog community compared to the community with no livestock operations. In particular, headache, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes were reported more frequently in the hog community. Members of the cattle community did not report similar elevations, nor did they report reduced quality of life. The quality of life measures concerning opening of windows and ability to go outdoors even in nice weather showed a large excess in the hog community." Long-term physical and mental health impacts of reduced quality of life could not be investigated in this study.

O'Neil and Phillips (O'Neill and Phillips 1992) conducted a literature review of the chemicals detected in and around livestock facilities or livestock wastes. The most commonly reported compounds in the literature review were volatile fatty acids (acetic, propionic, butanoic, and pentanoic), phenol, p-cresol, and ammonia. Some of these compounds have been identified as respiratory tract, skin, or eye irritants. The following table lists those chemicals identified in the literature review that have some acute or chronic health value associated with them, either from the Minnesota or California Departments of Health or from USEPA (**Table 14**).

The information in **Table 14** can be used in risk assessment. The EPA inhalation reference concentrations (RfCs) can be used to estimate a level of environmental exposure at or below which no adverse effect is expected to occur. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population that is likely to be without appreciable risk of effects during a lifetime. In general, the incidence of human disease or the type of effects that chemical exposures have on humans cannot be predicted. This is due to the numerous uncertainties involved in risk assessment, those associated with extrapolations

from animal data to humans and from high experimental doses to lower exposures. The organs affected and the type of adverse effect resulting from chemical exposure may differ between study animals and humans. In addition, many factors besides exposure to a chemical influence the occurrence and extent of human disease (EPA 1999).

The U.S. EPA's critical effects are those listed in the EPA's Integrated Risk Information System (IRIS). Critical effects are the first adverse effect, or its know precursor, that occurs as the dose rate increases (EPA 1999).

A few researchers have considered the effects of biogenic emissions from animal facilities and their potential as a respiratory health hazard and disease transmission to other animals (Bohm and Hartung 1994; Homes and others 1996; Seedorf and others 1998). Local topography, weather, emission rates and source characteristics will effect potential transmission (Seedorf and others 1998). Measurements at one swine facility found total bacteria concentrations decreased dramatically between inside and outside a swine facility. Concentrations were higher than background levels at 200 m but not at 300 m downwind of a swine facility (Homes and others 1996).

Summary of Outdoor Airborne Contaminants on Human Health

Airborne dust, gases, and biogenic particles can negatively impact human health. There are a number of research reports documenting that neighbors of large swine facilities experience higher incidences of health symptoms than comparable rural residences near minimal livestock production. Similar studies around other animal production facilities are limited. Clearly more research is needed to relate emissions from animal facilities to airborne concentrations and the health effects on individuals living near animal production facilities.

Table 14. Volatile organic compounds and gases identified in livestock wastes with documented subchronic, chronic, or acute health values.

Compound (names)	Minnesota's Proposed Inhalation Health Risk Values (µg/m3) Chronic	Subchronic	US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects	California's Acute REL (µg/m3) and Toxicologic Endpoints	EPA Hazardous Air Pollutant Listing
acetaldehyde ethanal	5				yes
acetone dimethylketone (2-)propanone			not available at this time		
acetophenone acetylbenzene methylphenylketone			not available at this time		yes
acrolein 2-propenal acrylaldehyde		0.07	0.02 squamous metaplasia and neutrophilic infiltration of nasal epithelium	$1.9*10^{-1}$ eye irritation	yes
ammonia	80		100	$3.2*10^{3}$ eye and respiratory irritation	
benzaldehyde benzen-carbonal			not available at this time		
benzene	1		not available at this time	$1.3*10^{3}$ reproductive developmental	yes
bis(2-ethylhexyl) phthalate					yes
carbon disulfide	700		700 peripheral nervous system dysfunction	$6.2*10^{3}$ reproductive developmental	yes
carbonylsulfide carbon oxysulfide					yes
chloroform			not available at this time	$1.5*10^{2}$	yes

Compound (names)	Minnesota's Proposed Inhalation Health Risk Values (µg/m3) Chronic	Subchronic	US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects	California's Acute REL (µg/m3) and Toxicologic Endpoints	EPA Hazardous Air Pollutant Listing
trichloromethane				reproductive developmental	
crotonaldehyde trans-2-butenal			not available at this time		
ethyl acetate acetic acid, ethyl ester			not available at this time		
formaldehyde methanal	0.8		not available at this time	$9.4*10^{1}$ eye irritation	yes
formic acid methanoic acid			not available at this time		
hexane					yes
hydrazine	0.002		not available at this time		yes
hydrogen sulfide		10	1 inflammation of the nasal mucosa	$4.2*10^{1}$ respiratory irritation	
isobutyl alcohol 2-methyl-1-propanol			not available at this time		
methanol methyl alcohol			not available at this time	$2.8*10^{4}$ CNS[4]-mild	yes
2-methoxyethanol methyl cellosolve methyl glycol		50	20 testicular effects		
naphthalene	1		3 nasal effects: hyperplasia and		yes

Compound (names)	Minnesota's Proposed Inhalation Health Risk Values (µg/m3) Chronic	Subchronic	US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects	California's Acute REL (µg/m3) and Toxicologic Endpoints	EPA Hazardous Air Pollutant Listing
			mataplasia in respiratory and olfactory epithelium, respectively		
phenol carbolic acid benzenol hydroxybenzene				$5.8*10^3$ eye and respiratory irritation	yes
pyridine azine			not available at this time		
sulfur dioxide				$6.6*10^2$ respiratory irritation	
toluene	400		400 neurological effect	$3.7*10^4$ CNS-mild eye and respiratory irritation	yes
triethylamine		70	7	$2.8*10^3$ CNS-mild, eye irritation	yes
xylene dimethylbenzene (isomer not specified)			not available at this time	$2.2*10^4$ eye and respiratory irritation	yes

THE IMPACT OF AIRBORNE CONTAMINANTS ON ANIMAL HEALTH

An animal's response to airborne contaminants will depend on the dose of contaminant absorbed, inhaled, or ingested and the impact that the contaminant has on the animal. Dose through the respiratory tracts is extremely difficult to measure because it depends in part on animal activity and respiration rate. Exposure is typically used as a surrogate for dose. Exposure describes the contact between the animal and contaminant in terms of contaminant concentration and duration of contact. Exposure also describes the contact in terms of the surfaces that are exposed to the contact (i.e., eyes, skin, respiratory tract, other).

Animals exhibit their responses to airborne contaminants in many ways and through various biological systems. Changes in production (e.g., average daily gain, feed conversion) or reproduction are common response indicators. Other indices include health, morbidity, mortality, and thermal comfort. Animals can also exhibit physiological and behavioral changes. Responses can be seen in the respiratory, circulatory, immunological, and thermoregulatory systems. Individual responses vary, requiring extensive studies to develop the statistical base to describe the probabilistic response of the animal population. The number, diversity, and interactions of response variables to multiple stressors, including air quality, makes quantification of the effects difficult at best (Janni 1989).

The impact of airborne contaminant on animals raised for food has been very difficult to assess. There are a number of published papers dealing with this issue, but there is no consensus to date as to whether airborne contaminants at levels found commonly in animal facilities has an impact on animal health and performance.

Particulates

Airborne particulate or dust is considered to be a health risk for workers exposed over a prolonged period of time. There is no literature demonstrating any effects of dust on the health of pigs, cattle, or poultry (Heber and Stroik 1988). Pigs exposed to ammonia, hydrogen sulfide, and airborne dust at concentrations at or higher than those typically found in pig finishing houses had little effect on body weight, rate of gain, or respiratory tract structure (Curtis and others 1975a).

Gases

Animals housed in intensive production systems (essentially housed indoors) such as those commonly found in Minnesota, are exposed to a number of different atmospheric gases at levels that are higher than those found outdoors. Although many gases were identified in and near animal housing systems only two, ammonia and hydrogen sulfide, have been studied extensively for their effect on animal health. Many of the other gases are at trace levels and are not normally considered to limit farm animal productivity (Scott and others 1983). Concentrations of carbon monoxide, hydrogen sulfide, nitrogen sulfide, and methane were below detectable levels in Minnesota turkey barns (Mulhausen and others 1987).

Studies on the effect of ammonia on swine have yielded mostly negative results, when studied with levels found in commercial farms (Jacobson and others 1985). Pigs exposed to ammonia and hydrogen sulfide concentrations at typically found in pig finishing houses had little effect on body weight, rate of gain, or respiratory tract structure (Curtis and others 1975a). A couple of studies have shown that pigs exposed to high ammonia concentrations, greater than 50 ppm,

develop more lung lesions due to Ascaris larvae migration and more Atrophic Rhinitis lesions when challenged with the causative organism for this disease (Hamilton and others 1999). Studies performed at farm ammonia levels have also found negative effects on growth, up to a 1-6% difference in feed efficiency in gilts. However, these studies compared two different production systems. The differences observed could have therefore been the result of less microbial exposure and not only the effect of the presence of ammonia (Diekman and others 1997; Diekman and others 1993).

Studies on turkeys have shown that ammonia can affect turkeys. Nagaraja et al. (Nagaraja and others 1983) found that prolonged exposure to ammonia at concentrations as low as 10 and 40 PPM damaged tracheal tissues in turkeys.

Hydrogen sulfide (H_2S) is a very toxic gas, as mentioned previously, which is also derived from the decomposition of manure. Unlike ammonia, which is water soluble and lighter than air, H_2S is heavier than air and tends to stay in the lowest points in a barn such as the pit area. As with the human safety concern when manure in pits or tanks are agitated and pumped onto cropland, the sudden death of housed animals in these confined barn has been reported (Curtis 1981). Several (estimated to be 5 to 10 per year) of these occur each year in Minnesota, even though numerous organization, including the University of Minnesota Extension Service, recommend that buildings be empty of animals when deep pits are agitated and pumped.

Biogenics

Airborne endotoxins, microbes, and pathogens are other airborne contaminants that may pose a health risk to animals housed inside buildings. Although colony forming units (CFU) have been measured in animal facilities, especially poultry units, the significance of this microbial exposure on the impact of health and performance of poultry is not well established. As noted by Hartung (Hartung 1994) this could be due to different responses to airborne microorganisms. One response causes respiratory disease if specific microbes (pathogens) are present in the environment in sufficient number to cause infection. Another response may be non-specific where the immune system is stimulated by exposure and over time it is compromised (Hartung 1994).

Another reason why it is difficult to separate the impact of microbial insult from that of other air contaminants, such as dust and ammonia, is that pathogens may attach themselves to dust particles thus making it difficult to distinguish or isolate the impact they have on an animal. For example, on-farm air quality monitoring of turkey flocks and their performance has indicated higher rates of carcass condemnation for turkeys marketed in the winter as compared to the summer (Debey and others 1995; Janni and Redig 1986). This carcass condemnation is most often attributed to air sacculitis indicative of respiratory disease. However, overall air quality in the winter season is poorer with higher observed levels of ammonia, dust, bacteria, and fungi.

Many poultry veterinarians are of the opinion that the microbes are opportunistic and that other conditions need to be present in order to allow infection to occur which is supported by research. Barnes (Barnes 1982)cites evidence that reproduction of respiratory disease is difficult in a research laboratory using the infectious agent alone. Poss (Poss 1994) has indicated that respiratory disease in turkeys is often preceded by exposure to ammonia and dust, which reduces defense capabilities of the respiratory system. In fact Janni and Redig (Janni and Redig 1986)

found that direct exposure of turkeys to aspergillus spores did not cause the expected development of aspergillosis in turkeys. Rearing of turkeys in the presence of varying levels of ammonia without dust exposure also resulted in no negative effects. However, exposure of poultry to ammonia followed by challenge to respiratory diseases often worsens infection rate (Anderson and others 1966; Nagaraja and others 1984). Dust is of concern as well due to the association of some bacteria and virus with dust particles of respirable sizes (Carpenter and others 1986). Once the disease organisms are introduced to the flock, dust plays a role in the transmission among the birds.

Thus the interaction of the air contaminants and other environmental conditions may be as important as defining the airborne microbial environment. As indicated in a review (Halvorson and Noll 1989), there are many factors in the environment and management of poultry houses that could affect respiratory disease. Litter moisture, ventilation rate, environmental temperature, heat stress, vaccination programs, and water sanitation.

Summary

Although a large number of studies on the effect of air contaminants on animal health have been published, the results are inconclusive. Some effects have been shown with some gases such as ammonia, but generally at levels that were higher than those found in farm conditions. Airborne pathogens may show the most potential for impacting animal health but even there it seems to take a combination of dust, gases, and pathogens to obtain a measurable health effect. Some studies have been able to show adverse effects of these air contaminants, but others have not.

MITIGATION AND EMISSION CONTROL TECHNOLOGIES (QUESTION 4)

INTRODUCTION

Odor and gas emissions from animal production sites originate from three primary sources: buildings, manure storage and treatment facilities, and land application of manure. In this review, a detailed description of the methods and technologies to control odor and other emissions from animal and poultry facilities include the following: dietary manipulations, dust control techniques, ozone systems, biofilters, covers, mechanical solid separation, composting, anaerobic treatment systems, aerobic treatment systems, electrolytic treatment, injection and incorporation of manure during land application, and various product additives that can be incorporated into the feed, waste treatment, handling or storage systems. A summary is provided in **Table 15**.

The table includes a short description of the system/process, advantages and disadvantages, cost (when available), and research status. Advantages and disadvantages are usually in terms of the ability or effectiveness of the process/system in reducing odor and gaseous emissions. There is also some information on costs (mainly capital costs), but this has not been standardized. Cost may be given on a per pig basis (because most research has essentially focused on swine manure) or on a per area basis (in terms of the amount of material needed). On the research status column, there is information on when research was done under a particular process/system, if there is on-going research, and if there is need for more research. Specific references have not been included in this table. Detailed information is given in the main text. In most topics, background information (*i.e.* how the mitigation technology works) is given in order to allow the reader better understand the concept behind the management, effectiveness and cost of different systems.

DIET MANIPULATION

Until recently, most of the research related to technologies for reducing livestock-related gases and odors has focused on manure handling and storage systems. Research related to diet manipulation to reduce excretion of odor and gas producing products from animal manure has been limited. However, several researchers believe that our ability to modify livestock diets to significantly reduce odors is a promising mitigation measure. In order to explore the full potential of diet modification for reducing odors, significantly more research is required to identify practical, cost effective dietary changes for each species. Most published research results have focused on dietary modification to reduce ammonia emissions, with only a few studies attempting to determine the effects of diet modification on odor or other odorous gases. Furthermore, the majority of studies have focused on swine, with fewer studies being conducted for poultry, dairy, and beef.

Livestock diets have been manipulated by adding feed additives to bind ammonia, change digesta pH, alter specific enzyme activity, and mask odors (Sutton and others 1999). However, these dietary modifications have either been costly or not consistently successful (Sutton and others 1999).

Binding Agents

Krieger et al. (Krieger and others 1993) tested the ammonia binding ability of a naturally occurring zeolite (clinoptilolite) in pig manure and found no benefit. Furthermore, Shurson et al. (Shurson and others 1983) fed a diet containing 5% zeolite A (synthetic zeolite) to growing pigs

and found an increase in fecal nitrogen excretion and an increase in urinary p-cresol excretion. Miner (Miner 1995) reported that addition of 5% charcoal to diets of weanling pigs showed a reduced odor score.

Change Digesta pH

In an earlier literature review, feeding microbial compounds resulted in no consistent effects on reducing odors (Kreis 1978). Attempts to reduce digesta pH of weanling pigs by feeding *Lactobacillus acidophilus* in liquid or dry form had no effect on odor panel scores (Miner 1975). However, feeding dry *L. acidophilus* and yeast reduced skatole and indole after a two-week incubation period (Miner 1975). Risely et al. (Risley and others 1992) showed that adding the organic acids, fumaric or citric acid, to the diet at a rate of 1.5%, had little effect on pH and volatile fatty acid production, suggesting little effect on odor control. Fermentable carbohydrates (i.e. soybean hulls) were included in the diets of finishing pigs by Canh et al. (Canh and others 1996)to lower the pH of the feces excreted which resulted in lower ammonia emissions but made an increse in VFA concentrations, and thus odor.

Alter Specific Enzyme Activity

Yucca schidigera extract has been shown to reduce ammonia emission from manure by inhibiting urease activity (Ellenberger and others 1985; Gibson and others 1985; Goodall and others 1988). Sutton et al. (Sutton and others 1992) showed that ammonia emission was suppressed by 55.5% in swine manure from pigs fed sarsaponin extract at a rate of 4 oz/ton of feed, but Kemme et al.(Kemme and others 1993) was unable to verify this response, and showed that much higher amounts of the extract (6000 ppm) was needed for maximal suppression of ammonia from urea. Similar results have been obtained with poultry.

Masking Agents

Work by Matsushima reported in *Feedlot Management* (Feedlot Management 1972) showed that adding sagebrush to cattle diets reduced cattle feedlot odor. However Kellems et al. (Kellems and others 1979)add sagebrush up to 1.5% of the diet for cattle and found no effect on reducing odor in cattle manure, but when 0.25% peppermint oil was added to the diet, odors were reduced.

IMPROVING DIETARY NUTRIENT UTILIZATION TO REDUCE EXCRETION PRODUCTS

The use of improved feeding management practices, selective feed ingredient use, precision in diet formulation, and dietary electrolyte balance have been shown to reduce nutrient excretion, and subsequent, odor and gas emissions from livestock manure.

Reduced Crude Protein Diets

Reduced crude protein diets containing synthetic amino acids have been shown to reduce nitrogen excretion by 25 to 30% in pigs, which can lead to reduced ammonia emissions (Bridges and others 1994; Cromwell and Coffey 1993; Jongbloed and Lenis 1993; Hartung and Phillips 1994). Reductions in ammonia emissions from 28 to 79% through diet modifications in swine have been reported (Sutton and others 1999). Reducing the crude protein content in dairy cattle rations has been shown to reduce hydrogen sulfide content of manure and emissions (Stevens

and others 1993). Feeding excessive levels of the amino acid tyrosine (3% of the diet), increases p-hydroxphenylacetic acid and p-cresol in urine of pigs (Radecki and others 1988)

Table 15. Summary of technologies for odor control

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Diet manipulation	Feed Additives	Binding agents (zeolite, charcoal)	May reduce odor	Increase in fecal N excretion	N/A	Research done in 1975, 1984 and 1993.
		Change digesta pH	Apparently none	Little effect on odor control	N/A	Research done in 1975, 1978 and 1992.
		Alter specific enzyme activity (*Yucca schidigera*, sarsaponin extract, etc.)	May reduce odor and NH_3 emissions.	Not known yet	N/A	Research done in 1992, 1993 and 1998. Needs more research.
		Masking agents	May reduce odor	Inconsistent results	N/A	Research done in 1972 and 1979.
		Add fat or oil to the feed	Reduces dust and may reduce odor	Not known yet	N/A	Research previously done in 1975, 1982, and 1987. Recent and on-going research.
	Improving dietary nutrient utilization	Synthetic amino-acids and low crude protein content	Lower N content in the manure, reduces odor, H_2S and NH_3 emissions	Excessive levels of synthetic amino-acids may increase concentration of odorous compounds in urine	N/A	Recent and on-going research.
		Ingredient selection and feed processing (reduced sulfur feed ingredients, distiller's dried grain, carbohydrates, etc.)	Reduces odor, H_2S and NH_3 emissions depending on the type of ingredient used	Not known yet	N/A	Recent and on-going research.
		Dietary electrolyte balance	Affects urinary pH and may reduce NH_3 emissions	Not known yet	N/A	Recent and on-going research.
	Manipulating microflora metabolism in the digestive tract	Non-starch polysaccharides and oligosaccharides that alter the microflora	May reduce odor emissions	Little effect on NH_3 emissions	N/A	Very little research has been done. Needs more research.
		Specific microbial cultures	May reduce odor, H_2S and NH_3 emissions	Not known yet	N/A	Very little research has been done. Needs more research.

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Diet manipulation	Manipulating microflora metabolism in the digestive tract	Antibiotics	May reduce odor emissions	Not known yet	N/A	Very little research has been done. Needs more research.
		Tea polyphenols	May reduce odor and NH_3 emissions	Not known yet	N/A	Recent and on-going research. Needs more research.
Dust reduction	Oil sprinkling	Vegetable oil is sprinkled daily at low levels in the animal pens	Helps in the reduction of airborne dust and odors	Creates an oily environment and greasy residue on the floor and pen partitions if too much oil is sprinkled	$1.00 per pig space	Recent research efforts. Needs more research, especially for curtain sided, naturally ventilated barns.
	Air filtration	Single and dual phase air filters, electrostatic precipitators	Very efficient in removing dust from air streams	Expensive and not very practical	N/A	Previous research done in 1981, 1984 and 1989. More recent research done in 1995.
	Biomass filters	Uses chopped cornstalks and corncobs as the filter substrate	Efficient removal of dust and odor (60 to 90%) at low ventilation rate	Lower efficiency at summer ventilation rates	N/A	Recent and on-going research. Needs more research.
	Wind-break walls	A wall made of tarp or with any other material (wood panels, metal sheets, straw) is placed about 10 to 20 ft from exhaust fans.	Trap dust particles in wall surface. Help disperse and dilute odors. Reduces dust and odor emissions.	Periodic cleaning of dust from the walls is necessary for sustained odor control. May be difficult to apply in naturally ventilated barns.	$1.50 per pig space	Recent and on-going research. Needs more research.
	Shelterbelts	Rows of trees and other vegetation are planted around a building, thus creating a barrier for both dust and odorous compounds removal from building exhaust air.	Help disperse and dilute odors. May reduce dust and odor emissions.	It may take several years to grow an effective vegetative wind-break	N/A	Recent and on-going research. Needs more research.

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Dust reduction	Biological and chemical wet scrubbers	Odorous gases are passed through a column packed with different media types; water (and/or chemical) is sprayed over the top of column to help optimize biological and chemical reactions.	Reduce dust, odors, H_2S and NH_3 emissions effectively	Capital and operational costs; disposal of collected pollutants	N/A	Recent and on-going research.
	Washing walls	A wetted pad evaporative cooling system is installed in a stud wall about 1.5 m upwind of ventilation fans and downwind of hogs in a tunnel ventilated building.	Reduces about 50% of dust and 33% of ammonia at medium ventilation rate	Residence time inside the pad is very small thus odor removal may not be highly effective	$5.70 per pig space	Recent and on-going research. Needs more research.
	Other controls	Building hygiene, water sprinkling in open feedlots, increase air exchange rates	Reduce dust emissions	May expose worker to high levels of airborne dust during cleaning operation or when higher ventilation rates are used	N/A	Research done in 1978, 1982, 1988, 1989, 1993 and 1996.
Air treatment	Ozonation	Odorous gases are oxidized by ozone that is distributed inside the barn at low concentrations	May reduce dust, odor, H_2S and NH_3 emissions	Ozone can be toxic to humans and animals at 0.1 ppm for an 8-hour exposure period	$6.00 to $11.00 per pig space	Recent and on-going research. Needs more research.
	Non-thermal plasma	Odorous gases are oxidized when passed through plasma	Reduces H_2S and NH_3 emissions effectively (from laboratory scale experiments)	Not known yet	N/A	Recent and on-going research. Needs more research.
	Biofilters	Odorous gases are passed through a bed of compost and wood chips; bacterial and fungal activity help oxidize organic volatile compounds	Reduce odors and H_2S emissions effectively	May need special fans because of pressure drop; some management required	$0.50 to 0.80 per pig space	Recent and on-going research. Needs more research on media characterization, design model, leaching and application to pit ventilation only.

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Covers	Rigid covers	A roof or concrete lid is placed on the top of the manure storage tank. Gases that are produced must be vented and may undergo treatment (*e.g.* through biofilters)	Reduce odor, H_2S and NH_3 emissions effectively	More expensive than other types of covers; the cover concept may affect the overall water balance on the farm; more land is needed for manure application (higher N content)	$50,000.00 (capital cost of a concrete cover for 200 sow to finish operation)	Recent and on-going research. Needs more research related to the effects on water balance and nutrient content of the covered manure.
	Flexible covers	Plastic cover is placed on the top of the manure storage tank. Cover may be inflated. Gases that are produced must be vented and may undergo treatment (*e.g.* through biofilters)	Reduce odor, H_2S and NH_3 emissions effectively	Usually need supporting structure; difficult to apply on earthen basins; require some management by the farmer for agitation and pumping; the cover concept may affect the overall water balance on the farm; more land is needed for manure application (higher N content)	$1.50 to 2.00 per ft^2 for a plastic cover; $90.00 to $100.00 per linear ft of diameter for an inflated cover)	Recent and on-going research. Needs more research related to the effects on water balance and nutrient content of the covered manure.
	Permeable floating covers	Straw and other materials (geotextile, polystyrene foam, air-filled clay balls, etc.) are placed on the surface of manure	Reduce odor, H_2S and NH_3 emissions	Straw covers are a temporary solution only; require some management by the farmer for agitation and pumping; geotextile may sink; the cover concept may affect the overall water balance on the farm; more land is needed for manure application (higher N content)	$0.10 per ft^2 for a straw cover; $0.20 to 0.25 per ft^2 for geotextile; $2.00 to 5.00 per ft^2 for air-filled clay balls	Recent and on-going research. Needs more research related to the effects on water balance and nutrient content of the covered manure.

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Manure treatment	Solid separation	Solids are separated from liquid slurry through sedimentation basins or mechanical separators	May reduce odor and NH_3 emissions; reduces liquid volume; easier agitation and pumping	Capital and operational costs; reliability; adds another "waste" stream to be dealt with by the farmer	$1.00 to 3.00 per pig	Some past research was related to separators' efficiency in removing solids, organic matter and nutrients. Needs more research related to the effect of separation techniques on odor and gaseous emissions.
	Chemical addition	Different chemicals are added to the manure prior to agitation and pumping in order to bind odorous compounds, keeping them in solution or facilitating their precipitation to the bottom of the tank	May reduce odor, H_2S and NH_3 emissions; may also precipitate P if needed	Chemicals may be expensive and hazardous in nature (*e.g.* corrosive)	N/A	Some past and recent research have focused on chemical addition for improving solid separation and precipitating phosphorus. Needs more research related to the effect of chemical addition for odor and gaseous emissions reductions during agitation and pumping.
	Solid and liquid composting	Biological process in which aerobic bacteria convert organic material into a soil-like material called compost;	Reduces odor and organic matter in the final product; produces a saleable product; can include other by-products	Capital and operational costs; actual composting operation may emit odor and gases (NH_3) if not properly managed; marketing skills required if product is to be sold	$0.20 to 0.40 per pig for solid composting; up to $6.00 per pig for liquid composting	Recent and on-going research. Needs more research related to odor and gaseous emissions control in composting facilities.
	Aerobic treatment	Biological process where organic matter is oxidized by aerobic bacteria; mechanical aeration is required in order to supply oxygen to the bacterial population	Reduces odor, organic matter effectively; also can reduce nutrients if needed	Capital and operating costs; separation step is necessary for most slurries	$2.00 to 6.00 per pig	Research done in the past focused on reduction of organic matter. Recent and on-going research is focusing on odor control and potential gas emissions. Needs more research on partial aeration strategies.

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Manure treatment	Anaerobic digestion - lagoons	Biological process where organic carbon is converted to methane by anaerobic bacteria under controlled conditions of loading; there is no control over temperature and gaseous emissions	Stabilizes organic matter; produces biogas (that is not usually collected);	Periodic overloading and turnover in the spring may result in odor emissions; there have been concerns on the leaching of earthen basin lagoons and NH_3 emission from the surface	$0.50 to 1.00 per pig	Research done in the past focused on reduction of organic matter and nutrients. There has also been some research related to leaching. Recent research on NH_3 but needs more research on this and other gaseous emissions.
	Anaerobic digestion - digesters	Biological process where organic carbon is converted to methane by anaerobic bacteria under controlled conditions of temperature and pH;	Stabilizes organic matter; produces biogas; retains nutrients; easier handling of liquid	Capital cost; may require a reasonably skilled operator; attractive where energy supply is an issue	$250,000 capital cost; may produce $$$ worth of energy if properly operated	Research done in the past focused on stabilization of organic matter. There has also been research related to the land application of anaerobically digested manure in terms of odor and NH_3 emissions.
	Electrolytic treatment	A pair of copper electrodes is used to treat stored manure; small quantities of metal ions dissolved through electrolysis are apparently able to kill some microorganisms	May reduce odor, H_2S and NH_3 emissions	Process is not completely understood and can be costly	N/A	Needs more research.
Product additives	Microbiological additives	Contain mixed cultures of enzymes or microorganisms designed to enhance solids degradation and reduce gaseous emissions	May reduce odor and gaseous emissions	Inconsistent results; variable success; may not achieve desirable results under field conditions	$0.25 to 1.50 per pig	Recent and on-going research.
	Masking agents	Made from a mixture of compounds that have a strong odor of their own; cover one smell with another "more pleasant"	Low cost and non-hazardous nature	Effectiveness is difficult to predict	$0.25 to 0.50 per pig	Recent and on-going research.

Process/System		Description	Advantages	Disadvantages	Cost	Research status
Product additives	Counteractants	Reduce the perceived odor level by eliminating objectionable characteristics of the malodor	Easy and safe to handle	Effectiveness is difficult to predict	$0.25 to 0.75 per pig	Recent and on-going research.
	Adsorbents and absorbents	Chemical or biological materials that can collect odorous compounds on their surfaces (adsorb) or interiors (absorb)	May reduce odor in certain conditions	Effectiveness is difficult to predict	$0.25 to 1.50 per pig	Recent and on-going research.
Land application	Manure incorporation	Manure is rapidly incorporated in the soil after spreading with ploughing	Reduces odor and NH_3 emissions	Requires some management by the farmer and additional energy for incorporating	N/A	Most research has been done in Europe. Very little research done in the U.S. More research needed on odor emission from manure spreading operations.
	Band spreading	Manure is discharged at ground level through a series of trailing pipes	Reduces odor and NH_3 emissions	Manure must be rapidly incorporated to avoid odor emission and NH_3 losses	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.
	Manure injection	Manure is injected into the soil (shallow and deep injection)	Reduces odor and NH_3 emissions effectively	Expensive equipment	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.
	Treated manure	Aerobically treated or anaerobically digested manure is applied to the soil	Reduces odor effectively	Biological treatment of manure is expensive	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.
	Acidified manure	A chemical compound is added and mixed into the manure just before spreading	Reduces NH_3 emissions effectively	Chemicals may be expensive and are hazardous in nature (*e.g.* corrosive)	N/A	Most research has been done in Europe. More research needed on odor emission from manure spreading operations.

Ingredient Selection and Feed Processing Methods

Ingredient selection and feed processing methods designed to reduce antinutritional factors have been shown to reduce nitrogen excretion (Jongbloed and Lenis 1991). Research that has been carried out at University of Minnesota (Whitney and others 1999) showed that use of reduced sulfur feed ingredients in diets for nursery pigs reduced sulfur excretion, tended to reduce hydrogen sulfide and odor emissions, but had no effect on ammonia emissions or pig growth performance. Additional studies at University of Minnesota are being conducted to determine if adding 20% distiller's dried grains with solubles to swine diets will reduce odor, hydrogen sulfide, and ammonia (Shurson 1999). Imbalances of the dietary carbon:nitrogen ratio in the intestinal contents of the pig will increase the level of odor producing compounds and reduced nutrient utilization efficiency (Drochner 1987; Kaufmann 1986). In swine, feeding diets containing a higher proportion of complex carbohydrates such as cellulose, B-glucans and other non-starch polysaccharides shift nitrogen excretion toward feces and away from urine, which reduces ammonia emissions (Kreuzer and Machmuller 1993; Mroz and others 1993). Feeding a low carbohydrate, high fiber diet (alfalfa meal and rice bran) to pigs reduces excretion of fecal volatile acids compared to pigs fed a corn starch and glucose diet (Imoto and Namioka 1978). However, Hawe et al. (Hawe and others 1992) showed that feeding a diet containing increased fiber from beet pulp, increased the concentration of two odorous compounds, skatole and indole, in feces, but levels of these two compounds tended to be reduced when pigs were fed the antibiotic tylosin phosphate. Lactose had no effect on reducing indole concentrations but did reduce daily excretion of skatole.

Dietary Electrolyte Balance

Canh (Canh and others 1998) and Mroz et al. (Mroz and others 1996) showed that dietary calcium salts and electrolyte balance significantly affect urinary pH and subsequent pH and ammonia emissions from slurry. Mroz et al. (Mroz and others 1998) showed that increasing the levels of calcium benzoate in sow diets reduced urine pH from 7.7 to 5.5 and reduced ammonia emissions up to 53%.

Manipulating Microflora Metabolism in the Digestive Tract through Nutrition

Although some studies have been conducted to show that the addition of nonstarch polysaccharides and specific oligosaccharides to the diet alters the route of nitrogen excretion and reduces odor emission, more research is needed to determine the effects of digestive microflora changes when various substrates are added to the diet. Furthermore, the effects of feeding specific microflora cultures (probiotics) to livestock on reducing odor, and the conditions where these microbial cultures have the ability to compete with indigenous populations are poorly understood. Very little research has been done to determine the effectiveness of feeding antibiotics on odor and gas reduction. Some microbial groups that have an ability to produce or utilize odorous compounds have been identified, but considerably more research is still needed to identify groups of microflora that significantly contribute to the production of odorous compounds.

Nonstarch Polysaccharides and Specific Oligosaccharides

Feeding diets containing complex carbohydrates (fructooligosaccharides, mannan oligosaccharide, lactulose, galactan, ammonium propionate, and sucrose thermal

oligosaccharides) or organic acids to swine alters the microflora in the digestive system (Bailey and others 1990; Mathew and others 1993; Orban and others 1997; Sutton and others 1991). Feeding fructooligosaccharides and sucrose thermal oligosaccharides to pigs and broilers increase bifido bacteria and reduce odorous compounds in manure (Hidaka and others 1986; Orban and others 1993; Orban and others 1997). However, including galactan (Mathew and others 1993) or ammonium propionate (Sutton and others 1999) in the diet had little effect on ammonia emissions, increased the volatile fatty acid propionate, and decreased production of butyric and acetic acids.

Specific Microbial Cultures

A study at the University of Minnesota is being planned (Shurson 1999) to determine the effectiveness of a *Bacillus subtilus* microbial feed additive on reducing odor, hydrogen sulfide and ammonia emissions. This product has apparently been successful in reducing odors in pig operations in Japan.

Antibiotics

Very little research has been conducted to determine the effectiveness of feeding antibiotics to livestock on reducing excretion of odorous compounds. One study conducted with swine showed that effectiveness of antibiotics in reducing excretion of odorous compounds appears to be antibiotic specific. Feeding the antibiotic combination of chlortetracycline, sulfamethazine, and penicillin, reduced urinary excretion of p-cresol, but feeding lincomycin sulfate had no effect on p-cresol excretion in swine (Yokoyama and others June 1982).

Tea polyphenols

Dietary inclusion of tea polyphenols has been shown to reduce the production of ammonia, phenol, p-cresol, ethylphenol, indole, and skatole in swine feces and chick cecal contents (Sutton 1998). Tea polyphenols have also been shown to reduce some pathogenic organisms including *Mycoplasma pneumonia, Staphylococcus aureus,* and *Clostridium perfringes* (Hara and Ishigami 1989; Chosa and others 1992). However, Veum et al. (Veum and others 1997) did not observe any effects of tea polyphenols on odor compounds.

Summary

The use of feed additives and/or dietary modifications for livestock and poulty to reduce odors from excreted manure has produced varied results. the chemical and biological processes of animal digestive systems are complex, often resulting in some odorous compounds being reduced but others increasing in concentration, as a result o fsome change or addition in the diet. Further research is necessary to make sure an integrated approach is used and the effects are found.

DUST AND BIOAEROSOLS CONTROL

Airborne dust levels in and emissions from animal facilities are an increasing concern for animal production systems. Dust in and from animal facilities consists of mainly organic materials like: feed, bedding, animal dander (skin and feathers), dried manure, and inert particles (Koon and others 1963; McQuitty 1985).

Dust has been shown to exert adverse health effects on animal and human health. It may also impair the performance of equipment (Carpenter 1986; Dawson 1990).

A multi-country northern European study (Seedorf and others 1998; Takai and others 1998; Wathes and others 1998) of emissions of airborne pollutants within and from livestock buildings has been recently carried out. Authors of this study note that the European Union requires its member states to develop limits on pollutant emissions from new, large production sites for poultry (>40,000 birds) and pigs (>2000 fattening pigs or 750 sows). European levels for animal exposures to pollutants are: 20 ppm ammonia, 3000 ppm CO_2, 3.4 mg/m^3 inhalable dust, and 1.7 mg/m^3 respirable dust.

Discussion of the results of this study describe the following techniques and issues with respect to airborne pollutant emission control:

No single technique will control airborne emissions due to complexity of sources

Care must be taken not to raise one pollutant while lowering another; calling for an integrated solution

A combination of husbandry practices and engineering controls will provide the best control of dust and airborne pollutants

More research is needed on preventing emissions at the source or cleaning the air prior to emission

Multiple demands are placed on ventilation systems, including the control of 1) air temperature, 2) relative humidity to relieve heat stress and suppress dust generation from bedding, and 3) airborne pollutants to lower animal and worker exposures as well as to prevent discharge of unwanted pollutants to the environment. Design algorithms are not sophisticated enough to handle all of these control needs.

Because of the relatively large concentrations of dust in livestock facilities, controlling dust in these environments is a problem. Takai et al. (Takai and others 1998) and Maghirang et al. (Maghirang and others 1993) suggested that there are three ways to reduce dust in ventilated animal facilities: reduce the generation or emissions of dust, remove or capture the airborne dust, and increase the dilution or ventilation rate. An example of each of these would be: (1) addition of animal fat in feed to lower dust generation rates; (2) circulating air through a dust filter to capture it from the air; and (3) using an open sided building (natural ventilation) to allow for greater levels of air exchange.

Change in Feed Composition

Reducing the generation of dust in and from animal facilities generally involves preventing particulate matter from becoming airborne. Some research has suggested that feed is perhaps the greatest source of dust in livestock buildings. Evaluation of changes in feed composition or feed coatings indicate that such changes can result in lower dust levels (Chiba and others 1985; Chiba and others 1987; Pearson and Sharples 1995; Takai and others 1996). Numerous studies have shown a sizable reduction (35 to 70%) in dust levels inside barns when anywhere from 1 to 4% fat/oil is added to the feed (Chiba and others 1987; Heber and Martin 1988; Takai and others 1996). This technique or practice has been used extensively in the pig and poultry industries, partially because of the dust reduction capabilities, but also because of the nutritional (additional

energy) benefits of the diets. Feeding system alternatives (Bundy and Hazen 1975), such as using pelleted vs. ground feed, using wet vs. dry feeders, and even the use of liquid feeding have not been extensively evaluated in regard to how they control dust levels in animal buildings (Pearson and Sharples 1995). It has been noted, however, that the benefits to animal and human health must be made more explicit to encourage farmers, feed producers and feed delivery system manufacturers to consider changing feed formulation or delivery as a means of lowering dust levels.

Oil Sprinkling

A similar approach to reducing dust is by spraying various types of vegetable oils inside animal buildings to reduce indoor airborne dust levels. Dust suppression by the sprinkling of oils and other materials have shown to effectively reduce airborne dust levels, with few apparent side effects (Mankell and others 1995; Takai and others 1995). Takai et al. (Takai and others 1993) found that dust levels could be reduced from 60 to 80% when canola oil was sprayed daily with a high pressure dispensing system in a pig nursery building. They also found that little or no health problems existed with the pigs that were exposed to this oil treatment. Zhang et al. (Zhang and others 1996) showed a similar reduction of dust by simply spraying or sprinkling canola oil once a day with a hand-held sprayer in the pens of a pig-finishing barn. Jacobson et al. (Jacobson and others 1998) used this same oil sprinkling technology (Zhang 1997) to determine if lowering the dust generation also reduced odor emissions from a pig nursery barn. Somewhat mixed results were found as were some disadvantages to this practice, including worker safety issues (slippery floors) and more time needed to clean the room between groups.

Air Filtration

Carpenter and others suggest that air filtration is the most cost-effective and efficient method for removing dusts (Carpenter 1986). Air filtration can serve many purposes, including the prevention of disease entry into the building by lowering the concentration of bacteria of inlet air and the minimization of cross-infection between buildings. Carpenter (Carpenter 1986) states that, "However, it is not normally practiced because of the high costs that would be incurred due to the large volumes of air and high dust loadings involved."

While external sources of dust are important, most of the larger particles and airborne microorganisms are generated by sources within livestock buildings. Internal recirculating filtration systems can be used to lower internal levels from these sources. Research with washable electrostatic filters demonstrated significant decreases in airborne dust levels (Carpenter 1986). A dual-phase filter (a coarse cleanable pre-filter followed by a more efficient filter for fine particles) also demonstrated significant decreases in dust levels (50 to 60 % of the dust mass) in swine confinement buildings (Carpenter and Fryer 1990).

Electrostatic precipitators have been used to reduce dust in the US (Bundy 1984; Bundy 1991) by 55 to 60 % and in Europe (Moller F.) by 40 to 60%. Several studies used a commercial wet scrubbing process to remove dust from the air with water (Wark and Warner 1981; Pearson and Sharples 1995) and one investigation reported up to a 90% reduction in dust levels in the exhaust air (Pearson 1989) by use of wet scrubber technology.

Using water to scrub odorous dust, ammonia, hydrogen sulfide and other gases from the airflow from swine building ventilation fans can be an effective method of controlling dust, odor and

some gaseous emissions. Many industrial air pollution control systems use sprays of water to scrub dust, NH_3, SO_x and NO_x from various polluting air streams. In a wet scrubber an alkali is usually added to react with acidic pollutants. This can be calcium oxide, quicklime calcium carbonate, or a magnesium or sodium alkali. The wastes produced in scrubbing must either be regenerated using additional energy, disposed of as a solid, or used in some manner.

Some swine producers in the U.S. and Taiwan have tried spraying water into the fan airflow (*e.g.* spray nozzles are mounted on the fan housing) with limited success (Bottcher 1999). However, this approach may require a large amount of water unless the spray is collected and recirculated.

Chiumenti et al. (Chiumenti and others 1994) used an air washing system in a mechanically ventilated swine unit in Northern Italy. Air cleaners were installed behind the fans to filter all the exhaust air. The air cleaning system operates using a two-stage mechanical wet separation system. Exhaust air (0.4 to 0.7 ft/sec) passed through a pre-cleaning chamber provided with 20 water sprinklers. It then passed through the main separation chamber that was made of steel with polycarbonate panels. A continuous fresh water curtain was created in this chamber by running water over a plastic net. Maximum water flow was 28 ft^3/hour. Wastewater was periodically discharged into the farm's manure treatment system. The air cleaning system reduced dust by 44% and ammonia levels by 58%. The estimated energy consumption for this system was 83 watts/pig-day.

A wet scrubber design that recirculates most of the water through the system has been tested in North Carolina (Bottcher and others 1999). This design involves a wetted pad evaporative cooling system installed in a stud wall about 4 feet upwind of ventilation fans and downwind of the pigs in a tunnel ventilated building. The scrubber is comprised of an evaporative cooling pad system with water recirculation, using 6 in. thick plastic evaporative pad media. A 1,500 gal. sump outside of the building contains system water and facilitates solids settling. The producers and system designers have termed this a washing wall, since all of the ventilation airflow passes through the wet pad before being exhausted through the fans, and some contaminants are washed from the air. The term wetted pad wall is more descriptive.

Recent measurements taken by Bottcher et al. (Bottcher and others 1999) show that the system can apparently reduce total dust levels as much as 65% at a relatively low ventilation rate, but only by about 16% at a high airflow rate typical of maximum, hot weather ventilation. Results from the model tests are consistent with these data. Particle reductions ranged from 0 to 63% at a pad face air velocity of 17 ft/min and from 14 to 77% at a face velocity of 63 ft/min. The estimated total dust mass, computed based on particle diameters (Parbst and others 1998), was reduced by 32% and 69% at the low and high airflow rates, respectively. Although the changes in odor levels across the wet pad scrubber were not as great as desired at the high ventilation rate, the data does indicate a modest odor reduction, consistent with the dust reduction. These results agree with other observations that dust removal from swine building airflow is associated with odor reduction (Hoff and others 1997a). The wetted pad wall also reduced ammonia levels in the ventilation airflow by 50% at low ventilation rates and 33% at a medium ventilation rate. It is possible that chemicals can be added to the pad water to enhance removal of ammonia, hydrogen sulfide and other gases and odorous compounds, but the contact time is probably too short for the chemical products to work effectively. In fact, air may spend as little as 0.1 seconds

Table 16. Operating data and removal efficiency from a biomass filter.

Filter type	Surface area	Air Flow	Dust removal	Odor reduction
Three-tiered horizontal	20.4 m^2	2298 m^3/h	67 %	61 to93 %
Vertical cascade impactor	8.8 m^2	3060 m^3/h	62 %	0 to 84 %

inside the pad at high ventilation rates. Wetted pad wall installation costs are approximately $5.70 per pig space for an 880-head finishing building (Swine Odor Task Force 1998).

Several researchers have evaluated bioscrubbers (where the packed bed of the scrubber is seeded with microbes) and wetscrubbers for the reduction of ammonia, odor and dust, especially on swine and poultry farms. Recent research has been reported in the Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities held in Vinkeloord, The Netherlands, between October 6 and 10, 1997. Dong et al. (Dong and others 1997) reported average ammonia removal efficiencies between 32% (wet scrubbing) and 54% (bioscrubbing) from laboratory experiments. Lais et al. (Lais and others 1997) evaluated three different bioscrubbers installed on pig farms. Ammonia reductions varied from 22 to 36% and odor reductions from 61 to 89 %. Siemers and Van den Weghe (Siemers and Van den Weghe 1997) evaluated the effect of different moisturizing methods on ammonia and odor efficiency of wetscrubber/biofilter combinations. Ammonia reductions ranged from 13 to 95% and odor reduction averaged 40%. Bioscrubbers and wetscrubbers can be effective in removing ammonia and odor from animal houses but have not been widely adopted because of difficulties in cleaning sufficient volumes of air at a reasonable cost. Lais et al. (Lais and others 1997), for example, reported capital costs ranging from $9.00 to $17.00 per finishing pig; thus, all of these technologies, although effective, may be quite expensive and not very practical for most animal production units because of the large physical size needed with the high ventilation requirements in animal buildings.

Particulate removal from livestock ventilation exhaust air could be used to control, but not eliminate, odor emissions (Hammond and Smith 1981). Researchers at Iowa State University, for example, have been testing biomass filters to remove particulate material and odorous dust from swine buildings (Hoff and others 1997b). Biomass filters use the principle that dust, if removed from the ventilation exhaust stream, will capture a large portion of the odors with it (Hartung 1985; Borrelli and others 1989; Hagen and Skidmore 1971). To achieve particulate removal Hoff et al. (Hoff and others 1997b) tested two designs of a biomass filter using chopped cornstalks and corncobs as the filter substrate. The first was a three-tiered horizontal filter and the second was a vertical cascade impactor. **Table 16** summarizes the data.

The results indicated that using readily-available crop residue configured as a biomass filter for retaining exhausted particles and the adhered odors may prove to be a worthwhile strategy (Hoff and others 1997a). Dust concentrations were reduced, especially for particles in excess of 10 microns, and rodents can become a management problem as well as changing the biomass periodically. Odor threshold reductions followed closely the particle reduction, although removing 100 percent of the particles will only remove about 75% of the exhausted odors. The above reductions occurred with low resistance to airflow at cold weather ventilation rates.

Windbreak Walls

Walls erected downwind from the fans that exhaust air from tunnel-ventilated poultry buildings are being used on more than 200 farms in Taiwan in order to reduce dust and odor emissions onto neighboring land (Hsia 1998). These structures, known as windbreak walls, provide some blockage of the fan airflow in the horizontal direction. They can be built with various materials covering a wood or steel frame. Plywood and tarp have been used in several places. Walls are placed 10 to 20 ft downwind of the exhaust fans of tunnel ventilated barns. Another variation of the windbreak wall is called a straw wall. Such a system has been built in North Dakota. It is made with a wood structure and "chicken wire." Straw is placed inside the structure, thus providing a barrier to dust and other air emissions. It acts as ab "impaction" plate as well as providing some filtration capability.

Windbreak walls work by reducing the forward momentum of airflow from the fans, which is beneficial during low-wind conditions, as odorous dust settles out of the airflow and remains on the farm. In addition, the walls provide a sudden and large vertical dispersion of the exhausted odor plume, which acts to entrain fresh outside air into the odor plume at a faster rate than would naturally occur, providing additional dilution potential.

The data and observations taken by Bottcher et al. (Bottcher and others 1998) using scentometers at a full scale windbreak wall site in Duplin County, North Carolina have shown that:

- dust builds up on the wall surfaces;
- the walls redirect airflow from the building exhaust fans upward;
- dust and odor levels are greater in the airflow from the fans than 10 ft downwind of the windbreak wall, which also results from the upward deflection of the fan airflow.

A study done in Iowa using a model predicted that tall wind barriers placed around a manure storage or lagoon would reduce odor emissions (Liu and others 1996). Although the operating cost of windbreak walls is relatively low, periodic cleaning of odorous dust from the walls is necessary for sustained odor control, unless rainfall is sufficient to clean the walls.

Research to evaluate windbreak walls for dust and odor control is continuing in North Carolina and also in other states (Iowa, North Dakota). Currently, it is difficult to determine the effectiveness of windbreak walls due to several factors. As wind speed and direction shift, the airflow from building fans changes direction. As a result, it is difficult to measure odor downwind. Also, odors emitted from nearby lagoons and earthen basin storages may complicate the situation. Several researchers believe that measurement of the impact of windbreak walls on airflow and the dust and odor levels in the airflow at the wall location should be incorporated into dispersion models to predict the downwind impacts of those emissions (Swine Odor Task Force 1998).

Rows of trees and other vegetation known as shelterbelts, which have historically been used for snow and wind protection in the Midwest, may also have value as odor control devices. They will also create a visual barrier. A properly designed and placed shelterbelt could conceivably provide a very large filtration surface (Sweeten 1991) for both dust and odorous compound removal from building exhaust air and help disperse and dilute odors, particularly under stable nighttime conditions (Miner 1995; National Pork Producers Council 1996). Currently, there are

no studies available that directly address the total impact of vegetative barriers on odor reduction from animal farms, but many people give testimonials to their benefit. Shelterbelts should be inexpensive, especially if the cost is figured over the life of the shelterbelt, but it may take 3 to 10 years to grow an effective vegetative windbreak. Research is needed to determine if vegetative windbreaks concentrate odor.

Other Controls

Building hygiene is also noted by some to be an important factor in dust levels; poor care of floor litter is related to higher dust concentrations (Heber and Stroik 1988). Removing dust with a vacuum cleaner in a barn has been done (Nilsson 1982; Dawson 1990; Pedersen 1992) and did lower total dust concentrations but it also exposed the worker during the cleaning process to very high levels of airborne dust. Phillips and Thompson (Phillips and Thompson 1989) noted that buildings that are ventilated naturally have significantly higher levels of dust than those ventilated with fans.

The issue of reducing dust emissions also is a concern for outdoor feedlots or feedyards. Techniques are being developed to reduce dust release from large beef feedyards. One experimental system being used sprinkles water periodically (every two hours) using irrigation nozzles over the surface area of the feedyard to prevent the dust from being aerosolized. This has subjectively reduced dust emissions from the outdoor yards but levels have not been quantified (personal communication with Brent Auvermann).

The final way of lowering or reducing dust levels is to increase the air exchange rates in a barn. Although this approach is valid for some units, there are some situations (Jacobson and others 1996) when dust levels were actually increased by high ventilation rates because it lowered the air humidity levels, resulting in a higher dust generation rate. Thus, ventilation or dilution of the air inside a building may have only a limited effect (Harry 1978) in controlling dust in an environment like an animal building with so many dusty surfaces and sources. Several studies have shown some benefits by manipulation of the ventilation system. Robertson (Robertson) "purged" a pig building with a high volume of air exchange for a 10 minute period to expel dust (60 % dust reduction) which can be a useful management tool for workers. Another study (van't Klooster and others 1993) modified the inlet system, in a standard negative pressure ventilation system, to bring in fresh air in the worker's zone and exhausted air underneath the slatted floor, resulting in a 40% reduction in dust exposure to the workers.

Control of dust and associated gaseous compounds attached to dust particles, is difficult to accomplish in animal production units. The most accepted methods seem to be adding fat or oil to feed that if fed to the animals or directly sprinkling it in the room where the animals are housed. Other techniques are being evaluated which either lower the indoor concentration sof dust for worker health safeguards and for lowering the emission of dust from builings to reduce the impact on nearby neighbors and properties.

OZONATION

Ozone is a powerful oxidizing agent and a very effective biocide. Ozone high in the atmosphere acts to protect the earth from solar radiation. At ground level, however, the gas can be toxic. A general consensus is that high ozone levels can cause harmful respiratory effects. The current OSHA permissible exposure limit for ozone is 0.1 ppm for an 8-hour, time-weighted average

exposure (Occupational Safety and Health Administration 1998). Ozone has been used for drinking water treatment on a municipal scale since 1906, when it was installed in treatment facilities in the city of Nice, France (Singer 1990). More than 2,000 water treatment works, primarily in France and other European countries, now use ozone for disinfection, taste and odor control (Tate 1991). There are currently about 100 plants in the US and Canada using ozone (Droste 1997). Ozone has also been used in processing food for human consumption (EPRI 1997).

Many of the ozone generators use a process called corona discharge. Corona discharge occurs by producing controlled sparks in the presence of oxygen. Ultraviolet irradiation (wavelengths < 200nm) of a gas containing oxygen is another alternative method to generate ozone. Irridations greatly enhances the ability of ozone to decompose humic acids and other organic compounds.

The molecular arrangement of ozone is three atoms of oxygen (O_3). Ozone is unstable and reacts with other gases changing their molecular structure. At low concentrations of 0.01 to 0.05 ppm, ozone has a "fresh or outdoor smell" associated with it. At higher concentrations it will begin to smell like an "electrical fire". The decomposition of ozone to oxygen is very fast. The half-life of ozone is near 20 minutes at typical conditions, but it can reach 60 minutes in a cool, sterile environment.

Ozone reacts with most organic material. It attacks organic compounds directly or free radical species formed by ozone decomposition (such as the hydroxyl radical, OH) oxidize organic matter. The most common products of a complete oxidation process are water vapor and carbon dioxide.

In animal production facilities, only limited published studies have been done evaluating the use of ozone for odor reduction. Ozonation can potentially reduce odors in livestock facilities by killing the odor producing microorganisms thus controlling the rate of production of odorous metabolites, and by oxidation of the odorous metabolites produced during anaerobic fermentation. Some researchers suggested that non-odorous molecules can actually be broken down into compounds more odorous than the initial molecules. However, most compounds when oxidized are reduced in odor intensity.

ASHRAE (ASHRAE 1989) determined that ozone is not an effective means of eliminating odors in ventilated air inside of buildings, but the fact is that there are several ozone systems on the market, and some are being tested on livestock farms with positive results. There are about a dozen ozonation systems operating in hog farms both in the United States (mainly in Minnesota, Iowa and North Carolina) and Canada.

Priem (Priem 1977) found that in a sixteen-month experiment, ozone (at concentrations up to 0.2 ppm) reduced ammonia levels in a swine barn by 50% under winter ventilation conditions and by 15% under summer ventilation conditions. The respiratory tracts of 37 normal and treated pigs were sampled and evaluated by veterinarians and they found no differences between the tissues from the two groups. It was also observed that animals in the ozonated room had slightly greater feed efficiencies and daily growth rates than animals in conventional rooms. Animals in the ozone treated rooms also seemed to be quieter. No noticeable corrosive effects were observed on the equipment in the ozonated room. Limited gas chromatographic data indicated that ozone breaks down indoles.

Researchers at Michigan State University reduced odorous compounds and disease-causing bacteria by treating swine manure slurry with high concentrations of ozone (Watkins and others 1996). In this study, ozone was bubbled directly into fresh and stored swine manure in a continuously stirred batch reactor. Ozone concentrations of 0.06, 0.12 and 0.2 lb/ft^3 were used. Olfactometric determinations (odor intensity measurements) showed a significant reduction in odors in ozonated samples as compared to raw and oxygenated samples. Volatile fatty acids, nitrate, phosphate and ammonia concentrations were unchanged by ozonation. Biochemical and chemical oxygen demand (parameters used to quantify organic material) were essentially unaffected by ozonation. The concentrations of odorous phenolic microbial metabolites (*e.g.*, phenol, p-cresol, p-ethylphenol) and odorous indolic microbial metabolites (*e.g.*, 3-methylindole and indole) were reduced to non-detectable levels by ozonation. Hydrogen sulfide concentrations were reduced slightly, with a concurrent increase in the sulfate concentration. *E. coli* counts were reduced by a factor of 3 log units (99.9%) and total coliforms showed a 1 log unit decrease (90%) after treatment with ozone at 0.06 lb/ft^3.

A more recent publication from Michigan State University researchers (Wu and others 1999) describes the results obtained from a pilot-scale ozonating system to reduce odor from fresh and stored swine manure slurry. A minimum dosage of ozone, 0.03 lb/ft^3, was established in order to reduce the odor intensity of fresh and stored manure slurry to an acceptable level (measurements made through ranking samples in terms of their odor acceptability by a human panel).

Researchers at North Carolina State University are evaluating a commercial ozone air treatment system in a tunnel ventilated swine finishing house at safe ozone levels for odor and dust reduction (Keener and others 1999). Preliminary results suggest that a significant decrease in NH_3 ($P<0.01$) and total dust ($P<0.02$) occurred in the ozonated building compared to the control building. It also appears that the concentrations of dust particles with optical diameters less than 1.0 μm were lower in the ozonated house than the control house. The evaluation of a commercial ozone treatment system for air quality is still underway. Further research is being conducted on this system at average ozone concentrations of less than 0.1 ppm (the OSHA 8-hour exposure limit). The ozone production is also being staged with ventilation rate to control ozone levels in the house at all times. The olfactometry panel did not measure significantly different levels of odor parameters in the air samples from the ozonated and control buildings. The reason for this difference between field observations and laboratory evaluation is still being investigated. Apparently, ozone changes the character of the odor, but odor units measured from air samples taken from an ozonated barn can be as high as the odor units measured from air samples taken from a non-ozonated barn. This is because human panels are not usually able to distinguish different odors when they are measuring odor thresholds. It seems that other odor evaluation methods need to be used when evaluating ozone effects on the air of animal houses, like odor intensity evaluation and hedonic tone characterization. Further investigation of the fate of small dust particles during ozonation is also being investigated. Additional work is needed to determine if the ozonation system adversely affects the pigs and to ensure that indoor ozone levels are adequately controlled.

Researchers at University of Minnesota have built an ozone generator and an automatic ozonation system (Ruan 1999). The system was primarily developed to produce ozonated water with a high oxygen-reduction potential in order to disinfect food products. Other potential

applications of this system include the use of ozonated water for the washing and cleaning of animal barns. The idea is to achieve not only reduction of odor and gaseous emissions, but also disinfection of premises.

The cost of ozonation systems can be significant. One particular ozone system for a swine finishing farm is projected to cost about $10,000 per building ($11 per pig space) for the ozone generating equipment and fans and tubes to distribute air in the building, and $50,000 to $60,000 for ozonating equipment for a large lagoon (roughly $6 to $7 per pig space for 10 buildings served by the lagoon) (Swine Odor Task Force 1998). The electrical costs are likely to be the largest operating cost. Since this technology has not been thoroughly tested, the costs may come down as ozonating requirements become better known. Also, there is concern over exceeding the OSHA exposure limiot of 0.1 ppm for an 8 hour time weighted average for those workers inside facilities.

NON-THERMAL PLASMA

Non-thermal plasma (NTP) is an innovative air pollution control technique being researched in the Biosystems and Agricultural Engineering Department at the University of Minnesota. A NTP reactor creates highly reactive chemical species that convert target gases to non-toxic gases. NTP has the ability to decompose dilute, complex polluting gases, which makes it suitable for treating exhaust air from animal and waste facilities. With further research and development, NTP could become another option for treating odorous gas emissions.

Non-thermal plasma (NTP) is created by discharging electrical energy into gases (Rosocha 1996). The electrical energy creates high-energy electrons that dissociate and ionize background gases to produce highly reactive species. These species react with target gaseous molecules (oxidative or reductive reactions) and convert them into non-toxic molecules. There are several NTP systems including pulse corona, silent discharge, surface discharge, and packed-bed.

Laboratory results reported by Ruan et al.. (Ruan and others 1997) indicate that silent discharge non-thermal plasma is a promising technique for animal house and manure odor control. These researchers achieved 100% removal rate for air containing 100 ppm ammonia and 60 ppm hydrogen sulfide using a pulsed corona plasma reactor. Other studies have shown that NTP is capable of treating dilute polluting gases with high energy efficiency and removing different polluting gases and VOCs simultaneously (Rosocha 1996; Chang and others 1991).

Non-thermal plasma (NTP) is a developing technology for treating dilute mixtures of odorous gases. It is still being researched as a treatment technology that can be used after gaseous emissions have been captured. Cost per animal is still not know since a commerical scale unit has not been operated long enough to report findings.

BIOFILTERS

Principle

Biofiltration is a viable air pollution control technology in Germany and in the Netherlands (Noren 1985), and is attracting interest in North America (Leson and Winer 1991; Janni and others 1998). Biofiltration uses aerobic microorganisms to break down organic compounds (or to transform some inorganic compounds) into carbon dioxide, water, salts and biomass.

Basic Design

Figure 2 illustrates a typical open face biofilter. Odorous air is exhausted from the building with either a wall or pit fan that is connected by a duct to the biofilter plenum. The plenum distributes the air evenly across the biofilter media. A supported porous screen holds the media above the plenum. The air passes through the media before it is exhausted to the atmosphere.

The basic component of the biofilter is the filter bed and a piping system or air plenum that forces the gas to pass through the filter bed. Perforated pipe embedded in round, washed gravel is the most common plenum used in industrial installations. A perforated block aeration floor to distribute the air can also be used, but at a significantly greater cost. The air distribution system must be as symmetrical as possible to minimize short-circuiting effects. Well engineered air distribution headers with graduated hole sizes or spacing are highly beneficial to improve airflow distribution down the length of a header pipe (Boyette 1998). Nicolai and Janni (Nicolai and Janni 1998a) devised an air plenum made out of shipping wood pallets covered with a plastic net, for a full-scale biofilter built for the treatment of odorous air from 700-sow swine facility.

Because the air from livestock units is generally quite corrosive, equipment and building materials should be made from fiberglass, stainless steel, or PVC rather than galvanized and carbon steel to extend the life of these components.

Polyethylene or PVC liners are often laid down on the top of the soil for groundwater protection. Alternatively, a concrete pad can be used at a greater cost. Excess condensate or precipitation is either pumped or allowed to flow by gravity out of biofilters to a treatment or collection system.

The air stream should be ideally free from particulate matter, which would contribute to faster clogging of the media. Pre-treatment systems can be used to remove airborne particulates in order to minimize clogging of filter media pore space. Boyette (Boyette 1998) recommends building a system that is flexible enough so that field adjustments can be made in order to allow performance optimization. Complex pre-treatment schemes result in increased biofilter system cost.

Media consisting of mixtures of compost, wood chips, peat, soil or other materials are placed on top of the aeration plenum. Media thickness is dependent on density of media materials, but should be greater than 8 inches, in order to reduce possible air channeling, and less than 18

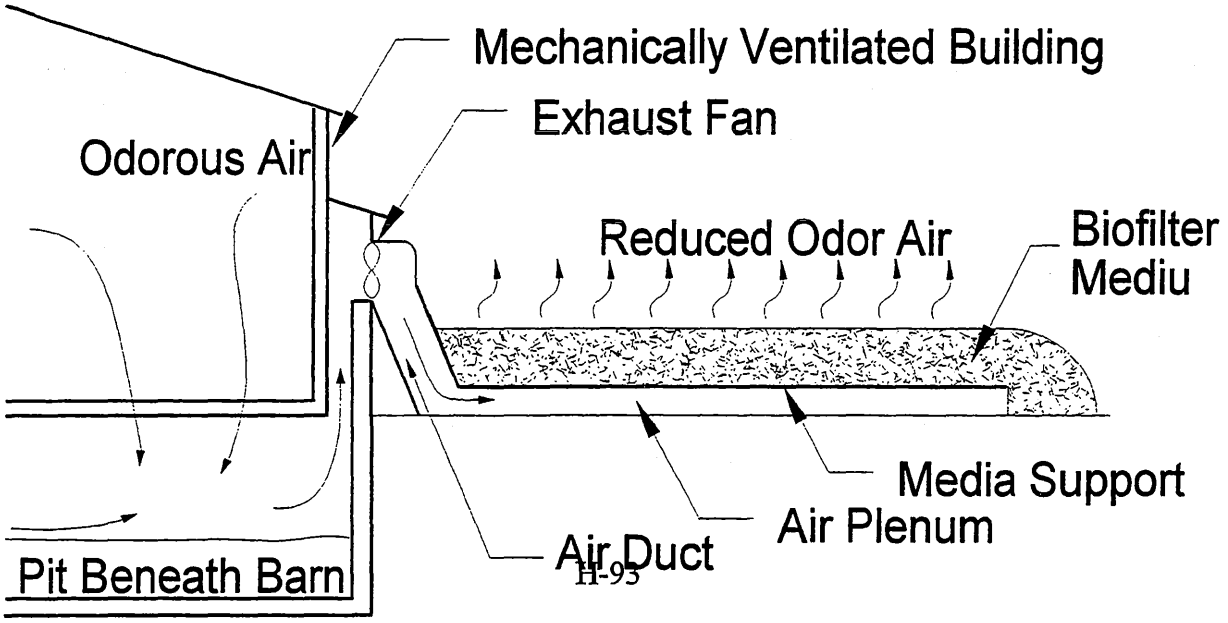

Figure 2. Open face biofilter

inches, to minimize pressure drop across the media. Media bed life is usually from three to five years. The full-scale biofilter studied by University of Minnesota research engineers has been operated for over one year (Nicolai and Janni 1997; Nicolai and Janni 1998a; Nicolai and Janni 1998b; Nicolai and Janni 1998c), and at this time, it is unknown when the media bed will need to be replaced.

The critical design features of the filter bed are to provide a high wetted surface area, a uniform airflow transmissibility and resistance to compaction and physical deterioration. Other important parameters include moisture content, temperature, oxygen level, and pH.

Beds are sized to provide a residence time of 30 seconds to 2 minutes or more (empty bed volume basis) for cases with high gas concentrations or other organic compounds. Adequate odor reduction can be achieved in livestock operations with much lower residence times, in the range of 5 to 15 seconds (Zeisig and Munchen 1987).

The system must be designed to allow for the irrigation of the media to prevent it from drying out plus for flushing the media for the removal of acids in the case where mineral anions are generated in the degradation process. Provision is also required for the capture and containment of condensate and leachate from the filter bed. In general, the biofilter should be placed on a sloped well-drained area to prevent water ponding.

Effectiveness

Biofiltration use on livestock facilities began in Germany in the late 1960s and in Sweden in 1984 (Zeisig and Munchen 1987; Noren 1985). Biofilters on pig and calf sheds had average efficiencies around 70% (Scholtens and others 1987). Noren (Noren 1985) reported ammonia and hydrogen sulfide average reductions of 80% with optimum moisture content from a swine barn biofilter.

Young et al. (Young and others 1997) in a pilot-scale biofilter recorded reductions on odor intensity from a swine barn ranging from 58% to 84%. Measurements were made with cotton swatches presented to a panel.

Nicolai and Janni (Nicolai and Janni 1997) reported an average odor reduction of 78% (minimum of 29% in April before a water sprinkling systems was installed and maximum of 96% in August) from a pilot-scale biofilter built to treat air exhausted from a pit fan on a farrowing barn in Minnesota. Hydrogen sulfide and ammonia concentrations were reduced an average of 86 and 50%, respectively. The pressure drop across the media ranged between 0.10 and 0.19 in. of water (25 to 47 Pa).

Similar results were obtained by the same researchers using four small biofilters (5 ft by 7 ft) treating pit fan exhaust air from a deep-pitted swine nursery (Nicolai and Janni 1998c).

Data from a full-sized biofilter used to treat all of the ventilating air exhaust from a 700-sow gestation/farrowing swine facility were recently reported (Nicolai and Janni 1998a; Nicolai and Janni 1998b). Average odor reduction was 82% over the first 10-months of operation. Average hydrogen sulfide reduction was 80% and ammonia reduction was 53% during the same period. Total pressure drop across the fans reached a maximum of 0.4 inches of water of which 0.2 inches could be attributed to the ventilation inlet system in the building.

Operation and Maintenance

Biofilter media plugging due to dust accumulation is expected to develop over time. When evaluating the performance of a biofilter, two areas to routinely examine are the airflow and the pressure drop. According to Boyette (Boyette 1998), pressure drop should be measured every week or every two weeks to establish a trend. This will help the farmer to identify when it is time to start replacing the media.

Inlet air temperature, and pH and moisture levels in the biofilter media are other parameters to be measured. The ideal moisture level is 55%, although it can be 60% or greater when a more porous mixture is used. Water addition to the biofilter can be automated with a soil moisture probe, a solenoid valve in the water supply system, and an electronic controller. The pH level has to be monitored because if it starts to decrease, some of the odorous gases might not be biodegraded sufficiently.

Walking by the biofilter and smelling gives a good indication if the biofilter is or is not working. Sometimes, observing the top of the biofilter is all it takes to evaluate its performance (e.g., looking for uneven dry and wet spots on the surface of the biofilter). Another way to verify biofilter performance at a reasonable cost is to conduct a smoke test. Smoke bombs placed into the inlets of the biofilter system will show where the air is going. The smoke emission will show whether the air is going through the biofilter or not. Periodic measurements of airflow by measuring pressure drop across the fans and referring to the fan performance tables are also important. They give an indication of the actual loading rate.

Good rodent control is essential. Mice and rats burrow through the warm media in cold winter months causing channeling and poor treatment. Rabbits, woodchucks, and badgers have also been suspected of burrowing through and nesting in biofilters.

Excessive vegetative growth on the biofilter surface can reduce its efficiency by causing channeling and limiting oxygen exchange. Root systems can cause plugging. Noxious weeds need to be removed before they produce seed. Excessive vegetative growth may also subtract from the aesthetic appearance of the site.

Economics

The amortized construction and operating costs over three years for a full-sized biofilter installed on a 700-sow gestation/farrowing swine facility were $0.22 per piglet (0 to 12 lbs) produced per year (Nicolai and Janni 1998b). Generally, electricity to operate the blowers is the largest portion of the operating cost of a biofilter. Electricity for water pumps, controls, etc. add minimal cost (about $125 per year for the 700 sow farrowing to wean facility).

The second largest operating cost is potential media replacement. Depending on factors such as air temperature, gas concentration, loading rates, etc., media replacement may occur between 3 and 5 years. The cost for media replacement consists of removing the old media, obtaining new media, and placing it in the biofilter system.

Other costs tha may be incurred with a biofilter system include the following: Nicolai and Janni (Nicolai and Janni 1998b) estimated rodent control costs to be $275 per year for the 700-sow facility. Boyette (Boyette 1998) gives O & M costs for biofilter systems ranging from $2 to $14 per cfm of capacity for the exhausted gas treated. A few mechanical and electronic parts are associated with a biofilter system. As a result, maintenance costs are typically minimal. Labor and laboratory costs associated with monitoring and checking the biofilter system are also minimal.

Biofilters are a proven odor control technology for fan ventialted livestock facilities. Innovative designs are being developed to reduce the initial cost of these units plus minimize maintenance/operating costs and labor

COVERS

Description

Open manure storage facilities can be a very significant source of on-farm odors and volatile gases. They are the most apparent odor source, especially if there are no visual barriers from neighbors or passersby. A method to reduce odors and gaseous emissions from open manure storage units is to place some type of cover on the surface. This seems to be an effective method, since reasonably low emissions have been observed from dairy manure storage basins that have a natural crust.

Rigid and Flexible Covers

A concrete or wood lid can reduce odor release until the storage is agitated and emptied. Other options for the containment of odorous gases include lightweight roofs (fiberglass, aluminum, etc.), and flexible plastic membranes. **Figure 3** shows the two different types of rigid covers used for odor containment.

Minimal headspace serves to reduce air exchange volumes and related odor control equipment when treatment is an option. Generally, odorous gases contained in a storage tank covered with a lid are either vented, or flared off. There are also various alternatives for their treatment (*e.g.*, biofiltration).

Mannebeck (Mannebeck 1985) have found greater odor reduction percentages for permanent

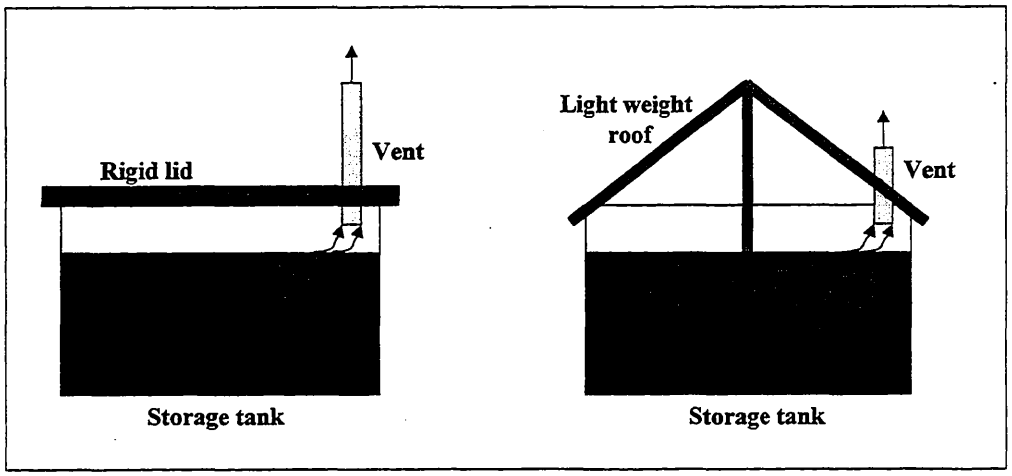

Figure 3. Rigid covers used for odor containment

roofs constructed of wood or concrete (>95%). De Bode (De Bode 1991) showed that a roof over the storage tank could reduce ammonia losses by more than 80%. Sommer et al. (Sommer and others 1993) observed less than 5% ammonia losses from storage tanks with either cattle or pig manure covered with a wooden lid.

Rigid covers are usually more expensive than other types of covers, but they usually last longer (10 to 15 years, depending on the material). Zhang and Gaakeer (Zhang and Gaakeer 1996) estimated that a concrete cover for a 200-sow farrow to finish operation might cost as much as $50,000. But depending on the type of material used, this cost can be significantly reduced.

Another type of cover used for the containment of odors that is becoming popular, especially in Canada, is the inflatable cover (**Figure 4**). In this system, a tarp is fastened to the tank perimeter as tight as possible. A center support column with radiating straps supports the outer shell. Air is delivered through a low-pressure blower. The cover is maintained at a constant operating pressure (usually about 1 in H_2O, or 250 Pa). Zhang and Gaakeer (Zhang and Gaakeer 1996) observed that at an operating pressure of 0.4 in H_2O (100 Pa), the air leakage was 60 l/s. This leakage is approximately equivalent to the rate of a bathroom exhausting fan.

For agitation and pumping, the structure is deflated allowing the tarp to lay over the radiating straps. Access doors are then opened for the introduction of pumping equipment.

The odor reduction efficiency of an inflated cover can be as high as 95 % (Mannebeck 1985). Zhang and Gaakeer (Zhang and Gaakeer 1996) measured over 95% reduction in ammonia and hydrogen sulfide emission rates using an inflated cover with an operating pressure of 0.4 in H_2O (100 Pa).

The cost of an inflated cover varies between $90.00 and $100.00 per linear ft of diameter. The life expectancy is about 10 years.

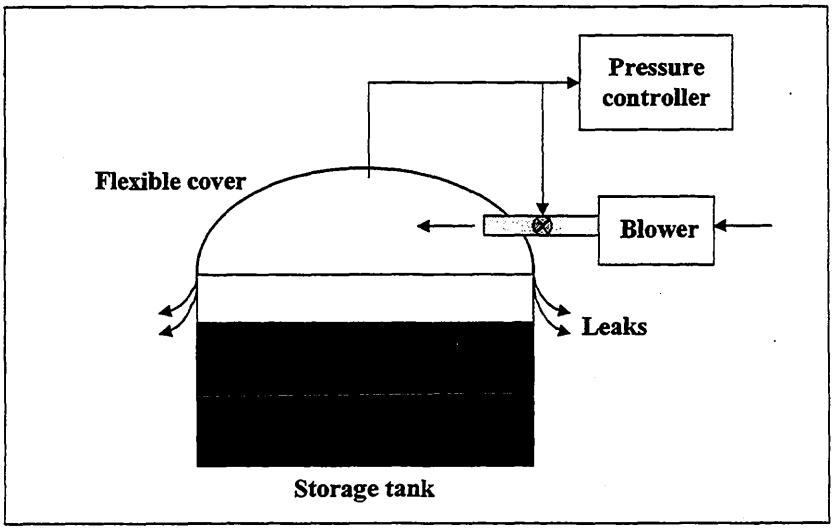

Figure 4. Flexible plastic inflated cover and control systems (Zhang and Gaakeer 1996)

Floating Covers

Floating covers can be made with a variety of materials. Natural floating covers are those formed by the fibrous material in the manure (*e.g.*, crust). Artificial floating organic covers, also called biocovers, include straw, chopped cornstalks, sawdust, wood shavings, rice hulls, etc. Polystyrene foam, plastic mats, air-filled clay balls like Leca® and Macrolite®, and geotextile have also been used as floating covers.

Basically, there are two types of floating covers (**Figure 5**). The first is an impermeable material (plastic or hydrocarbon-based material), which simply captures the odors that are later treated with a biofilter or are flared off (in the same way as if there was a rigid cover). The impermeable covers have had limited success because of high initial and operating costs, difficulty in collecting the odors, and the need to treat the odors before releasing into the atmosphere. Managing the system has been difficult and time consuming.

The second is a permeable cover that increases the surface-to-air resistance, and possibly causing a biofilter effect, which reduces odor emission. Floating organic materials, such as straw, are relatively low cost and have little labor requirements to maintain. Other floating permeable covers, such as geotextile materials, may provide a better solution than straw for certain type of storage basins which are not annually agitated and pumped, even at a higher initial cost.

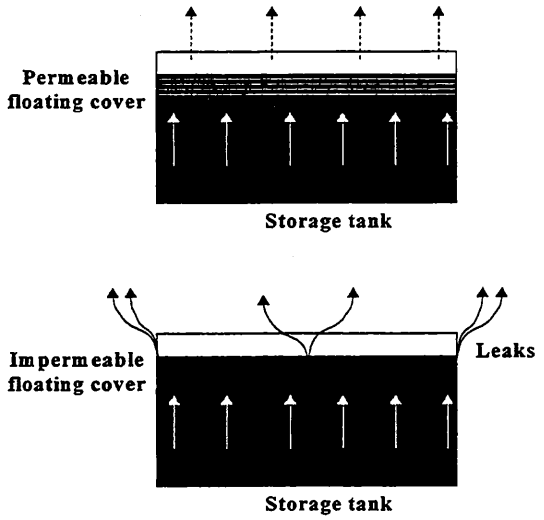

Figure 5. Schematics of odor reduction using permeable and impermeable floating covers

Adding a cover to the manure surface reduces the transfer of hydrogen sulfide and other odorous compounds from the liquid to the atmosphere, basically due to an increase of the surface-to-air resistance at the liquid-air interface. When a cover is placed directly over the manure surface, the following processes apparently take place:

- resistance to mass transfer is increased;
- gas concentration builds up under the cover;
- the rate at which a gas diffuses out of the manure is significantly reduced (because the gradient has decreased);
- volatile compounds are mostly kept into solution.

Permeable covers, such as straw, have been shown to be more suitable for reducing odor from livestock manure facilities than impermeable material. An aerobic layer is established on the top of the cover, so that some of the odorous compounds that escape to the atmosphere may be aerobically broken down. Impermeable floating material allows odorous compounds to escape through leaks at joints and near the tank walls.

Natural floating covers are those formed by the fibrous material in manure. Artificial floating crusts are composed of chopped straw, plastic foam pellets, a combination of straw and pellets, mats, or tarpaulins. Tight covers include plastic covers sealed at the edge and light constructed roofs. Mannebeck (1995) estimated the lives of the covers in his study: straw, six months; plastic pellets, two years; mats and tarpaulins, 10 years; and a lightweight roof, 15 years.

De Bode (1991) stated that covering manure storage could reduce ammonia emissions by 70 to 90%. However, if exchange was not adequately prevented between air above the manure and the outside air, the reduction was only 50%. Sommer(Sommer 1992) determined that an uncovered pig manure storage unit could emit approximately 4 g/m^2 day of ammonia-N. This figure was roughly reduced to 1.0 g/m^2 day when covered by a natural crust, 0.5 g/m^2 day when covered with straw, 0.5 g/m2 day when covered with Leca® clay balls, and 0.25 g/m^2 day when the surface was covered with oil and the storage facility had a sealed lid.

Meyer and Converse (Meyer and Converse 1982) evaluated several manure storage covers: chopped cornstalks, sawdust, wood shavings, rice hulls, ground corncobs, and grass clippings, alone or mixed with waste oil. Ammonia and hydrogen sulfide emissions were measured and a five-member odor panel ranked air samples. Covers made of rice hulls with oil resulted in the lowest ammonia and hydrogen sulfide emissions at 31% and 4% of uncovered facilities, respectively. The odor panel rated the cover made of grass clippings combined with oil as producing the least odor emissions, followed by corncobs with oil, cornstalks with oil, and rice hulls with oil.

Bundy et al. (Bundy and others 1997) compared chopped straw, cornstalks, polyethylene open mesh with a liquid surface film, Leca® clay balls, and foam generated from air bubbles and manure solids. They concluded straw and cornstalk covers may be cost-effective and Leca® has an excellent ability to control odor. Sommer et al. (Sommer and others 1993), reported about 15% ammonia losses from cattle slurry, and between 5 and 12% from pig slurry covered with Leca®, as compared to 100% losses from uncovered control tanks.

Miner and Pan (Miner and Pan 1995) developed a permeable blanket of straw and/or zeolite to cover manure storage units. They found odors were absorbed and oxidized on the moist aerobic bacteria-entrained surface of the fabric blanket. These authors also indicated that this type of

technology has resulted in a 90% reduction in ammonia and hydrogen sulfide concentration in the space above the manure liquid.

Miner and Suh (Miner and Suh 1997) studied ten different polystyrene foam materials that reduced ammonia concentration by 45% to 90% compared to uncovered manure storage. The more effective cover materials were those with sufficient gas permeability to allow gases to pass through the cover material and breakdown aerobically, compared to less effective impermeable covers that allowed ammonia to pass around them. In a field study, Williams and Nigro (Williams and Nigro 1997) found that a supported corrugated plastic-coated steel cover reduced ammonia emissions by 68%. In a laboratory study, the team increased the reduction to 93% with a better designed cover and improved sealing, thus a reduction in leakage. They also found emissions increase about fourfold when temperature increases from 4 to 25°C (39 to 77°F).

Clanton et al. (Clanton and others 1999) studied seven covers including no cover (control), straw mat, vegetable oil mat, straw/oil mat, clay ball mat, PVC/rubber membrane, and geotextile membrane. The six covers reduced odor units and hydrogen sulfide concentration at various points in the study, but not in a consistent manner. The straw mat and PVC/rubber membrane significantly reduced both odors units and hydrogen sulfide concentration consistently up to a 94% reduction. Mixing vegetable oil with straw appears to increase longevity of the cover as compared to straw only with approximately the same removal efficiency. The vegetable oil layer, when mixed with the manure, produced a distinctively offensive non-swine odor. The clay ball mat reduced emissions, although not as well as other covers with only up to a 64% reduction. A geotextile membrane may be a possible cover choice, since the fabric is self-floating and the biofilm that grew on the mat could self-seal the cover with a removal efficiency up to 71%. A straw mat (possibly including vegetable oil) and PVC/rubber membrane appear to be the most effective covers in reducing both odors and hydrogen sulfide. Oil alone should not be used as a cover because of the offensive odor it emits.

Longevity plus the cost to install and maintain covers are important issues. Mannebeck (Mannebeck 1985) estimated the useful life of their evaluated covers varied from 1/2 year for straw up to 20 years for a concrete cover. Others have indicated that a 2- or 3-inch layer of straw will only last for several weeks. Canadian researchers (PAMI 1993) found that a 6-inch depth of barley straw lasted the full season (three to five months) with some reapplication of straw to small exposed areas of the storage unit. Jacobson (Jacobson 1998) observed both barley and wheat straw covers of 12-inches thick floating from two to four months with only an initial straw application on swine manure earthen basins. A single large round straw bale (6-ft diameter) covered about 500 ft^2 of storage area (100 bales/acre) and the cost for purchasing the straw varied from \$5 to \$10 per 100 ft^2. Application costs for straw are not well established but could equal the cost of the straw itself. Mannebeck (Mannebeck 1985) estimated that straw would cost as little as \$5 per 100 ft^2 while a floating tarpaulin would be \$250 per 100 ft^2. Geotextile covers have been estimated to cost between \$20 to \$40 per 100 ft^2 which includes both the initial and application costs.

Effectiveness

Covers can be an effective method of reducing odors and gaseous emissions from open manure storage units on farms. Reductions in odor levels are variable but are relatively high (greater than 70 %) for most types of covering materials. The main challenge in using this technology is to

make it economically feasible for producers by reducing both initial and operating costs along with minimal maintenance. Other important issues include the effect of covering manure on the overall water balance on a farm and the potential need for more land to apply the manure (because there will be more nutrients retained in the manure). Floating organic covers like straw also create agitiation and solids/sludge accumulations and removal concersn which can be managed with the proper agitiation (chopper) and pumping equipment.

MECHANICAL SOLID SEPARATION

Solid-liquid separation has been generally used in the last few years as a physical treatment process for animal wastes, mainly for the improvement of manure handling properties by taking coarse solids and fiber out of slurry. Relatively low cost and simple technologies, such as settling basins and screen separators, have been applied for the removal of solid material from dilute slurries. Expansion of animal production in some regions with highly specialized operations, and increasing public concern with odors, water and air pollution is leading towards the utilization of more advanced technology and equipment (press augers, decanter centrifuges, etc.). Such equipment have long been employed in both municipal and industrial wastewater operations, but have not been commonly used for livestock wastes because these wastes are typically applied to land for fertilizer value and this utilization has not required solids and nutrient removal. However, in regions of concentrated confined animal production, there is more interest and need to remove nutrients and transport them from the farm.

There are several advantages related to mechanical separation of liquid manure including reduction of (i) nutrient content in manure; (ii) the solid content and improvement of homogeneity in the liquid phase; (iii) energy requirements for pumping and mixing before land application; (iv) ammonia emissions during land application of the separated slurry; and (v) energy requirements for aerobic treatment (Burton 1997). However, it must be realized that storage, handling and spreading techniques for both liquid and solid manure are required, higher investments for equipment have to be made as well as for operation and maintenance, and more farm management skills are needed.

Zhang and Westerman (Zhang and Westerman 1997) did a recent review on solid-liquid separation of animal manure for odor control and nutrient management. They also reported performance and economics of solid-liquid separators. Performance data of mechanical separators vary widely. Total solids content in separated solids vary from as low as 5% with a stationary screen, up to 27% with centrifuges. Separation efficiencies for TS varied from less than 10% to about 60%. Presses and centrifuges are found to have higher separation efficiencies and produce drier solids than screen separators. These large variations are not only due to the different testing and reporting procedures, but also because the characteristics of the manure used were sometimes largely different.

Unfortunately, there is limited research on how solid-liquid separation affects odor and ammonia emissions. Zhang and Westerman (Zhang and Westerman 1997) concluded from their review that fine particles in the manure decompose faster than coarse particles and most of the reduced carbon compounds, protein and nutrient elements are contained in fine particles. Because these compounds are the precursors for odor generation and the carriers of organic nitrogen and phosphorus, they recommend that solid-liquid separation processes are designed to remove both coarse material and particles smaller than 0.25 mm in order significantly reduce odor and

nutrient contents. Therefore, if the goal of solid-liquid separation is odor reduction, it is important to have a separation process that removes the smaller particles.

Solid-liquid separation processes do not necessarily produce fewer odors. Additional treatment may be necessary. Theoretically, the separation of the solid and liquid portions of animal manure can reduce odor from subsequent storage and treatment facilities. If the separated liquid contains less solids and organic matter, it is likely that it will generate less odor and gases when stored. Unfortunately, quantitative information about this reduction is scant or it is not available.

The addition of chemicals to enhance mechanical solid separation is drawing more research attention (Gao and others 1993; Brionne and others 1994; Barrow and others 1997), but there is little or no information regarding odor and ammonia emission reductions from such systems. Recently, Westerman and Bicudo (Westerman and Bicudo 1998) reported on an innovative treatment system for swine manure that includes physical and chemical separation of solids. A few samples were analyzed for odor intensity (concentration), odor irritation intensity and odor quality (pleasantness or unpleasantness) using descriptive scales by a human panel. Statistical analysis performed with the experimental data indicated that there was no significant difference in odor (intensity, irritation and pleasantness) between flushed swine wastes and the liquid slurry after mechanical separation at the 5 % probability level. The chemically treated effluent was found to have less odor intensity and irritation than either flushed wastes or the separated liquid. However the odor intensity was "strong" and irritation was "moderately strong." There was no significant difference in pleasantness between flushed wastes and the treated effluent or between the separated liquid and treated effluent ($P < 0.05$).

Sneath (Sneath 1988) studied the effects of removing solids from aerobically treated piggery slurry on volatile fatty acids (VFA) levels during storage. Stability was measured in terms of the time taken to reach two specific concentrations of VFA, 0.23 and 0.52 kg/m^3 (1 lb/gal = 120 kg/m^3). Slurries stored until a VFA concentration reaches 0.23 kg/m^3 were found not to cause odor problems, while those containing above 0.52 kg/m^3 have shown to release offensive odors. It was found that removal of solids using fine sieves or decanting centrifuge extended the storage times of the liquid portion by one-third before the VFA level indicated that offensive odors had returned to the slurry.

Solid-liquid separation theoretically should reduce odors if small manure particlas are removed from the liquid fraction. Practically, this is difficult to accomplish and thus relatively low odor reduction levels have been reported in the few studies done. There is a need to develop a better understanding of the impact of solids-liquid separation (including chemical addition) at different separation levels on odor and ammonia emissions in the subsequent liquid manure storage and/or treatment units, and the economics of the different methods. The odor potential of the separated solids must also be considered. While separated solids have potential as a valuable nutrient product, if not properly handled, they can be a significant source of odors. Composting or drying immediately after separation may help keep the odors of manure solids at a minimum level.

COMPOSTING

Composting is an aerobic, biological process in which microorganisms convert organic materials such as manure, sludge, leaves, paper and food wastes into a soil-like material called compost. It is the same process that decays leaves and other organic debris in nature. It offers several

potential benefits including improved manure handling, enhanced soil tilth and fertility, and reduced environmental risk. The composting process produces heat, which drives off moisture and kills pathogens and weed seeds.

Composting can be used as a treatment system in animal or poultry farms where solid manure and solid material removed from liquid slurries by mechanical separators (with at least 15 percent dry matter content) are available. It is usually necessary to blend together several materials, in suitable proportions, to achieve a mix with the desired overall characteristics. Composting can reduce manure volume, stabilize manure nutrients, kill pathogens and weed seeds, and produce a homogeneous non-odorous product.

Researchers from the Agricultural University of Norway reported on the development of a liquid composting reactor using aeration for the treatment of animal manures (Skjelhaugen and Saether 1994). An insulated, cylindrical tank with a conical bottom was used. A submerged aerator supplied air that was used by aerobic bacteria to break down organic matter. Because of intense activity within the reactor, the biological process releases a large amount of heat that raises the temperature of the reactor content up to 140 °F. The duration of the treatment is adjusted to suit the needs related to the material being processed. A stable and hygienic product can be obtained after a retention time of 7 days. Hahne and Schuchardt (Hahne and Schuchardt 1996) described a similar system developed by the Institute of Technology, FAL Volkenrode, in Germany, that worked with three days retention time.

Although composting is a relatively expensive and labor intensive process, most of the operations that were established in dairy farms, for example, are self-contained. Farmers compost the manure produced on their farm, manage the effort themselves and own the finished product. Factors relating to the quality, handling, and distribution of the manure are the main reasons why people start and continue a composting operation (Rynk 1994).

Ammonia and odor emissions are perhaps the most common problems associated with composting, and failure to adequately address them can lead to neighbor complaints and the closure of large-scale facilities.

Gaseous and odorous emissions from animal and poultry manure composting are usually high during both the initial stages of composting and during the process of turning the material (Kuroda and others 1996). Emissions of carbon dioxide and ammonia during composting of various materials, including animal and poultry manure, have been well studied, particularly in respect to the degradation of organic matter and nitrogen losses (Martins and Dewes 1992; Lau and others 1992; Piccinini and others 1996). Martins and Dewes (Martins and Dewes 1992) measured gaseous losses during composting of poultry, cow and swine manures. The average gaseous losses ranged from 51 to 59% of the total N and consisted mainly of NH_3 (more than 95%). Kuroda et al. (Kuroda and others 1996) measured emissions of nitrous oxide (N_2O), hydrogen sulfide, methylmercaptans, dimethyl sulfide, dimethyl disulfide, methane and VFA. Emissions of N_2O, NH_3, and sulfur compounds changed with temperature and occurred during the periods of high temperature and after turning. VFA rapidly declined in the gas from the initial and did not increase afterwards. Methane emission was high in the beginning of the composting process, but then fall steadily throughout the monitoring period. Schmidt and Moon (Schmidt and Moon 1998) measured emissions from a composting site in Minnesota that processed caged-layer manure. They reported nitrogen losses to be about 70% of the initial

nitrogen content. Emission of odor paralleled hydrogen sulfide emissions, *i.e.* emissions were higher from the 5-day old pile than from either raw manure or the older piles. Emission rates from the 5-day old pile were 3.74 odor units/s-ft^2, 1.5 μg H_2S/s-ft^2, and 55 Mg NH_3/s-ft^2. Emission rates from a 27-day old pile were reduced by more than 90% as compared to the 5-day old pile.

The research that has been carried out so far indicates that the use of sufficiently high initial C:N ratio and drier materials can help minimize odor and gaseous losses from composting operations. Lower ammonia emissions can be achieved by adding a large amount of dry, high-carbon amendment or bulking agent, such as straw. Other products, such as zeolite, have also been added to compost mixtures in order to minimize ammonia volatilization (Burton 1997). Zeolites have high cation exchange capacity and marked ammonia ion selectivity, and are thus able to reduce ammonia losses. Georgacakis et al.(Georgacakis and others 1996) reported results from a study on the composting of separated solids from swine manure mixed with ground lignite, ginned cotton residues and rice seed peels. Ground lignite residues were used as an odor absorbent and mixed with separated solids at a ratio of about 1:1 (by volume). The other two amendments were used as bulking agents and also to increase the C/N ratio. However, there was no quantification of odors or gaseous emissions from such a system.

Liquid composting at high temperatures usually lead to large ammonia emissions. Researchers from Norway developed a system to trap ammonia in the outlet air from their reactor using a heat exchanger together with a biofilter (Saether 1997). The heat exchanger condensed the humid outlet air to bring ammonia back to the composting process as ammonium. Excess ammonia was removed through a biofilter filled with peat. Saether (Saether 1997) claimed that 100% of the ammonia was removed by such a system. Skjelhaugen and Donantoni (Skjelhaugen and Donantoni 1998) reported on odor emission from the same liquid composting reactor. Odor from the untreated slurry was considered unpleasant during the whole experimental period (45 weeks). Odor from the composted liquid was noticeable, but not unpleasant. It varied during the storage period and had a different character to that of untreated slurry. The system was also able to reduce significantly the number of microorganisms due to the high operating temperatures (between 130 and 140 °F). Thermotolerant coliform bacteria were reduced from 10^4 per gram of slurry to less than 10^2 per gram of slurry, i.e. a 2 log units reduction or about 99% removal.

At many composting sites odors originate with the incoming ingredients, which may have been stored anaerobically for a week or more before transport to the site. Once these ingredients are incorporated into the composting system, subsequent odor problems are usually a result of low oxygen or anaerobic conditions. Odors and gaseous emissions from composting operation appear to be more significant in the early stages of the process and also during turning. Management seems to be a key factor in reducing odors and gaseous emissions from composting operations.

Because of limited experimental data on actual odor and gaseous emissions from real composting sites, it has been difficult or even impossible to assess the effect of composting on the overall air quality near or in livestock and poultry buildings. Up to now, composting has not been viewed as a treatment technology intended to reduce odor and gas emission from solid manure systems. Rather, composting has been viewed as a process that produces an odorless value-added material. If managed properly, or more importantly correctly, the composting process does not seem to produce significant odor and gas emissions.

AEROBIC TREATMENT

Process

In the last few years, researchers and producers have had a renewed interest in aerobic treatment of livestock wastes, especially swine wastes. Recent research has shown that the amount of aeration required to control odor could be much less than required for significant treatment of the manure to reduce the biological oxygen demand. New technologies include low-rate aeration systems, liquid-solid separation prior to aerobic treatment, and aerobic treatment following anaerobic treatment. Many of these new technologies are still in the development phase, and additional basic and on-farm research is needed.

Aerobic treatment is usually suitable for separated liquid slurry or dilute effluents. It is a natural biological degradation and stabilization process. Optimizing the oxygen supply to microorganisms accelerates the biodegradation process. The degree of oxidation depends on the amount of oxygen provided and the reaction time allowed in the treatment process. Slurry aeration allows microorganisms to metabolize dissolved components such as organic acids, phenols, indoles, nitrogen and sulfur compounds, low molecular weight proteins, etc., which are responsible for most offensive odor emissions. Since complete stabilization of livestock manure by aerobic treatment is normally not economically justifiable (Westerman and Zhang 1997), lower levels of aeration have been recommended for partial odor control. Continuous aerobic treatment may remove odor from hog manure within three or four days (Evans and others 1986; Sneath and others 1990). It has also been demonstrated that aerobic treatment can reduce odor emissions from land spreading operations up to 90% (Pain and others 1990).

Biodegradable organic material contained in animal manure can be oxidized into stable inorganic end products by aerobic bacteria. When slurry is sufficiently aerated, aerobic microbial activity dominates and free oxygen becomes the final electron acceptor. The relatively strong oxidizing environment leads to a more extensive breakdown of organic compounds, with water, carbon dioxide and other simple molecules being the products. In this way many of the organic compounds related to offensive odors are removed. A complete oxidation process can be expressed as (Westerman and Zhang 1997):

Organic matter (C, H, O, N, S) + $O_2 \rightarrow CO_2 + H_2O + NO_3^- + SO_4^{2-}$

The fate of the nitrogen component of the slurry in an aerobic process is of particular importance. Nitrogen in livestock slurries is approximately equally divided between organic and inorganic nitrogen (ammoniacal nitrogen). The composition of nitrogen compounds can be changed during aeration and these changes are dependent on the treatment time, temperature and dissolved oxygen concentration (Svoboda 1995).

Between 5 to 35% of slurry organic nitrogen can be converted to ammoniacal nitrogen by aeration. Ammoniacal nitrogen (NH_3-N) can be conserved or oxidized, first to nitrite (NO_2) and then to nitrate (NO_3). Treatment times over 3 days with aeration level over 1% of the saturated value for dissolved oxygen enable populations of nitrifying bacteria to develop (Smith and Evans 1982). Nitrate nitrogen in the treated slurry acts as a reservoir of oxygen and is utilized during storage. This helps prevent the development of anaerobic conditions in storage and emission of offensive odors. In the absence of nitrification, large ammonia losses are likely, particularly if airflow rates are excessive.

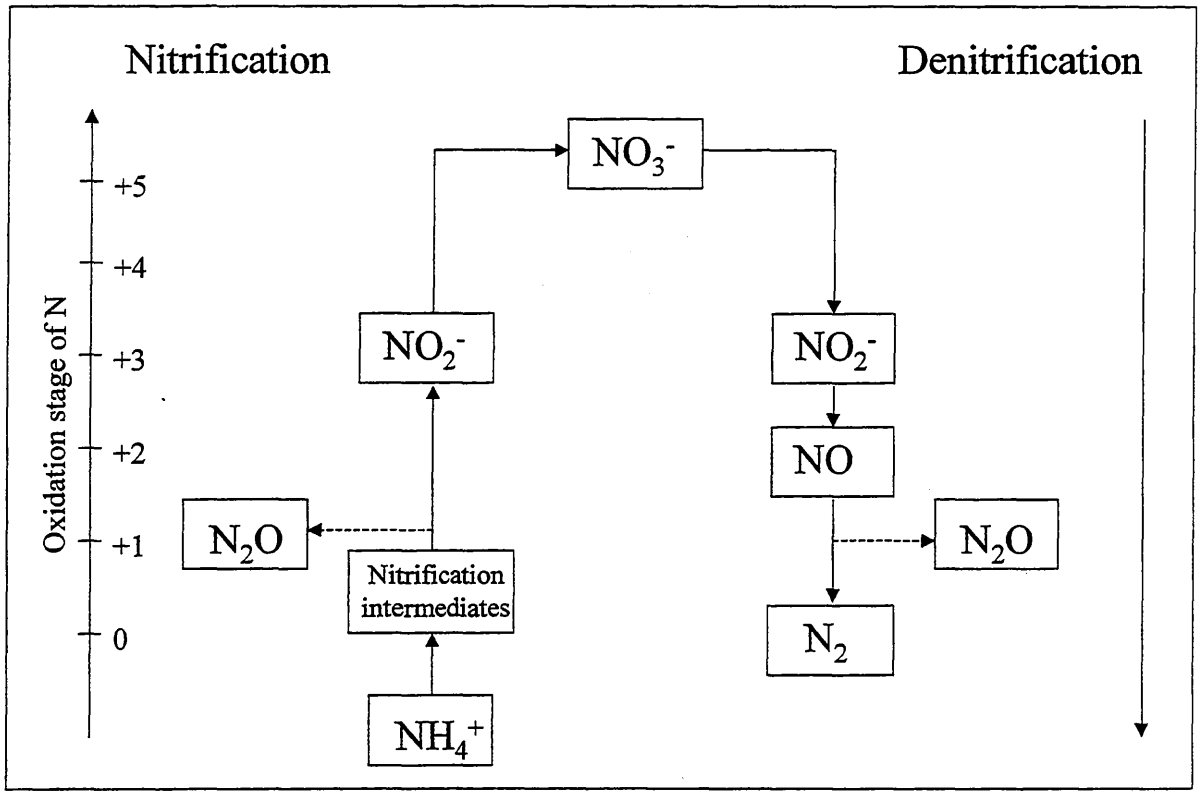

Figure 6. Possible routes (dotted lines) of N_2O production from nitrification/denitrification pathway (Pahl and others 1997)

Denitrification, i.e. reduction of nitrate to nitrogen gas, can occur during storage of nitrified slurry or during treatment if the aeration level is kept close to the minimum for nitrifying activity (Smith and Evans 1982). More recently, research carried out in the United Kingdom and The Netherlands has shown that the slurry nitrogen can also be released in the form of nitrous oxide (N_2O) during combined aerobic/anoxic treatment (Burton and others 1993; Willers and others 1996). N_2O is a strong greenhouse gas and depletant of stratospheric ozone and therefore a serious pollutant. The emission of N_2O are undesirable and may jeopardize the environmental benefits of treatment.

Both nitrification and denitrification are reported to be a possible source of N_2O. **Figure 6** (Pahl and others 1997)shows the possible routes of N_2O production from the nitrification/denitrification pathway. It is still unclear if either nitrification or denitrification is a major contributor to the production of N_2O during aerobic/anoxic treatment. Sulfur compounds in the manure are converted to sulfate (SO_4^{2-}) in the aerobic environment, thus preventing emission of odor-causing sulfide and mercaptan compounds to the atmosphere.

Volatile fatty acids (VFA) are almost completely removed from manure with aerobic treatment, and apparently, VFA destruction is independent of treatment time in the range 1 to 4.5 days. According to Williams et al. (Williams and others 1989), VFA are the main soluble biodegradable components of slurry and are probably the most readily biodegradable substrate, given that simple sugars are unlikely to be found in significant quantities. Thus, as treatment time decreases, the microbial population must rely increasingly on simple soluble substrates. As a consequence, VFA becomes the largest fraction of substrate degraded.

The environmental conditions within aerated slurry (temperature, ammonia concentration, predation by microorganisms, etc.) are unfavorable for the survival of pathogenic microorganisms. Munch et al. (Munch and others 1987), for example, showed that Salmonella species could be significantly reduced in 3 to 7 days with aerobic treatment.

It should be noted that aerobic systems would likely require screening or removing the larger solids in the manure before the aeration treatment and would also produce biosolids from the treatment system. Both of these by-products would tend to have more odor than the liquid discharged from the treatment system and would likely require more treatment, such as the addition of lime or other chemical compounds to eliminate odor.

The main disadvantage of aerobic digestion systems for the control of odors from animal operations is the cost of supplying air. The cost of aeration, depending on the objective, if partial or complete stabilization odor control, may vary between $1 and $6 per pig-year.

Oxygen Requirements

The energy requirement for aeration constitutes a major proportion of the running costs of the aerobic treatment of any organic waste. It is normal practice in the activated sludge process for sewage treatment to maintain a dissolved oxygen (DO) concentration of around 2 mg/l. These high DO concentrations are used to ensure an adequate supply of oxygen to all cells within the floc. The air supply must also be adequate to provide adequate mixing throughout the aeration tank.

The theoretical oxygen requirements can be determined from the biochemical oxygen demand (BOD) or chemical oxygen demand (COD) of the waste. The minimum oxygen capacity should be twice the total daily BOD loading for complete oxidation of organic matter and also for converting ammonia (NH_3) to nitrate (NO_3) through nitrification processes, with a hydraulic retention time (HRT) of 10 days or more (NZAIE 1984).

Lower levels of aeration have been recommended for partial odor control from livestock manure. According to some reports, aeration for odor control requires only sufficient oxygen to equal the 5-day BOD of the manure during the six warmer months of the year, though this is not a well proven concept. Other sources recommend oxygenation capacity to supply 1/3 to 1/2 the BOD load for partial odor treatment (NZAIE 1984). Using a lower rate of aeration (compared to that needed for complete stabilization) reduces the release of volatile acids and other odorous gases and compounds as well as allowing some oxidation to less odorous compounds (Westerman and Zhang 1997).

According to Williams et al. (Williams and others 1989), two oxygen requirements can be defined:

- oxygen required to eliminate odors;
- oxygen required to stabilize the slurry during any subsequent storage.

Smith and Evans (Smith and Evans 1982) investigated the effects of reducing DO as low as 1% of saturation (equivalent to 0.1 mg/l) in continuous culture treatment of piggery slurry (residence time of 4 to 8 days). They found out that aerobic treatment at low DO levels would substantially reduce energy requirements. The efficiency of aeration was greatest when the DO content was

minimal, and there was no loss in the efficiency of oxidation either by the heterotrophs or by the nitrifiers. The oxygen requirement for nitrification continued even at the lowest DO level used. Unlike the situation at high DO where the total oxygen requirement is the sum of heterotrophic and nitrification oxygen requirements, at low DO the total oxygen requirement is closer to the heterotrophic oxygen requirement only. This is because most of the oxygen used by the nitrifiers subsequently becomes available to the heterotrophs through denitrification. The main advantage of nitrification during treatment is that inhibition of the methanogenic bacteria that utilize volatile fatty acids (VFA) by free ammonia is minimized (Williams and others 1984). As a consequence, VFA destruction is accelerated and threshold levels of VFA may not be reached or will be reached later than would otherwise be expected.

Williams et al. (Williams and others 1989) found that the minimum oxygen requirement for treating separated pig slurry containing 39 kg/m^3 total solids to control odor was 0.11 kg/pig-day, which assuming an aerator efficiency of 1 kg O_2/kwh input, gives a minimum energy requirement of 0.11 kwh/pig-day. For very dilute slurries containing 14 kg/m^3 total solids, they found that 2-day residence time treatment would give complete stability for an energy requirement of 0.135 kWh/pig-day. The cost of aeration was estimated to be between $1.19 and $2.38 per finishing pig.

Williams et al. (Williams and others 1989) also investigated the stability of the treated slurries during subsequent anaerobic storage. VFA were used as indicators of odor offensiveness. Stability was measured in terms of the time taken to reach two specific concentrations of VFA, 0.23 and 0.52 kg/m^3. Slurries stored until a VFA concentration reaches 0.23 kg/m^3 was found not to cause odor problems, while those containing above 0.52 kg/m^3 have shown to release offensive odors. They found that the stability of treated slurries during subsequent anaerobic storage increased significantly (P=0.001) with residence time (between 1 and 5 days).

Burton et al. (Burton and others 1998) have recently reported that a farm scale continuous aerobic treatment was able to reduce odor concentrations by 50 to 75% with treatment times between 1.7 and 6.3 days. A reduction in the offensiveness rating of the slurry odor was achieved in all cases. The target aeration level was a redox potential in the slurry in the range of –50 to –150 mV E_{cal}. The effect of the duration of treatment on odor abatement was also quantified. No odor regeneration was discerned over the first 28 days after anaerobic storage of pig slurry treated for 2.4 days.

Aerobic and Facultative Lagoons

Aerobic lagoons are either mechanically aerated or designed to be naturally aerobic. Required design volume for a mechanically-aerated lagoon is about half that of an anaerobic lagoon; whereas the volume of a naturally-aerobic unit should be 4-5 times greater than the anaerobic type. This volume, together with a 3-5 foot depth limit, requires a land area so large as to make naturally-aerobic lagoons generally impractical for farm use.

Aerobic lagoons that are mechanically aerated are called aerated lagoons. Usually, surface aerators are used to add air to wastewater and promote growth of aerobic bacteria. Aeration rapidly reduces hydrogen sulfide emissions from swine manure, but less volatile and less offensive compounds such as phenols can persist (Sweeten 1991). Aerated lagoons are an alternative when space constraints limit the area available for manure storage or to reduce an

odor nuisance problem. Aerated lagoons are able to reduce odor significantly by avoiding the anaerobic treatment environment that can produce odorous compounds. The biggest drawbacks to aerated lagoons are 1) the cost of energy to run the aeration units; 2) biosolids production, which is higher than in anaerobic systems; and 3) the potential for release of ammonia if the aeration level is not correct. More recently, research carried out in the UK and The Netherlands has shown that significant amounts of the slurry nitrogen can actually be released in the form of nitrous oxide (N_2O) during combined aerobic/anoxic treatment (Burton and others 1993; Willers and others 1996).

Aerators should be sized to provide sufficient oxygen to minimize odor production potential and promote decomposition of organic matter. Oxygenation capacity sufficient to satisfy at least the five-day biochemical oxygen demand (BOD), or the majority or all of the chemical oxygen demand (COD) plus the nitrogenous oxygen demand, is generally required (ASAE 1994). If only part of the organic waste is converted under aerobic conditions, lagoon odor emissions will be reduced somewhat. Partial aeration would, of course, lower the energy cost of aeration.

The biosolids produced during aerobic treatment of manure in lagoons and in other biological treatment systems must be collected, transported, processed, stored and utilized. There is the potential during all of these biosolid-related activities for significant odor production.

The concentration of biological solids produced is usually estimated by applying growth and substrate removal kinetics to biological treatment. The kinetic coefficients for different animal manures must be determined in the laboratory, with bench-scale studies. Bicudo and Svoboda (Bicudo and Svoboda 1995) estimated a biomass yield of 0.43 for an aerobic system treating pig slurry. The typical range for domestic wastewater is from 0.4 to 0.8. The endogenous decay coefficient varies from 0.025 to 0.075 day^{-1} for domestic wastewater; more specific data for

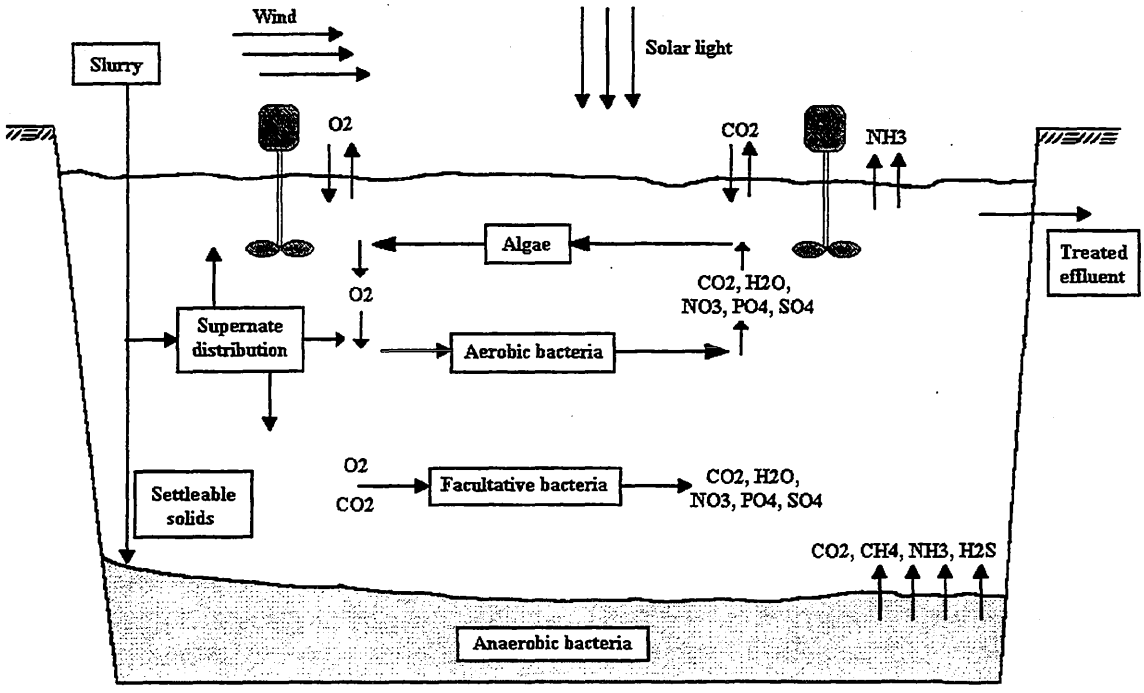

Figure 7. Schematic representation of a facultative lagoon with surface aeration

animal manures are missing. An approximate estimate of the biosolids produced can be obtained by multiplying the assumed growth-yield constant (BOD basis) by the BOD removed.

It has been estimated that the electrical cost for running an aeration system continuously is about $6 per year per finishing pig using an electrical energy cost of $0.06 per kW-h. If each pig gained 200 lb during finishing, the energy cost would be $0.03/lb for the finishing period (Westerman and Bicudo 1999).

Facultative lagoons combine anaerobic and aerobic bacterial treatment (**Figure 7**). Although the concept of shallow aeration of deep treatment lagoons is not new, most information on the development of the process is from laboratory scale studies. There are two main mechanisms for organic matter and odor reduction in facultative lagoons:

- Sedimentation and subsequent anaerobic digestion of settleable solids;
- Aerobic bacterial oxidation of the non-settleable organic compounds together with the solubilized products of anaerobic digestion.

The oxygen needed for the aerobic oxidation is provided mainly by low rate surface aeration. A continuous loading scheme is recommended for best results. Schulz and Barnes (Schulz and Barnes 1990) tested this concept in two full scale lagoons and found that the process can effect up to 75% removal of organic material without generating nuisance odors, and using about 1/3 of the power required for a fully aerobic lagoon. This would cost about $1.80 per year per finishing pig space. However, aeration to supply only partial BOD removal could result in promoting ammonia volatilization depending on some specific operating conditions, which may be an undesirable tradeoff. In order to design such a system particular attention must be given to lagoon depth, specific power input and type of aerator.

Aerobic Digestion

Aerobic digestion is based on the biological principle that microorganisms metabolize their own cellular mass under aerobic conditions when the available food supply in the surrounding wastewater is inadequate. This phenomenon is called endogenous respiration. Cell tissue is oxidized aerobically to carbon dioxide, water, and ammonia. In practice, only about 75 to 80% of the cell tissue can be oxidized; the remaining 20 to 25% is composed of inert components and organic compounds that are either difficult to degrade or are not biodegradable. The ammonia from this oxidation can be further oxidized to nitrites and nitrates, depending on the amount of oxygen supplied.

Some of the advantages of aerobic digestion system as compared to anaerobic processes are as follows:

- Volatile solids reduction is at least the same as that obtained in anaerobic digestion, but usually greater;
- Lower BOD concentrations in supernatant;
- Production of an odorless, humus-like biologically stable material;

The major disadvantages are that:

- A high power cost is associated with supplying the required oxygen;

- Digested biosolids are produced with poor mechanical dewatering characteristics;
- The process is affected by temperature.

An additional disadvantage is that a useful by-product such as methane is not recovered.

Aerobic digestion normally takes place in reactors or tanks. The process requires tankage, aeration equipment, a solid-liquid separation capability, pumping with its associated valves and pipes, and automated controls. The digestion units consist of separate concrete or steel tanks, rectangular or circular in shape. To prevent freezing in extremely cold climates, it may be necessary to cover the digesters. Aeration can be continuous or intermittent, and it is most efficiently done with diffuser systems.

The process operates on either a batch or a continuous basis. Many batch aeration treatments carried out in farms can be described as fed batch or semi-continuous, if slurry is either added or removed during the aeration process. This tends to be the result of practical needs rather than process requirements (Burton 1992). On the other hand, continuous aeration offers the option of a controlled steady-state process, and the phenomenon of the initial surge in activity is avoided.

The process is called *activated sludge* when the biosolids are separated and part of these are returned to the reactor (**Figure 8**).

The biosolids contain a variety of heterotrophic microorganisms, including bacteria, protozoa and higher forms of life that are responsible for the degradation of organic material. By returning these microorganisms to the reactor the overall biological process is significantly optimized. In this case, the oxygen requirements have to be adjusted since a portion of the waste is converted to new cells subsequently wasted from the system.

The application of the principles of the activated sludge process to the treatment of animal slurries has been investigated by a number of researchers (Osada and others 1991; Liao and Maekawa 1994; Bicudo and Svoboda 1995). Both carbon and nutrient transformations have been addressed in these studies, but there are only a few experimental data related to the performance of activated sludge treatment in reducing odor and gaseous emissions from animal manures (Voermans and Verdoes 1995; Willers and others 1996). Voermans and Verdoes (Voermans and Verdoes 1995) reported on a system similar to the one shown in Figure 7 that was able to reduce ammonia emission by 70%. Willers et al. (Willers and others 1996) described gaseous emissions measurements at a veal calf slurry treatment plant with

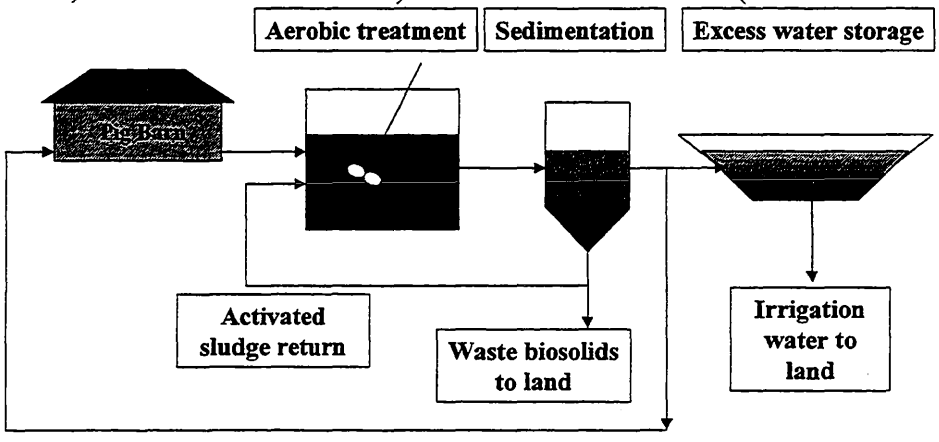

Figure 8. Activated sludge process for the treatment of flushed swine wastes

capacity to treat 0.13 mgd. Ammonia emission was between 0.1 and 0.2% of total Kjeldahl nitrogen (TKN) in the slurry. Emissions of nitrous oxide were between 9 to 13% of TKN in slurry.

Operation of aerobic digesters as a fill-and-draw sequential process is called sequencing batch. A schematic of sequencing batch reactor operation is given in **Figure 9** for a hypothetical pilot plant with capacity to treat 400 gal of manure per day. The unit processes involved in a *sequencing batch reactor* and conventional activated sludge systems are identical.

Aeration and sedimentation/clarification are carried out in both systems. The main difference is that in conventional plants, the processes are carried out simultaneously in separate tanks, whereas in a sequencing batch reactor, the processes are carried out sequentially in the same tank.

Bicudo et al. (Bicudo and others 1999a) have recently indicated that a sequencing batch treatment of flushed swine manure (5-day HRT and 30-day SRT) with intermittent aeration is able to significantly reduce odor intensity. Odor ratings decreases from 6.5 in the influent to 0.75 in the treated effluent, using a descriptive scale varying from 0 (none at all) to 8 (maximal). Results of the odor quality analysis also showed that the SBR significantly improved odor quality from a pretreatment odor descriptive of very unpleasant/extremely unpleasant to a post-treated descriptive of neutral odor for most operation conditions tested.

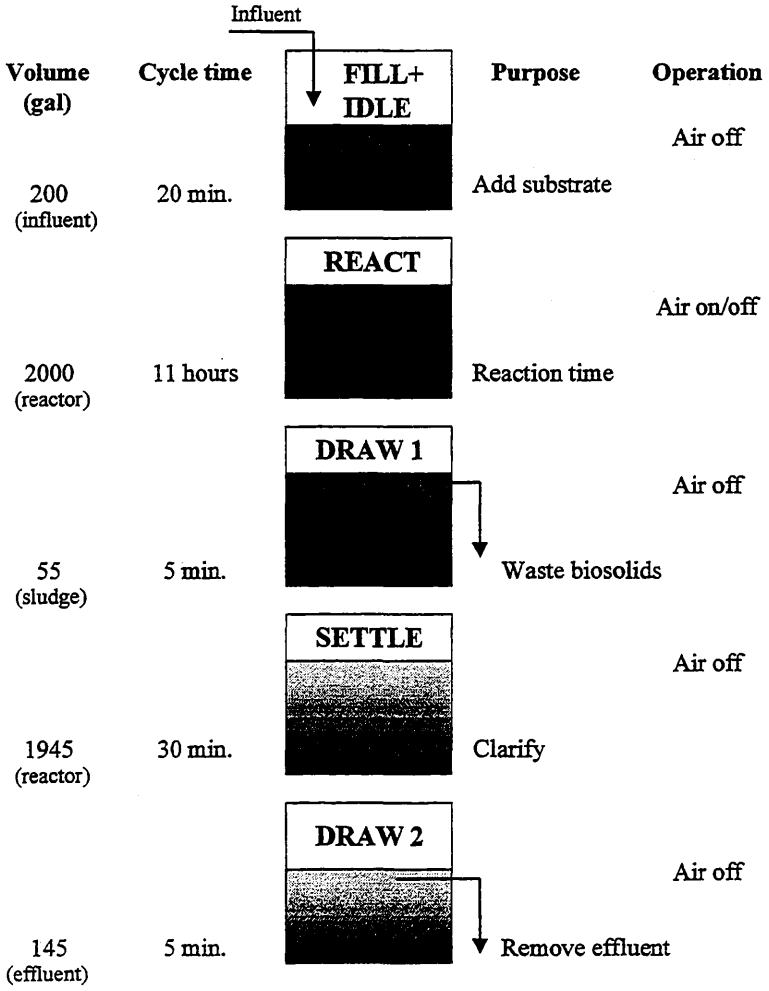

Figure 9. Typical SBR operation for 12-hour cycle

Other Aerobic Systems

There are different methods to promote retention of the bacteria responsible for biological treatment. One of these methods is usually referred as suspended growth. In this case bacteria are in suspension within the liquid. Aerobic lagoons and activated sludge processes, as discussed above, are good examples of the suspended growth method to retain bacteria. The other method is known as fixed growth, and bacteria grow

attached to a certain material (plastic, rocks, etc.). Trickling filters and biofilters, for example, use fixed media to retain bacteria.

Packed bed reactors and biological aerated filters represent attached growth processes that have been utilized to some extent for nitrification of municipal wastewaters. Unlike trickling filters, the hydraulic design of these systems is such that the media are submerged in the reactor liquid. In packed bed reactors and biological aerated filters (also known as BAF), the media are stationary during normal operation, held in place by gravity. Westerman et al. (Westerman and others 1998) have summarized some of the most important aspects related to aerated biofilters and its applications for the treatment of municipal and industrial wastewaters, and agricultural wastes.

Westerman et al. (Westerman and others 1998) described a series of experiments that were carried out during 12 months in a pilot plant with capacity to treat up to 8 m^3/day of supernate from settled flushed swine wastes in North Carolina. The system was composed of two upflow-aerated biofilters connected in series and two polishing tanks, also connected in series. The aerated biofilters were evaluated in terms of reduction of organic matter, nutrients and odor. Average removals during warm weather conditions (about 80°F) were over 80% for organic matter (BOD) and TKN. Operation at lower temperatures (about 50 °F) resulted in lower performances.

A mass balance average for the 12 months indicated that about 30% of the influent volume, 35% of Total-N and 60% of Total-P are removed with the biofilter backwash. Thus, management of the relatively low solids content backwash is a critical factor in implementing this type of system on a farm. The unaccounted-for nitrogen was about 24% and could have been lost as ammonia volatilization or possibly through denitrification within the biofilm.

Liquid samples were taken for evaluation by an odor panel on four different occasions during the monitoring period. They were analyzed for odor intensity (concentration), odor irritation intensity and odor quality (pleasantness or unpleasantness). Descriptive scales for odor intensity, irritation intensity and pleasantness utilized by odor panelists varied from 0 to 8. A trained odor panel evaluated all samples. Positive control (butyric acid) and blank samples (fabric and water, not exposed to odorants) were used throughout the evaluation. There were significant reductions in odor intensity from about 5.5 to about 2 and odor irritation from about 4.5 to less than 2 in the biofilter effluents, with most of the reduction taking place in the first biofilter. The backwash from the two biofilters was also sampled for odor on the three occasions. The backwashes had higher odor intensity, irritation, and unpleasantness than the effluents. If the backwash material is stored for a period of time, the odor could increase further. The backwash also has the capacity to be furthered settled and supernate removed. Thus, depending on how the backwash is managed, further analysis of odor potential may be needed.

Aerobic treatment of animal manure is not commonly done on livestock and poulty farms because of the high costs of operating, due mainly to electrical energy to supply the air or oxygen to the waste but also because of initial costs and management and labor requirements. If done properly, aerobic treatment will significantly reduce odor and other odorous gas concentrations, but the process is very sensitive to numerous factors which make it fairly unpractical in the short run.

ANAEROBIC TREATMENT

Process

Anaerobic processes are biological treatment processes that occur in the absence of oxygen. The goal of an anaerobic process is to stabilize the organic matter. This stabilization is the conversion of organic matter to gases (carbon dioxide, methane, water vapor, hydrogen, etc.) and microbial cell tissues. The process occurs in two steps. The first step, hydrolysis, converts long-chain carbon molecules to volatile short-chain organic acids (e.g., acetic and propionic acid). The second step, the methanogenic stage, converts these short-chain organic acids to methane and carbon dioxide. Most manure management systems are anaerobic which primarily include lagoons, digesters, and storage ponds.

These characteristics are associated with anaerobic treatment:

- Low initial and operating costs
- Simple operation
- Wide range of potential loading rates that remain constant
- Deep lagoons with less surface area
- Crusting and self-sealing in most soils
- Mixing is a function of gas production
- Takes one to two years to build up microbial population
- Odors are produced
- Cold temperatures and freezing limit the process
- Loses up to 80% of nitrogen through ammonia volatilization

The advantages of the anaerobic process are:

- High degree of stabilization
- Low production of biological sludge
- Low nutrient requirement by the microorganisms
- No oxygen requirement
- Methane can be a useful end product

The disadvantages of the anaerobic process are:

- Production of odors
- Slow rate of biological growth
- Slow adjustment to changes in temperature and loading rates
- Works best at elevated temperatures

Lagoons

The most popular anaerobic reactor is the anaerobic lagoon. They are generally unheated, uncovered and there is no control over gaseous emissions. Treatment by anaerobic lagoons is controlled mainly by the loading rate per unit volume and routine removal of liquid and eventual removal of sludge. An anaerobic lagoon is a basin specifically designed to treat (stabilize) manure even though some storage takes place. In Minnesota, an anaerobic lagoon contains six to eight times the volume of a storage unit that can be pumped out completely. This extra volume is

used as the minimum design volume and this material is never removed. In the anaerobic lagoon process, there is little or no control of environmental conditions and loading rates can vary considerable. This can cause the two-step process to become unbalanced and volatile malodorous intermediate chemicals are allowed to accumulate unchecked. These products can then be emitted into the atmosphere as odors. Therefore, the loading rate and temperature in anaerobic lagoons are critical parameters for the minimization of odor, both in the biogas produced and in the treated effluent.

Periodic overloading and turnover in the spring season may result in complaints about odors being generated from lagoons. It was suggested by Barth et al. (Barth and others 1990) that increased odor levels from lagoons in the spring may be partially explained by over production of volatile acids by acid-forming bacteria during the winter. Apparently, acid-forming bacteria can be active under 4°C, while methane-forming bacteria has very little activity under 15°C. Therefore, volatile acids produced by acid-forming bacteria are not used or processed by methane bacteria when temperatures are in the 4 to 10°C range, thus resulting in potential increase of odor levels in the lagoons in early spring.

Greater potential for odor emission occurs when retention times are too short, or lagoon loading rates increase due to expanding animal numbers, slug loading, concentrated waste streams, and/or inadequate water for dilution. Odor emission from anaerobic lagoons is more likely when the lagoon surface is disturbed during windy conditions, during agitation and pumping for land application, during spring turnover – defined as very vigorous bacterial activity during the spring due to incomplete metabolism of material during winter. An anaerobic lagoon will produce minimum odors when acid-forming and methane-forming anaerobic bacteria are in balance.

Odor tends to be proportional to lagoon loading rates (Fulhage 1995). Lagoon loading rate refers to the mass of volatile solids per unit of lagoon liquid volume reserved for treatment, in pounds per cubic foot (ASAE 1994). In general, this rate is reduced for lagoons in areas of lower temperatures, and is greater in areas of higher temperatures. The assumption is that increased lagoon volumes will provide similar end results in low-temperature areas as a smaller lagoon in a higher-temperature area. These loading rates have been developed largely through experience based on 40 years of research to optimize biological treatment processes for biochemical oxygen demand (BOD), odor and solids reduction (Swine Odor Task Force 1998).

Purple or pink colored lagoons, indicating the presence of purple sulfur bacteria, are less likely to be considered an odor nuisance than more typical non-purple lagoons. Design and management factors that encourage the growth of these bacteria are poorly understood. Schulte et al. (Schulte and others 1997), for example, have recently observed that organic loading may not be a critical factor for the growth of purple sulfur bacteria in anaerobic lagoons and that purple lagoons had a somewhat less reducing environment than did the non-purple lagoons, especially in the spring.

There have recently been some concerns on the ammonia emissions from anaerobic lagoons to the atmosphere, but there is little experimental data to support any definite conclusions. The impact of loading rate on mean lagoon TKN (Total Kjeldahl Nitrogen) and NH_3-N has been recently described by Bicudo et al. (Bicudo and others 1999b). It was found that lagoons that served finishing facilities typically had considerably higher TKN and NH_3-N concentrations for a given loading rate as compared to non-finishing facilities. The same observation is true for other

parameters such as COD and Total-P. The effect of reducing loading rates on the ammonia emission from lagoons has not been quantified yet.

Ammonia losses from storage tanks are reasonably well documented (Sommer and others 1993), but there are only a few experimental data concerning ammonia emission from large open treatment/storage areas. Fulhage (Fulhage 1998) reported that both measured data and model results indicate that 50 to 60% of the excreted nitrogen may be volatilized in Missouri anaerobic swine lagoons. Initial attempts to quantify ammonia emission from lagoons were based on nitrogen mass balance (Koelliker and Miner 1973). A nitrogen balance of known quantities of nitrogen added, removed and accumulated in the lagoon had to be used and the unaccountable loss was assumed to be by ammonia desorption. A value of 3.6 g NH_3-N/m^2 day was obtained. This amount was equivalent to 64% of the total nitrogen going into the lagoon. More recent, Harper and Sharpe (Harper and Sharpe 1998) reported average NH_3 emissions estimated from measurements taken from two lagoons in North Carolina (micrometeorological mass balance technique). The values range from 0.29-2.2 g NH_3-N/m^2 day. It appears that NH_3 emissions from lagoons depend on NH_3 concentration in the lagoon liquid, pH and temperature in the lagoon liquid, and wind speed, a physical factor to account for turbulence. The same authors reported high N_2 emissions from anaerobic lagoons, ranging from 0.9 to 12 g N_2/m^2-day. They attributed these large N_2 emissions to chemical denitrification and biological denitrification (or combination of the two) processes.

Biogas production from anaerobic swine waste lagoons has been studied by several researchers (Chandler and others 1983; Safley and Westerman 1988). The rates at which biogas is produced from anaerobic lagoons are usually low compared to high rate digesters, and are mainly affected by temperature and organic loading. Measured rates vary from as low as 0.05 to over 1 m^3 biogas/m^2-day. Methane usually accounts for between 60 % to 80 % of the total biogas content. Temperature drop in the winter is reflected by a low biogas production rate, so that the reliability of such systems as an energy source is often questionable.

Digesters

An anaerobic digester is a system for biological conversion of biodegradable organic materials into collectable methane, carbon dioxide, water, and other gases under a controlled and maintained environment. The main components of the system are the digester chamber, slurry preparation, slurry storage, sludge sotrage, effluent storage, gas collection and usage, and the supporting mechanical equipment. This set of equipment integrates into an existing livestock manure management system and does not take the place of any other components.

Anaerobic digestion advantages include:

- Organic content of the residue is reduced and stabilized so that final disposal presents reduced pollution potential.
- Digested effluent is somewhat-odorless, free-flowing liquid.
- Fertilizer nutrients are preserved.
- Methane, a constituent of the gases produced by the process, has significant value as fuel.
- Weed seeds and some pathogens may be destroyed during digestion.
- Rodents and flies are not attracted to the digested residue.

- Particulate matter in sludge may have refeeding potential.
- Organic nitrogen will be hydrolyzed to ammonia nitrogen.

Anaerobic digestion disadvantages include:

- Equipment is complex and involves high initial investment.
- Daily feeding of digesters at controlled loading rates is desirable.
- Energy input is required.
- High standards of maintenance and management are required.
- Strict explosion-proof standards must be maintained.
- Temperature (and perhaps volatile acid concentration and pH) must be controlled to optimize gas production.
- Some chemicals, if present in excessive quantities, can inhibit the digestion process.
- Digestion systems will reduce (but not eliminate) solids content; digested liquid slurry remains a pollutant unless subjected to further treatment.

Centralized anaerobic digesters, facilities that serve most of the livestock farms within a 6-mile radius, are used in some areas Europe for manure and odor management. The country with the greatest experience using large-scale digestion facilities is Denmark, where 18 large centralized plants are now in operation. In many cases the facilities co-digest manure, clean organic industrial wastes, and source-separated municipal solid wastes. One of the key policy tools used to encourage technology deployment is "green-pricing," *i.e.* allowing manufacturers of biogas-generated electricity to sell their product at a premium (Danish Ministry of Energy and Environment 1996).

Types of Anaerobic Digesters

There are two broad categories of digesters: batch process (all-in / all-out) or continuous-feed in small amounts as a conventional stirred tank reactor (CSTR) or plug flow (PF). A CSTR is continuously mixed or mixed for a few minutes every hour. A PF system adds manure to one end of a tank, allowing the effluent to overflow and be removed from the other end into a storage unit. A PF system is not mixed, except for natural mixing by gas production. Both CSTR and PF rely on suspended growth, where the solids and particulate matter, along with the bacteria, float in suspension. Fixed-film digesters are those in which a media is added to the tank to increase the surface area and give the microorganisms a surface to which they can attach. Examples include spherical or ringed plastic media, PVC pipe, wood chips, corn cobs, and spheres. Another possible process is the sequencing batch reactor (SBR), in which the operation consists of filling, reacting, settling, draw-down, and idling.

Anaerobic Digestion Biogas

Biogas quality is as follows:

- Methane: 50-60%
- Carbon dioxide: 35-50%
- Water vapor: 2-12%
- Hydrogen sulfide: 0.35%

Biogas typically has an energy content about 60% that of natural gas. Hydrogen sulfide concentrations are usually too high for the recommended use in engines because of a decrease in engine life.

Biogas can be stored between the manure surface and a flexible top cover, at low pressure in a flexible bag or rigid tank, compressed to a medium pressure into rigid (propane) tank, or compressed into a high pressure vessel. The best option is to use the biogas as it is generated.

The most common method of biogas usage is in an internal combustion engine. These engines will be 15% to 30% efficient and have a 20% to 40% power reduction from the rated engine output. Some of this inefficiency can be recaptured by placing a heat exchanger on the water jacket and exhaust manifold to help heat the digester and passing incoming fresh ventilation air past the engine-generator set to preheat the air. Boilers and water heaters are about 70% efficient, with a typical 40% reduction in expected output compared to the rating of the heater.

Anaerobic Digester Effluent

Compared to digester influent composition, the effluent composition has 2% to 5% less volume, the same N, P, and K, and fewer odors. Note that in an economic evaluation of digestion, nutrients cannot be considered since these nutrients are present whether a digester is used or not.

Anaerobic Digestion Economics

The economics of digestion take into consideration operation size (larger is more economical), energy price (propane, fuel oil, and/or electricity), energy savings vs. energy selling, new vs. used equipment, labor cost, replacement costs, and odor control value with no cost savings for fertilizer value. Minimum operation size to consider installing an anaerobic digester is about 250 milking cows, 400 sows farrow-to-finish, or 100,000 layers. **Table 17** provides guidelines for electricity generation (Parsons 1984).

A case study done by Edgar et al. (Edgar and others 1992) evaluated the feasibility of a centralized digester in Tillamook County, Oregon. The study included 26,000 dairy cows with 68% located within a 16-km radius and 92% within a 40-km radius. The digester-power plant was projected to operate at a $514,000/yr deficit. A $2.20/tonne surcharge was assessed to livestock producers for handling the manure.

Current Status of Anaerobic Digestion

Lusk (Lusk 1998) summarized the status of farm-based anaerobic digesters in the U.S. by indicating there are 28 digesters operating and 10 more under construction/planning phase. There are no operating digestors in Minnesota and only one under construction. The most common types of digesters found on U.S. farms are high-solids anaerobic digester, plug flow, complete mix and covered lagoon.

CSTR and PF digesters are the most popular options for the anaerobic treatment of animal manures. The PF digesters were adopted with some success in the cooler climate of the northeast, where dairy farms primarily use scraping systems for manure removal. Because flushing systems and anaerobic lagoons already are in widespread use in warm regions of the country, attention is being focused on earthen lagoon digesters with floating covers that operate at ambient temperatures. This type of digester would potentially be less costly to construct and operate; however, the biogas production rate would be lower (Swine Odor Task Force 1998).

According to Lusk (Lusk 1998), surveyed producers who have installed and continue to operate digesters are generally satisfied with their investment decisions. Some chose to install digesters for non-economical reasons, primarily to control odor or contain excess nutrient runoff. On the other hand, the performance data does not appear to be encouraging to a producer who is considering whether to install an anaerobic digestion system. Overall, the chance of failure, *i.e.* the chance of having a non-operating digester, is about 50% in the United States (Lusk 1998). The failure rates for CSTR and PF technologies are 70% and 63%, respectively. The list of reasons explaining why some anaerobic digesters fail is probably headed by bad design and installation. Poor quality equipment and materials selection is the second most common reason for failure.

The bottom line with anaerobic digestion is that the process is technically feasible, but economically unsound, especially for medium-to small-size operations. However, these shortcomings may be overcome in the future if environmental constraints and economic forces change.

Odor Control

Digestion will not completely solve the odor problems from animal production sites. However, it will help reduce odors by stabilizing organic (odorous) compounds. Hydrogen sulfide and ammonia concentrations are increased because of the conversion of organic sulfur and nitrogen to inorganic forms. Thus, there is the potential for increased hydrogen sulfide and ammonia emissions.

Odors are reduced when controlled loading and environmental conditions of the anaerobic digester keep the two-step process in balance. Most odors associated with anaerobic treatment are associated with overloading. An overloaded digester will sour when the pH drops due to overproduction of organic acids and the methanogenic bacteria that produce methane and carbon dioxide are inhibited by the lower pH and decrease their activity. These organic acids are the precursors of odorous compounds.

Using an 11-pt hedonic scale, Welch et al. (Welch and others 1977) determined that anaerobically digested swine manure dropped 1.9 units between the influent and effluent. They also found that operating the digester at higher temperatures (35°C vs. 25°C) was more effective at controlling odors provided that agitation occurred at least once per hour and solids retention time was greater than 10 days. After storing the manure for 30 days, the digested manure had lower odor ratings compared to stored undigested manure. Digested manure stored for three

Table 17. Guidelines for electricity generations (Parsons 1984)

	Animal Weight kg	Electricity production kW-h/d/animal
Holstein milking cow	570	2
Beef feeder	360	1
Feeder pigs	360	1
Sow unit*	590	2

*Farrow-to-finish, sow plus average weight of 16 pigs/yr

months had lower odor ratings by one unit compared to freshly digested manure.

Increasing retention time will help reduce odors. Powers et al. (Powers and others 1997) found that odor intensity decreased linearly with increased hydraulic retention time (HRT) with an approximate 50% reduction in odor intensity (another measurement parameter) between the feedstock (untreated) and the treated effluent at a 20-day retention time. They also demonstrated that when more methane is produced, the less the odor intensity. Screening fibrous solids before loading the digester to reduce percent total solids (TS) from 2.0% to 1.3% increased treatment efficiency of the process, increased methane output, and helped reduce odors. Hydrogen sulfide concentrations in the head space did not follow this odor intensity pattern as the feedstock began at approximately 2 ppm, jumping to over 2000 ppm at a 6-day HRT, then dropping to approximately 1700, 780, and 580 ppm at 10-, 15-, and 20-day HRT, respectively.

Pain et al. (Pain and others 1990) studied land application of swine manure on grassland. Their work indicated that treating manure with anaerobic digestion could reduce odors by up to 80% during land spreading.

ELECTROLYTIC TREATMENT

The electrolytic treatment is based on oligodynamic action, where small quantities of metal ions dissolved through electrolysis may be able to kill some microorganisms. The treatment, as described by Italian researchers (Ranalli and others 1996), takes place in a storage tank and lasts for several months. Although this process is not completely understood, the effect seems to be based on the following actions (Ranalli and others 1996):

- Oligodynamic action: dissolved copper ions reduce the fermentation and/or respiratory activities of microorganisms in slurry;
- Binding action: odorous compounds are bound by dissolved copper ions;
- Electric action: fermentative and respiratory activities of the microorganisms in the slurry are reduced by means of electric current that can affect cellular membrane mechanisms and ATP (adenosine tri-phosphate) synthesis;
- Anti-flocculating action: the electric field in the slurry seems to affect the formation of a crust on the surface.

Recently, Skjelhaugen and Donantoni (Skjelhaugen and Donantoni 1998) described an electrolytic system for the treatment of cattle slurry. The unit described creates an electric potential of about 4 V and a current of 0.5 and 1.25 A between two copper electrodes. One pair of electrodes, each about 3-ft long, was used to treat about 8,000 gal. The electrodes were suspended in the slurry 3 to 4 inches above the bottom. The polarity of the electrodes was switched regularly in order to reduce the average resistance in slurry. The power required was 50 W per pair of electrode and the energy consumption was about 0.22 kWh/ft^3 of treated slurry. After 8 months iron electrodes replaced the copper electrodes. This operation allows for the replacement of dissolved copper ions in the slurry with iron ions.

The above researchers applied electrolytic treatment to aerobically treated cattle slurry. They concluded that a combined aerobic and electrolytic treatment helped kill thermotolerant coliform bacteria and minimize odor and gaseous emissions from storage. Aerobic treatment reduced

hydrogen sulfide emission from about 1,400 ppm in the air above the untreated slurry to about 300 ppm. Additional electrolytic treatment reduced hydrogen sulfide levels to 150 ppm in the beginning of the storage period, and to zero after 10 weeks. Similar results were obtained in terms of odor reductions.

More research is necessary, especially concerning the odor reduction capability of this treatment, before an accurate assessment can be done.

PRODUCT ADDITIVES

As a result of the increased public, regulatory, and legal attention directed to the odor issue, many producers are considering the use of commercial manure and/or feed additives as an effort to minimize odor and other air emissions from livestock farms. In addition to odor control, many of these products are marketed as having other beneficial effects such as improved nutrient value of the manure, improved animal performance, fly control, etc. Product additives are generally described as compounds that can be added directly to freshly excreted or stored manure for purposes of odor abatement. They are generally made of enzymes, of a mixed/selected culture of microorganisms or are chemically based. Each product has a specific method of application, frequency, quantity, and length of time before the product is "most effective". Some products are pH and temperature dependent and only work within narrow ranges of pHs and temperatures. Although bacteria usually to certain extent are able to adapt themselves to the changes in the environment, large deviations from their optimum growth conditions undoubtedly will interfere with the normal metabolic activities, thereby resulting in a slow growth. This was already evidenced by an evaluation on a commercial product containing enzymes and selected bacteria, which showed that the product did not accelerate the degradation of the malodorous substances even at 15°C (Bourque and others 1987).

The idea of using manure additives to control odors was proposed about twenty years ago and a considerable amount of research effort has been spent in this field. Past researchers rarely found any of the pit additive products to be effective in reducing odor levels of swine manure (Cole and others 1975) (Ulich and Ford 1975) (Sweeten and others 1977) (Warburton and others 1980) (Ritter and Eastburn 1980) (Al-Kanani and others 1992). This is probably due to the complexity of odorous components in animal manure. However, Zhu (Zhu 1999) points out the fact that the key difficulty in the development of effective manure additive products rests with a lack of understanding of the biological activities occurring within the stored manure. The widely used trial-and-error methods to evaluate manure additive products not only are time consuming, but also provide little information on the biochemical mechanisms.

Commercial additives may control specific parameters such as ammonia and hydrogen sulfide from the array of odorants. Objective information regarding the actual impact of the products on odor, as perceived by smell, is becoming available through laboratory and field tests being carried out in different places. Zhu et al. (Zhu and others 1996), for example, tested the effects of five different commercial pit additives on the release of odor and volatile compounds from swine manure. Their results showed that all five products reduced the levels of odor threshold by different degrees ranging from 58 to 87% as compared to the control samples. Three of the five products showed reductions in volatile fatty acids and total volatile solids. Johnson (Johnson 1997) ran field tests with eight different pit additives. The tests were run comparing a barn treated with a manure additive product, against an untreated control barn on the same site with

variables isolated. Results obtained showed statistically significant reduction in ammonia levels in the treated barns as compared to untreated control barns. Odor threshold results were variable, and most products tested had only a slight effect on odor reduction.

Microbiological Additives

Microbiological additives, or digestive deodorants, generally contain mixed cultures of enzymes or microorganisms designed to enhance the degradation of solids and reduce the volatilization of ammonia and/or hydrogen sulfide. The microorganisms are meant to metabolize the organic compounds contained in the manure. Digestive deodorants may act to inhibit selected biological or digestive processes by changing the enzyme balance (ASAE 1994). Most digestive deodorants are applied directly into the manure collection area and/or the lagoon and must be added frequently to allow selected bacteria to predominate (Sweeten 1991).

There have been only a few efforts made to investigate the bacterial decomposition of odorous compounds in swine manure by some specific bacterial species. Ohta and Ikeda (Ohta and Ikeda 1978) conducted a laboratory study regarding the possibility of deodorizing pig feces by *Streptomyces*, which is a genera belonging to a group of microbes encompassing a wide range of bacteria called *Actinomycetes*. They found that under optimum "deodorization conditions" (pH, 8.6 to 10; temperature, 35 to 40°C; moisture content, 42-63%), two bacterial genera (*Streptomyces griseus* and *Streptomyces antibioticus*) demonstrated strong ability of deodorization. Bourque et al. (Bourque and others 1987) conducted research on microbial-degraded odorous substances of swine manure on a laboratory scale under aerobic conditions. The bacterial culture under study was inoculated into sterilized swine manure and incubated for a maximum of 6 days at 29°C. They found that three bacterial species (*Acinetobacter calcoaceticus*, *Alcaligenes faecalis*, and *Arthrobacter flavescens*) could completely degrade all types of VFAs in swine manure while *Corynebacterium glutamicum* and *Micrococcus* sp. could only degrade acetic and propionic acids. Another laboratory experiment done by Jolicoeur and Morin (Jolicoeur and Morin 1987) also reported that *Acinetobacter calcoaceticus* could degrade VFAs in both sterilized and non-sterilized swine slurry incubated at 22 °C within pH 6.2-8.6 for 21 days.

Although there exist bacterial genera or species that can decompose odorous compounds like VFAs to reduce odor emission, little success has been reported in using these microbes as manure additives to control odor generation in the field.

According to Grubbs (Grubbs 1979), the key in using bacterial cultures for deodorization of manure is to have the added bacteria become the predominant strain of bacteria in the manure. In order for the added bacteria to flourish, the real environment should not deviate tremendously from the optimum growth range for the bacteria. Past work was mainly focused on determining the bacterial functions in digesting odorous compounds under optimum conditions. This usually does not guarantee that bacteria growing well under optimum conditions will also grow well in the field. Bourque et al. (Bourque and others 1987) showed in their study that none of the inoculated microorganisms became dominant in the non-sterilized swine manure samples. The indigenous flora (not necessarily those reducing odors) of the wastes always grew better than the inoculated microorganisms. In addition, the selected microorganisms may even use other organic compounds in preference to the malodorous substances when inoculated in some wastes, which impairs the values of the additives.

Miner (Miner 1995) reviewed several studies of digestive deodorants and concluded that "the variable success measured for the effectiveness of microbial and digestive agents to control odor may be due to the inability of these products to degrade many of the compounds which collectively make up odor from a swine operation." And "supplemental microorganisms, as additives, may not readily adapt to the natural conditions in manure handling systems and are often susceptible to competition from the naturally occurring indigenous microbial populations."

Masking Agents, Counteractants, Adsorbents and Absorbents

Masking agents cover one smell with another. They are made from a mixture of compounds that have a strong odor of their own (for example, pine), thus masking the undesirable odor. They can be effective as an emergency, short-term solution for the symptom, but generally, long-term control of the odor problem will be necessary.

Masking agents are normally used as vaporized material. They usually consist of organic aromatic compounds such as heliotropin, vanillin, eugenols, benzyl acetate, and phenylethyl alcohol. They are injected into the air right above the liquid surface of the odor source (in this case, stored manure).

Non-vaporized agents are applied directly to the manure. Miner (Miner 1995) concluded that "the organic chemical composition of most masking agents makes them susceptible to degradation by the microorganisms indigenous to manure." And thus, "the odor control capacity of most masking agents and counteractants may be too short lived for practical use in swine production environments."

The effectiveness of masking is difficult to predict due to varying odor characteristics and changing weather conditions. Masking agents primarily used where the level of odor is relatively low, always increase the total odor level. Without any chemical reaction, the individual constituents of the odor remain unchanged. The main advantages of masking agents are their low cost and non-hazardous nature (WEF 1990). The disadvantage is the tendency of the agent to separate from the odor downwind.

Counteractants do not react chemically with the malodor, but reduce the perceived odor level by eliminating the objectionable characteristics of the malodor. They usually have a neutral pH, are easy and safe to handle, and are moderately more expensive than masking agents (WEF 1990). Counteractant chemicals neutralize the following odor types: phenols, amine, mercaptan, aldehydes, solvent odors, aromatics, and organic fatty acids. They usually lower or maintain the same odor level. Their effectiveness is not always predictable.

Adsorbents and absorbents are biological or chemical materials that can collect odorous compounds on their surfaces (adsorb) or interiors (absorb). Examples are Sphagnum peat moss, sawdust, rice straw, sodium bentonite, and certain natural zeolites. Absorbents with a large surface area, such as sphagnum peat moss, have been found to reduce odor in some lagoons (Swine Odor Task Force 1998). Floating organic lagoon covers (straw) and soil biofilters are other examples of the use of odor absorbing materials.

Chemically-Based Additives

This type of additive acts by chemically altering odorous compounds or enzymes. They may also kill the bacteria, which produce the volatile organic malodorous compounds. Chemical additives

are made from chemical compounds that can promote oxidation or precipitation of undesirable odor compounds. Chemical compounds can also be added for pH control and also as electron acceptors. If properly applied, the operating cost of reactive chemicals may actually be less than for masking agents or counteractants.

When dosing chemicals into manure, side reactions will occur in addition to the desired reaction. In calculating dosing rates, a generous factor of safety must be allowed to account for these side reactions. Most of the chemical products are pH dependent and only work within a very narrow range. Pilot testing is recommended for all chemical-dosing systems. Chemical additives are usually classified in terms of their mode of action:

Oxidizing Agents: chlorine (as gas or sodium hypochlorite), potassium permanganate, and hydrogen peroxide will oxidize sulfides and inhibit sulfide production. Ozone has also been used as an oxidizing agent.

Precipitants: iron and zinc salts will react with sulfides to form insoluble compounds. Ferrous and ferric chloride have been used for that purpose.

pH Control: sodium hydroxide or lime can be added to manure to raise the pH, inhibiting sulfide production and preventing hydrogen sulfide off-gassing, but probably increasing ammonia production.

Electron Acceptors: electron acceptors are taken up preferentially to the sulfate ion, and thus prevent sulfide formation. Sodium nitrate can be used for this purpose.

Researchers in Iowa and Indiana are experimenting with products that are injected into the building air climate through high-pressure mister systems. The function of a periodic mist injection is to neutralize volatile odor compounds that accumulate in the building prior to being exhausted. Heber et al. (Heber and others 1997) reported on a 63-day field test in a 1000-head commercial naturally-ventilated swine finishing house. The chemical solution was sprayed into the top of the pit creating an aerial mist in the headspace and covering the entire surface of the manure slurry. Their results show a reduction of mean NH_3 emissions from 5.9 to 1.8 g/pig-day as compared to an identical untreated house. The mean H_2S emission rate of 0.15 g/pig-day did not change with the treatment. No current conclusive results on odor emissions have been published on this type of system.

Miner (Miner 1995) pointed it out that long-term use of chemical additives may require large amounts and frequent applications, making their continual use expensive and potentially damaging to the environment (soil, surface water and groundwater). However, chemical additives may be effective at controlling odor and gas emission during agitation and pumping of manure storage facilities. Researchers at the University of Minnesota (Clanton unpubl.) and at University of Kentucky (Turner unpubl.) are currently testing various chemicals that are capable of reacting with sulfides, thus minimizing hydrogen sulfide emission during agitation and pumping of manure.

Table 18. Effect of land application technique on the reduction of ammonia emissions after spreading cattle and pig slurry on grassland and arable land (adapted from Burton 1997)

Spreading technique	Application on grassland				Application on arable land			
	Trials	Handling rate (gal/ac)	% NH_3 loss[1]	% Reduction on NH_3 emission[2]	Trials	Handling rate (gal/ac)	% NH_3 loss[1]	% Reduction on NH_3 emission[2]
Deep injection (12 in deep)	6	4,000	0.9	98	4	3,400	1.0	98
Shallow injection (3 in deep)	32	2,300	9.4	87	2	2,000	2.8	90
Drag shoe	27	1,500	20	63	5	2,200	9.5	73
Band spreader	3	1,300	43	41	2	2,000	33	31

1 – as a percentage of the NH_3-N in the slurry.
2 – compared to the emission from broadcasting application.

LAND APPLICATION

Land application of slurry manure is one of the most significant sources of odor complaints (Ministry of Agriculture 1992). Odors can be smelled a long distance from the field, depending on the weather, method of spreading, application rates and other more specific conditions.

Land application of manure to cropland is a critical factor in the long-term sustainability of animal agriculture. Manure application returns nutrients and organic matter to the soil, keeping it healthy and productive. Unfortunately, manure application to cropland does present some environmental risk. Over application of manure can lead to nitrate leaching into groundwater, phosphorus runoff into surface water, and a variety of other pollution problems. Proper manure application requires knowledge of the nutrient content of manure, the nutrient requirements for the crops, the availability of the manure nutrients, the physical limitations of the application equipment, and some understanding of the critical environmental hazards associated with manure application.

Along with water quality problems are nuisance odor concerns. Odor from manure is, in general, offensive to most people. One of the key factors in odor control is the surface area of the emitting source. The larger the surface area the more odors are emitted. As such, manure applied on the surface of cropland presents one of the most significant sources of odor for any livestock operation. This odor may last for a few hours to as much as two weeks depending on weather

conditions. Manure that is applied underneath the soil surface (injected) or covered with soil immediately after spreading (incorporation) nearly eliminates manure odor. This is because the odorous gases must travel through a soil layer before being emitted into the atmosphere. This soil layer acts as both a trap for odorous gases and a treatment system, changing odorous gases into less odorous gases through a microbial process. Manure injection or incorporation also reduces manure nitrogen losses to the atmosphere through ammonia volatilization.

Therefore, in order to minimize the risk of pollution and generation of odor, two general requirements must be observed (Kack and others 1994): (i) faster penetration of slurry into the soil after spreading; and (ii) high spreading accuracy. Various types of equipment have been developed in the last few years in order to comply as much as possible with the above requirements. Nevertheless, broadcasting liquid and solid manure followed by immediate incorporation is still very popular among farmers both in the US and Europe, compared to direct injection of manure, mainly because of energy requirements.

Band spreaders are becoming popular in Europe as regulations on odor and ammonia emissions are becoming stricter. Band spreaders discharge slurry at ground level through a series of trailing pipes. Odor measurements show a reduction of 55 to 60% compared with conventional broadcasting with splash plate spreaders (Ministry of Agriculture 1992). After application, the slurry is rapidly incorporated into the soil in order to minimize odor and ammonia emissions.

Injection techniques (shallow and deep injection) are very effective for minimizing ammonia emissions during manure spreading on land (about 85% less odor than from conventional spreaders – (Ministry of Agriculture 1992)). The equipment is very expensive and it is likely that a farmer will contract with a professional applicator in order to inject manure. The technique is generally not suitable for soils with more than 20% clay content, stony soils and hilly terrain (Frost 1994). A new technique for injecting slurry into soils, especially on grasslands, has been recently developed in Norway (Morken and Sakshaug 1997). The Direct Ground Injection - DGI® concept involves slurry injection under high pressure (5 to 8 bar) directly into the soil. After being pressurized the slurry is distributed to nozzles. The nozzles jet out the slurry in pulses forceful enough to inject the slurry into the ground in elongated, discontinuous cavities at depths between 5 and 10 cm. Trials conducted so far indicate a significant reduction in ammonia emissions (between 80 to 90%) compared to band spreaders.

Various researchers have evaluated the effect of different equipment for land application of manure on the reduction of ammonia emission. Burton (Burton 1997) has compiled much of the information that was available in Europe between 1992 and 1997 (**Table 18**).

Phillips et al.(Phillips and others 1990) compared different spreading techniques for odor emission reduction. Compared with that of a conventional vacuum tanker (broadcasting), a deep injector, a shallow injector, and a band spreader reduced odor emission immediately after application by 83, 70 and 38%, respectively.

Pain et al. (Pain and others 1991) conducted several experiments with three different incorporation methods (plough, rotary harrow and rigid tines) with different delay times before incorporation (*i.e.* the time between land spreading and incorporation of manure into the soil – at 0, 3 and 6 hours). Their results showed that only plowing immediately after spreading gave a significant reduction in odor emission. Compared with the control, immediate plowing gave a

52% reduction and rotary harrow a 20% reduction. No reduction was achieved with the rigid tines, or when incorporation was delayed 3 or 6 hours.

The effectiveness of a range of methods for reducing odor emission after slurry spreading was evaluated by Pain et al. (Pain and others 1990; Pain and others 1990; Pain and others 1991). Spreading aerobically treated slurry (continuous aeration for 4 days and dissolved oxygen values between 1 and 2 mg/l) resulted in 86% reduction in odor (Pain and others 1990). Anaerobic digestion (retention time between 8 and 10 days, and temperature of 95 °F) reduced odor emissions during spreading by 84% (Pain and others 1990). In both cases reductions were compared with spreading slurry with a vacuum tanker. Odor emission was still significantly lower for digested slurry following storage for two weeks (Pain and others 1991).

Morken (Morken 1992) has reported on the effect of application techniques and type of slurry on ammonia losses after application to grassland. He found that shallow injection could reduce ammonia losses between 17 and 40%, depending on weather conditions and on the chemical composition of the slurry used. He also compared ammonia emissions from surface applied slurry using different types of slurry: urine drained-off from gutters, separated liquid slurry, slurry diluted with water (1:1), aerated slurry, and slurry mixed with bentonite. Ammonia losses due to urine application were less than 15%. Application of diluted slurry and bentonite-treated slurry resulted in 20 to 30% ammonia losses. Emission figures after spreading untreated and aerated slurry were in the range of 70 to 85%.

Chadwick et al. (Chadwick and others 1998) measured nitrogen losses and methane emission after application of excessive volumes of swine manure in a soil filter system (Solepur process – (Martinez 1997)). About 10,000 gal/ac of swine manure was applied in the Fall and 24,000 gal/ac in the Summer. Manure was applied using a tow hose system connected to a 130-ft wide spray boom. The total amount of nitrogen applied was 585 lb N/ac in the summer and 1,050 lb N/ac in the fall (excessive application rates). Between 6 and 31% of the total N applied was lost through ammonia volatilization following fall and summer applications, respectively. These losses are within the reported range following surface broadcasting of pig slurries at agronomic rates (see **Table 18** for comparison). Emissions of N_2O were very high following the application in the fall, representing 23% of the total N applied. Methane emissions following slurry applications were between 0.04 and 0.12% of the total carbon added.

Dilution of liquid manure prior to land application is a traditional technique in regions with high rainfall that results in reduction of ammonia emissions. Water addition in the proportion 3:1 reduced NH_3 loss by 20 to 80% compared to undiluted slurry (Burton 1997).

Safley et al. (Safley and others 1992) reported on loss of nitrogen during irrigation of swine anaerobic lagoon liquid (which is relatively dilute as compared to untreated manure). TKN losses occurring during sprinkler irrigation using a center pivot were found to range from 15 to 43%. Of this amount 54 to 100% was accounted for in volumetric losses (evaporation and drift). Ammonia losses were found to range from 14 to 37%. These losses are comparable to losses found when untreated pig slurry is applied with band spreaders or drag shoes (see Table 3 above). However, they are much lower than ammonia losses reported by other researchers who have surface-applied untreated cattle or swine manure to soil or grassland (Hoff and others 1981; Lockyer and others 1989; Pain and others 1989).

Acidification of liquid manure during storage or in the slurry tanker just before spreading results in significant reductions of ammonia and nitrous oxide emissions as a low pH inhibits NH_3 volatilization during and after land application (Burton 1997; Berg and Hornig 1997). Lenehan et al. (Lenehan and others 1994) reported on equipment design for on-tanker acidification system for slurry treatment prior to land application. Carton et al. (Carton and others 1996) analyzed the effect of cattle slurry acidified with nitric acid on nitrogen efficiency for grass silage production. The slurry was acidified with nitric acid to pH 5.5 and was either broadcasted or band-spread. The average efficiency values for N offtake (Eff-N%) relative to inorganic N fertilizer (over all sites and cuts) with acidified cattle slurry were between 81 and 85%. Untreated slurry gave Eff-N% values between 37 and 59%. It was concluded that unfavorable economic and safety aspects would make acidification with nitric acid unlikely to be adopted in agricultural practice.

Misselbrook et al. (Misselbrook and others 1997a) presented results related to control by dietary manipulation of emissions from pig slurry following land spreading. Slurries collected from 2 groups of finishing pigs, fed either a standard commercial diet (CD) or a reduced crude protein diet (RD), were spread in early spring on grass/clover swards at 5,350 gal/acre. Slurry from the reduced crude protein fed pigs had a lower ammoniacal-N, total-N and volatile fatty acid content, lower pH and a higher dry matter than slurry from the pigs on the standard diet. Following land application, ammonia volatilization over the first five days were 60% less from RD slurry. Denitrification losses over 51 days were 73% less from RD slurry. Nitrous oxide emissions were similar for the two slurries applied. Methane emissions were also lower from RD slurry.

Currently there is very little work being done in regard to the measurement of odor and gaseous emissions from land application of animal and poultry manure in the United States and there is apparently no experimental data available. Only initial work with passive samplers have been reported by Zupanci et al. (Zupanci and others 1998) in a study for the determination of ammonia flux from swine effluent applications in the southern great plains.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

A suggested future research area is the quantification of airborne contaminant emissions from animal production systems. During the past 20 to 30 years there have been many studies to determine the indoor air quality of animal facilities, but mainly only contaminant concentrations have been measured and reported. Only recently (the last five to ten years) have ventilation or airflow rates also been measured so that actual emission levels of gases, dust, and pathogens can be determined. These studies need to be expanded to outdoor or ambient air, especially for odor and gases. Emission levels as a function of species, operation size (animal units), and housing systems need to be more accurately determined so decision makers, producers, and the public can identify and prioritize contaminants that are causing the problems. This will allow industry and government to target specific contaminants so future production systems will minimize air quality impacts that have the greatest effect on the environment and humans.

The health risks associated with animal production systems is an important area for further research. Additional research is primarily needed for human health issues dealing with outdoor or ambient air levels adjacent to animal production sites, rather than the indoor air human (worker) health issues, for which there is sizeable body of information. However, both indoor and outdoor health issues are critical to the viability of animal agriculture in Minnesota for neighbors, producers, and others working in and around animal facilities.

The modeling of air contaminant emissions from animal production systems is a current topic of study in the research community and this needs to continue. Models currently used to predict odor and gas plumes from animal production sites were developed for other industrial point source emissions that have some distinct differences from current agricultural applications, thus, the models need to be validated by in-field measurements. These measurements are difficult to make but need to be done to increase the confidence and believability of models to predict air contaminant plume movement and concentration. This will require increased sophistication of in-field measuring equipment to record air contaminant levels, which are generally at very low concentrations and are highly variable due to weather conditions.

Mitigation and control technologies for air contaminant emissions from animal production systems are an active area of research. This needs to continue since the criteria or constraints for agriculture are considerably different from other industries. One major difference is the need for systems that have both low initial and operating costs in order to be economically viable. In addition labor requirements to operate the control technology need to be low because of the limited availability of skilled individuals to management complex systems. This remains a challenge to engineers and researchers developing systems to mitigate air quality concerns.

Summary of Major Current or Ongoing Research

Title: Odor and Gas Emission Reduction form using Four Separate Control Technologies in Deep Pitted Curtain-sided Pig Finishing Buildings

Objective: Evaluate the effectiveness and economics of four new low cost odor control technologies for deep pitted curtain sided pig finishing barns.

Organization – Investigators: U of M - Larry Jacobson and Philip Goodrich

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $68,000

Title: Biocover Longevity and Crust Formation

Objective: Evaluate the long term effectiveness of geotextile covers for manure storage structures and determine critical parameters for the establishment and preservation of natural crusts.

Organization – Investigators: U of M - Charles Clanton

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $115,000

Title: Chemical Addition for Hydrogen Sulfide

Objective: Determine dosage rates, effectiveness, economics, and management criteria of several chemical additives to control hydrogen sulfide emissions from manure storages during agitation and pumping.

Organization – Investigators: U of M - Charles Clanton

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $27,000

Title: Biofilters —Factors Affecting Long Term Efficiency

Objectives: Evaluate the effectiveness of different biofilter mixtures on long term odor control, pressure drop in the filter bed, and nitrogen removal.

Organization – Investigators: U of M - Kevin Janni

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $60,000

Title: Dietary Manipulations on Swine Manure Characteristics

Objective: Determine the effect of various dietary factors in the diets of growing-finishing pigs and dairy heifers and their potential impact on manure characteristics that affect odor emissions.

Organization – Investigators: U of M - Samuel Baidoo

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $100,000

Title: Solids-Liquid Separation for Controlling Odor and Improving Manure Handling

Objective: Determine the relationship of manure slurry particle size on odor emissions and assess various separation and handling systems for swine and dairy manure.

Organization – Investigators: U of M - Jun Zhu

Funding Agency: Minnesota Legislature/Dept of Agriculture -

Duration of Study: July 1, 1999 to July 1, 2001

Amount: $70,000

Title: Development of a Standardized Method for Odor Quantification from Livestock Production Facilities: Stage II, Field Testing

Objective: Develop a standardized method to quantify odor using indicator gases.

Organization - Investigator: Iowa State University – Alan DiSpirito

Funding Agency – ID : National Pork Producers Council – 99-056

Amount - $24,420

Title: Health Significance of Airborne Particles at Pork Production Facilities

Objective: Determine the health significance of airborne particles emitted from pork production facilities.

Organization – Investigator; North Carolina State University – Robert Bottcher

Funding Agency - ID; National Pork Producers Council - 99-116

Amount - $50,000

Title: Odor, Ammonia and Hydrogen Sulfide Emission Factors for Grow-Finish Buildings

Objective: Determine the odor, hydrogen sulfide and ammonia emissions from a grow finish swine building.

Organization – Investigator; Purdue Research Foundation - Albert Heber

Funding Agency – ID; National Pork Producers Council - 99-122

Amount - $28,907

Title: Reduction of Odorous Compounds in Pig Manure through Specific Dietary Manipulation – A Practical Field Study

Objective: Determine the effectiveness of swine diet manipulation on odor reduction.

Organization – Investigator; Purdue Research Foundation - Alan Sutton

Funding Agency – ID; National Pork Producers Council - 99-103
Amount - $36,705

Title: Ammonia Emission in a Room For Weaned Piglets with a sloped pit wall

Objective: Determine the effectiveness of a new manure pit design on ammonia emissions.

Organization – Investigator: Research Institute for Pig Husbandry, Netherlands - A.J.A.M. van Zeeland and G.M. den Brok

Funding Agency - ID - Ministry of Agriculture (Netherlands) - Report P4.31

Title: Ammonia Emission in Farrowing Rooms with Manure Trays

Objective: Determine the effectiveness of a new manure handling method on ammonia emissions.

Organization – Investigator: Research Institute for Pig Husbandry, Netherlands - A.J.A.M. van Zeeland and N. Verdoes

Funding Agency - ID - Ministry of Agriculture (Netherlands) - Report P1.201

Title: Evaluation of New Nutritional Technologies for Situation Dependent Diet Formulation in Swine.

Objective: Evaluate the effect of dietary changes to reduce nutrient excretion and odor emissions.

Organization – Investigator; Minnesota Agricultural Experiment Station (MAES) – Jerry Shurson, Animal Science Department

Funding Agency – ID - U of M, AES – 16-064

Title: Animal Manure and Waste Utilization, Treatment, and Nuisance Avoidance for a Sustainable Agriculture

Objective: Develop and refine methodology, technology and management practices to reduce odors, gases, airborne microflora, particulate matter and other airborne emissions in animal production systems.

Organization – Investigator; Minnesota Agricultural Experiment Station (MAES) – Larry Jacobson, Uof M, Biosystem and Agricultural Engineering Dept.

Funding Agency – ID - U of M, AES – 12-082

Title: Stakeholders Feedlot Air Emission Data Collection Project

Objective: Evaluate emission and dispersion of odor, ammonia, and hydrogen sulfide from livestock and poultry facilities.

Organization – University of Minnesota, National Pork Producers, Minnesota Deparment of Agriculture, Minnesota Pollution Control Agency, and Minnesota Livestock and Poultry Producer Groups.

Funding Agencies – National Pork Producers Council, Minnesota Pork Producers Association, Minnesota Department of Agriculture, MN Pollution Control Agency

Duration of Study: July 1999 to July 2002

Amount - $14,000

SUMMARY OF REVIEW TEAM, CAC & EQB COMMENTS

The team of authors received comments on our first (preliminary) draft of this document from the CAC and EQB after our oral presentation on May 11, 1999. Oral comments were received during the presentation and written comments were received about one week later (May 18, 1999).

Most of those comments addressed specific questions that were either not included in the report or not given enough attention. These included requests for more information on human health impacts, environmental impacts, and economics. Items not covered in the first draft were animal health impacts, land application emissions, and other less common gas and contaminate emissions. Also, more definitions of terms were requested for ease of understanding by lay readers. A few statements in the report were found to contain biased language. More lists and tables were requested to provide more completeness to topics and show the magnitude of the issue. Too much of the report was on mitigation or control with more needed on the problem rather than simply the solutions. Although information pertaining to Minnesota is needed other state's standards and guidelines should be included.

Most of the comments from the first draft were incorporated into a second draft that was sent to the outside reviewers in late May. Those reviewers were asked to read specific sections of the document based on their expertise; one individual was asked to review the complete report.

The attached review forms show that we received a wide range of overall responses. Overall, the reviewer's comments were positive although some individuals indicated that the review should include more information (was not complete) or did not address the questions asked. Even those indicating some problems with the report admitted that it is impractical to include all research completed in any given area and some judgements must be made in the selection of references.

The final draft incorporated reviewer comments as much as possible within time constraints. Most of the changes suggested by reviewers related to details, as might be expected from professional peers. Some new material was added, but it was a relatively small amount compared to the overall length of the document. The emphasis was on improving the quality of the existing document. We believe that this review, although not perfect, provides a fair and honest assessment of the literature related to environmental and health impacts of air quality and odor issues associated with animal agriculture in the state of Minnesota.

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Soils

I

Generic Environmental Impact Statement on Animal Agriculture:
A Summary of the Literature Related to Soils (I)

Prepared for the Minnesota Environmental Quality Board

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EXECUTIVE SUMMARY

The impact of animal agriculture on Minnesota soils depends both on manure applications and on the type of feed crops grown. Both manure and the perennial forages used to feed animals improve soil quality and productivity. The structure of animal agriculture determines where manure is applied and whether soil-enhancing crop rotations are used.

In the past, animal and crop production were closely linked. As these two operations are increasingly separated from one another, manure is not returned to the cropland that fed the animals. This means that nutrients are exported from cropland, and fewer acres receive the soil quality benefits of manure application. As manure is concentrated in smaller areas, it becomes more difficult to handle as a nutrient source and its pollution potential increases.

The effect of animal agriculture on soil depends on

- how much manure is applied,
- whether manure is applied with minimum nutrient losses
- whether manure is applied when soil is dry enough to avoid soil compaction,
- what crop rotation is used to feed the animals. Perennials or densely-rooted forages that generate high residue improve soil quality.

These factors are not necessarily linked to operations of a particular size.

RESEARCH RESULTS

Studies of the effects of manure applications often compare manure application to the application of a comparable level of inorganic fertilizer nutrients. Thus, the effects summarized below usually represent the effects of manure in contrast to commercial fertilizers. These results are summarized in the table at the end of the executive summary.

Agronomic rates of manure application are based on the soil nutrient test levels and crop needs. Disposal rates of manure application are amounts greater than agronomic rates. The issues involved in the calculation of agronomic rates are addressed in the Manure and Crop Nutrients Report.

Manure generally has positive effects on soil physical and biological properties when it is applied at agronomic rates. Research into the effects of disposal rates of manure have generated mixed results. It is likely that environmental problems such as movement of nitrates to ground water and phosphorous pollution of surface waters will occur before soil physical properties are adversely affected.

Physical Properties

Soil productivity and environmental quality depend on several related soil physical properties: soil structure, aggregation, density, water holding capacity, infiltration, and aeration. These properties are impacted to varying degrees by management practices, including manure application and cropping system practices (i.e. crop rotation, tillage).

Livestock systems that promote the rotation of sod or hay crops reduce tillage frequency, stimulate soil microbial activity, provide protective cover and dense root growth, and improve soil physical properties relative to continuous row cropping. Improvements in soil physical properties are also seen in reduced tillage systems.

Manure application improves soil physical properties by building soil organic matter content and improving soil structure, which in turn reduce erosion. The organic matter aids in stabilizing soil structure, reducing soil density, and increasing water holding capacity. Generally soil physical properties improve with increased rates of manure application, and this applies to all types of manure. Organic matter enhancement from manure application can increase water holding capacity but may not increase the amount of water available to plants. The improvements in soil physical properties from manure application are not achieved with mineral fertilizers.

Manure applied at very high rates results in short term degradation of soil tilth, due to changes in soil properties, such as infiltration rate. However, these are overcome with time and the manure application usually results in net soil tilth improvements.

Perennial pastures grown for rotational grazing can improve soil structure. However, animal traffic can contribute to compaction and may reduce infiltration rates depending on the soil type, soil fertility practices, climate, indigenous soil properties, the cropping/pasture system, and how the animals are managed on the pasture. In grazing systems, pasture management is critical. In addition, efficient use of recycled manure nutrients can contribute to more uniform pasture fertility, and improvements of soil properties.

Management practices that reduce erosion are critical for Minnesota. To protect water quality, erosion control is especially important where and when manure is applied to soil. Manure application reduces soil erosion by improving infiltration rates and structural stability. Cropping systems that include hay or sod crops reduce erosion by providing protective soil cover, compared to continuous row crop production. In some cases, the use of conservation tillage in row crop production can minimize these differences.

Nutrients

The nutrient loading of high manure applications generally does not have a negative impact on soil productivity. However, with high loading, nitrogen and phosphorus from manure can have negative environmental impacts.

Salts

Manure application at agronomic rates is unlikely to create salt problems in Minnesota. The exception may be the long-term application of manure in highly localized areas where salts are already a problem. Such areas can be found on some prairie soils with restricted drainage, such as the heavy soils of the Red River Valley. However, in the Red River Valley, the current density of animal operations is not high.

Weeds

Under some conditions manure can be a source of weeds but in general this is not a problem for farmers.

Biological Attributes

Soil biological activity is impacted by animal agriculture. Manure additions build organic matter and improve soil physical properties, both of which result in increased biological activity. However, the degree and direction of manure's effect depends on a number of factors: the type of soil to which it is applied, method of incorporation, the degree of compaction caused by application, carbon-to-nitrogen ratio of the manure, and decomposability of the manure. Manure can also have beneficial effects for disease and pest control.

Cropping systems which include perennial forages and grasses promote soil biological activity compared to row crops. Animal grazing also can increase soil biological activity when stocking rates, animal traffic and forage removal are well managed.

Some potential problems of manure application include: stimulation of denitrification which results in nitrogen losses; contribution to selection of antibiotic-resistant bacteria in the environment; and fecal coliform contamination of soil and water.

KNOWLEDGE GAPS

The authors recommend the following studies to improve understanding of the effect of animal agriculture on Minnesota's soil resources.

- Estimations of the inputs, outputs, and recycling of nutrients in livestock systems of Minnesota.
- Examination of erosion potential for different types of livestock and cash-grain farms in Minnesota.
- A geographical and historical analysis of Minnesota crop and livestock farming.
- The effects of antibiotic feed additives on microbial activity in soils.
- Investigations of the long-term effects of grazing management systems and their impacts on soil quality.
- The value of manure applications for renovating degraded soils.
- The benefits to soil quality of various types of manure amendments versus crop diversity through rotations, green manures, and cover crops.

Effects of Animal Agriculture in Minnesota on Soil Characteristics Compared to Inorganic Fertilizer

	Manure applied at agronomic rates	Manure applied at disposal rates	Animal treading	Forage crops
Biological Characteristics				
Biological Activity	↑	↕	↕	↑
Earthworms and Arthropods	↑	↕	↕	↑
Soil Organic Matter Levels	↑	↑	↔	↑
Pests and Disease	↓	↕	↔	↓
Bacterial Contamination	↔	↑	↔	↔
Physical Characteristics				
Aggregate stability	↑	↑	↔	↑
Bulk density	↓	↓	↑	↓
Infiltration	↑	↕	↕	↑
Water holding capacity	↑	↑	↔	↑
Erosion potential	↓	↓	↕	↓
Soil Aeration	↑	↑	↓	↑
Soil Tilth	↑	↑	↔	↑
Salts	↔	↔	↔	↔
Weeds	↕	↔	↕	↕

↕ = may increase or decrease this characteristic

↔ = has little or no effect

INTRODUCTION

A Soil Primer

Our agricultural economy, and our lives, depend on the soil beneath our feet. It provides the food we eat, cleans the water we drink, and supports the diverse biological habitats around us.

Soil is not a static pile of crushed rock, but a structured mix of minerals, organic matter, air, water, and living organisms. Thousands of years are needed for rock to develop into soil, and hundreds of years for rich organic surface layers to develop. Soil is formed when **parent material,** such as weathered rock, alluvial stream deposits, or glacial deposits, are subjected to climatic and biological forces. Each soil is unique because of its particular developmental history.

Soil is a dynamic body. Gases and water move into and out of the soil. Organic matter is transformed among many different forms. Soil structure is continually being formed, strengthened, or weakened. Living organisms, including microbes, roots, and insects change the physical and chemical environment of the soil. All of these processes occur simultaneously.

Healthy soil performs several functions. It gives us bountiful crops and forests, diverse wildlife, beautiful landscapes, and clean air and water. Soil does each of these by performing five essential functions:

- **Regulate water.** Soil regulates and partitions the flow of water and solutes into and over the land.
- **Sustain plant and animal life.** Soil sustains biological activity, diversity, and productivity.
- **Decompose and filter pollutants.** Soil filters, buffers, degrades, immobilizes, and detoxifies organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition.
- **Cycle nutrients.** Soil stores and cycles carbon, nitrogen, phosphorus, sulfur, and other nutrients and elements within the earth's biosphere.
- **Support structures.** Soil supports socioeconomic structures and protects archeological treasures associated with human habitation.

Six soil processes will be discussed below. Many terms used in Part II are explained in this section.

- Formation of soil structure
- Soil water movement
- Gas exchange
- Nutrient cycles
- Biological processes
- Organic matter dynamics

Formation of soil structure

Soil particles (sand, silt, and clay) range in size from gritty sand particles as large as 2mm (1/16 inch) down to microscopic clay particles 1000 times smaller. The relative amount of sand, silt, and clay is called **soil texture.** These particles rarely exist separately in the soil. They are normally combined into clumps called **aggregates** or peds. A few particles bind into tiny microaggregates. Microaggregates, in turn, combine to form larger aggregates. Ideally, soil will have a wide range of aggregate sizes and pore sizes. Soil texture and the organic matter content of a soil control the degree of aggregation that is possible.

Aggregates form as a result of physical, chemical, and biological processes. Physical and chemical processes are especially important in the formation of smaller aggregates. Particles are physically pushed closer together by freezing and thawing, wetting and drying, roots pushing through the soil, and the burrowing of earthworms and other organisms. At the molecular level, electrochemical charges bond clay particles together and organic matter then binds with the clay particles.

Biological processes are very important in the formation of soil aggregates. Humus and compounds produced by soil organisms help bind soil particles together. Fungal strands and fine roots surround aggregates and help stabilize them. Plant residue is food for the fungi and bacteria that help form and stabilize soil aggregates. All of these processes explain why plant residue, manure, and other forms of organic matter improve soil structure.

Larger organisms, such as insects and earthworms, enhance soil structure when they burrow through the soil and deposit fecal pellets that become stable soil aggregates.

The structure of agricultural soils is generally measured and compared in terms of the size and strength of the soil aggregates. **Aggregate stability** is the strength of soil aggregates to withstand chemical and physical forces, such as tillage or rain. Aggregates in healthy soil will vary in size and will have high aggregate stability. Soils with poor aggregate stability are susceptible to formation of **surface crusts** when rain drops hit aggregates and detach soil particles. Then fine clay particles clog the spaces between aggregates and form a crust on the soil. Biological activity and organic matter (such as from manure and crop roots) help stabilize aggregates and prevent erosion and the formation of surface crusts.

Soil structure is the arrangement and stability of aggregates (clusters of soil particles) and pore spaces in soil. The pore size and shapes affect the ability of a soil to transmit water and air. This impacts root and plant development. Soils with good structural development are more porous and less dense than poorly structured soils.

Soil density, usually called **bulk density,** is a measure of the proportion of solids and voids in a volume of soil. Soils with good structural development are more porous and less dense than poorly structured soils. Soil bulk density is dependent upon the soil texture, with sandy soils having higher density than fine textured soils. Degradation in soil structure due to depletion of organic matter or other factors can increase bulk density over the long term. Compaction from wheel traffic or grazing can increase soil bulk density.

Soil water movement

Soils store water that can be utilized by plants and other organisms. Like animals, plants need large amounts of water every day. Yet, too much water deprives roots of air and makes soil susceptible to compaction. Water management is basic to erosion and pollution control.

Several soil properties that affect soil water movement are:

- **Available water holding capacity**— the amount of water soil can hold against gravity's pull, and that is readily available to plant roots. The **plant available water** is the difference between the amount of water stored when the soil is wet to field capacity and the **permanent wilting point**—the amount remaining in the soil when plant roots can no longer extract water. The amount of stored water that is available for plant uptake is controlled by organic matter content and soil type.
- **Infiltration rate**—the rate at which rain, irrigation, or snowmelt gets through the surface and into the soil. Water that does not infiltrate, generally becomes **runoff.** Infiltration rate depends on factors such as structure, aggregate stability, and density. Living crop vegetation and decaying crop residues on the soil surface protect soil from rain drop impact and slow runoff, resulting in higher infiltration. Rough soil surfaces increase infiltration by creating depressional areas where water can pond and not runoff.
- **Hydraulic conductivity**—a measure of water transmission through soil and is often used to assess effects of management. Hydraulic conductivity is generally measured by assessing the flow of ponded water through a volume of soil. Hydraulic conductivity is a good assessment of soil structural changes; however, it does not include the effect of soil particle detachment caused by raindrop impact on soil and crusting. Thus, hydraulic conductivity measurements assess soil structure and porosity, while infiltration rates measured with simulated or natural rain assess hydraulic conductivity in combination with soil surface conditions.
- **Drainage** or **percolation**— the excess water that soil cannot hold that moves out of the rooting zone so that roots and organisms can get air. Soil texture, soil structure, and landscape position determine how much water percolates through the soil.

Gas exchange

Plant roots and other soil organisms get essential gases from soil air. Gaseous exchange with the atmosphere is required in order to maintain an adequate supply of oxygen and to avoid excess accumulation of the carbon dioxide generated by biological respiration. Aeration refers to the volume of air in the soil as well as the exchange of air at the soil surface. The air-filled porosity is controlled by the total amount of pore space and the volume of the pores occupied by water.

The factor that exerts the most change on soil aeration is the soil water content. Constant changes in water content due to precipitation, evapotranspiration, and drainage result in simultaneous changes in soil air content.

The development of soil macropores can be important for soil aeration. **Macropores** are large pores generated from root channels, earthworm burrows, cracks, or fissures. When a soil is saturated, the macropores are the first pores to drain and fill with air. Management practices that promote development of macropores include limited tillage, high surface residue, perennial forage and hay crops, and organic matter additions, such as animal and green manure.

Nutrient cycles

Soil is the storehouse for the nutrients that plants need. It is a dynamic environment in which soil biological, chemical, and physical processes are continually changing the form of plant nutrients.

Soil particles and plant residue are made of large quantities of nutrients that are unavailable to plants. Through chemical and biological activity, some mineral particles weather into mineral ions or form clay minerals made of sheets only several atoms thick. Plant residue may also decompose into mineral ions or may be transformed into humus. **Mineralization** is the conversion of organic compounds by soil organisms into inorganic compounds. **Immobilization** is the reverse process--plants and soil organisms convert inorganic compounds to organic form in their tissues.

Clay and humus are not absorbed by plants, but they hold nutrients on their surfaces. The amount of places available on clay and humus to hold nutrients is called the "exchange capacity" of the soil. **Cation exchange capacity** is the sum of exchangeable cations that a soil can hold, or the number of places available for positively charged ions, including calcium, magnesium, sodium, potassium, copper, zinc, manganese and iron ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Zn^{2+}, Mn^{2+}, and Fe^{2+}). Nutrient ions attached to the exchange sites on clay and humus are released into the soil solution for use by plants and soil organisms such as bacteria and fungi.

Plant roots draw most of the nutrients they need from the **soil solution**—the water and dissolved minerals in soil pores. The amount of nutrients in the soil solution at any one time is just a fraction of those needed by plants over the course of their life cycle. The soil solution must be continually replenished from the store of nutrients in minerals and organic matter. As plants draw nutrients out of the soil solution, more may be released into solution from exchange sites on clay or released from the organic fraction due to mineralization. Many farmers also contribute nutrients to the soil solution by adding chemical fertilizers each year. Fertilizers added to soil do not remain unchanged, waiting to be used by plants. Like minerals from other sources, either they become attached to exchange sites, or are used by microorganisms and transformed into other forms.

Soil fertility is not just a measure of the amount of nutrients, but whether plants can get the nutrients when they need them. To thrive and use soil nutrients, plants need deep, crumbly soil for good root growth, adequate water holding capacity, appropriate pH, adequate organic matter levels, and a healthy biological community to cycle nutrients, enhance plant growth, and control pathogens.

Biological processes

Soil organisms were mentioned in connection with all of the previous soil processes. Their life cycles are an integral part of the soil formation process, development of soil structure, and nutrient cycles. Their activity is highly dependent on the air and water status of soil, temperature, food supply, and pH.

The food web of organisms that live underground is at least as diverse and complex as the ecosystem of plants and animals living above ground. Practically all the energy for the food web comes from the sun. Plants and other photosynthesizers convert the sun's energy and carbon dioxide into the carbon compounds used by other organisms. Plant-eaters create compounds that other organisms need. As bacteria, fungi, earthworms, microscopic insects, and other organisms consume and transform carbon compounds, they release carbon dioxide back into the atmosphere and make nutrients available to plants.

Measuring biological characteristics

Soil biological activity is evaluated by measuring a number of soil processes, including some related to organic matter cycling.

- **Total organic carbon and nitrogen**, or total organic matter
- **Microbial biomass—** the quantity of soil microbes, including mostly fungi and bacteria, as well as protozoa, algae, nematodes and very small animals (mites, insects, etc.)
- **Mineralizable carbon and nitrogen—** the fraction of organic matter that can be decomposed by microbes. Laboratory measures of **respiration rate** (CO_2 released from the soil) reflect mineralizable carbon. Mineralizable nitrogen is the ammonium or nitrate nitrogen released during decomposition.
- The '**active**' or **readily decomposable fractions** of organic matter
- **Enzyme activities**
- The activity of **indicator organisms** such as earthworms and specific groups of nematodes

These factors tend to be useful tools for evaluating soil quality because most of them respond fairly quickly to management changes, so they can serve as early indicators of improvement or degradation.

The importance of soil organic matter

The amount and type of organic matter in the soil plays a central role in how well soil performs functions such as producing crops and protecting water quality. The effect of animal agriculture on soil quality is largely related to its effect on soil organic matter.

Organic matter is the vast array of carbon compounds in soil. For simplicity, organic matter can be divided into two major categories: **stabilized organic matter** and **biologically active organic matter**.

The stabilized organic matter fraction can increase the amount of water and nutrients stored in soil. Stabilized organic matter are compounds that have been decomposed and transformed into forms that organisms cannot readily use. Thus, nutrients cannot be released from these compounds, though nutrient ions may be associated with the surface of these substances, as described in the Nutrient Cycles section above. Some stabilized organic matter may be decades or centuries old.

Biologically active organic matter is continually used and transformed by soil organisms. It is a source of nutrients for the soil organisms as it decomposes.

High levels of organic matter in the soil can either be maintained by continual additions of large amounts of plant residue or other organic inputs, or by maintaining soil environmental conditions that reduce decomposition. For example, intensive stirring of soil by tillage increases decomposition and thereby reduces organic matter levels. On the other hand, the wet conditions in poorly drained soils, which may not benefit the crop, will reduce decomposition rates and thereby increase soil organic matter.

Soil Quality

What is soil quality?

Soil quality is how well soil does what we want it to do. More specifically, soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al., 1997). In short, soil quality is the capacity of the soil to function.

People have different ideas of what a quality soil is. For example:

- for people active in production agriculture, it may mean highly productive land, sustaining or enhancing productivity, maximizing profits, or maintaining the soil resource for future generations;
- for consumers, it may mean plentiful, healthful, and inexpensive food for present and future generations;
- for naturalists, it may mean soil in harmony with the landscape and its surroundings;
- for the environmentalist, it may mean soil functioning at its potential in an ecosystem with respect to maintenance or enhancement of biodiversity, water quality, nutrient cycling, and biomass production.

Key soil quality concepts

Soil quality has an inherent and a dynamic component.

Dynamic soil quality is how soil's changes in response to management. This is the focus of current soil quality discussions. Each soil type also ---has an inherent ability to perform its functions. For example, fine-textured soil will usually hold more water and nutrients than coarse, sandy soil. For practical purposes, the texture of soil does not change. Land capability classifications are based on inherent soil quality.

Soil quality is an assessment of multiple functions

In addition to bountiful crops, agricultural land provides clean air and water, healthy forests, wildlife habitat, and beautiful landscapes. "Soil quality" refers to how well soil performs all of these functions simultaneously. A single measure such as crop yield or water infiltration is not an adequate assessment of soil quality.

The definition of soil quality depends on use and soil type

Is 72 beats/minute a healthy heart rate for a person? The answer depends on the individual's genetics, age, and desired level of physical activity. Similarly, the parameters of a healthy soil depend on the inherent characteristics of the soil and on how it is used. A healthy sandy soil should have higher water infiltration than a healthy clayey soil. Undisturbed prairie soil will have a higher level of soil organic matter than healthy agricultural soil.

Soil quality is inextricably linked to sustainability.

A quality soil is one that functions well without degrading over time. It must be resilient and recover its ability to function after stresses such as flooding, fire, or ordinary agricultural practices such as tillage. Changes in soil quality measurements over time indicate whether land management practices are sustainable.

Assessing soil quality

Like human health, soil quality is too broad a concept to measure directly and must be inferred by evaluating **indicators**. Indicators are measurable properties of soil or plants that provide clues about how well the soil is functioning.

Useful indicators:

- are easy to measure,
- measure changes in soil functions,
- encompass chemical, biological, and physical properties,
- are accessible to many users and applicable to field conditions,
- respond to variations in climate and management.

Indicators are usually measures of soil characteristics, such as bulk density or organic matter properties, but assessments may also include measures of soil functions, such as crop yield or erosion rates. Measurements that are commonly used as indicators in soil quality research are listed in Table 1 (Lewandowski and Zumwinkle, 1999).

Table 1: Commonly Studied Soil Quality Indicators

Chemical measurements:	*Physical measurements:*	*Biological measurements:*
Biologically active organic matter	Water infiltration	Microbial biomass
Organic C and N	Aggregate stability	Potentially mineralizable N
Cation exchange capacity	Rooting depth	Basal respiration
Extractable bases	Penetration resistance	Earthworms
pH	Water holding capacity	Enzyme activity
Electrical conductivity	Bulk density	
Sodium adsorption ratio		

Scale of indicators

The indicators in Table 1 describe soil properties at a single point in time and space. Other indicators that summarize soil characteristics over larger areas or time spans may be more useful in assessing soil resources at larger scales (Tables 2 and 3).

Table 2: Potential field-, farm-, or watershed-scale indicators of soil quality (From Karlen et al., 1998)

Biological	*Chemical*	*Physical*
crop yield	organic matter changes	topsoil thickness
crop appearance	pH changes	soil color
weed pressure	available P & K	subsoil exposure
disease pressure	cation levels	compaction
nutrient deficiencies	N availability	crusting
earthworms	heavy metals	ponding (infiltration)
decomposition rates	salinity	runoff
root growth pattern	nutrient loss in streams	rill and gully erosion
	nutrient loss to groundwater	poor plant emergence
		ease of tillage
		soil structure

Table 3: Potential regional-, national-, or international-scale indicators of soil quality (From Karlen et al., 1998)

Biological	*Chemical*	*Physical*
productivity (yield stability)	OM trends	desertification
taxonomic diversity at the Group level	acidification	loss of vegetative cover
species richness, diversity	salinization	water erosion
keystone species & ecosystem engineers	water quality	wind erosion
biomass, density & abundance	air quality	siltation of rivers and lakes

Farmers' Assessments of Soil Quality

Understanding and managing soil quality is a site-specific endeavor. It is about reading soil characteristics and selecting optimum practices for each unique situation. For this reason, soil quality research is enhanced by long-term, systems-oriented studies, and by the local observations of farmers and those who work with farmers.

Planners, researchers, and farm managers each observe soil differently, and communicate soil characteristics differently. The Wisconsin Soil Health Program has done extensive work with farmers to learn their priorities with regard to soil health. The goal of their project has been to integrate farmers' observational knowledge with scientists' analytical expertise (Garlynd et al., 1994; Harris and Bezdicek, 1994; and Romig et al., 1995).

Based on the Wisconsin work with farmers, the Natural Resources Conservation Service has written a protocol for developing locally-based, qualitative soil health assessment cards for use by farmers. Several different soil health cards have been created in regions around the country to help farmers track changes in soil quality. (For example, see the Willamette Valley Soil Quality Card, 1998.)

Table 4 ranks the soil properties used by farmers to assess soil health, as identified by the Wisconsin project. Although expressed somewhat differently, farmers identified many of the same priorities as soil scientists. Romig and his colleges noted that farmers tend to have a stronger temporal perspective of their soil than do scientists. They can observe how a given field responds to different kinds of storms, or how crops respond to a variety of climatic extremes, and they have a feel for how soil aggrades or degrades over long periods of time. Farmers do not separate management and measurement of soil health. In fact, they seemed to focus more on the processes they believe create or destroy soil health than on the soil properties themselves (Romig et al., 1995).

TABLE 4: Soil Properties Used Most Often by Farmers to Assess Soil Health (Romig et al. 1995)

1. organic matter	8. pH	15. water retention	22. growth rate
2. crop appearance	9. soil test	16. phosphorus	23. weeds
3. earthworms	10. yield	17. nutrient deficiency	24. fertility
4. erosion	11. compaction	18. decomposition	25. feel
5. tillage ease	12. infiltration	19. potassium	26. chemicals in groundwater
6. drainage	13. color	20. roots	27. surface cover
7. structure	14. nitrogen	21. mature crop	28. surface crust

Managing for soil quality

Many combinations of management practices can be beneficial to soil quality. Generally, systems with good soil quality are those that maintain or increase the amount and quality of organic matter in the soil. Organic matter and the organisms that feed on it are central to nutrient cycling, the formation of soil structure, and water dynamics. Organic matter increases the soil's capacity to hold water and nutrients. It improves soil structure and reduces the effects of compaction.

The practices that affect soil quality (either positively or negatively) can be discussed in five groups.

1. **Organic matter additions**—Organic matter must be regularly added to the soil to maintain a healthy soil biological community and to maintain or increase the level of organic matter in the soil. Manure can contribute significant amounts of high quality organic matter to the soil, though organic matter from crop residues and cover crops sometimes can be more desirable.
2. **Cropping patterns**—The choice of cropping system has a substantial effect on soil quality. Generally, a longer rotation with diverse crops contributes a variety of organic residues to the soil, and supports a healthy biological community. In particular, perennials and sod crops with dense root systems are beneficial to soil quality. Some animal production systems improve soil quality because they make it economically possible for farmers to grow perennial forages and pastures.
3. **Tillage**—Tillage is useful for mixing organic matter into the soil and preparing a seed bed, but it also increases the decomposition and loss of soil organic matter, reduces soil aggregation, and destroys the habitats of some important organisms by burying surface residue.

   A wide variety of tillage systems are used in Minnesota, ranging from frequent and intensive turning of the soil, to no-till systems in which only a narrow furrow is cut to plant seeds into last season's crop residue.

   Reduced tillage is attractive in some large scale cropping systems, because it requires less labor than conventional tillage, can reduce erosion rates, and prevents the rapid decomposition of soil organic matter that occurs when soil is aerated. In some reduced tillage systems, more herbicides are used compared to conventional tillage.

   One type of reduced tillage used in Minnesota is **ridge tillage**. It has several advantages, especially on cold poorly drained soils, including improvement of infiltration, and reduction of runoff, and compaction. Residues left on the soil surface prevent wind and water erosion.
4. **Amendments**—Amendments which increase crop production, such as fertilizer and irrigation, may increase the amount of organic residue contributed to the soil. Some amendments, such as high-salt fertilizers, may at least temporarily reduce some biological activity. Some pesticides reduce biological activity. The use of manure can reduce the need for some fertilizers and pesticides.
5. **Traffic**—Heavy or frequent traffic can compact soil, especially when soil is wet. Heavy liquid manure tanks can create deep soil compaction that is difficult to remedy. Even large animals are light compared to tractors, but they can cause surface compaction where they concentrate in small areas or graze on wet soils with insufficient cover.

Animal Agriculture and Soil Quality

Manure in soil

Soil quality is the ability of soil to sustain productivity and maintain environmental quality. In contrast to inorganic fertilizers, regular manure application can protect soil quality because it enhances biological activity and soil structure.

Manure has several effects when added to the soil.

Supplies nutrients immediately. Manure contains nitrogen (as ammonium), phosphorus, potassium, and micronutrients (e.g. Cu and Zn) that can be used directly by plants. This is the most commonly recognized value of manure.

Supplies nutrients over time. Other nutrient pools in manure are part of organic (carbon-containing) compounds. These compounds trigger biological activity which ultimately makes nutrients in the manure available to plants.

Lowers pH. Regular manure application generally lowers soil pH. The acidifying effect of nitrogen added as manure is less than that of nitrogen added as anhydrous ammonia or urea.

Salt and ammonia toxicity. Manure contains high levels of salts that will burn leaves if applied to growing plants. Salts are usually not a concern in Minnesota because they are quickly leached by rain. High levels of ammonia or ammonium in fresh manure can be detrimental to germinating seeds.

Improves soil structure. The increased biological activity and organic matter content improve soil structure by helping to bind soil particles into aggregates. In some situations, manure can serve as a protective mulch on soils that are vulnerable to erosion.

Enhances biological activity and diversity.
Manure is known to affect the mix of organisms in soil, but these changes are poorly studied. Manure may affect pest and nutrient cycles by changing the diversity of soil organisms.

Soil and management of grazing animals

Grazing animals are a key to a dynamic recycling process for pasture ecosystems. An understanding of pasture management and uniform distribution of manure nutrients is critical.

Permanent pastures often have low productivity. Rotational or short-duration grazing can often double forage production and lengthen the grazing season.

Classic work in Missouri has demonstrated the importance of pasture design and management to minimize nutrient losses and reduce the potential of severe soil compaction. The researchers demonstrated that excretion patterns by grazing livestock are influenced by placing of water troughs, location of shade and the topography of the land. Phosphorus and potassium concentrations are likely to build-up where animals congregate. Nitrogen losses will vary by pasture design and lane access. It was noted that sheep tend to defecate and urinate in a more uniform pattern than cattle (Peterson and Gerrish, 1994).

The longer the rotation period between pastures, the greater opportunity for manure to concentrate in certain areas. For example, a 12-paddock system for a beef cow/calf herd, with water access in the paddocks less than 600-800 ft from the grazing herd, is more efficient than a 3-paddock system in terms of spatial distribution of manure nutrients where water may or may not be as accessible. Short rotation periods between paddocks are better if shade trees are located in paddocks. Square paddocks with minimal landscape variation within paddocks are recommended.

The Link Between Soil Quality And Water Quality

One soil function is to regulate and partition the flow of water. The structure of soil partially determines how much water flows overland to streams and lakes, and how much enters the soil and flows through it to become groundwater.

The biological, physical, and chemical characteristics of soil are responsible for filtering water. Soil generates clean groundwater by adsorption, decomposition, and buffering of potential pollutants.

Phosphorus is concentrated in the topsoil on manured fields, and can be carried in runoff along with sediments to surface water. Thus it is especially important to protect high-phosphorus soils from erosion. Nitrate leaching can result in potential groundwater degradation. Because of these effects, manure application at high rates on some soils could impair water quality (See the Manure and Crop Nutrient report, section on the Economic Liability of Manure for more information).

The Link Between Soil Quality And Air Quality

Another function of soil is regulation and partitioning of gas emission. Volatilization of ammonia from manure into the atmosphere can be expected with manure handling. Nitrification and denitrification of manure applied to soil can also lead to formation of nitrous oxide (N_2O). Nitrous oxide is a "greenhouse" gas and can contribute to ozone layer depletion if the manure is not handled correctly. Other air quality problems include emission of volatile sulfur and organic compounds which are discussed in the Air Quality and Odor report.

ANIMAL AGRICULTURE AND SOIL QUALITY

Critique of the Study Questions

The authors of this report were asked to answer the following question.

How are the following properties of soils affected by manure application and livestock production systems?

- Moisture holding capacity
- Soil tilth
- Air incorporation
- Erosion potential
- Biological activity
- Structure and density
- Weed content
- Productivity

Because the properties specified by the question are properties used in the assessment of soil quality, the Soils team chose to rephrase the question in terms of the effect of manure and livestock production on soil quality. The following changes were made to the study question.

1. Items were grouped into physical, biological, and chemical categories.
2. Nutrients and nutrient cycling cannot be separated from other soil properties, and are discussed briefly in this report. For a more complete discussion of soil nutrients, see the Manure and Crop Nutrients report.
3. Water infiltration was added to the report because of its importance to productivity and soil and water quality.
4. Soil aeration was substituted for air incorporation.
5. Soil erosion potential and soil productivity are only touched on briefly. The characteristics of farming systems that determine erosion rates and productivity go beyond factors directly related to animal agriculture.

How Animal Agriculture Affects Soil

Farming specialization

One of the most dramatic transformations of the Midwestern agricultural landscape resulted from the shift from mixed crop-and-livestock farming to specialized cash-grain farming over the past 50 years (Hart, 1986). Before WWII most farms had a small number of animals. Now, animals are concentrated on fewer farms that often purchase much of their feed. Many other farmers specialize in cash grains to be sold to other regions.

Specialization in either animal or crop production has two effects on soil. First, nutrients are becoming more unevenly distributed over the land. Most of the nutrients fed to livestock pass through animals and accumulate in the manure— most notably, nitrogen, phosphorus and

potassium. If feed and animals are raised in the same area, most of the phosphorus and potassium and some of the nitrogen removed in growing forage and feed grain can be returned to the soil as manure. However, nutrients removed from the soil during crop producton are often shipped to another county, state, or country, fed to animals, and concentrated in manure far from the feed source (DeLuca and DeLuca, 1997). The cost of transporting manure prevents it from being shipped back to the land where the feed came from.

Second, specialized farming can result in the loss of perennial forages from crop rotations. Before WWII a typical Minnesota farm had pigs, chickens, and cattle. Cattle are ruminants that can utilize forages such as alfalfa or grasses. With increased specialization, most farms do not have ruminant animals and have no need for forages. Forages and pastures are difficult to incorporate into cash grain operations.

Size of animal operations

The size of an animal operation is not associated in a simple way with soil quality. Both small and large operations without manure management plans can have negative soil quality impacts. However, good or bad management on a large operation can affect a larger area.

There is one direct link between animal operation size and soil quality. The size of an animal operation is related to the amount of acreage available for spreading manure. Generally, larger operations are expected to have more difficulty finding adequate crop acres to apply manure economically. The availability of land is a separate issue from whether the manure is applied appropriately.

Rotational grazing

Rotational grazing is an operation in which animals get most of their feed by grazing a small paddock for a short period and then moving to a new paddock. The short grazing periods allow the pasture to recover for multiple grazings during the growing season.

Because most feed comes from pastures, the farmland is planted mostly to soil-building and soil-protecting perennials. As animals harvest much of their feed, they spread manure over the same land that produced their feed. These soil quality benefits of rotational grazing depend on proper management of animal traffic and pasture plants.

What determines the effect of an animal operation?

The effect of a particular animal operation on soil quality depends on the interaction of many aspects of the operation. The effect of an operation can be estimated by asking three questions:

1. How is the manure handled? Is it being applied at agronomic rates? (Section Manure Handling)
2. What is being fed and how is it grown? Does the diet support the production of perennials, other dense-rooted and soil covering crops? (Section Cropping Systems)
3. Does the operation as a whole support soil quality? (Section Whole Farm Effect on Soil Quality)

With answers to these questions, the research reviewed in Part C will support an educated guess of whether an operation is having a positive or negative impact on soil quality. However, in most cases the research will not support a calculation of the degree of the positive or negative effect.

Manure handling

Three factors determine whether manure will have a positive or negative effect on soil.

1) Rate of application.
Manure generally has a positive effect on soil if it is applied at **agronomic rates**. Agronomic rates are levels calculated to match the crop needs and to minimize nutrient overloading. **Disposal rates** are high levels applied to dispose of the manure rather than to enhance crop production. Any rate higher than an agronomic rate can be considered a disposal rate. Application of manure at disposal rates can have negative effects on soil quality due to deterioration in physical properties, and toxicity for plant growth and microbial activity.

Calculating agronomic rates: Land managers must decide whether to base manure application rates on crop nitrogen needs or soil phosphorus levels. Currently in Minnesota, agronomic rates are usually computed to meet the nitrogen needs of crops. Nitrogen is more valuable to the farmer, but, in terms of crop needs, manure typically contains far more phosphorus than nitrogen. Thus, if manure is applied based on crop nitrogen needs, soil phosphorus levels will rise.

The Manure and Crop Nutrients report includes a discussion of how agronomic rates can be calculated and the difficulty of applying predetermined rates. Agronomic rates vary, but are less than 20 tons of dry matter per acre. Because some animal operations have insufficient land close by to apply all the manure at agronomic rates, cropland has been used as a disposal site for manure.

Interpreting application rates for manure is difficult because of the different ways manure data are reported. Applications of liquid manure can be reported in tons or gallons of wet manure slurry or as the oven dry equivalent. Solid manure application rates are most often reported as tons of wet weight.

2) Application method
Application methods can make a great difference in contribution of manure to soil quality. For example, manure injection can reduce potential environmental impacts. Application on the soil surface without immediate tillage to incorporate manure into the soil can result in significant losses of nitrogen (Schmitt, 1999). See the Manure and Crop Nutrient report for more information about nutrient losses with different application methods.

Heavy liquid manure tanks on wet soil can cause deep soil compaction.

3) Type of manure
Manure from each animal species has characteristic levels of salts, pH, and nutrients. Even within species, manure characteristics vary depending on feed content and how the manure is handled and stored.

The levels of nutrients and additives in feed will be reflected in the manure composition. Innovations in feeding practices may have dramatic effects on the nutrient value of manure. For example, the use of phytase enzymes in feed and the use of a genetically improved, low phytate

corn variety can improve animal use efficiency of phosphorus and can reduce the phosphorus concentrations in manure (Bosch et al., 1998; Spencer et al., 1998).

There are many different types of manure handling systems discussed by the Manure and Crop Nutrients team. Some generate solid manure that include bedding. Other systems generate liquid manure that can be pumped and injected into the soil. A variety of storage systems are available. These variations have some impact on the nutrients in manure and each system puts limitations on how the manure can be handled. Different systems may have different effects on water quality (see Water Quality report). However, with any of the major systems, it is possible to use the manure in a way that enhances soil quality.

Composting of manure has several effects that could change the impact of manure on soil quality. It substantially reduces the bulk of manure, making it cheaper to transport. Weed seeds, fly eggs, and pathogens can be reduced when high temperatures are generated during the composting process.

Cropping systems

Two aspects of cropping systems determine their effect on soils.

1. *Inclusion of perennial forages, sod crops, legumes, or high residue crops.*
   Dense-rooted perennials such as alfalfa, grasses, and some other forages, are better (by some standards) for soil quality than row crops that leave the ground bare of living cover much of the year, and take a long time to generate a root system and canopy that will protect the soil. The dense root structure of perennials improves soil structure and contributes high-quality organic matter to the soil. Perennials and cover crops provide food and habitat for soil organisms that would otherwise die back during an annual fallow period, and they protect the soil from wind and water erosion.
   Pasture systems for raising animals allow farmers to produce these soil-enhancing crops. Forages are more expensive to transport than grains, so markets for forages depend on the distribution of animals over the landscape.
2. *Length and diversity of crop rotation.*
   By rotating among several crops, a farmer can increase the diversity of organic matter that is added to the soil, and the types of tillage that are used. This increases the diversity of organisms in the soil and reduces pest infestation and weed populations.

Whole-farm effect on soil quality

The section on managing soil quality in the Introduction section of this report describes the components of farming systems that affect soil quality. Practices that are valuable for protecting soil quality include organic matter additions, rotating row crops with perennials and other densely-rooted crops, keeping the ground covered with plants, and preventing erosion.

Research Results: The Impact of Manure and Cropping Systems

Soil organic matter

Soil organic matter may be the single most important indicator of soil quality and productivity. Additions of organic matter, whether animal manure, green manure, organic sludges and wastes, or crop residues, can be beneficial to the biological and physical properties of the soil. However, appropriate amounts and timing of application are important to ensure that soils do not become degraded by compaction, crusting, accumulation of salts and other processes. The increase in biological activity and plant health due to manure application is both a result of additional food sources for the soil organisms, as well as improved soil structure, which allows for better air exchange and moisture holding capacity.

Research examining the effects of manure and cropping systems on soil organic matter are part of many of the studies described in this report. See Section on Biological Activity, for more research comparing the effects of various cropping systems and manure applications on the different types of soil organic matter.

Particularly informative for understanding organic matter dynamics is the Farming Systems Trial at the Rodale Research Center in Pennsylvania. This trial is a set of long-term plots fertilized with either animal manure, conventional fertilizers, or a cover crop nitrogen source. In spite of similar carbon and nitrogen inputs, the manure treatment sequestered significantly more carbon in the soil than the conventional treatment (Drinkwater et al., 1998). In another study of the Farming Systems Trial, the authors suggest that long-term manure amendments increase short-term carbon pools (which decompose more rapidly), while cover crops may increase the soil's ability to store carbon long term (Wander et al., 1994). The manure amended plots had greater carbon and nitrogen mineralization rates and higher soluble carbon contents. This implies that the most biologically active soil organic matter fraction was relatively increased compared to other soils in the Farming Systems Trial. On the other hand, the soils under the organic cover crop treatment showed a greater accumulation and retention of total carbon, particulate organic matter, and a reduced soluble carbon content. The amount and proportion of the less active, but still labile, organic matter was higher than that for the manure or inorganic fertilizer treatment. These findings suggest that higher carbon to nitrogen ratios, or more resistant forms of carbon, (which are higher in green manures than in animal manures) may be more beneficial for long-term organic matter buildup and soil quality.

Effects of manure on long-term buildup of organic matter depend partly on soil texture. Long-term trials in Denmark (the Askov experiments initiated in 1894) and England (Rothamsted Classical Experiments, begun in 1843) have shown that the lighter-textured, sandy loam soils in the Askov trials require much higher animal manure inputs to maintain or increase soil organic matter than the medium-textured soils at the Rothamsted Experiment Station (Christensen and Johnston, 1997).

Soil physical properties

This section will discuss the impacts of manure application and of the cropping systems used to feed and bed animals on individual physical parameters. For some soil quality parameters, elements of specific livestock systems are important, e.g. the impact of grazing on soil compaction. For others the differences among livestock systems are not as important.

Soil structure and density

The impact of manure on soil structure is closely related to porosity and other soil properties such as infiltration rate, hydraulic conductivity, air permeability, compaction, crusting, and erodibility. Management practices, including manure additions, have a significant impact on soil structure and bulk density. Incorporation of organic matter usually improves structure and lowers bulk density. Tillage decreases bulk density in the plow layer in the short term.

Impacts of Livestock Production on Soil Structure and Density

Livestock and cropping systems that maintain soil organic matter content will result in larger and more stable soil aggregates than systems that deplete soil organic matter. Increasing tillage intensity, decreasing the frequency of perennial forage crops, and decreasing manure applications can decrease aggregate stability.

Results of a study of cropping systems in Iowa showed that aggregate stability differs with farming system. One cropping system based on a diverse rotation (including corn, soybeans, oat, and hay), manure applications, and conservation tillage resulted in higher soil organic matter content and higher aggregate stability than that of the same soil managed in a corn and soybean rotation, without additions of manure (Jordahl and Karlen, 1993). Cropping systems studies with regular organic matter additions in Ohio (Jackson, 1988) and in the Netherlands (Droogers and Bouma, 1996) showed similar differences in soil physical properties.

Each of these cropping systems included multiple elements that impact soil quality (tillage practice, rotation, manure additions) and the relative impacts of individual management factors are difficult to separate. In general, management systems that maintain or build soil organic matter and stimulate microbial activity are associated with increased structural development in soils. In each case, livestock production was part of the system that gave the best aggregate stability.

1) Cropping System Impacts. Crop species and crop rotation sequence impact soil structure. Grass and perennial forage crops improve aggregation and aggregate stability. This is due to protection of the soil surface from rain drop impact, the root distribution and architecture of perennial forages and grasses, and the stimulation of biological activity in the soil. Livestock systems that support crop rotations including perennial forages are expected to result in improvements in soil physical properties compared to continuous row crop systems (Curtin et al., 1994). In Minnesota, the most common perennial forage crop is alfalfa. Alfalfa in a crop rotation improves soil aggregation and these impacts often exist for years after the alfalfa crop (Neher, 1950; Meek et al, 1990). Other forages such as clover, reed canary grass, orchardgrass, etc. have effects similar to alfalfa on aggregate stability. These effects have been attributed to the high density of roots of forage crops (Dexter, 1991; Drury et al., 1991).

Other management practices can be used to improve soil structure when rotations do not include hay or sod crops. In southern and central Minnesota, the most common cropping system is the corn-soybean rotation. Soil aggregates break down more during cropping with soybeans than for corn (Stauffer, 1946; Alberts and Wendt, 1985). High amounts of crop residue from corn production result in higher soil organic matter content than for soybean production and these residues are responsible for the observed increase in aggregate stability (Havlin et al., 1990). Similarly, reduced tillage systems generally have higher organic matter content and higher aggregate stability than conventional tillage approaches (Lal et al., 1994).

2) Manure Impacts. The impact of manure application on soil physical properties has been the subject of considerable research. In general, the research has evaluated changes in physical properties by comparing one or more rates of manure application to a control treatment with no manure applied. Manure application decreases soil bulk density and increases aggregate stability. The magnitude of these changes increases with increasing rates of manure (Sommerfeldt and Chang, 1985; Mathers and Stewart, 1984; Tiarks et al., 1974; Unger and Stewart, 1974). An example of this kind of research is a study in Virginia, where annual poultry manure applications decreased bulk density and increased aggregate stability in a clay loam soil. These changes increased with increasing rates of manure. Infiltration rates were also much greater for soil with manure additions, but the effect did not appear until several months after manure application (Weil and Kroontje, 1979). Long-term application (up to 14 years) of modest rates of solid dairy manure resulted in lower density and higher hydraulic conductivity than soils without manure (Mathers and Stewart, 1984).

Manure addition changes soil properties due to both the organic matter addition and increased crop growth. A stimulus in crop growth increases root penetration, crop residue, and microbial activity. Stimulation of crop growth from addition of mineral fertilizers to soils has been shown to improve soil physical properties relative to unfertilized soil, but not to the same extent as from manure addition (Wood and Hattey, 1995; Biederbeck et al., 1984).

Soil structure and density improvements have been observed with manure from varying livestock species including beef and dairy cattle, hogs, and poultry. Similar improvements in soils have been observed for manure from both solid and liquid manure, although most research has been conducted with solid manure.

3) Grazing. Grazing systems increase the amount of perennial forages grown. Grazing (as opposed to harvesting the forage) does not substantially alter soil aggregation or eliminate the benefits of forages on soil structure. In some cases, however, grazing animals can compact the soil surface (Alderfer and Robinson, 1947). Studies that have evaluated changes in bulk density due to grazing have yielded inconsistent results, since compaction due to grazing is highly dependent upon soil type, soil moisture content at the time of grazing, stocking rate and stocking frequency. No comparisons have been made to determine the relative importance of compaction due to grazing verses compaction from tillage or harvesting equipment. Compaction damage due to light equipment (and presumably animals) is generally limited to surface soil.

A 5-year North Dakota study compared light (37% pasture use), moderate (47% pasture use), and heavy (93% pasture use) grazing intensity on reclaimed cool-season pasture. Soil compaction increased with grazing intensity (Hofmann and Ries, 1988).

In the southern plains of the U.S., comparisons of soil compaction by grazing cattle showed increased bulk density and soil strength for silt loam and sandy loam. The sandy loam was more sensitive to compaction than the silt loam. It was noted that tillage practices in these areas could not eliminate the compaction from cattle grazing pastures (Krenzer et al., 1989).

Field studies in the United Kingdom, on sandy-loam cattle pastures, showed increased soil bulk density and cone penetrometer resistance in the 3-4 inches depth, due to soil compaction caused by trampling. These dense areas impeded drainage and caused soil structural and hydrological changes (Mulholland and Fullen, 1991). Simulation experiments verified that on saturated pasture soil the most severe structural damage occurs on initial impact.

Soil moisture holding capacity

Soils store water that can be utilized by plants and other organisms. The capacity of soils to hold water depends upon the soil texture, soil structure, porosity, and organic matter content. Management factors impact water holding capacity by altering structure and porosity as well as organic matter content. Highly eroded soils may lose water holding capacity due to a reduction in the topsoil depth.

Impacts of Livestock Production on Soil Moisture Holding Capacity

Crop and livestock production systems that maintain soil organic matter content can result in higher moisture holding capacity than systems that deplete organic matter. The increase in moisture holding capacity with increasing organic matter content is greatest for sandy soils (Bauer and Black, 1992). Although water holding capacity may increase with increasing organic matter, the amount of plant available water may not. In some cases, increasing organic matter content may decrease the amount of plant available water (Bauer and Black, 1992; Sommerfeldt and Chang, 1987). Manure application to a Canadian soil increased water holding capacity, but did not increase the plant available moisture. In the Netherlands, a soil with regular manure additions over several decades had only slightly higher available water holding capacity than a soil without manure addition (Droogers and Bouma, 1996).

Application of animal manure to Texas soils increased moisture holding capacity and decreased evaporation rates (Unger and Stewart, 1974). Compacted, poorly structured soils hold less moisture than similar soils with good structure and lower density. Comparison of summertime soil moisture contents in Washington under contrasting management systems showed that moisture content was consistently higher when the soil was managed with a legume green manure crop in rotation with wheat and pea, compared to wheat and pea without the green manure (Reganold, 1988).

Perhaps more important than the moisture holding capacity of a soil is the soil's ability to transmit water. Infiltration rate is an important soil quality indicator because it integrates numerous elements of soil quality, including density, structure, susceptibility to crusting, etc. Infiltration and hydraulic conductivity of soils are discussed in the next section.

Infiltration

The rate of water infiltration into a soil is an excellent indicator of soil quality. Soils with poor aggregate stability are susceptible to formation of surface crusts due to detachment of soil particles by rain drops.

Impacts of Livestock Systems on Infiltration

1) Cropping System Impacts. Cropping systems that protect the soil surface with a crop canopy, or allow the accumulation of crop residue on the surface, promote infiltration. Perennial forage crops are especially effective in promoting infiltration. In a long term study in Pennsylvania, infiltration rates were measured for soils cropped to corn in differing crop rotations. Including a hay crop in rotation with corn and soybeans increased infiltration rates (Radke and Berry, 1993). These differences were due to changes in soil structure, since tillage and residue cover were similar in both cases.

For row crops, conservation tillage approaches that leave residue at the soil surface result in higher infiltration rates than when crop residues are incorporated into the soil (Ginting et al., 1998; Dick et al., 1991).

Reduced tillage approaches result in higher infiltration rates due to the presence of residue cover at the soil surface, improved soil structure, and an increased presence of macropores (Radke and Berry, 1993). With both crop cover and conservation tillage, the protective cover prevents formation of a surface seal and allows for greater infiltration rates. Residue cover has a more important impact on infiltration than differences in soil structure or density due to differences in tillage (Zuzel et al., 1990).

2) Manure Impacts. Manure application generally increases hydraulic conductivity and infiltration rates of soils, especially when soil structure is improved (Albrecht and Sosne, 1944; Tiarks et al., 1974; Mathers et al., 1977). Infiltration rates, inferred from differences in runoff, were higher in soils with manure than for soils without manure, regardless of the type of tillage, in both Minnesota (Ginting et al., 1998) and Wisconsin (Mueller et al., 1984). However, infiltration rates of soils that already have good structural stability might not be further improved with manure (Sommerfeldt and Chang, 1985). For crop production in areas where water is a factor that limits crop production, increasing infiltration allows for greater capture and storage of water for crop uptake. Likewise, higher rates of infiltration reduce runoff and the associated losses of sediment and nutrients.

Manure applied at heavy (disposal) rates can reduce infiltration in the short term. In one study, high application rates of poultry manure restricted infiltration initially and resulted in much higher runoff after several months. The initial decrease in infiltration was suspected to be due to hydrophobicity (non-wettability) of the partially decomposed manure (Weil and Kroontje, 1979). However, these high application rates resulted in substantially higher infiltration than conventionally fertilized plots at the end of one growing season.

Soils are effectively sealed by clogging soil pores at or near the surface when relatively concentrated feed yard runoff is applied (Lehman and Clark, 1975). However, infiltration rates increase if the surface soil is disturbed.

3) Grazing. Grazing influences infiltration rate but not in a consistent manner. A comparison of different grazing management approaches in Wyoming, showed that infiltration rates are lower with higher animal stocking rates (Abdel-Magid et al., 1987). A similar study in Pennsylvania showed that compaction of the soil surface due to heavy grazing reduced infiltration rates, while moderate grazing did not (Alderfer and Robinson, 1947).

A Western Australian study examined the effects of sheep stocking rates (a normal stocking rate, 3 sheep/acre; low stocking rate, 1.5 sheep/acre, and no sheep), and trampling of the pasture after winter rains. This work showed that the magnitude of soil structural damage was affected by initial condition of the soil and stocking rate. The topsoil was damaged by sheep trampling. The lower stocking rate reduced the degree of soil structural damage. Growth and decay of pasture roots, disruption of a surface crust, and soil compaction, all contributed to differences in infiltration rates between grazed and ungrazed pastures (Proffitt et al., 1995).

Erosion potential

Erosion is of major importance in Minnesota and worldwide. The loss of topsoil to erosion results in reduced productivity and sustainability of the soil resource. Erosion is also responsible for degradation of surface water quality. Measures to reduce erosion rates are critical to Minnesota.

The susceptibility of a soil to erosion is closely related to the aggregate stability of the soil. Well-aggregated soils are less prone to dispersion by raindrops, surface sealing, and erosion. Furthermore, higher infiltration rates generate less runoff. Thus, much of the discussion on aggregate stability and infiltration rate applies also to the erodibility of the soil.

Impacts of Livestock Production on Erosion

1) Cropping System Impacts. Pasture or hay crops substantially reduce the susceptibility of soil to erosion (Curtin et al., 1994; Smith and Hallam, 1990). Livestock systems that include these crops in rotation, especially on highly erodible soils, will substantially reduce erosion. In Washington, a soil managed since 1908 with a green manure crop (alfalfa-wheatgrass) in rotation with wheat had 16 cm more topsoil than a similar soil managed without the green manure crop. The differences were due to erosion (Reganold, 1988). Tillage practices also impact erosion rates. Reduced tillage systems that maintain crop residues on the soil surface are effective in reducing soil erosion (Dickey et al., 1985; Ginting et al., 1998). Erosion may be less for continuous corn than for a corn-soybean rotation because of higher levels of residue from the continuous corn system (VanDoren et al., 1984).

2) Manure Impacts. Manure application has been shown to reduce the erodibility of soils (Mueller et al., 1984; Ginting et al., 1998). This is due to increased aggregate stability and infiltration rates and decreased bulk density. Although both runoff and erosion can be reduced by heavy manure applications, the losses of nutrients may not be reduced because of the higher concentrations in heavily manured soils. By contrast, some researchers have speculated that continuous application rates of manure slurries could increase erodibility of soils by increasing the concentration of the potassium or sodium salts and the degradation of soil structure. Although this has been shown to be true in the laboratory at very high rates of manure application, fields with long histories of slurry manure applications have not been shown to be more dispersive or susceptible to erosion (Auerswald et al., 1996). In field studies the degradation of soil structure due to salts is seen only where disposal rates of manure are applied and not when agronomic rates are applied (see Section on Salts in Manure).

The erosion reduction due to manure application is most notable when the structure of the soil at the surface is stabilized. Thus, plowing down or injecting manure below the soil surface will not have an immediate impact on erodibility of soil. However, in subsequent years following tillage, the organic matter applied with manure will be mixed and brought to the surface (Ginting et al., 1998).

Soil aeration

The pore space of a volume of soil is occupied at any one time by either water or air. Aeration is critical to the quality of a soil to provide essential gases to plants and soil organisms. Plants differ in their tolerance to wet, poorly aerated soils. Although alfalfa requires a well-drained

soil, many perennial forage species such as alsike and ladino clover are more tolerant of poor aeration.

Impacts of Livestock Production on Aeration

1) Manure Impacts. Manure application reduces bulk density and thus increases pore space and the potential for better air entry (Sommerfeldt and Chang, 1985; Mathers and Stewart, 1984; Tiarks et al., 1974; Unger and Stewart, 1974). Soil structure and aggregate stability also influence the density, porosity, and aeration of a soil. Practices that improve these properties by maintaining organic matter content have a beneficial effect on soil aeration (Curtin et al., 1994; Neher, 1950; Meek et al, 1990).

2) Grazing. Management factors that impact soil aeration are factors that alter soil density and porosity, such as compaction. A potential compacting force can change soil mass-porosity, and pore-size distribution, (Freitag, 1971).

A long-term (>30 years) study in New South Wales in Australia, indicated that grazed pastures had lower porosity, in the top 2 inches, than ungrazed pastures. After 30 years, pastures grazed at 4, 8 or 12 sheep/acre had similar soil properties. Maintenance of pasture cover was considered more of a priority than stocking rate for long term management (Greenwood et al., 1997).

Soil tilth

Soil tilth is a qualitative description relating the physical condition of the soil to plant growth. There is no single measure of tilth, but it is the combined result of numerous other properties such as bulk density, soil strength, aggregate size and stability, moisture content, and aeration. Tilth generally refers to ease of tillage, fitness as a seedbed, and suitability for root penetration and seedling emergence. An index was developed in Minnesota and Iowa for quantifying soil tilth based on five soil physical properties (Singh et al., 1992). For soils in a corn-soybean rotation, values of the tilth index changed significantly during the year. Farmers use tillage equipment, in large part, to promote good soil tilth. The effects of livestock systems on specific properties that influence soil tilth were discussed in the preceding sections. In this section only a few studies that directly comment on soil tilth will be discussed.

In a comparison of the effects of different long-term management systems on a silt loam soil in Washington, tilth was better when a green manure crop was included in the rotation. This was due to better structure and higher organic matter content (Reganold, 1988). In Minnesota, rotations that include a perennial forage such as alfalfa, would be the most common system similar to the green manure system in Washington.

A long-term study in Alberta, Canada compared physical properties of a soil with,and without manure addition under several different tillage practices. Manure application improved soil tilth, as indicated by a decrease in the tractor drawbar draft (power requirement) for tillage equipment at higher manure application rates. The study also suggested that the decreased energy required for tillage involved more than a simple reduction in bulk density. There was also a change in soil consistence (Sommerfeldt and Chang, 1985). However, in the same study, manure applied at three times the agronomic rate resulted in poor seedbed conditions and poor germination for the first year, but not in subsequent years. Other work has shown short-term degradation of soil tilth with heavy manure application rates, followed by long term improvements (Weil and Kroontje, 1979).

Recent Dutch research compared the effect on soil physical properties of five farm management systems--high input cropping; integrated lower input (a reduced N- fertilizer, herbicides, insecticides and shallower soil tillage); minimum tillage just initiated (3 inch plowing depth); minimum tillage over the previous 18 years; and permanent pasture. Soil water retention, hydraulic conductivity, air-filled porosity and workability were some of the factors examined. Pasture and the old minimum tillage system had the most favorable soil properties for growing crops due to improved soil structure and increased biological activity. The conventional and integrated system had the least favorable tilth. They found that systems that stimulated the presence and activities of structure-forming soil fauna would also stimulate more favorable soil properties such as better aeration and more workable days in a growing season (Vos and Kooistra, 1994).

Nutrients

The nitrogen, phosphorus, and potassium added to soil in manure contribute to soil productivity. Manure added to soils can provide the high fertility needed for high-yield production. This is discussed in detail in the Manure and Crop Nutrient report. Manure addition can especially contribute to long-term increases in N and P fertility. Nitrogen accumulates in soil organic matter, which is a slow-release source of N. Phosphorus accumulates in soils by adsorption on soil particles or by formation of low solubility precipitates with iron, aluminum, and calcium. With long-term heavy applications of manure, P fertility can become much greater than that needed by crops. While this is not detrimental for crop growth, it can have negative impacts on nearby surface waters.

Copper and zinc are nutrient elements that are often added to feeds and can accumulate in manure. With very long-term additions of manures high in these elements, the lifetime loading limit set by USEPA for sewage sludge can be exceeded. With application at agronomic rates the life-time limit for these elements will not be exceeded for more than 350 years (see Manure and Crop Nutrient report).

Salts in manure

Animal manures contain salts of ammonium, potassium, and sodium which in arid and semiarid regions can accumulate in sufficient concentrations to inhibit plant growth (Mathers and Stewart, 1974). In soils, ammonium is converted into nitrate by microbes and nitrate salts can accumulate. In western Minnesota the climate is sub-humid, which is dry enough for some salt problems to occur. Salts in soils can impair the ability of plants to absorb water, and in alkaline pH soils can cause the dispersion of soil particles and degradation of soil structure. Many of the soils in western Minnesota are alkaline and have pH values greater than 7.0. Generally, the rainfall in western Minnesota is sufficient to leach salts. Salt accumulation does not occur except at low spots where drainage is poor and natural and/or added salts accumulate, causing problems for crop production. Accumulation of natural salts is commonly observed in soils of the Red River Valley.

Manure applied at disposal rates can have a very significant impact on salts in soils, especially in dry climates. Studies in California, Arizona, Texas, and Nebraska demonstrated that salt build-up from heavy application of liquid and solid manure can deteriorate soil structure, reduce

permeability, contaminate groundwater, and reduce crop yields (Adriano et al., 1971; Amoozegar-Fard et al., 1980; Mathers and Stewart, 1974; Tiarks et al., 1974).

More interesting for understanding the effect of manure on soils in Minnesota are the results of an Indiana study on liquid swine manure. Manure was applied to corn at rates varying from approximately an agronomic rate (based on N need) to four times the agronomic rate. The experiment was conducted on three sites, including prairie silt loam and clay loam soils not greatly different from soils found in western Minnesota. Over the three years of the experiment, levels of soil sodium, potassium, phosphorus and nitrate increased, especially at the highest application rate. However, sufficient leaching and uptake of sodium, potassium, and nitrate occurred such that salt toxicity did not occur at the agronomic rate, and the increase in salts was small. Measurable increases in sodium and potassium content were obtained at the disposal rates. Greater dietary sodium resulted in greater sodium content of the manure (Sutton et al., 1984).

Similar results were obtained in a four year study of manure application on corn at the West Central Experiment Station in Morris, Minnesota. About 30 dry tons per acre (disposal rate) of solid and liquid beef manure, and liquid hog manure were applied for two consecutive years, and the residual effects of manure application were monitored for an additional two years. Greater accumulations of sodium and potassium were measured at Morris than in Indiana, because the rate of application was greater and leaching intensity is less in Morris. During both years of manure application, corn in plots receiving liquid beef manure showed signs of wilting, in localized areas early in the season, due to elevated salt levels. Measurable increases in salt content with depth were found for all three manure treatments. Sodium levels increased in all manure treated plots. Yield results showed that salt levels were not high enough to decrease yields below those from inorganically fertilized plots. The authors speculated that continuous application of manure to corn, at disposal rates, would eventually lead to yield reductions due to salt accumulation (Evans et al., 1977).

Manure as a source of weeds

Wild birds and animals excrete plant seeds and are important agents of seed dispersal. Livestock feed is often a source of weed seeds that will survive the trip through the gut of animals and into manure. Manure can be a source of weeds if animals spend at least part of their time on a weedy pasture, are fed weedy hay, or are fed course ground feed containing weeds (Muenscher, 1987). Silage is not a source of weeds because weed seeds do not survive in a silo. Composted manure does not contain high counts of viable weed seeds (Crafts and Robbins, 1987). The high temperatures generated by some composting systems can greatly decrease weed seed survival.

Few studies have been conducted to quantify the contribution of manure to weeds on farms under modern management conditions. Most of the research on weed seeds in manure dates from before World War II. Recently, researchers in New York studied dairy manure from 26 farms as a source of weeds. They found that the seed contributed by manure was not an important source for weeds compared to the seed density already in the soil. The researchers did stress that if soil weed seed density is low and manure weed seed density is high, manure could be a relatively important source of weed seeds (Mt. Pleasant and Schlather, 1994).

Researchers in Canada found no evidence that liquid dairy manure compared to commercial fertilizer altered weed density or species diversity. The results suggest that the amount of weeds

introduced with liquid dairy manure was negligible and that the species composition of introduced weed seeds from liquid dairy manure was similar to those that already existed at the site (Stevenson, et al., 1997).

Biological activity

As for other soil properties, the effects of animal agriculture on biological activity depend on the response to manure additions as well as the types of cropping and/or grazing systems employed. The effects of agricultural systems on biological activity largely depend on the type and amount of organic matter added to the soil. Thus studies of the effect of manure and cropping systems on biological activity often include measurements of changes in soil organic matter quality and quantity.

Manure impacts on soil biology

Manure Applications Increase Biological Activity

Many studies have confirmed that animal manures applied at agronomic rates increase soil biological activity compared to commercial fertilizer. In one study in Quebec, researchers evaluated effects of 14 years (1977-1991) of manure and inorganic fertilizer applied at recommended rates. They found significantly higher soil earthworm abundance and diversity, greater biological activity as measured by rate of carbon dioxide production (respiration rate), a higher organic matter content, and greater soil aggregate stability (Estevez et al., 1996). In another study at a different site, N'Dayegamiye and Angers (1990) found that manure application improved soil structure and increased fungal and bacterial populations.

Studies on long-term plots in eastern Oregon showed that soils with a long history of organic amendments maintain higher levels of microbial biomass, total carbon and nitrogen, and relatively more carbon and nitrogen in the bodies of living organisms. Soil enzyme activities are also higher (Fauci and Dick, 1994). Researchers in California also found that animal manures, as well as green manures and crop residues added to soils increase enzyme activities within a few weeks, compared to unamended soils (Martens et al., 1992).

The increase in biological activity in response to manure application often can be explained by the increase in soil organic carbon. In a Nebraska study comparing organic farming methods and conventional management, (in a four year crop rotation of oat/clover-corn-soybean-corn), soil bacterial and fungal numbers, dehydrogenase enzyme activity, and soil biomass were highest in manure-amended soils. These soils had better water status. The total carbon, nitrogen and potentially mineralizable nitrogen in the surface 3" of soil were 20-40% greater for manured soil than for soils receiving the same nutrients as conventional fertilizer. These factors promoted greater soil biological activity, and increases in the microbial populations paralleled the increases in soil organic carbon content (Fraser et al., 1988). In an Oregon study of pasture soils with and without dairy manure additions, researchers found 50% more total bacteria and fungi in spring and winter, and twice as many in the fall where manure had been applied (Entry and Emmingham,1995).

Manure also affects larger soil organisms. A field experiment in a pasture in South Australia showed that manure promoted reproduction and local aggregations of earthworms (Hughes et al., 1994). In another Australian study, the presence and distribution of sheep manure changed the

vertical and horizontal distribution of burrows and the amount of burrowing activity of two earthworm species. The earthworms tended to concentrate under dung patches. One species concentrated more near the soil surface in response to the presence of sheep manure. The earthworms burrowed less actively when manure was present and resources were not scarce (Hughes et al., 1996).

While application of manure generally increases soil biological activity, compaction from heavy equipment used to spread manure can have the opposite effect. On a dairy farm in Norway converting from conventional to organic practices, different cattle manure treatments, fertilization levels and soil compaction were studied over six years. Increasing the manure rate from 80 to 160 lbs N/acre increased yields of a mixed pasture from 2.8 to 3.1 tons dry matter/acre. However, the soil compaction from tractor applied manure decreased yields from 4 to 3 tons dry matter/acre. Soil compaction reduced air-filled pore space and the number of earthworms (Hansen, 1995). Nitrogen mineralization was also decreased by compaction, presumably because organic materials and microbial biomass were protected from attack by nematodes (Breland and Hansen,1996).

Differences in Quality and Types of Manure

As described in the section on soil organic matter, research at the Rodale Research Center in Pennsylvania suggest that amendments with higher carbon-to-nitrogen ratios, (such as in green manures as opposed to animal manures) may be more beneficial for long-term organic matter buildup and soil quality.

Similarly, manure amendments with lower nitrogen contents (higher carbon to nitrogen ratios) may be preferable for maintaining soil organic matter levels, and improving soil structure and biological activity. In a study comparing long-term application of solid beef manure, with a carbon to nitrogen ratio of about 20, versus pig slurry with a carbon to nitrogen ratio of 6, researchers found that relatively greater amounts of the native soil organic matter were mineralized where the pig slurry had been applied. They suggested that long term pig slurry applications in soils with low carbon to nitrogen ratios could result in enhanced mineralization of the existing soil organic matter to the extent that soil organic matter would be depleted (N'Dayegamiye and Cote, 1989). In long-term plots in Oregon, as well, researchers found that beef manure increased microbial biomass more than poultry manure, in proportion to the amounts of carbon added for an equivalent amount of nitrogen input. Because the beef manure is lower in nitrogen, more organic carbon was added for the same addition of nitrogen. Both microbial biomass and enzyme activity for all the treatments correlated with the total amounts of organic carbon added over time (Collins et al., 1992).

Other studies have examined effects of manure on bacterial and fungal feeding nematodes, since they play such a crucial role in the turnover of soil biomass and the mineralization of nutrients. Researchers at Ohio State University showed that additions of organic inputs, whether legume cover-crop or cow manure, led to significant increases in populations of fungivorous (fungi-eating) and bacterivorous (bacteria-eating) nematode groups. Interestingly, there were relatively more bacterivores in the manure treatment and fungivores in the legume cover crop treatment, probably because of the difference in the quality of the organic matter (Bohlen and Edwards, 1994). The more resistant compounds in cover crop plant material compared to animal manure are more likely to encourage fungal growth. These results are consistent with the differences observed in the distribution of different forms of soil carbon in the Rodale Farming Systems

Trial mentioned above, where the researchers found that manure apparently increased the short-term carbon pools and the legume cover crop seemed to affect longer-term pools. In a Scottish study, addition of cattle manure had no effect on different types of nematode populations, but poultry manure increased numbers of bacterial feeders (Griffiths et al., 1994).

Manure Applications Can Increase the Loss of Nitrogen

So far, we have reported the benefits to soil biological activity associated with the application of manure. However, the concomitant addition of carbon with manure nitrogen can stimulate losses of nitrogen to the atmosphere through microbial denitrification. In denitrification, nitrate nitrogen is transformed to nitrous oxide gas or dinitrogen gas, and nitrogen is lost from the soil. This occurs in zones in soils that are anaerobic (without oxygen) where there is decomposable organic matter. In a manure-treated soil this process is concentrated at the interface between wet manure and soil, where readily decomposable organic matter in the manure consumes oxygen, and nitrate from the soil can encounter the denitrifying bacteria. In one Swedish study, nitrogen loss due to denitrification was 14-fold higher with fresh manure than with anaerobically-digested manure although amounts of dissolved carbon differed only by a factor of 3 (Petersen et al., 1996). Losses are not always significant. In Ontario, accumulated nitrous oxide losses from the soil surface of manured plots was equal to only 1% of the potentially mineralizable N. Two thirds of the total nitrous oxide loss occurred in the first 7 weeks after application (Lessard et al., 1996).

Manure Affects Community Structure

Little work has been done to determine the changes in microbial community structure in response to manure addition. One laboratory study using phospholipid fatty acid analysis (PLFA) showed that community structure was altered within a few millimeters of the manure/soil boundary, mostly due to diffusion of dissolved organic carbon from the manure. However, after 3 days, PLFA composition gradually became more like the bulk soil again (Frostegard et al., 1997).

Manure Affects Crop Diseases and Pests

There is evidence that manure additions can have beneficial effects by reducing the incidence of diseases and pests. One study examined diseases of winter wheat in three different rotation patterns in western Oregon. It was found that the disease pathogens were collectively least prevalent where N, in a wheat-fallow rotation, was supplied as manure or pea vines (green manure) rather than as inorganic fertilizer (Smiley et al., 1996). In another case, germination of the pathogenic fungus (*Fusarium oxysporum)* was significantly higher in a soil amended with chemical fertilizer than in soil amended with farmyard manure (Toyota and Kimura, 1992). Average emergence rates of western corn rootworm were reduced by 45% in manured plots compared with nonmanured plots, during one year of the study, and in the other year were not different. Thus manure applications do not lead to increased western corn rootworm populations as had been proposed, and may in some years reduce them (Allee and Davis, 1996).

Plant parasitic nematode (*Meloidogyne incognita*) populations in cotton-cropped land decreased linearly with increasing rates of poultry manure addition (Riegel et al., 1996). In a study with squash and cotton in South Carolina, poultry manure and litter reduced root-knot nematode

infection while bacterial- and fungal-feeding nematodes increased (Fortnum, 1994). In greenhouse and field trials with tomato, total numbers of plant parasitic nematodes in the roots, and numbers of nematode eggs decreased with increased rates of chicken litter (Kaplan and Noe, 1993).

Manure Can Contribute to Selection of Antibiotic-resistant Bacteria

Antibiotic use in subtherapeutic doses as feed additives for animal production is a common practice in the U.S. and throughout the world. This practice can lead to selection of resistant microbial populations (including pathogens) in both the animal's native microbial community and in the local environment due to shedding in fecal material (Kelley et al., 1998). Normally, about 2% of a 'wild-type' bacterial population are resistant to any given antibiotic. However, up to 10% of bacterial populations from animals regularly exposed to antibiotics have been found to be resistant (Novick, 1981). A very high percentage (80-100%) of the isolated bacterial populations from poultry litter, suitable for soil application, were multiple-antibiotic resistant (Kelley et al., 1998). No reports on this topic were found for cattle or swine manure.

Manure Can be a Source of Bacterial Contamination

Fecal bacteria are present in manure and may move down through the soil profile into springs or wells, or with surface runoff and sediment into streams and waterways. Constructed wetlands can help to reduce fecal coliform concentrations in runoff from confined livestock operations (Cooper and Lipe, 1992). These issues are discussed in the Water Quality report.

Manure Can Contribute to Toxic Levels of Elements

In some manure amendments, such as from pigs fed high copper rations, high (disposal) rates of manure application can result in significant reductions in soil biological activity due to copper toxicity (Huysman et al., 1994). This is discussed in more detail in the Manure and Crop Nutrient report (Section on carrying capacity for nutrient and toxic substances).

Cropping system impacts

Growth of perennial grass or alfalfa in an animal production system is an excellent way to improve soil structure. Depending on the type of perennial forage, benefits can be realized in one cropping season (Angers and Mehuys, 1988; Stone and Buttery, 1989). Extensive, fibrous grass root systems can improve soil structure by:

1. Binding larger soil aggregates with fine roots and mycorrhizal hyphae, and
2. Feeding soil bacteria, that help bind microaggregates with adhesive metabolic products.

Thus, forages increase both microbial biomass and aggregate stability, which are often well-correlated (Drury et al., 1991; Huggins et al., unpublished).

In Ontario, Canada, reed canary grass increased aggregate stability and improved microbial biomass more than alfalfa, orchard grass, or red clover, possibly because fungal growth is favored by the higher carbon-to-nitrogen ratio in reed canary grass. However, all these crops had significantly higher aggregate stability than corn and soybeans (Drury et al., 1991). Microbial biomass was greater for reed canary grass than all other crops tested, except alfalfa at the first

and last sampling dates. The legumes (alfalfa and clover) tended to favor bacterial biomass, and the grasses increased fungal biomass. In a cropping system comparison in Maryland, researchers showed that total and labile carbon were significantly higher under grass, and lower under conventionally tilled (CT) corn. Grass resulted in twice as much soil metabolic activity compared to CT continuous corn. Less tillage and more grass also improved other soil biologicalactivity indicators, including nitrogen mineralization, earthworm (*Lumbricidae*) populations, microbial respiration, and extractable organic carbon (Weil et al., 1993).

In one Ohio study, researchers found better aggregation, lower bulk densities and greater organic carbon in continuous corn and a corn-soybean rotation than in a corn-oat-meadow rotation. They suggested that this unexpected result might be due to a number of factors including relatively low crop residue, poor soil cover, and excessive vehicular traffic for harvesting forage, resulting in poor soil structure and low aggregation (Lal et al., 1994).

Grazing impacts

Well-managed grazing systems generally enhance soil biological activity, while high stocking rates or grazing when soils are too wet causes compaction and degrades structure—resulting in less biological activity.

A number of studies have confirmed that compaction can reduce biological activity. A UK study compared a permanent pasture, with high organic carbon content, to a continuous cereal (28 years) with low organic carbon. Compaction was simulated using five tractor passes each of 10,736 lbs to selected plot sites. Compaction reduced net nitrogen mineralization in the pasture, but not on the cropped site. Respiration decreased with compaction on both sites (Jensen et al., 1996). These researchers concluded that soil biological factors, such as soil respiration and nitrogen mineralization, may be more sensitive to heavy traffic than physical properties (Jensen et al., 1996).

Soil compaction under grazing animals depends on the type of livestock grazed. In a grazing experiment in Vermont, compaction was found to be greater under cattle than sheep. Microbial respiration rates, soil nematode numbers, and average earthworm numbers were all higher in sheep-grazed than cattle-grazed treatments and were inversely related to the degree of soil compaction (Murphy et al., 1995). Depending on soil texture and moisture, these researchers concluded that low stocking densities with continuous grazing or long paddock occupations of several days in a rotational grazing system can potentially cause serious compaction problems. They suggested that periodic soil aeration might benefit pasture production under cattle grazing.

Other biological processes affected by compaction include earthworm activity and cycling of nitrogen. In a study of cattle grazing on permanent pasture, trampling cattle destroyed earthworm burrows at the 1 inch soil depth. At the 9 inch depth, castings by earthworms rather than trampling were the most important source of burrow disintegration (Ligthart, 1997).

Welsh studies with compacted grassland soil have shown that simultaneous nitrification and denitrification at shallow soil depths resulted in nitrogen losses (Abbasi and Adams, 1998).

In a two year study in North Dakota, moderate grazing (45% removal of plant growth) resulted in higher decomposition and soil nitrogen mineralization rates, and lower nitrogen release from litter and root decomposition, than in the heavily grazed (77% plant removal) or long term ungrazed treatments (Shariff et al., 1994). These increases in net soil nitrogen mineralization with moderate grazing appeared to contribute to the higher levels of plant production and

nitrogen uptake found in this treatment. They suggest that moderate grazing may also contribute to conservation of nitrogen due to greater retention of nitrogen in plant litter and roots.

A field experiment in South Wales, UK demonstrated the benefits of grazing for soil biological activity. Researchers found that when sheep-grazing intensity was reduced or removed completely, total soil microbial biomass was dramatically reduced and bacterial/fungal ratios changed significantly (Bardgett and Leemans, 1995). In laboratory microcosm studies on these same soils, continuous defoliation (as would occur with grazing) caused increases in microbial biomass either as a result of increased soluble nutrients exuded from live roots or nutrients released from dead and decomposing roots (Mawdsley and Bardgett, 1997).

Another effect of grazing is the tendency for nutrients to become unevenly distributed, and this in turn can affect biological activity and productivity. One study showed potassium accumulation in "camping zones" near water, the mineral feeder and shade, and depletions in non-camping zones (Wilkinson et al., 1989). Sheep manure tends to be more uniformly deposited than cattle manure, so sheep pastures are less likely to manifest this problem (Murphy et al., 1995).

KNOWLEDGE GAPS

Significant gaps exist in the knowledge of how livestock management impacts soil quality in Minnesota. Most of the research discussed in this report examines the effects of single practices, or a small set of practices, on specific soil characteristics. From this research we get a picture of the effect of some farm practices on soil quality, but we do not have complete understanding of how crop and livestock management interact on real farms in Minnesota. We propose the following research topics to fill the knowledge gaps.

A. Studies that could be accomplished in 18 months or less if adequately funded include:

- **Nutrient balances (inputs, outputs, and recycling) for livestock systems in Minnesota.**

Data obtained from farms representing different sizes and types of livestock operations on different soils could be obtained and estimates of the nutrient balances could be made.

The nutrient balance calculations combined with information on the capacity of soils to retain nutrients are needed to define the number of animals per area of available cropland that is environmentally sustainable, assuming manure nutrients are not exported from the area. Additionally, the calculations could be used to estimate where, and at what rate, nutrients are concentrated on or exported from cropland.

- **Examination of the erosion potential for different types of livestock and cash-grain farms in Minnesota.**

Estimates of the effects of different types of livestock and grain farming operations could be generated using computer simulation models for individual operations, local watersheds, and regions of the state. This could include estimation of the effects of reduced tillage versus conventional tillage and the effects of different grazing systems.

Although computer model calculations provide imperfect estimates of actual erosion losses they can generate valid rankings of the erosion potential for different livestock and cropping systems.

- **A geographical and historical analysis of Minnesota crop and livestock farming.**

An analysis of animal agriculture systems would allow interpretation of the significance of the soil quality research presented in this report and gained from other research investigations.

Some questions that might be addressed are: Where, and in what situations, are perennial forages grown? How has this changed over the last 50 years? To what extent are productivity and sustainability affected where forages are not grown? How far can farmers economically transport manure? Where do markets exist that transfer manure from livestock to cropping operations? What are the regional conditions that encourage the return of manure to cropland? What are trends in soil quality and soil erosion around the state? Can they be linked to differences in animal agricultural systems?

- **The effects of antibiotic feed additives on microbial activity in soils.**

This research would examine the long-term potential for selection of antibiotic resistant bacteria and any possible negative effects on soil quality, as well as human and animal health. Soil

microbial activity could be compared on farms with long-term application of manure with and without antibiotics. Sites where there has been a recent change in antibiotic use could be used to evaluate how quickly microbial populations respond.

B. Studies that would require greater than 18 months include:

- **Investigations of the long-term effects of grazing management systems and their impacts on soil quality.**

This research would provide information on concerns related to the effects of grazing management. For example, soil compaction research in Minnesota has traditionally focused on continuous cropping systems and compaction related to mechanical forces. However, there are a number of specific questions to be answered regarding recognition and control of soil compaction by grazing livestock in Minnesota. Other concerns in grazing systems are with the potential for nitrate leaching from urine spots, and spatial variation of nutrients in soil.

- **The value of manure applications for renovating degraded soils.**

Repeated manure application can increase the organic matter in soils and increase crop productivity of soils that have been degraded by erosion. Systematic data on the use of manure to renovate degraded soils in Minnesota are not available.

Results of this study could be used to develop site-specific recommendations for the renovation of degraded fields, as well as degraded areas within fields.

- **The benefits to soil quality of various types of manure amendments versus crop diversity through rotations, green manures, and cover crops.**

Manure can have important positive effects on soil quality. Perennial forages in crop rotations, as well as green manures and cover crops, also have positive effects on soil quality. The relative advantages and disadvantages of these different practices are not well understood for Minnesota conditions. This research will address the question of how to achieve maximum benefit to soil quality on livestock farms: Should manure be applied mainly to annual crops? Must perennial forages be included in crop rotations, regardless of manure inputs? Is it best to apply manure to perennial forages to achieve the largest, most persistent gains in soil quality?

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RESPONSE TO REVIEWERS' COMMENTS

The reviewers thought that the report adequately addressed the topic and they did not identify major omissions in the research review. The reviewers did make a few suggestions for changes. Below is a discussion of how we responded to the suggestions

Diane Stott suggested that we should have discussed leaching of nitrate to ground water. This topic is discussed in the Manure and Plant Nutrients report.

John Doran commented that the link was not made strongly enough between manure and soil quality (in terms of sustainability). We are not sure what he meant by this comment, but in response we included more discussion about sustainability and manure. As suggested by Dr. Doran, we now explain the link between soil quality and air quality in the introduction to soil quality. We also revised our explanation of the significance of respiration measures and clarify phytase and low phytate corn. Phytase and low phytate corn are discussed in more detail in the Manure and Plant Nutrients report.

Richard Dick suggested some reorganization of the Primer section, including adding a section about soil organic matter. In response, we added a more explicit explanation of the central importance of organic matter to soil quality, and explained that the long-term benefits of manure are linked to its contribution to soil organic matter. As suggested we moved the section explaining measures of soil biological activity from the research review section to the Primer. Dr. Dick suggested we reorganize the Primer around a description of soil morphology. We chose to retain our focus soil processes so as to emphasis the dynamic nature of soil. Some sentences were added to clarify how the document is organized. As suggested, we did remove some of the introductory material that was in the research section. Dr. Dick also suggested we discuss cover crops. Although cover crops are valuable for improving soil quality, we chose not to discuss them because their use is not directly related to livestock production systems.

Literature Review

SOILS TOPIC: SUMMARY OF CAC COMMENTS ON THE DRAFT REPORT

June 22, 1999

[Replies by Soils Team are in brackets]

1□ **Up front "primer" additions?**

- Definitions or clarification of forage, disposal rate, salty soils, carrying capacity *[We have rearranged and added material to clarify]*
- What do we know about trends *[Little material is available on trends. This is a research gap]*
    - soil quality
    - soil erosion
    - cover crops / cropping systems as it relates to soil erosion
- Connection to water quality – phosphorus and surface water; nitrogen and groundwater *[This is handled by the Water Quality and the Manure and Crop Nutrients teams]*
- Connection to commercial fertilizer *[This is implicit in most manure and cropping systems research. Generally, comparisons are made to commercial fertilizer treatments. We have clarified this in the rewritten text.]*

2□ **Lacks some focus on environmental impacts**

- Clarify understanding of "carrying capacity" as the point at which soil is impacted by the emissions associated with animal agriculture *[This is in the Manure and Crop Nutrients report]*
- What about soil erosion? Rates of erosion by system type or cropping system or ex: threat of losing dairy farms in SE Karst area and resulting potential for erosion *[This is a knowledge gap]*
- Phosphorus connection *[We include some discussion of this but most of this discussion is in Manure and Water Quality report]*

3□ **Manure compared to commercial fertilizer**

- Clarify differences *[Clarified]*
- Cross references to manure topic *[Done]*
- Charts *[Added chart with up and down arrows summarizing effects of manure and cropping systems in contrast to inorganic fertilizer treatments.]*

4□ **Variations by Animal Agriculture System / Management Type**

- Differences in soil quality by system type *[Added material on reduced tillage]*
- Distinguish different types of grazing systems in above. *[This is difficult because the research studies are not usually presented in terms of grazing system.]*
- Application rates *[We presented the difference between agronomic rates and disposal rates.]*
- Precision application *[No information yet available. This is an area of active research.]*
- Manure injection *[Little information is available on the effects of injection on soil quality.]*

5□ **Missing contaminants of concerns**

- Antibiotics chain *[Discussion added]*
- Pathogens chain *[This is covered by the Human Health team]*
- Heavy metals chain *[This is in the Manure and Crop Nutrients report]*

6□ **Compaction / Treading**

- What is known about impacts *[Material added]*

7□ **Where is the need for additional research?** *[We added a Knowledge Gaps section.]*

8□ **Report Structure / Format**

- Organize by production system / management type? *[We could not do this because most research studies are not presented in terms of management systems. We did add a section explaining what factors determine the effect of management system, and what questions to ask to assess a system.]*

ATTACHMENTS

Ongoing Research

Notes from interviews with principle investigators for current, unpublished research.

Ongoing Research

List of major relevant on-going work for current, unpublished research.

Title of Study	***Investigators***
• Integrated approaches to manure management and biological control of plant diseases.	Hoitink, HAJ, WA Dick, and TL Loudon
• Use of phytase enzymes and low phytate corn in Delaware's poultry grain agriculture: Assessing the agronomic, animal nutrition, and environmental impacts.	T. Sims
• Long-term manure application and phosphorus transport in poorly drained soils.	R. Simard, S. Beauchemin
• Phosphorus requirements for dairy cows.	L.D. Satter
• Reducing non-point phosphorus runoff and ammonia emissions from animal manure with alum.	P.A. Moore
• Evaluation of Alternative Crops in Dryland Multi-Crop Rotations on Farms in the North Eastern Colorado Region.	James M. Krall
• Land application of liquid hog manure at environmental vs. agronomic rates.	Neil Hansen, Peter Gessel, John Moncrief
• Beef Cattle Feedlot Manure for Site Specific Application.	Bahman Eghbal
• Impact of accelerated erosion on soil properties and productivity.	Larry Cihacek, K.A. Ringwall, R. Carcoana
• Managing dairy manure nutrients in a recycling compost program within the Le Sueur River watershed.	Chester-Jones, Peters, Busch, Busman, Norm and Sallie Volkmann

Investigators: T. Sims

Institution or Affiliation: University of Delaware, Department of Plant and Soil Science

Title of Study: Use of phytase enzymes and low phytate corn in Delaware's poultry grain agriculture: Assessing the agronomic, animal nutrition, and environmental impacts

Funding Agency: State of Delaware Research Partnership, BASF

Duration of Study: 1997-1999

Objectives: Assess agronomic, animal nutrition, and environmental impacts of low phytate corn.

Key Words: poultry, phytase, low phytate corn

Location (or Locations) of Study: Sussex County, DE

Type (or types) of Soil Used: Sandy loam

Climate: Warm, humid.

Approach: This study was primarily conducted in the laboratory. Phosphorus content of poultry manure from animals fed low phytate corn was analyzed phosphorus. Corn in the feed was also analyzed for supplying adequate phosphorus for animal nutrition.

Progress: on-going. Data collected, approximately 300 acres of low phytic acid corn planted

Potential Implications: Produce low phytate corn for use in animal feed which supplies the necessary P levels for animal nutrition while at the same time reducing total P in animal manure. If successful this approach to reducing P in animal manures would be environmentally beneficial for reducing P inputs in to the soil.

Publications: In progress

Other Comments: Interview done with Dr. April Leytem.

Further related research by Dr. Sims is listed at the following web site: http://bluehen.ags.udel.edu/envsoil/projects/default.htm#projects

Investigators: R. Simard, S. Beauchemin

Institution or Affiliation: Agriculture and Agrifood Canada

Title of Study: Long-term manure application and phosphorus transport in poorly drained soils

Funding Agency: Internal and external

Duration of Study: 1992 - ongoing

Objectives: Long term impact of swine manure on P.

Key Words: redox, swine, dairy manure, compost, poorly drained soils

Location (or Locations) of Study: Quebec, Canada

Type (or types) of Soil Used: Sandy loam to heavy clay in poorly drained soils

Climate: Cool, humid.

Approach: Evaluate long-term manure application to poorly drained soils, evaluate phosphorus pools (partitioning) using field scale studies, evaluate runoff and drainage water for nutrients primarily P, measure the degree of P saturation, in response to manure application rates, for Canadian soils with a variety of textures.

Progress: on-going

Potential Implications: The results of this study will be beneficial for making recommendations pertaining to the implications of long-term manure application on soil P saturation levels. This study may also characterize process of movement of P through soils in a management system of long-term manure applications.

Publications: Soil Science Society, Canadian Journal of Soil Science

Other Comments:

Investigators: L.D. Satter

Institution or Affiliation: USDA-ARS Dairy Forage Research Unit

Title of Study: Phosphorus requirements for dairy cows

Funding Agency: USDA-NRI

Duration of Study: 1996-2002

Objectives: Reduce amount of P in manure..

Key Words: dairy, phosphorus, nitrogen

Location (or Locations) of Study: Prairie du Sac, Wisconsin

Type (or types) of Soil Used: Silt loam intermixed sandy, glaciated terrain

Climate: humid.

Approach: Farm management of manure through mass balance of phosphorus for crop production and environmental protection while maintaining animal nutrition requirements is the approach being used in this study. Experimental procedures include analyzing dietary phosphorus requirements for dairy cattle and then if possible reduce dietary consumption through reduced phosphorus in livestock feed and consequently animal manure.

Progress: Submitting publications to journals of Dietary P. in process of collecting data on cropping systems

Potential Implications: This study may provide need information regarding phosphorus budgets for whole farm management. This research may lead to recommendations for dietary P which may lead to further research on reduced P in animal feeds as well as reduced P in animal manures and the effects on the environmental fate of P from live stock manure. This study may also lead to reduced energy requirements for the manufacture of N and for management of N from manure supplemented with commercial fertilizers plus N credits from other crops.

Publications: Journal of Dairy Science – 2 publications
Nutrition conference plus manuscripts.

Other Comments:

Investigators: P.A. Moore

Institution or Affiliation: USDA-ARS Poultry Production and Product Safety Research Unit

Title of Study: Reducing non-point phosphorus runoff and ammonia emissions from animal manure with alum.

Funding Agency: Internal (USDA), External (US Poultry Assoc.), EPA

Duration of Study: 20 year study beginning in 1994

Objectives: Reduce P in runoff of surface applied manure, decrease ammonia volatilization, improve animal productivity

Key Words: Alum, aluminum sulfate, precipitate P, ammonia volatilization, poultry litter, P runoff, pasture, soluble P

Location (or Locations) of Study: Northwest , Arkansas

Type (or types) of Soil Used: silt loam

Climate: warm, humid.

Approach: Initial lab studies and small plot field trials of P movement through soils with Alum and non-Alum treated poultry litter. Poultry house research was conducted on ammonia volatilization, animal health, and human health. Watershed scale experiments comparing Alum treated litter with non-Alum treated litter showed P in runoff was reduced by 75%. Alum treatment poultry litter has reduced heavy metal runoff (Cu, Zn, As) by 50%.

Progress: Found success using Alum to treat poultry litter to reduce P movement through and across soils

Potential Implications: Reduced environmental quality degradation by reducing P in runoff, improved poultry production, and improvements in human and animal health.

Publications: JEQ

Other Comments: Other on-going long-term studies related to manure applications (rates, treatments)

--Also looking at other manures (swine)

--estrodial – estrogen compound reduced in

Investigators: James M. Krall

Institution or Affiliation: University of Wyoming

Title of Study: Evaluation of Alternative Crops in Dryland Multi-Crop Rotations on Farms in the North Eastern Colorado Region

Funding Agency: USDA - SARE

Duration of Study: 1995-1999

Objectives: Compare a winter-pea/winter-wheat rotation with the conventional winter wheat/fallow system.

Key Words: dry land, grazing

Location (or Locations) of Study: southeast Wyoming, northeast Colorado

Type (or types) of Soil Used:

Climate: dryland

Approach: An alternative, livestock-based, crop rotation is compared to the conventional wheat-fallow rotation for dry land production. The alternative rotation involves fall-sown winter pea. The pea is grazed in spring, disked in summer and followed by winter wheat.

Progress: Will assess soil quality indices this fall after 4 complete rotation cycles. Yield data suggest improved soil condition with inter pea in rotation.

Potential Implications: including winter pea and grazing systems in rotation with wheat may promote soil quality.

Publications:

Other Comments:

Investigators: Hoitink, HAJ, WA Dick, and TL Loudon

Institution or Affiliation: Ohio State University, Plant Pathology Dept

Title of Study: Integrated approaches to manure management and biological control of plant diseases

Funding Agency: USDA Cooperative Research NRI Competitive Grants

Duration of Study: 01 April 1998 - 31 Mar 2000

Objectives: 1) Develop and demonstrate best management practices for on-farm composting capitalizing on natural convective gaseous transfer to minimize turning and reduce labor and odor problems; 2) Improve disease control in no-till crop production utilizing manures and composted manures; and 3) Develop and demonstrate novel procedures for biological control of soilborne diseases of nursery crops utilizing composted manures.

Key Words: manure management, biological control, on-farm composting

Location (or Locations) of Study: several locations all over the state of Ohio

Type (or types) of Soil Used: numerous including Wooster silt loam and Hoytville clay

Climate: humid, temperate

Approach: 1) Compost windrow conditions will be simulated in a pilot-scale chamber utilizing existing in-vessel gas transfer models. Field scale windrow data will be used to validate the most promising model. This model will be used to develop BMPs for on-farm composting. 2) A four-replicate complete factorial experiment will be conducted on two soils, one well-drained and the other poorly-drained. Variables will include organic amendments (manure and composted manures), rates (four levels), and tillage (reduced and plow-tillage). Data collected will include climatic information, agronomic practices, yield, disease severity, and soil quality (chemical and biological properties). 3) Natural and biocontrol agent-fortified container media amended with composted manures will be evaluated for suppressiveness to Rhizoctonia crown and root rot, Pythium and Phytophthora root rot and Verticillium wilt of nursery crops. The most suppressive systems will be demonstrated in cooperating nurseries.

Progress: A commercial scale hog-finishing facility has produced 2 crops of 1000 hogs each with manure produced under the slatted floor in a dry form and no liquid by-products at all. This manure has just completed the composting process and will be sold as potting

mix and for field application. Fifteen new finishing facilities at various locations are under construction at this time, one of which will have capacity for 8000 hogs at a time. Under objective two, these researchers are in the second year of a study where large amounts of dairy manure and/or compost are applied and worked in to the top 1-2 inches of soil to try to convert fields from conventional to minimum tillage in one year, with yields and soil properties comparable to a long term no-till field. Finally, Dr. Hoitink has shown, with a number of students over the last 25 years, that composted or aged manure can impart systemic-induced (broad spectrum) resistance to plants. On the other hand, fresh manure or too much manure can actually activate plant diseases. Mechanisms for this include: too much free nutrient availability in fresh manure, so plant and animal pathogens are stimulated and there is no competition from suppressive organisms. There is no parasitism or antibody production in very nutrient rich soils. Thus, a certain stability of organic matter is required before systemic induced resistance occurs.

Potential Implications: According to Dr. Hoitink, the technology exists to avoid any problems with manure handling in chicken broiler and layer, hog and beef production. Only for dairy production is the volume of water too great to be handled with the present technology, but this is being worked on at present at Ohio State. These systems completely bypass all liquids so leakage and pollution are not concerns. Ammonia levels are maintained within safe bounds, and the ammonia is trapped and converted to nitrate. Odor problems are also solved with this technology. The problem is how to convert existing facilities, and those still being constructed without this manure handling feature.

Publications:

Hoitink, H.A.J. and M.J. Boehm, 1999. Biocontrol within the context of soil microbial communities: A substrate-dependent phenomenon. Annual Reviews in Phytopathology 37: 427-446. *In press.*

Hoitink, H.A.J., A.G. Stone, and D.Y. Han, 1997. Suppression of plant diseases by compost. HortScience 32: 184-187.

DeCeuster, Tom J.J. and Harry A.J. Hoitink, 1999. Prospects for composts and biocontrol agents as substitutes for methyl bromide in biological control of plant diseases. Compost Science and Utilization , issue 3, *In press.*

Zhang, W., D.Y. Han, W.A. Dick, K.R. Davis, and H.A.J. Hoitink, 1998. Compost and compost water extract: Induced systemic acquired resistance in cucumber and Arabidopsis. Phytopathology 88: 450-455.

Hoitink, H.A.J. 1998. Control of nuisance and detrimental molds (fungi) in mulches and composts. Fact Sheet HYG-3304-98. Ohio State University Extension, Wooster, OH 44691.

Hoitink, H.A.J., W. Zhang, D.Y. Han, A.G. Stone, M.S. Krause and W.A. Dick, 1998. How to optimize disease control with composts. Pg 50-65 *In* Ornamental Plants, Special

Circular #157. 117 pages. Ohio Agricultural Research and Development Center, Wooster, OH 44691.

Other Comments: **Manure and erosion**: By composting manure, applications can be made to 25-40% slopes without erosion. Fresh dairy manure applied on slopes is a disaster. For **egg production**, on-site composting has been incorporated into the facilities for henhouses as large as two million hens, with a guaranteed composition of 4.5% nitrogen, ammonia is trapped out, and there is no odor problem except from the hens themselves. This composting procedure results in no net loss and sometimes a slight profit on the production of the manure. For **broiler production**, it has been shown that manure can be rototilled in and kept moist on the floor of the broiler house for up to 10 crops of broilers; the manure can then be taken off and marketed directly without composting. This aged manure has beneficial effects on the birds, with the worst disease losses occurring in the first flock and the least in the tenth flock.

Investigators: Neil Hansen, Peter Gessel, John Moncrief

Institution or Affiliation: University of Minnesota

Title of Study: Land application of liquid hog manure at environmental vs. agronomic rates.

Funding Agency: University of Minnesota graduate school

Duration of Study: 1999 - 2001

Objectives: Evaluate impact of variable rates of land applied, liquid hog manure on soil and water quality

Key Words: runoff, manure, aggregation

Location (or Locations) of Study: Morris, MN

Type (or types) of Soil Used: Barnes loam

Climate:

Approach: 12 runoff plots are used to replicate 4 rates of liquid hog manure application which range from environmental (p-based) rates to agronomic (N-based) rates. Natural runoff is measured as well as soil quality parameters.

Progress: First manure application made in fall of 1998.

Potential Implications: Determine "ideal" application rates that consider minimizing water quality problems and maximizing crop response.

Publications:

Other Comments:

Investigators: Bahman Eghbal

Institution or Affiliation: USDA Lincoln Nebraska

Title of Study: *Beef* Cattle Feedlot Manure for Site Specific Application

Funding Agency: USDA

Duration of Study: 1999-2004

Key Words: Site specific, precision agriculture, beef manure, soil quality,

Location (or Locations) of Study: Central Nebraska, near Grand Island (irrigated corn) and the Nebraska Northeast Experiment Station

Type (or types) of Soil Used: Mollisols

Climate: 25 in of rain, wet-dry sub humid. The Central Nebraska site is irrigated.

Approach: Manure is applied in a site-specific manner only to areas with soil carbon less that 1.5%, to meet N needs of the crop. One objective is to see if organic C in the low organic matter areas can be increased to the organic matter content in the remainder of the areas on the study sites. Greenhouse gas emissions (methane, CO_2 and N_2O) will be measured where manure is applied.

Progress: The initial data from 1998 show that in the low organic matter soils manure increases yield of corn over commercial fertilizer by 15 bu/ac. The organic C contents increased by 0.15%.

Potential Implications: Manure is a valuable resource for the renovation of degraded soils. This study will determine the time frame for renovation and the improvements in crop yields and soil quality.

Publications: None

Other Comments:

Investigators: Larry Cihacek, K.A. Ringwall, R. Carcoana

Institution or Affiliation: North Dakota State University, Department of Soil Science

Title of Study: Impact of accelerated erosion on soil properties and productivity

Funding Agency: USDA – NCR committee 174

Duration of Study: 1992-1999

Objectives: Evaluate the use of feedlot manure for restoring the productivity of severely eroded soil.

Key Words: manure, productivity, erosion

Location (or Locations) of Study: Manning, SD

Type (or types) of Soil Used: severely eroded Cabba and Chena soils, formed in siltstone

Climate:

Approach: Variable manure application rates and frequencies. 50 tons of manure/acre either 1 of 3 years, 2 of 3 years, or 3 of 3 years. Assess production, soil aggregation, and tilth.

Progress: Manured soils have increased in productivity and soil quality. These changes were not noted until after about 4 years of manure treatment.

Potential Implications: Manure is a valuable resource, but more frequently is treated as a waste.

Publications:

Other Comments:

Investigators: Chester-Jones, Peters, Busch, Busman, Norm and Sallie Volkmann (dairy producers)

Institution or Affiliation: University of Minnesota and commercial dairy producers

Title of Study: Managing dairy manure nutrients in a recycling compost program within the Le Sueur River watershed

Funding Agency: Minnesota Dept of Ag

Duration of Study: March 1998 to March 2000

Objectives: 1. To monitor manure nutrient flow from a 600-cow dairy through a solid/liquid separator and evaluate nutrient recycling of manure solids through composting used as bedding or land application for forage crops; 2. Monitor the effect of composted manure nutrient availability when land applied at varying rates to corn land to be harvested as corn silage.

Key Words: dairy manure; compost; nutrient recycling; bedding; land application

Location (or Locations) of Study: Dairyfield farm, Janesville MN

Type (or types) of Soil Used: Webster clay-loam

Climate:

Approach: The farm is one of 6 dairy units that have been used for a nutrient profile project. The approach is to take frequent samples of the liquid and solid stream on a 600-cow freestall barn. The solid stream in monitored from the compost pile through the compost windrows. Compost temperatures and nutrient composition are taken frequently. Compost is recycled with addition of woodchips as a bedding source for freestalls. A 10 x 1/3 acre plot area has been established to evaluate the spring and fall application of 30 vs. 45 tons/acre of compost or raw dairy manure vs. urea and zero N application. All plots are planted to the same corn variety. All plots received 50 lbs. of a 34-10 starter fertilizer. Each plot has a corresponding control. Soil samples are taken twice/yr; corn silage yields are taken/plot. MN Dept of Ag are using a rain simulator to look at run-off effects within each plot. The project will contribute to the whole-farm nutrient balance

Progress: First year of spring compost application to the plots completed; second year of fall compost application to same plots well under way.

Potential Implications: Implications of improving the recycling of the waste stream on a dairy using composting; project will allow for more efficient accountability of manure

nutrients; project will provide information on the availability of compost nutrients to support forage crops growth and the effect on soil fertility and organic matter base. Overall impact of refining crop and soil fertility program and reduce purchased fertilizer costs on a dairy farm within a sensitive environmental river watershed area.

Publications:

Other Comments: The above farm is 1 of 6 Waseca County farms that are being used for nutrient profile project. This latter project is not funded from an outside source. Soil, manure and feed analyses have been supported by my internal gifts account which has now run dry. We have been turned down for 3 external grants to date to support the study. Hopefully GEIS research needs can utilize these farms which offer a microcosm of the Minnesota dairy industry

Manure and Crop Nutrients

J

Generic Environmental Impact Statement on Animal Agriculture:
A Summary of the Literature Related to Manure and Crop Nutrients (J)

Prepared for the Minnesota Environmental Quality Board

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PART I. EXECUTIVE SUMMARY

This topic covers: current manure storage and application practices, the environmental and economic benefits and risks of manure in comparison to other sources of crop nutrients, and the carrying capacity of soils to absorb nutrients and heavy metals. We grouped the Scoping Document questions into the following three categories: I. Storage and Handling, II. Value and Environmental Impacts, and III. Inventory of nutrient sources and soil levels. A fourth category, recommended research, is also presented.

Storage and Handling

Scoping Question 1. What manure storage and application practices are in current use in Minnesota and how do they compare to the practices in use in the past? To what extent do the current practices adhere to existing requirements?

We have presented a detailed description of current storage and application practices. There is no data base that provides an inventory of storage and application practices for Minnesota. The Minnesota Pollution Control Agency has data on a subset of animal operations. Their database represents only about 25% of the total and the sample is weighted heavily toward large operations and those that have received complaints. In this report, we offer an inventory based on the collective opinion of faculty that have knowledge in this area. This question could be answered by using a statistical sampling approach or a complete tally (similar to the census issue). It would be limited by resources, and by cooperation from property owners.

Scoping Question 5. Which management, construction, storage, and application techniques in Minnesota and other places maximize the positive and minimize the negative impacts of manure?

Environmentally sound storage and application requires good management. It also requires investment in well constructed storage facilities and investment in the proper handling and application equipment. There is no single manure storage, handling, and application system that can be recommended as best, because the physical nature of livestock manures, available labor and time, management skills, soil properties, and weather conditions vary spatially and temporally in Minnesota.

Value and Environmental Impacts

Scoping Question 2. To what extent is manure an asset or liability to the environment, community, and the economy? What are the comparative benefits and risks of manure compared to commercial fertilizer and other sources of fertility (such as legumes and sewage sludge) including comparative energy use, and how does the comparison vary according to geography and geology and by manure management method?

Manure can have value in several respects. The first obvious one is the direct nutrient value. The value depends on the site-specific soil nutrient levels and nutrient concentrations of manure. In some areas of Minnesota soil levels of phosphorus and potassium and most micronutrients are

already at adequate levels. Therefore, the value of these constituents in certain cases may be questionable. Manure also imparts biological and physical properties to the soil that make it more productive and less erosive. It is difficult to put a dollar figure on this benefit. The cost of manure includes those associated with storage, handling, and application. There can be also an environmental cost.

If manure is over-applied, applied at the wrong time in the growth cycle, applied unevenly, allowed to experience losses in storage, handling, and application, then it can degrade water and/or air quality. Depending on the manure source, varying levels of part of its nitrogen can be present in a slow release form that is very beneficial environmentally. Part of the nitrogen is similar to commercial fertilizer in a soil system. This is an advantage of manure. Commercial nitrogen is relatively cheap. It can be applied very uniformly, precisely, and at ideal times to maximize crop uptake. In contrast, manure will often behave like other organic nutrient sources such as sewage sludge and compost in soil.

The most sensitive environmental regions in Minnesota are the deep glacial outwash sands in the central part of the state with surficial aquifers and the karst area in southeastern Minnesota where fractured limestone bedrock provides for entry of nitrogen and other mobile contaminants directly into the aquifer. The relatively impermeable glacial till and glacial lakebed sediments pose a risk of nitrate loss to surface waters through tile drainage. These landscapes also pose the greatest risk of losses of pollutants from runoff.

Surface runoff losses of phosphorus, and oxygen demanding materials are a major concern in Minnesota. Manure applications near water bodies, surface applied without incorporation, applied at excessive rates, and applied on frozen or snow covered ground pose a greater risk. The erosion potential of the site is an important consideration. The use of conservation tillage has been shown to reduce total P losses. Increased P concentration near the soil surface and contributions from plant residues with these systems needs further evaluation. Set backs, buffer strips, and sand filters at surface tile inlets also need further research.

Most nitrogen fertilizers are produced by combining nitrogen from the air with natural gas. The price of nitrogen fertilizer is linked to energy prices. A potential by-product from manure is energy, produced by methane generation or by burning manure directly, but these usually are not competitive with coal or other energy sources.

Inventory of Nutrient Sources and Soil Levels

Scoping Question 3. What is the carrying capacity of the soils in the agricultural areas of Minnesota for the nutrients and toxic substances contained in manures? What are the current levels of those substances in the soils in agricultural areas of Minnesota (including phosphorus and trace metals)?

Soils vary in the amount of nutrients they can hold. Many nutrients are held tightly by soil unless very high concentrations are present. Other nutrients are not held tightly by soil and move with soil water. Nutrient forms can change after entering the soil and become more or less

mobile. Generally, the finer the soil texture (that is, the higher the silt and especially clay content), the more water and nutrients it can hold.

Some farmers and other land managers have soil analyzed for nutrient levels. Generally, soil tests have increased to high levels in the last several decades. As was mentioned earlier, some soils are natively high in certain nutrients.

Scoping Question 4. What is the total amount and proportion of plant nutrients applied to soils in Minnesota from: a) animal manures, b) commercial fertilizers, c) legumes, d) plant decomposition, e) sewage sludge, and f) atmospheric deposition?

It is difficult to answer certain aspects of this question. There are records on the amounts of commercial fertilizer sold. One can infer the amount of manure that is generated by the numbers of animals, but there are good databases on some species and not on others. Legumes can take nitrogen gas from the atmosphere and convert it to plant-available forms. If there is nitrogen present from other sources (manure, fertilizer, plant residues, soil organic matter release, atmospheric deposition, etc.), then legumes will "fix" less atmospheric nitrogen, and take up what is available. Therefore, it is hard to estimate nitrogen fixation by legumes. Plant decomposition is a nutrient cycling process, rather than an input of new nutrients. There are fairly good records on sewage sludge application. There is also a national network of monitoring sites for atmospheric deposition of various forms of nitrogen. This is a small part of the total. Very important to the whole farm nutrient balance is the purchase of feeds, which contain large amounts of nutrients. These nutrients are added to soils when manure is applied.

Recommended Research

Recommended research is organized into two broad categories: environmental protection and improved crop production which follow. Quantify benefits of manure in addition to the nutrient content, including erosion control, increased water holding capacity, and in the case of composts-weed control and disease suppression. Evaluate the extent to which nitrate leaching and phosphorus runoff losses from Minnesota animal agriculture can be reduced. Characterize and evaluate whole-farm nutrient balances for different classes of livestock. Develop initial P application guidelines to protect surface water quality. Identify the best manure strategy when applying to land with surface tile inlets? Determine the impact of winter application on runoff losses from snowmelt and rainfall runoff under Minnesota conditions? Conduct a manure survey to determine the metal content by species and investigate their transport in soil systems.

Enhance manure's value as a resource by better assessment of the nutrient release patterns for different types of manure. Evaluate synchronicity of nutrient release with crop demand by blending synthetic fertilizers with manure. Develop new application equipment designed to evenly and efficiently distribute manure. Evaluation of real-time nutrient analysis coupled with precision application. Estimate how much the transportability and value of manure is enhanced by dewatering and composting?

PART II. CRITIQUE OF SCOPING DOCUMENT QUESTIONS

Scoping Question 1. What manure storage and application practices are in current use in Minnesota and how do they compare to the practices in use in the past? To what extent do the current practices adhere to existing requirements?

There is no database that provides an inventory of storage and application practices for Minnesota. The Minnesota Pollution Control Agency has data on a subset of animal operations. Their data base represents only about 25% of the total and the sample is weighted heavily toward large operations and those that have received complaints. This question could be answered (at least present practices) by using a statistical sampling approach or a complete tally (similar to the census issue). It would be limited by resources, and by cooperation from property owners.

Scoping Question 2. To what extent is manure an asset or liability to the environment, community, and the economy? What are the comparative benefits and risks of manure compared to commercial fertilizer and other sources of fertility (such as legumes and sewage sludge) including comparative energy use, and how does the comparison vary according to geography and geology and by manure management method?

We saw this question as being much too broad. It literally covers the entire GEIS in scope. In an effort to narrow the scope we focused on manure viewed as an asset or environmental liability with discussion on geologically sensitive areas and management techniques. We did not address manure effects on communities. Nor did we pursue a complex economic analysis of manure generating enterprises but did offer some simple value estimates. We felt that these issues would be found in other topic areas. Some aspects of this question are presented from published research but research is needed to answer other aspects.

Scoping Question 3. What is the carrying capacity of the soils in the agricultural areas of Minnesota for the nutrients and toxic substances contained in manures? What are the current levels of those substances in the soils in agricultural areas of Minnesota (including phosphorus and trace metals)?

We interpreted "carrying capacity of soils" in the context of how much of the different constituents found in manure can be held by various soils before losses are excessive. To evaluate current levels we gathered data from the University of Minnesota and North Dakota State University Soil Testing Laboratories. By adding data from private laboratories (who do most of the soil tests in Minnesota) we could get a much better picture. A state-wide survey of manure content of micronutrients and toxic compounds would also be helpful.

Scoping Question 4. What is the total amount and proportion of plant nutrients applied to soils in Minnesota from: a) animal manures, b) commercial fertilizers, c) legumes, d) plant decomposition, e) sewage sludge, and f) atmospheric deposition?

It is difficult to answer certain aspects of this question. There are records on the amounts of commercial fertilizer sold. One can infer the amount of manure that is generated by the numbers of animals, but there are good databases on some species and not on others. Legumes can take nitrogen gas from the atmosphere and convert it to plant-available forms. If there is nitrogen present from other sources (manure, fertilizer, plant residues, soil organic matter release, atmospheric deposition, etc.), then legumes will "fix" less atmospheric nitrogen, and take up what is available. Therefore, it is hard to estimate nitrogen fixation by legumes. Plant decomposition is a nutrient cycling process, rather than an input of new nutrients. There are fairly good records on sewage sludge application. There is also a national network of monitoring sites for atmospheric deposition of various forms of nitrogen. This is a small part of the total. Very important to the whole farm nutrient balance is the purchase of feeds, which contain large amounts of nutrients. These nutrients are added to soils when manure is applied. Whole farm nutrient budgets would help answer this question.

Scoping Question 5. Which management, construction, storage, and application techniques in Minnesota and other places maximize the positive and minimize the negative impacts of manure?

Environmentally sound storage and application requires good management. It also requires investment in well constructed storage facilities and investment in the proper handling and application equipment. There is no single manure storage, handling, and application system that can be recommended as best, because the physical nature of livestock manures, available labor and time, management skills, soil properties, and weather conditions all vary across time and from farm to farm. In the literature review presented here the pros and cons of various storage and handling techniques commonly found in Minnesota are presented.

PART III. MANURE AND CROP NUTRIENT PRIMER

Background

Historically, livestock manure was a primary source of plant nutrients. Its value for maintaining and improving the productivity of the soil has been recognized from antiquity (Nowak, et al., 1998). Fertilizing crops with livestock manure nutrients began several millennia ago and is mentioned in the Old Testament of the Bible and other ancient documents.

Before the advent of commercial fertilizer production, access to manure was considered necessary for the long-term sustainability of farming systems. Results from long-term cropping system trials confirm this in every case where commercial fertilizers have not been added. For example, after 40 years of cropping without manure, crop yields were only 20% as large as those where manure was applied annually.

In the middle of this century, commercial fertilizer production changed crop nutrient management in the USA and other countries. This technology affected the structure of American agriculture, and eventually made possible the concentration of livestock production we see today. For example, in 1996 the combined value of all livestock and poultry on Minnesota farms was over $ 2.1 billion. Animal agriculture in Minnesota is predominated by pork, dairy, and poultry production and is mostly concentrated in south, south central, and southwestern parts of the state (Minnesota Agricultural Statistical Service, 1997). The manure associated with these animals presents some unique challenges and opportunities. Manure can be recycled for uses such as potting soil, compost for gardens, and other off farm uses.

Value of Manure

The fundamental reason for input of nutrients into agroecosystems is the need to produce high crop yields, whether or not the crop have relatively low value and low marginal return. In modern cropping systems crop nutrient needs are achieved through addition of inorganic and organic nutrient sources. Inorganic nutrient sources, such as fertilizers, are excellent sources of crop nutrients and are usually readily available. Organic nutrient sources such as animal manures, biosolids and various agricultural and industrial byproducts, also can effectively supply crop nutrients. Essential elements in manure have been shown to contribute to the effects of commercial ammonium-nitrate on corn yield (Durieux, et al., 1995). Manure nutrient effects on wheat and corn yield are comparable to commercial fertilizer (Weidemann, 1943).

The value of manure is largely viewed in terms of its nutrient content. Nutrient value can range widely. The concentration of nutrients depends on dilution with wash water and barnyard runoff as well as losses. The biggest influence is probably water content. As an example, data from survey of poultry manure showed that manure value ranging from about 5 to 80 dollars per ton for N, P, and K only (Moncrief, et al., 1991).

There are other beneficial effects of manure associated with less tangible economic returns. Manure can improve soil physical and biological properties improvement because of its content

of humus, and organic constituents. Soil physical and biological improvement results in a more favorable medium for plant growth and reduced runoff losses of pollutants. For decades researchers have noted the benefits of manure additions to soil, from renovating eroded sites (Latham, 1940) to improving soil physical properties and fertility following centuries of manuring (DeLuca and DeLuca, 1997;Sandor and Eash, 1991). Manure additions to sandy soil improves water holding capacity and improves structure (Hornick, 1988). Other researchers indicated that manure additions can tolerance to corn rootworm, possibly by maintaining higher soil nutrient levels (Allee and Davis, 1996). These have been more thoroughly discussed in the Soil Literature Review

The cost associated with manure is the storage, handling, and application costs. Generally these costs are smallest closer to the source, with economical storage construction, and when manure is applied without soil injection. If animal manure is concentrated and relatively dry it can be economically transported greater distances.

Storage and Handling

Manure can be stored on a daily or an annual basis. Increased storage allows more flexibility in timing the application to coincide with crop demand. This generally reduces environmental losses. Liquid or gaseous losses of nutrients and pollutants can occur during storage and handling or after land application. Generally as storage capacity increases allowing for more flexibility in timing applications costs also increase. There are many different methods of storing and handling manure. A brief summary of many common methods is presented in the first section of the literature review.

Environmental Impact

Manure can have a positive or negative impact on the environment depending on the management. If applied at too high a rate, too far in advance of plant recovery of nutrients, on an environmentally sensitive area, using an improper application method, or without regard to soil levels environmental damage can result. The main constituents of manure that are important from an environmental standpoint are nitrogen, phosphorus, and oxygen demanding materials. Nitrate nitrogen can result in "Blue Baby" syndrome or be toxic to livestock in high enough concentrations. Ammonium-ammonia nitrogen will be partitioned into both species depending largely on water pH. Ammonia is a very toxic biocide and in high enough concentrations is lethal to aquatic and terrestrial plants and animals. Oxygen demanding materials are reduced compounds that consume oxygen that is dissolved in water when they are converted to oxidized states, largely by microorganisms which derive energy from the conversion. This can be organic compounds or inorganic compounds such as ammonium. When dissolved oxygen levels are reduced fish become stressed and/or die and unpleasant odors develop. Phosphorus is important because algae growth in most freshwater lakes is limited by this essential nutrient. When algae are allowed to grow they convert carbon dioxide to reduced organic carbon with energy from the Sun. When they die and decompose this carbon becomes a source of dissolved oxygen demand.

When manure is applied to the soil and its constituents are not lost by runoff or leached to groundwater these same characteristics have a positive impact on soil quality as a growth medium for plants.
Besides nutrients essential for plant growth, Animal manure also contains certain metals (trace elements), pathogens, small quantities of biocides and growth hormones (Eck and Stewart, 1995;Edwards and Daniel, 1992;Hansen, 1996;Sims and D.C. Wolf, 1994). Elements of potential environmental concern added to soil by land application of animal manure include nitrogen (N), phosphorus (P), copper (Cu), zinc (Zn), chromium (Cr), and arsenic (As) (Bouldin and Klausner, 1998;Brumm, 1998;Mikkelsen, 1997;Sims, 1997);VanHorn and Hall, 1997). Excessive input of N and P from animal manure is a potential threat to surface and/or ground water quality. Environmental concern over metals stems from their potential toxicity to plants and their biological magnification through the ecological food chain. Environmental impacts of these elements are discussed in other sections of the report.

Soil Properties and Retention of Nutrients and Metals

In Minnesota, as in other states, land application is the most cost effective and widely used method of animal manure management. As a result, nutrients and additives excreted by animals eventually end up in agricultural soils. Chemical composition of manure is dependent on the type of animal, animal diet, and pre application treatment practices. Typical amounts of nutrients in manure from five species of livestock are presented in Table 1.

Once animal manure is applied to soil, the fate of its constituents is determined by the nature of the individual constituent and by an array of complex chemical reactions and physical processes. Soil chemical and physical properties such as pH, organic matter, amount of clay, and moisture profoundly influence many of these reactions. Soil microorganisms are driving forces for many other reactions.

Chemically speaking, clays and organic matter are the most active fractions of soil solids. Clay particles are very small (< 2 micron) and are primarily made up of aluminum (Al), silicon (Si), oxygen (O), and iron (Fe) arranged in an orderly crystalline structure. The organic fraction in soil is the byproduct of breakdown and alteration of plants, animals, and microorganisms and is often termed 'humus.' In general, the dominant electrical charge on soil clay and humus is negative. Thus, clay and humus impart a net negative charge to soil and can retain positively charged ions. Positively charged ions are called cations and negatively charged ions are called anions. Cations in soil include the metallic cations, potassium (K^+), copper (Cu^{+2}), zinc (Zn^{+2}) etc, as well as ammonium (NH_4^+). Nitrate (NO_3^-), phosphate (PO_4^{3-}), and arsenate (AsO_4^{3-}) are three anions of potential environmental concern.

The cations have different abilities to bind with the soil minerals, due to variation in their binding strength (a function of their charge) and concentration in soil water (National Research Council, 1989). As a result, cations dissolved in the soil water can displace other cations attached to the soil, through a process called cation exchange. Cation exchange plays an important role in retention of the ammonium form of nitrogen and metals. Cation exchange capacity is a quantitative measure of the number of cation binding sites available per unit weight of

soil (National Researach Council, 1989). The unit for expressing cation exchange capacity is centimole of positive charge per kilogram of soil (cmol/kg). Thus, if a soil has a cation exchange capacity of 20 cmol/kg, one kg (2.2 lb) of that soil is capable of adsorbing (holding onto) up to 20 cmol of potassium ions (K^+), because (K^+) has a positive charge of 1. The same soil can adsorb only 10 cmol of calcium ion (Ca^{+2}), because (Ca^{+2}) has a positive charge of 2. If no other cations were present in this soil, it could hold up to 8 tons of K^+ or about 4 tons of Ca^{+2} per acre in the top 6 to 8 inches (the plow layer). A typical Minnesota prairie soil with a cation exchange capacity of 18 cmol/kg contains, 5600 pounds of Ca, 720 pounds of Mg, and 780 pounds of K, and much smaller amounts of other cations per acre in the plow layer. This calculation is based

Table 1. Typical range of nutrients in manure from five species of livestock.[a] Composition of manure varies widely with diet, animal age, lactation, and other factors.

	Type Waste				
Elements	Cattle (steer)	Swine	Cage layer	Broiler	Dairy
CP	20.3	23.5	30	29.7	150
N	3.2	3.8	4.8	4.75	2.4
Ash	11.5	15.3	30.4	17.5 -	
Ca	0.87	2.72	8.13	3.4	1.9
P	1.6	2.13	2.22	2	0.76
Na	0.88	2.75	0.46	0.47	0.24
Cl	1.32 -		1.01 -		0.6
Mg	0.4	0.93	0.65	0.53	0.32
K	0.5	1.34	1.63	1.38	0.75
S	-	0.3	-	-	0.24
Fe	1340	190	1773	1690	560
Cu	31	114	70	32	20
Co	-	6	2	-	-
Mn	147	342	374	432	800
Zn	242	530	477	326	80
Se	-	-	0.6	-	-
Mo	-	0.3	-	-	-

[a] Mineral composition of animal wastes, dry matter basis; Adapted from National Research Council (1983); Fontenot, 1981;ASAE standards, 1990, and Fontenot et al., 1996.

on the assumption that there was 14 cmol/kg of exchangeable Ca, 3 cmol/kg of exchangeable Mg, 1 cmol/kg of exchangeable K.

The negative charge associated with humus is pH dependent. Under very acid conditions the negative charge is not very high, however, under neutral to alkaline conditions the charge associated with humus can exceed the charge of crystalline clays. In general, soils with high clay content retain nutrients better than soils with high sand content, and soils with a high silt content are between clay and sandy soils.

Similar to positively charged ions, negatively charged ions (anions), such as nitrate (NO_3^-), phosphate (PO_4^{-3},) and arsenate (AsO_4^{-3}) may also be adsorbed on some soil clay or humus. This is called anion exchange. Although adsorption of anions is not nearly as great as that of cations, it is nonetheless an important mechanism for retaining negatively charged ions. Many anions, (for example, phosphate and arsenate) can also be retained by forming insoluble compounds.

Soil Testing and Nutrient Recommendations

Plants obtain fourteen elements essential for their growth from the soil. These elements are present in soil in water soluble and insoluble forms. The soluble fraction of nutrients are readily available for plant uptake, but only a fraction of the insoluble form of various elements is available for plant uptake.

The task of measuring the amount of water insoluble elements that can potentially become available for plant growth has been an area of intensive research. Soil scientists have developed chemical reagents to extract a fraction of the insoluble elements that is related to the amount that becomes available for plant uptake during a growing season. These measurements are used in conjunction with information from field and laboratory data to issue fertilizer recommendations for crop production.

Other Nutrient Sources

Meeting the challenge of nutrient management for animal based agriculture requires information on various input and outputs of nutrients on a regional scale such as:

- animal manures
- commercial fertilizers,
- legumes
- plant decomposition
- sewage sludge
- atmospheric deposition.
- Purchased feeds

Sewage sludge, for example, is a small source of nutrients on a state-wide scale, but may be quite significant for a particular farm. Similarly, one could consider livestock manure to be an input in both-large scale and field-scale analysis, whereas within an individual farm, manure serves as a

temporary storage pool for nutrients that entered the farm in other sources. A number of researchers have developed nutrient budgets on state and/or national scales {National Research Council 1993 #526}

Nutrients are introduced into an agroecosystem from a number of sources. Quantification of the contribution of various sources represents a challenge to the agricultural scientists due to the complexity of the processes involved. A number of complex and often mutually exclusive processes are often involved. Utilization of nutrients contained in various organic fertilizers is accomplished through microbial conversion. Soil bacteria and fungi are important organisms in converting plant residues and manures into usable crop nutrients. These transformations include conversion of nitrogen-containing compounds into ammonium followed by conversion to nitrite and nitrate. Breakdown of organic nutrient sources takes considerable time with only a fraction of the applied nitrogen being available the first year. As a very broad generalization, approximately 50% of the total nitrogen applied will be available the first year with approximately half of the remainder available the next year. Actual mineralization rates are difficult to determine given the fact that this is a biological process that is sensitive to temperature and moisture ranges in the soil system. Estimates of nitrogen and phosphorus mineralization rates are needed to accurately determine application rates of organic nutrient sources (Gilmour, et al., 1996) as well as determining the availability of heavy metals that may be contained in the manure (Berti and L.W. Jacobs, 1996). The topic of nitrogen mineralization is addressed in more detail in other sections of this report.

An estimate of nutrients from fertilizer can be obtained from fertilizer sale data. The assumption is that fertilizers purchased in Minnesota are applied in the state. In this analysis we have estimated nutrients produced from animal manure in Minnnesota by using the data on the number and species of animals. Chemical composition and storage aspect of animal manure has been addressed in the other sections of this report. No losses have been calculated for nutrients cointained in manure, as data are not available on the proportion of various manure held in the various storage type. We assumed that volatilization of ammonia from manure likely re-enters the system (plants and soil) within state border, and assigned the source as manure. This assumption could be checked in future research.

Another important source of nitrogen for cropping systems in Minnesota is fixation of atmospheric nitrogen gas by legumes. A discussion on dynamics of legume fixation in Minnesota is presented here due to its ecological and economical significance in crop production in Minnesota.

Symbiotic Nitrogen Fixation

Basic Concepts

Legumes are the second largest family of seed plants in the world. Soybean, an annual grain crop, and alfalfa, a perennial forage crop, are the most widely grown legumes in Minnesota. Red clover, birdsfoot trefoil, and white clover are also grown for hay and pasture, while field peas, edible beans, and lupin are grown for grain. Legumes are noted for the production of grain and

forage that contain significantly more protein than grasses (such as corn, wheat, oats, and other cereals, and forage grasses). Legumes also are appreciated for their ability to grow in the absence of nitrogen fertilizer inputs.

Legumes can convert atmospheric nitrogen gas (N_2) into protein for plant growth through a symbiotic process involving the plant and a specific bacterial partner. The plant provides food energy generated by photosynthesis to bacteria that are located inside specialized root structures called nodules. In return, the bacteria convert atmospheric N_2 into inorganic nitrogen, which the plant converts to organic forms such as amino acids and proteins

Legume species require specific bacteria for effective N_2 fixation and N production. For example, the bacteria nodulating alfalfa are *Sinorhizobium meliloti*, whereas *Bradyrhizobium japonicum* nodulates soybean. Therefore, a recommended management practice is to add the appropriate bacteria to legume seed before planting. In fields where the same legume species have been grown within 5 years, inoculation is not required because previously applied bacteria can survive for several years. However, with some environmental conditions, such as very low soil pH, addition of new bacteria is required with each legume planting.

Under optimum conditions, biological nitrogen fixation can provide the total nitrogen need of the plant and, in addition, can provide a net input into cropping systems. However, legumes typically also obtain nitrogen from the mineralized soil organic matter and fertilizer residues, so that the percentage of nitrogen in the plant derived from fixation usually ranges from 50 to 80%, depending on stand age, species, and soil nitrogen levels (Figure 1).

The diagram also shows that legume add new organic N from atmospheric nitrogen fixation to the soil during growth, the amount being regulated in part by available soil N supply.

Legume Nitrogen Contribution

What is the actual amount of N_2 fixation by legumes? This amount often is estimated using only the harvested forage or seed. Because both of these plant tissues usually have high nitrogen (protein) concentrations, much of the nitrogen in the plant is removed from the field. Typical numbers from the scientific literature are shown in Table 2. Differences in N_2 fixation among legumes are related to differences in biomass production, biomass nitrogen concentration, effectiveness of the symbiosis, and environmental factors, such as nitrogen supply from the soil, fertilizer, or manure.

These estimates are based on a variety of experiments using different techniques. There is a need to develop a better understanding of atmospheric N fixation by legumes in Minnesota with respect to the varying amounts of available N in the soil.

Harvested forage and seed often are used on the farm as feed for livestock. Thus, the fixed nitrogen is partly used to produce animal products and much of this feed nitrogen is excreted in manure. This manure is spread on the fields, returning some of the fixed nitrogen to the soil.

However, legumes also have direct effects on the amount of soil nitrogen present on the farm. Several factors influence the potential level of legume nitrogen contribution to soil nitrogen reserves:

- The N_2 fixation capacity of the legume species (Table 2).

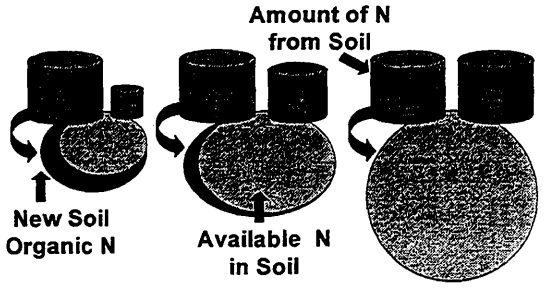

Figure 1. Schematic showing how the amount of soil nitrogen available to a grass crop (G) regulate growth and total N in the crop, whereas it simply alters the amount of fix vs. soil N in a legume crop (L), with little effect on yield or total N uptake.

Table 2: Typical amount of reported N fixation by legumes in Minnesota and surrounding states.

Crop	Fixation (lb/acre)
Alfalfa	130 - 200
White clover	115
Red clover	75 - 132
Birdsfoot trefoil	50 - 115
Soybean	68 - 135

- The quantity of legume residues remaining in the soil. Only a portion of the nitrogen in legumes typically remains in the soil, after harvest of forage or grain. Roots and other plant parts that are not harvested remain in the field, as are plant parts that die during the year.

- The nitrogen concentration in plant residues. Crowns and thick roots of legumes like alfalfa contain lower nitrogen concentrations that the foliage, whereas the small diameter roots have similar nitrogen concentrations as foliage (Dubach and Russelle, 1994)

- The proportion of symbiotically fixed N_2 in the residues. An equal or lower proportion of fixed nitrogen is found in roots than in foliage of legumes like alfalfa and its relatives (Lory, et al., 1992;Zhu, et al., 1991;Zhu, et al., 1998).

Quantifying the Nitrogen Contribution by Alfalfa and Soybean

With normal alfalfa production, most of the foliage is removed in three or four harvests per year. Given a yield of 3.8 tons of forage per acre with 18% crude protein concentration, about 188 pounds of nitrogen are removed from each acre. Based on Minnesota research, about 60 to 80% of this nitrogen comes from the atmosphere (112 to 150 pounds per acre); the remainder (38 to 76 pounds per acre) is absorbed from the soil. Leaf loss during growth and harvest is often 20% or more per year, and alfalfa also loses and then replaces 30 to 50% of its small roots per year (Dubach and Russelle, 1994;Goins and Russelle, 1996). Both of these tissues contribute nitrogen to the soil, with some of that being re-absorb by the alfalfa crop itself. For alfalfa grown in climates like we have in Minnesota, this contribution results in a net buildup of 50 lbs of nitrogen per acre each year of alfalfa growth (Peterson and Russelle, 1991).

If soil nitrogen content *increases* by 50 pounds per acre and between 38 and 76 pounds of soil nitrogen are removed in alfalfa forage, then alfalfa must add 88 to 126 pounds of nitrogen from the atmosphere to the soil each year. This means that total biological nitrogen fixation by alfalfa must be at least equal to the fixed nitrogen removed in foliage plus the amount of fixed nitrogen added to the soil 238 pounds per acre in this example. The amount of fixed nitrogen added to the

soil can be greatly increased if part of the foliage is incorporated before growing the next crop.

Alfalfa is grown on about 1.4 million acres in Minnesota with a production of about 5.3 million tons of forage (assuming an average yield of 3.8 tons per acre). In an analysis conducted by (Peterson and Russelle, 1991), alfalfa fixed over 400 million pounds of nitrogen annually, and resulted in a net annual increase of soil nitrogen of about 174 million pounds. In addition, they concluded that about 220 million pounds of fixed nitrogen was returned to the soil via manure. A critical assumption in their calculation is the estimation of 50 pounds of fixed N being added each year of alfalfa when a stand is maintained about 3.5 years. There is relatively little data in the literature to support this assumption, and it is not known how different amounts of available N in soil alters net nitrogen fixation by alfalfa or other legumes (Figure 2).

In contrast, growth and harvest of a soybean crop may actually result in a decline in soil nitrogen. When 35 bushels of soybean per acre are harvested, the export of soil-derived nitrogen

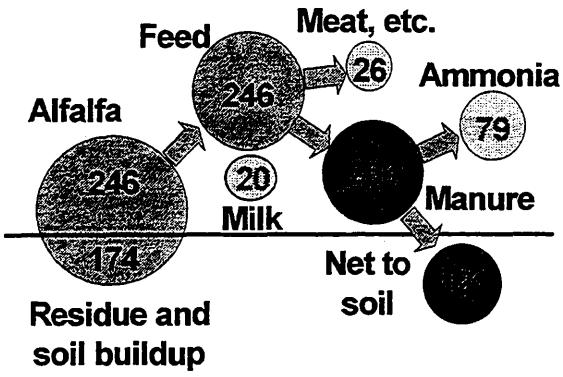

Figure 2. Schematic diagram of the annual amount of fixed N contributed by alfalfa to Minnesota soils (Peterson and Russelle, 1991). Each number represents millions of pounds (for e.g., 20 million pounds of N originally fixed by alfalfa or in the milk produced by Minnesota dairy cows.

in the seed may substantially exceed that of the symbiotically-derived nitrogen in the residue that is returned to the soil (Heichel and Barnes, 1984). On a high organic matter soil in Minnesota, when soybeans obtained about 40% of the nitrogen from symbiosis and 60% from the soil, a nitrogen deficit of about 80 pounds per acre resulted from growing this crop. While the proportion of grain and herbage nitrogen derived from symbiosis may increase on soils with low or medium organic matter concentration, it is apparent that on many soils soybeans do not contribute a significant amount of fixed nitrogen to the soil, other than indirectly when they are fed and the manure is spread on the field.

Legume N Contributions to Crop Rotations

Legumes like alfalfa traditionally have been used to supply nitrogen for cereal crops in crop rotations. For example a traditional 5-year rotation involving alfalfa would consist of alfalfa seeded with oats in year 1, 2 years of alfalfa, and then 2 years of corn. In this system, the alfalfa would be harvested or grazed for livestock feed and the corn crops utilize the residual nitrogen in the fourth and fifth year. Very little fertilizer nitrogen is needed in this cropping system. A commonly used rotation in western and southern Minnesota is to alternate corn and soybean each year. Soybean is not very efficient in fixing nitrogen from the air, so nitrogen fertilizer requirements for corn are higher in this case.

The contribution of nitrogen that legume crops make to subsequent crops is usually expressed in terms of the 'nitrogen fertilizer replacement value' or 'nitrogen credit.' This credit is the amount of fertilizer nitrogen that the farmer can withhold and still produce optimum yields of the non-legume. In Minnesota, fertilizer replacement values the first year after alfalfa range up to 150 pounds per acre, while soybean usually can replace 40 pounds. If the alfalfa stand was very good before rotating to another crop, a second year credit of up to 75 pounds of nitrogen per acre can be taken.

Although nitrogen fertilizer replacement value is used in adjusting recommended nitrogen fertilization rates, it does not accurately reflect the actual nitrogen addition legumes make. To illustrate this, consider that a small grain crop, such as wheat, also is given a nitrogen fertilizer credit under typical conditions. If the stubble was tilled in during the summer before corn is grown, about 40 pounds less nitrogen is needed per acre of corn, because the nitrogen released from soil organic matter after the small grain harvest is available to the next crop.

In conclusion, legumes make a very high contribution of nitrogen to Minnesota. If about 30% of the alfalfa is rotated to corn each year and a modest nitrogen fertilizer credit of 100 pounds per acre were taken the first year, then alfalfa reduces the need for nitrogen fertilizer by about 36,000 tons and saves farmers over $15 million dollars. It is well documented by surveys conducted by the Minnesota Department of Agriculture and other studies that farmers and their advisors do not credit legumes as much as they should. The same is true for manure, despite long-standing efforts to educate both groups. This is one area that may require enhanced means of motivating a change in behavior.

Glossary

The main source of this section are the Glossary of Soil Science Terms (SSSA, 1997), the Resource Conservation Glossary (NRCS, 1982), and the Manure Management Practices for the Minnesota Pork Industry (Schmidt and Jacobson, 1994).

Aerobic-Occuring in the presence of molecular oxygen (said of chemical or biochemical processes such as aerobic decomposition)

Ammonia-the nitrogen component of the gas (NH_3) released by the microbiological decay of plant and animal proteins. Loss of ammonia to the atmosphere is commonly referred as "**ammonia volatilization**".

Ammonium- ion (NH_4^+) form when ammonia gas comes in contact with water. Ammonium binds tightly to soil particles and is not typically leached into the ground water.

Anaerobic-occurring in the absence of free oxygen (such as biochemical process).

Broadcast-the spreading of manure on top of soil surface.

Chelates- Organic compounds that can bind with metals to increase the soluble fraction of some metals.

Composting-a controlled biological process, which converts organic constituents, usually wastes, into humus like material, inert, safe and suitable for use as soil amendments or organic fertilizer.

Deep pit-a deep (6-8 feet) storage area directly below an animal confinement building.

Denitrification-the chemical or biological process in which nitrate or nitrite is reduced to gaseous nitrogen.

Earthen basin-a large hole dug in the ground, typically lined with clay or some synthetic material, in which manure is stored. The basin is emptied at least once per year.

Facultative-having or occurring in the presence or absence of free oxygen.

Fertilizer-any organic or inorganic material of natural or synthetic origin that is added to a soil to supply one or more plant nutrients essential for the growth of plants.

Flushing system-a flushing system is a manure collection system that uses large volumes of water flowing down shallow gutters to scour and clean the dung area several times per day. The shallow gutters can be open gutters or gutters under open flooring.

Gravity drain-a system where manure is temporarily collected in shallow gutters under a slotted floor. The gutters are drained on occasion by means of a plug or valve. Manure then drains or is pumped to along-term storage area.

Ground water-the supply of fresh water that forms a natural reservoir under the earth's surface.

Immobilization-the conversion an element (e.g. nitrogen, phosphorus, etc.) from the inorganic form to various organic compounds in microbial or plant .

Incorporation-the tilling of the soil after the broadcasting of the manure to move the manure from the surface of the soil to under the soil surface.

Injection-the application of manure underneath the soil surface.

Inorganic nitrogen-nitrogen in the form of ammonia, ammonium, nitrate, nitrites, nitrogen gas or nitrogen oxides.

Lagoon. A treatment structure, typically earthen, for agricultural wastes. Lagoon can be aerobic, anaerobic, or facultative depending on the loading and design. Lagoon can be one stage or multi-staged. An anaerobic lagoon is different from earthen storage in that the lagoon is managed to allow for treatment of the manure. Anaerobic lagoons are only partially pumped each year (approximately one third of the total volume) whereas earthen storages are emptied once or twice a year.

Leaching-the removal of soluble materials, such as nitrates or chlorides, from soils or other material via water movements.

Manure-manure is the fecal and urinary excretion of livestock and poultry. Often referred to as a livestock manure, this material may also contain bedding, spilled feed, water or soil. It may also include wastes not associated with livestock excreta, such as milking center wastewater, contaminated milk, hair, feathers, or other debris (ASAE, 1998). Manure is stored until it is recycled to cropland or treated so it may be recycled for uses such as potting soil, compost for gardens, and other off farm uses.

Nitrate (NO_3^-)-the nitrogen component of the final decomposition product of the organic nitrogen compounds. Nitrate is extremely water-soluble and is negative charge excludes it from adsorption on to soil particles. This characteristic render it highly susceptible to leaching.

Nitrification-the biological oxidation of ammonium to nitrite and nitrate.

Nitrite (NO_2^-)-nitrite is an intermediate product in the conversion of ammonium to nitrate. Nitrite is extremely unstable (nearly immediately converting to nitrate) and therefore is rarely detected in groundwater.

Nitrogen cycle-the succession of biochemical reactions that nitrogen undergoes as it is converted to organic or available nitrogen from the elemental form. Organic nitrogen in waste is oxidized by bacteria into ammonia (NH_3). If oxygen is present, ammonia is bacterially oxidized, first into nitrite (NO_2^-) and then into nitrate (NO_3^-). If oxygen is not present, nitrate and nitrite are bacterially reduced to nitrogen gas, completing the cycle.

Nutrients- elements or compounds essential as raw material for organism growth and development. For plant growth, seventeen elements have been found to be universally essential, three mostly from air and water (carbon, hydrogen, oxygen) and fourteen from soil solids (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, boron, molybdenum, copper, zinc, chlorine, and cobalt)(Brady, 1984). Six of the fourteen (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) are used in relatively large amounts by plants and so called **macronutrients**. The other eight, even though as just essential as the macronutrients, are required in such a small quantities, thus so called **micronutrients**

Odor-foul scent or aroma. Most odors emanating from manure are due to decomposing manure.

Organic matter-the organic fraction of plant, animal, and microorganisms at various stages of decomposition.

Organic nitrogen-nitrogen in the form of urea, protein, or amino acids.

Phosphorus-one of the primary nutrients required for the growth of plants. Phosphorus is often delimiting nutrient for the growth of aquatic plants or algae in lakes and rivers.

Pollutant-any introduced substance that limits a resource use for a specific purpose.

Pollution-the condition caused by the presence in the environment of substances of such character and in such quantities that the quality of the environment is impaired or rendered offensive to life.

Eutrophication-a means of aging of lakes whereby aquatic plants are abundant and waters are deficient in oxygen. The process is usually accelerated by enrichment of water with surface runoff containing nitrogen and phosphorus.

Runoff-the portion of precipitation or irrigation water on an area that does not infiltrate, but instead is discharged from the area by flows across land surface or subsurface and eventually appeared in streams and other water-bodies.

Scraper system-a system of removing manure from a shallow gutter by means of blades scraping the gutter surface.

Settling basins-a concrete or earth bottom settling structure where the solid in runoff or the waste settles out.

Slotted floor-floor in a facility that has open spaces to allow manure and other waste material to pass through.

Stock pile-long term solid manure storage.

PART IV. LITERATURE REVIEW

MANURE STORAGE AND HANDLING

The main source of this review on manure storage and handling (from on Animal Manure Production and Characteristics to section on Manure Storage) is the Mid West Plan Service (MWPS) Publication No. 18, Livestock Waste Facilities Handbook MWPS (1985). This section is intended to provide back ground on basic storage and handling techniques for readers without farming familiarity. MWPS is sponsored by the 12 land grant universities in the North Central Region to produce extension educational materials addressing a range of engineering issues related to agriculture that are common to the 12 states. Materials are intended for producers, consultants, extension educators, contractors, and equipment suppliers. MWPS No. 18 Livestock Waste Facilities Handbook is the most recent comprehensive summary of current technologies in use or applicable to Minnesota. Basic handling and storage techniques have not changed since 1985. Comments on specific Minnesota circumstances are based on the expert opinion of the storage and handling subgroup that prepared this document.

Animal manure utilization technology is subject to regulation (local, state, and federal). In Minnesota, the feedlot ordinance is administered by the Minnesota Pollution Control Agency (MPCA). In the ordinance, the MPCA is to regulate proper collection, storage, and land application of manure (MPCA, 1998a).

Besides regulations, manure utilization technology is also influenced by factors such as

- farm (size, soil type, typography, crops);
- operation (size and type, capital, mechanization level, owner preferences);
- climate (precipitation, temperature norms, prevailing winds);
- livestock management;
- animal (species and ration);
- manure characteristics; and
- local changes in human population and land use.

System selection is based on economics, engineering, public reaction and regulation, and numerous factors related to agriculture and the operation.

Manure can be handled and stored as a solid, a semi-solid, or liquid. The amount of bedding or dilution water influences the form. In turn, besides the quantity and properties of manure, manure form influences the selection of collection and spreading equipment and the choice of storage type.

Animal Manure Production and Characteristics

The properties of manure depend on several factors:

- animal species;
- ration digestibility;

- ration protein and fiber content;
- animal age;
- environment; and
- animal productivity.

An overview of fresh manure properties (physical properties, nutrients, heavy metals, and bacteria) across animals species by a common unit of livestock mass/day is shown in Table 3. The standard deviation of manure output and nutrient composition indicates the challenges of defining standard manure properties as they can be influenced by many factors. Production and nutrient content of manure by subsets of animal size within species are shown in Table 4, focusing on N, P, and K output. This table describes manure production in units that can be applied to nutrient management and for sizing manure storage systems. A large portion of N, P and K from feed is excreted in the manure, which is then available for whole-farm nutrient recycling through the soil, plant, and animals. The range of N, P, and K in excreted manure expressed as a percentage of input are generally 70-80% N, 60-85% P, and 80-90% K of that fed to animals are excreted in the manure (Moore and M.J.Gamroth., 1993).

In addition, whatever system is in place, a key fact is that 100% of excreted manure is seldom recovered due to physical losses on the farm. A recent survey (NRCS, 1995) of Midwest confinement livestock farms, NRCS indicated that percentages of manure (feces and urine) recovered the highest in cage layers and broiler units (95%). Eighty percent was recovered in lactating dairy cow units, but only 60% from other units on the dairy farm. In beef feeder units, 75% of the manure was recovered. Confined swine and turkey units had 70% recovery rates. Only 35% was recovered from sheep units.

Grazing animals will distribute the majority of their manure within the pasture system, so recovery for field application is not necessary, but some manure may be recoverable inside loafing barns, milking barns, and feeding areas. One of the major factors contributing to animal manure output and composition is the feeding regimen and digestibility of the feed nutrients. A good example would be the changes in a typical lactation of a dairy cow. Daily and annual excretion estimates of various fractions and nutrients by Holstein dairy cows are shown in Table 5 (Van Horn, et al., 1996). This example represents a cow producing 18,150 lbs. milk per lactation which is close to the average level found in Minnesota herds that are on the Dairy Herd Improvement Association (DHIA) program, and also close to the average production reported by dairy farmers in a Minnesota survey (Russelle, 1999). As milk production increases the total amount of manure and the ratio of urine to feces increases. The digestibility of the feed averages 62% in this example with 38% of the dry matter intake (DMI) excreted. The example shows the effect of feeding varying dietary protein, P, K, Ca, and Mg levels. It also shows typical outputs of Na and Cl.

Efforts are underway to find ways of improving the efficiency of utilization of dietary nutrients and reduce manure excretion rates in all animal systems. Feeding 0.6% vs. 0.4%

ble 3. Fresh manure production and characteristics per 1000 kg (2200 lb) live animal mass per day.

Parameter	Units~		Animal Types										
			Dairy	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
Total Manure	kg	Mean{	86	58	62	84	40	41	51	64	85	47	110
		SD	17	17	24	24	11	8.6	7.2	19	13	13	**
Urine	kg	Mean	26	18	**	39	15	**	10	**	**	**	**
		SD	4.3	4.2	**	4.8	3.6	**	0.74	**	**	**	**
Density	kg m^{-3}	Mean	990	1000	1000	990	1000	1000	1000	970	1000	1000	**
		SD	63	75	**	24	64	**	93	39	**	**	**
Total Solids	kg	Mean	12	8.5	5.2	11	11	13	15	16	22	12	31
		SD	2.7	2.6	2.1	6.3	3.5	1.0	4.4	4.3	1.4	3.4	15
Volatile Solids	kg	Mean	10	7.2	2.3	8.5	9.2	**	10	12	17	9.1	19
		SD	0.79	0.57	**	0.66	0.31	**	3.7	0.84	1.2	1.3	**
Biochemical Oxygen Demand, 5-day	kg	Mean	1.6	1.6	1.7	3.1	1.2	**	1.7	3.3	**	2.1	4.5
		SD	0.48	0.75	**	0.72	0.47	**	0.23	0.91	**	0.46	**
Chemical Oxygen Demand	kg	Mean	11	7.8	5.3	8.4	11	**	**	11	16	9.3	27
		SD	2.4	2.7	**	3.7	2.5	**	**	2.7	1.8	1.2	**
TH	kg	Mean	7.0	7.0	8.1	7.5	**	**	7.2	6.9	**	**	**
		SD	0.45	0.34	**	0.57	**	**	**	0.56	**	**	**
Total Kjedahl Nitrogen<	kg	Mean	0.45	0.34	0.27	0.52	0.42	0.45	0.30	0.84	1.1	0.62	1.5
		SD	0.096	0.073	0.045	0.21	0.11	0.12	0.063	0.22	0.24	0.13	0.54
Ammonia Nitrogen	kg	Mean	0.079	0.086	0.12	0.29	**	**	**	0.21	**	0.080	**
		SD	0.083	0.052	0.016	0.10	**	**	**	0.18	**	0.018	**
Total Phosphorus	kg	Mean	0.094	0.092	0.066	0.18	0.087	0.11	0.071	0.30	0.30	0.23	0.54
		SD	0.024	0.027	0.011	0.10	0.030	0.016	0.026	0.081	0.053	0.093	0.21
Orthophosphor s	kg	Mean	0.061	0.030	**	0.12	0.032	**	0.019	0.092	**	**	0.25
		SD	.0058	**	**	**	0.014	**	0.0071	0.016	**	**	**
Potassium	kg	Mean	0.29	0.21	0.28	0.29	0.32	0.31	0.25	0.30	0.40	0.24	0.71
		SD	0.94	0.061	0.10	0.16	0.11	0.14	0.091	0.072	0.064	0.080	0.34
Calcium	kg	Mean	0.16	0.14	0.059	0.33	0.28	**	0.29	1.3	0.41	0.63	**
		SD	0.059	0.11	0.049	0.18	0.15	**	0.11	0.57	**	0.34	**
Magnesium	kg	Mean	0.071	0.049	0.033	0.070	0.072	**	0.057	0.14	0.15	0.073	**
		SD	0.016	0.015	0.023	0.035	0.047	**	0.016	0.042	**	0.007	**
Sulfur	kg	Mean	0.051	0.045	**	0.076	0.055	**	0.044	0.14	0.085	**	**
		SD	0.010	0.0052	**	0.040	0.043	**	0.022	0.066	**	**	**
Sodium	kg	Mean	0.052	0.030	0.086	0.067	0.078	**	0.036	0.10	0.15	0.066	**
		SD	0.026	0.023	0.063	0.052	0.027	**	**	0.051	**	0.012	**
Chloride	kg	Mean	0.13	**	**	0.26	0.089	**	**	0.56	**	**	**
		SD	0.039	**	**	0.052	**	**	**	0.44	**	**	**
Iron	g	Mean	12	7.8	0.33	16	8.1	**	16	60	**	75	**
		SD	6.6	5.9	**	9.7	3.2	**	8.1	49	**	28	**
Manganese	g	Mean	1.9	1.2	**	1.9	1.4	**	2.8	6.1	**	2.4	**
		SD	0.75	0.51	**	0.74	1.5	**	2.1	2.2	**	0.33	**
Boron	g	Mean	0.71	0.88	**	3.1	0.61	**	1.2	1.8	**	**	**
		SD	0.35	.064	**	0.95	0.30	**	0.48	1.7	**	**	**
Molybdenum	g	Mean	0.074	0.042	**	0.028	0.25	**	0.083	0.30	**	**	**
		SD	0.012	**	**	0.030	0.38	**	0.033	0.057	**	**	**

Table 3. Continued

Parameter	Units~		Animal Types										
			Dairy	Beef	Veal	Swine	Sheep	Goat	Horse	Layer	Broiler	Turkey	Duck
Zinc	g	Mean	1.8	1.1	13	5.0	1.6	**	2.2	19	3.6	15	**
		SD	0.65	0.43	**	2.5	1.0	**	2.1	33	**	12	**
Copper	g	Mean	0.45	0.31	0.048	1.2	0.22	**	0.53	0.83	0.98	0.71	**
		SD	0.14	0.12	**	0.84	0.066	**	0.39	0.84	**	0.10	**
Cadmium	g	Mean	0.0030	**	**	0.027	0.0072	**	0.0051	0.038	**	**	**
		SD	**	**	**	0.028	**	**	**	0.032	**	**	**
Nickel	g	Mean	0.28	**	**	**	**	**	0.62	0.25	**	**	**
		SD	**	**	**	**	**	**	**	**	**	**	**
Lead	g	Mean	**	**	**	0.084	0.084	**	**	0.74	**	**	**
		SD	**	**	**	0.012	**	**	**	**	**	**	**
Total coliform bacteria	colonies	Mean	1100	63	**	45	20	**	490	110	**	**	**
		SD	2800	59	**	33	26	**	490	100	**	**	**
Fecal coliform bacteria	colonies	Mean	16	28	**	18	45	**	0.092	7.5	**	1.4	**
		SD	28	27	**	12	27	**	0.029	2.0	**	**	**
Fecal streptococcu bacteria	colonies	Mean	92	31	**	530	62	**	58	16	**	**	590
		SD	140	45	**	290	73	**	59	7.2	**	**	**

e:{ASAE 1998}
alues wet basis; 1 kg = 2.2 lb; 454 g = 1 lb.
a not found.
rences within species according to usage exist, but sufficient fresh manure data to list these differences was not found. Typical live animal s for which manure values represent are: dairy, 640 kg; beef, 360 kg; veal, 91 kg; swine, 61kg; sheep, 27kg; goat, 64 kg; horse, 450 kg; layer, ; broiler, 0.9 kg; turkey, 6.8 kg; and duck, 4.8 kg.
s and Urine was voided.
meter means within each animal species are comprised of varying populations of data. Maximum numbers of data for each species are : dairy, eef, 50; veal, 5; swine, 58; sheep, 39; goat, 3; horse, 31; layer, 74; broiler, 14; turkey,18 and duck, 6.
nutrients and metals are given in elemental form.
n bacteria colonies per 1000 kg animal mass multiplied by 10^{10}. Colonies per 1000 kg animal mass divided by kg total manure per 1000 kg l mass multiplied by density kg/m^3 equals colonies per m^3 of manure

P in the diet will require an additional acre of land per cow to dispose of manure and prevent potential P accumulation effects on the environment (Linn, 1994). Reduction of dietary P in dairy cow diets is becoming well accepted, and a dietary level of only 0.38% P appears to be adequate (Satter and Wu, 1999). At this level of phosphorus in the dairy cow diet, farmers have a better chance at avoiding P buildup in their soil (Powell, 1999). Proper balancing of total dietary protein and digestibility of protein for dairy cows at different production levels will help in controlling N excretion rates as indicated in Table 5. The amount of K excreted is becoming more critical from an animal health viewpoint, as high levels of K in manure are taken up by the plant and are returned in the forage fed to cattle. High K affects availability of other minerals, such as Mg and Ca, which can cause metabolic problems during the calving period.

Dairy farming in the Netherlands has seen some dramatic improvements of nutrient use as nutrient flow in soils, crops, forage, cattle and manure has been characterized the main components (Aarts, et al., 1992). This has continued throughout the decade. In beef, cattle, swine, and poultry much research in the last 5 years has been focused on nutrient management strategies to reduce nutrient excretion rates. More discussion of dietary effects can be found in the section on Manure Nutrient Accountability and Whole-Farm Balance.

Table 4. Production and nutrient content of manure from various farm animals[a]

Animal Species	Animal size, lb	Manure lb/day	Manure cu ft/day	Manure Gal/day	N lb/day	P lb/day	K lb/day
Dairy cattle	150	13	0.19	1.5	0.06	0.011	0.04
	250	22	0.32	2.4	0.11	0.023	0.07
	500	43	0.66	5.0	0.22	0.047	0.15
	1000	89	1.32	9.9	0.45	0.094	0.29
	1400	120	1.85	13.9	0.59	0.131	0.41
Beef cattle	500	30	0.50	3.8	0.17	0.051	0.12
	750	45	0.75	5.6	0.26	0.079	0.19
	1000	60	1.0	7.5	0.34	0.109	0.24
	1250	65	1.2	9.4	0.43	0.12	0.31
Beef cow		63	1.05	7.9	0.36	0.11	0.26
Nursery pig	35	2.9	0.038	0.27	0.018	0.0052	0.01
Growing pig	65	5.3	0.070	0.48	0.034	0.0099	0.02
Finishing pig	150	12.4	0.16	1.13	0.078	0.023	0.045
	200	16.6	0.22	1.5	0.104	0.036	0.059
Gestating sow	275	11.3	0.15	1.1	0.069	0.023	0.04
Sow & Litter	375	15.0	0.21	1.4	0.1	0.031	0.054
Boar	350	14	0.19	1.4	0.081	0.023	0.051
Sheep	100	4	0.062	0.46	0.045	0.0066	0.032
Poultry-layers	4	0.26	0.0035	0.027	0.0034	0.0012	.0.0012
Poultry-broile	2	0.17	0.0024	0.018	0.0024	0.0006	0.0008
Horse	1000	51	0.75	5.6	0.31	0.072	0.25

[a] Adapted from (Moore and M. J. Gamroth, 1993)

Manure Collection

Selection of a collection system depends on

- type of facility;
- labor requirements;
- investment; and
- manure handling system.

Table 5. Daily and yearly excretion estimates of various fractions and nutrients by Holstein cows.[a]

	Daily milk and dry feed intake for:				Total for
	0-30 days	31-70 days	71-205 days	206-365 days	Year
Milk, lb/cow	100	70	50	Dry	18,150
Dry feed intake, lb/cow	55.8	46.3	39.2	25.2	14,462
	Excretion for cow described in column above				
Fraction or Nutrient	lb/day	lb/day	lb/day	lb/day	lb/yr/cow
Raw manure (feces + urine)	195.0	160.0	125.0	80.0	47,475
Feces (wet)	125.0	100.0	75.0	45.0	28,825
Urine	70.0	60.0	50.0	35.0	18,650
Total solids (38% of DMI)	21.2	17.6	14.9	9.6	5,496
Volatile solids	17.7	14.7	12.4	8.0	4,580
Total N (NRC, low)[1]	0.899	0.727	0.601	0.364	223
Total N (NRC, high)[1]	1.030	0.846	0.698	0.439	260
Urea + ammonium N (NRC, low)	0.408	0.308	0.249	0.125	92
Urea + ammonium N (NRC, high)	0.500	0.391	0.319	0.178	118
P (diet 0.40% P)	0.123	0.115	0.107	0.101	40
P (diet 0.45% P)	0.151	0.138	0.126	0.103	46
P (diet 0.60% P)	0.235	0.208	0.185	0.151	69
K (diet 0.8% K)	0.296	0.265	0.239	0.201	88
K (diet 1.2% K)	0.519	0.450	0.396	0.302	146
Ca (diet 0.65% Ca)	0.242	0.217	0.195	0.164	72
Ca (diet 0.90% Ca)	0.382	0.333	0.293	0.227	108
Mg (diet 0.20% Mg)	0.102	0.086	0.073	0.050	27
Mg (diet 0.35% Mg)	0.185	0.155	0.132	0.088	49
Na (diet 0.35% Na)	0.145	0.127	0.112	0.088	42
Cl (diet 0.55% Cl)	0.197	0.178	0.161	0.138	60

[a] Adapted from (Van Horn, et al., 1996). Crude protein percent of total diet dry matter used in calculations for cows producing 100, 70, 50, and dry cows for "NRC (National Research Council -nutrient requirements for dairy cattle, 1989), low diets" were 16.0, 14.8, 13.8, and 11.0%, respectively. Respective crude protein percents for "NRC, high diets" were 17.5, 16.4, 15.3, and 12.0% of total diet dry matter.

Some systems combine collection and storage functions, such as built-up manure pack or slotted floors over a liquid tank. Slotted flooring refers to slats and perforated or mesh flooring. Slotted flooring rapidly separates an animal from its manure. Slotted flooring materials, spacing, and width depend on the manure properties and animal responses such as slipping and foot injury.

Manure collection depends on manure forms. Solid and semi-solid manure can be collected with tractor scrapers, front-end loaders, or mechanical scrapers. Liquid manure can be collected with scrapers, flushing systems, manure gutter, gravity flow channel, slotted floors, or recirculation flush pits.

For smaller operations, shallow manual gutters work well behind dairy stalls or under cantilever swine farrowing stalls. Manure is hand scraped from the gutter directly outside or into a sump or deep narrow collection gutter at the end. Mechanical scrapers can reduce manual labor depending on the storage method and the degree of cleanliness. Scrapers remove manure regularly, so building and livestock cleanliness are easier to maintain. These buildings have fewer odors than buildings with pits under slats because of frequent manure removal (at least once a day), but some ammonia is still released from the wet gutter surface. Types of scrapers are tractor-mounted blades, barn cleaners, underslat scrapers, and front-end loaders.

In a flush system, a large volume of water flows down a sloped, shallow gutter or alley. Deep narrow gutters were popular in the 1960s because they are usually self-cleaning. Thus odors are reduced because the manure is removed from the building before malodorous anaerobic bacteria have a chance to multiply. Gravity drain gutters are commonly installed in swine buildings under raised farrowing stalls and nursery decks with totally slotted floors. Recirculation flush pits are a modification of the gutter flushing concept to help alleviate pit odor problems in remodeled buildings, but they are also being installed in new swine, beef, and dairy buildings. Gravity flow channels are rectangular shaped channels with a flat, level bottom and a 6"-8" high dam at the outflow end. The main application has been tie stall and free stall dairy barns

Manure Transfer to Storage

Transferring system selection depends on individual farm's:

- manure characteristics;
- housing system;
- bedding practices;
- labor availability; and
- manure storage system.

Manure is transferred from an animal facility to storage with a large piston pump, pneumatic pump, centrifugal pump, gravity flow, or reception pit and pump. Mechanical pump transfer is very reliable. The success of a system depends on the careful matching of pump capabilities to manure characteristics. Gravity flow transfer uses the hydraulic head exerted by the relatively liquid manure to force the manure to flow. Little or no bedding should be in the manure. Reception pit and pump method refer to collection of manure in a small concrete pit and then pump it to an outside storage with a centrifugal chopper pump.

Manure Storage

Stored manure (a mixture of unused feed, bedding, water, feces, and urine) is usually kept in some sort of enclosure or container for a period of time. Fresh manure has less objectionable odor (Miner, 1975). During manure storage, however, significant odor is generated by anaerobic decomposition. The longer the manure is stored the greater the potential for gases and odors to become a problem. In Minnesota, storage of manure is almost always in the anaerobic state (Goodrich, 1999) and storage time is limited by Minnesota Pollution Control Agency regulations to a maximum of one year (MPCA, 1998b).

Cover

Storage may be covered or not covered. A cover may be a rigid structure: for example the building and roof that is constructed over a manure pit beneath a swine building. The rigid roof constructed of "T" beams on top of a liquid manure pit used to flush a swine building is another example of a covered storage. An impermeable membrane made of rubber, reinforced plastic, or even fiberglass may cover an above ground liquid manure storage. Examples of temporary covers on storage ponds are those using blankets of wheat straw, clay balls, or floating plastic (Jacobson, et al., 1998).

The decision to cover a storage is usually based on

- economics;
- siting requirements;and
- preference of the owner.

A covered tank will reduce odors around the farmstead. It will also reduce the amount of precipitation entering the tank resulting in a 15% to 20% reduction in volume to handle. However, a concrete cover may double the construction cost compared to an open top tank (Hilborn, 1995).

The liquid manure storage can be located directly under the barn or outside the barn. A fully slatted, storage under the barn is generally not recommended due to ventilation concerns and gas problems when agitating. To address this, many swine operations construct storage under the barn with a solid roof. On top of this roof, a 2' deep fully slatted pit is constructed. The small pit is periodically emptied into the larger storage by opening a valve.This effectively avoids ventilation and gas problems associated with long term storage under the barn (Hilborn, 1995).

Uncovered storage examples are open storage ponds, open slurry tanks, mounds on feedlots, manure piles, and open manure pits. Wind moving across the surface will move more odors to the neighbors from uncovered than from covered manure, as a general rule (Zahn, et al., 1997). The drying effect on solid manure is sometimes a benefit, but rainfall usually offsets this advantage, given Minnesota conditions of equal evaporation and rainfall.

Considerations Prior to Building Storage

Storage design varies by state and locality because of climate, pollution control regulations, and decisions made by local jurisdictions.

A number of considerations must be addressed prior to building storage facilities. A person must evaluate site and soil conditions carefully to avoid contaminating ground and surface waters. Unlined storage should not be located over shallow fractured bedrock or below the water table. If shallow bedrock is present, a registered professional engineer or board of health should be contacted. Obviously, the site should be checked for buried utilities and drainage tiles. Storage basins in sandy or gravelly soils or other areas where serious leakage can cause groundwater pollution should also be avoided. The soil characteristics to a depth of at least 3' below the proposed storage bottom needs to be considered. A soil survey is helpful in evaluating a site. County extension personnel or NRCS staffs are qualified to help in site evaluation.

Storage facility location should consider all farmstead operations, building locations, and prevailing winds. At least 100 feet should be allowed between a water supply and the nearest part of storage. Dairy operators need to check with milk and health authorities for minimum spacing requirements between manure storage and milking facilities. Manure storage should be located, sized, and constructed for convenient filling and emptying, all weather access, and to keep out surface runoff.

Required storage capacity depends on

- regulations;
- number and size of animals;
- amount of dilution by spilled and cleaning water;
- amount of stored runoff; and
- desired length of time between emptying.

The designer should provide enough storage to spread manure only when field conditions, labor availability, weather and local regulations permit.

Handling large volumes of manure can delay other farm activities. Large manure storage facilities require many hours, usually over a period of several days, to remove material from storage and apply it to land. This job often comes at prime times for fieldwork. If spring application is required, the land is often not ready for manure spreader traffic before it is time to till and plant. Post-harvest spreading saves time during busy spring planting activities. It also provides a chance for winter freezing and thawing to lessen effects of soil compaction from the spreading operation. However, manure spreading in fall is not a best management practice in many areas of Minnesota, because of the increased risk of nitrate leaching loss.

Storage Design

We discuss storage design of liquid manure first, then solid manure, and finally semi-solid manure. This approximates the importance, and approximate volume of manure that exists in Minnesota at the present time (Goodrich, 1999)

Liquid Manure

Liquid Manure Pits

Liquid manure has become the most prevalent way of handling and storing manure for swine and dairy. Some chicken manure is stored as a liquid. The ability to use pumps to move the material and the reduction in volume of bedding used are two reasons that this has occurred in Minnesota (Goodrich, 1999).

For this discussion, liquid manure pits have vertical side-walls are lined, and are below grade. They may be either in a building under slats or solid floors or outside and usually separated from the building. Below ground storage can be used for semi-solid and liquid manure. Manure with up to about 15% solids can be agitated and pumped. Storage depth may be limited by soil mantle depth over bedrock, water table elevation, and possibly, effective pump lift.

Typical storage periods range from 5 to 12 months. The designer needs to provide capacity for dilution water, rain, snow, and milking center waste. Pits must be designed to withstand all anticipated earth, hydrostatic, and live loads, plus uplift if a high water table exists.

It is often necessary to dilute manure to aid pumping. Frozen manure, long fibrous material, and debris may require special pumping equipment. Sand and gravel cannot be pumped.

Liquid manure pits are used for storing swine manure beneath barns, swine manure outside of barns, liquid dairy manure beneath barns, liquid dairy manure outside barns, poultry manure beneath barns, and poultry manure outside barns. Liquid manure pits are sometimes also used beneath slatted beef barns. The pits outside of barns may or may not have covers

Pits are sized to contain the manure for various sizes of animal units. Therefore they are really size independent. There are some economies of scale in that the cost per unit volume decreases as size goes up, but the cost per unit of storage is higher than earth basins. When the storage is beneath the building, a cover is on the pit, and the pit is used as the foundation for the structure, saving some cost.

However there is a large liability in having the mass of decaying material generating gases and odors that move into the building housing the animals and into the area where workers must be present for long periods of time. Severe safety problems can occur during agitation and cleaning of the pits that are located beneath buildings (Goodrich, 1999, Hilborn, 1995).

Ventilation problems occur when the pits get too full, when the mechanical ventilation systems fail, or the curtain systems fail to open properly. Even micro-bursts of gases from the decaying material in the pits may cause serious problems for the animals, which are located small distances above the bubbling anaerobic mass.

Earth Storage Basins

Earth basins are earth-walled structures formed by excavation and earth berm, so they are generally partly above and partly below grade. They may or may not be lined. Earth basins can extend the capacity of indoor pits or provide total storage needs. Earth basins provide long-term storage at low to moderate investment. They are designed and constructed to prevent ground and surface water contamination. They also eliminate the problem of hazardous gas entrapment and reduce the potential of fatalities. It is important to thoroughly evaluate site suitability, dike construction, and bottom sealing for any earthen basin.

Earth basin design is key to having a suitable storage that is environmentally sound. The design must keep the bottom of the storage at least 3' above bedrock and at least 2' above the water table, depending on local pollution control regulations. Soil characteristics must be studied to determine basin wall sideslope design. The contractor must follow accepted construction methods for sealing, building dikes, and bank seeding. In general, steeper inside banks conserve space, reduce rainfall runoff entering the basin, and leave less manure on banks as the basin is emptied. Inside bank slopes of 2:1 to 3:1 (run: rise) are common for most soils. The outside sideslopes should be no steeper than 3:1 for easier maintenance. The embankment should be wide enough (at least 12') to mow and to get a tractor on for agitation. The engineer will determine the basin depth after considering the site, storage volume needed, groundwater conditions, and emptying equipment. A deeper basin requires less area for the same capacity as a shallow basin.

When placing concrete access ramps, a slope no steeper than 10:1 should be used for tanker or spreader access. A 5:1 slope is acceptable for tractor and pump access. Provide a rough surface for improved traction when wet. Deep groves or ridges (1" deep or more) across the ramp will assist traction.

Basins are either top- or bottom-loaded. Top-loaded solids pile up around the loading point, because the manure does not flow away, particularly in cold weather. Bottom loading pushes solids away from the inlet and distributes them evenly. Top loading methods usually are used on dairy farms and a barn cleaner extension is located so it can empty into the storage next to the barn. Freezing of manure machinery can be a problem. A shroud or an extension of the barn is often built over the extension to reduce the problems associated with the cold Minnesota winters.

A tractor scraper or loader can be used to push the manure out to the storage and into the storage. Sometimes there is a pileup at the push point and that can be a problem in freezing weather.

Bottom loading methods can be used with both liquid manure and semi-solid manure. Chopper-type liquid manure pumps may be used. A small sump and a chopper pump transport the manure the storage basin. The pump chops long bedding material for easier pump-out later. If the sump is outdoors, pump freezing can be a problem.

Piston manure pumps can move manure through 10"-15" diameter PVC or steel pipe. The pump is usually in the barn and the storage may be up to 300' from the barn. Pneumatic manure pumps use compressed air injected into a sealed tank to force manure through 12" diameter PVC pipe to

the storage. Centrifugal and other liquid pumps can be used in manure characteristics allow. Liquids from milk houses, barn floor washing, etc. can be pumped into the storage, because it is a convenient way to store that material and dilutes the manure so that pumping to the field is easier.

Gravity loading storage below the level of barn does not need any pumps for loading. Manure is worked down into the storage by the animal hooves as they move about on slats. Slats are individual supports made of wood, plastic, or concrete. They have spaces between them, which allow the manure to pass into the pit below.

Liquid manure basins are used for storing swine manure outside of barns, liquid dairy manure outside barns, and poultry manure outside barns. Runoff from outside dairy and beef lots is often stored in basins and this is usually very dilute material. The pits outside of barns may or may not have covers. Those that have covers are much less likely to contribute strongly to odor problems.

The term "lagoon" is often used, but this is an incorrect term for these manure storage facilities. A lagoon is an earthen facility for the biological treatment of wastewater. It can be aerobic, artificially aerated, anaerobic or facultative depending on the loading rate, design and type of organisms present (ASAE, 1998).

Minnesota winter conditions slow biological treatment to such low levels for months. Therefore the term lagoon does not describe animal manure storage basins in Minnesota.

Aboveground Manure Tanks

Aboveground manure tanks are circular silo types or rectangular structures. They are more expensive than earth basins and are usually not used to store runoff or dilute manure. They are an excellent alternative where basins cannot be used due to site limitations, such as space constraints, shallow fractured bedrock, or where earth basins are not acceptable.

Aboveground tanks work well for enclosed buildings, but they are difficult to use for open lots because of the variation in manure consistency. In addition, an aboveground tank is too expensive to be used for runoff water from feedlots, which must be handled separately.

Construction options for aboveground tanks include concrete stave similar to that used for silo storage. The diameter of this type of construction is limited because of the shape of the staves and the strength of the steel bands used to hold staves in place.

Reinforced monolithic concrete structures are very durable. Lap or butt joint coated steel has been marketed by a number of companies and these have worked well for storage. Spiral-wound coated steel has not had good success in Minnesota because the coatings have not been durable.

The joint between the foundation and the sidewall can be a problem if improperly constructed. The reliability of the dealer and construction crew is as important as the tank material in assuring

satisfaction. These tanks must have special safety devices to prevent back flow from the tank from escaping if there is a rupture in a valve or a malfunction of the pump system.

The engineer must size aboveground tanks for the manure volume, intercepted rainfall, and either milking center wastewater, if included, or added dilution water. The desired storage period should be determined based on when land and labor is available for land application. Next, the volume of manure that will accumulate over the storage period is calculated to determine the volume needed.

Some tanks are loaded with a large piston or a pneumatic manure pump through a large diameter underground pipe. Piston and pneumatic manure pumps can move material into storage that may be difficult to remove. With aboveground tanks, the operator should use little bedding or use only chopped bedding, and add extra dilution water to reduce agitation problems. Providing a water faucet at the pump will allow addition of dilution water during loading.

Aboveground liquid tanks are used for storing swine manure outside of barns, liquid dairy manure outside barns, and poultry manure outside barns. The tanks outside of barns may or may not have covers. Those that do have covers are much less likely to contribute strongly to odor problems.

The cost per unit of storage is slightly higher for aboveground tanks when compared with concrete below ground tanks. The additional pumping equipment needed to transfer from the barn to the tank is considerable and is somewhat expensive. Maintenance is an additional cost.

Pre engineered solutions are available for different sizes of storage. Covers are rather expensive and more difficult to apply and maintain because of the elevation above ground. European standards often require these types of storage for most operations, but they are not common in Minnesota except on dairy operations.

Semi-solid Manure Storage

Semi-solid manure is manure with excess liquids drained off and some bedding added to increase solids content. Solid manure has relatively large amounts of bedding added to give it a stackable consistency. Both semi-solid and solid manure can be handled with equipment already present on many farms. Thus, semi-solid manure storage allows waste from many sources to be stored in one facility and handled with the same set of equipment. For example, dairy stanchion barns, calf pens, maternity pens, and young stock housing produce various consistencies of manure that can be handled in one semi-solid storage. Semi-solid storages can be an outside facility with picket dams to drain off rainwater or may be roofed structures.

The hauling schedule from a semi-solid storage facility is flexible. Storage can be designed for any period of storage, from a few days to several months. Whenever time allows, farmers can haul a few loads of manure without planning ahead to agitate the storage facility, as is required with liquid manure. Also less total material is hauled from storage, because no water is added.

If rainwater is drained from an uncovered storage, manure with semi-solid characteristics can be handled with loaders and endgate or flail-type spreaders. These drained storages allow a producer to deposit semi-solid manure in an uncovered storage and maintain semi-solid handling characteristics by draining off rainwater. All excess water (runoff from roofs, pads, etc.) must be kept out of the manure storage. A picket dam removes only rainwater that falls on the storage; it does not reduce the water content of the manure. Farmers should not expect to put slurry in and get a solid out. Dimensions of drained storages should be limited to 100 feet to enhance drainage.

The structure should allow rainwater to drain from the storage regardless of the manure level. A picket-type structure with continuous vertical slots about 3/4 inch wide between standing planks (pickets) holds manure solids back but allows liquids to drain through. Vertical slots work much better than horizontal slots. The storage should be loaded using a stacker, a piston pump of a type that does not require the addition of water during pumping, or a tractor push-off ramp.
Picket dams may be in earth storages, or in the walls of bunker-type storages having concrete or post-and-plank walls. The manure surface is highest at the loading point and slopes toward the surrounding earth walls. A channel for runoff water forms where the manure meets the earth dike. When a drainage structure is properly located, rain water runs off the crusted surface of the manure, flows around the edge along the channel formed between the manure and earth bank, and runs through the vertical slots of the structure. A channel should be maintained behind the picket for the liquids to drain away. It is critical to locate a picket dam anywhere water will accumulate. Dam length is not as important as location. One picket dam must extend 2/3 of the way up the ramp to drain water from the ramp.

These drained storages require that some bedding be added to the manure for convenient handling with spreaders having endgates. This storage method should not be used for sand-bedded free stalls.

The drainage water from the manure storage is polluted with microorganisms and nutrients and must be directed to a holding pond, a lagoon, or an infiltration area.

Semi-solid manure also can be stored in a roofed structure. The aboveground roofed storage system was developed for dairy comfort stall barns in high rainfall areas where large amounts of bedding are mixed with manure. However, some dairy producers are now building them for free stall barn manure, because new equipment designed for handling semi-solid manure is now available. The roof protects stored manure from rainwater to keep it as dry as possible. Manure in the storage crusts over, reducing odor and fly breeding problems. This system provides an aesthetically pleasing structure that appears to be another building on the farmstead. These storages are typically bottom-loaded using a large diameter piston pump. A hoist on a beam above the doorway lifts the planks from a bulkhead in one end of the building. Manure then flows over the bulkhead onto a cone slab where a front-end loader is used to fill a spreader. When all planks are removed, the loader can go inside the structure to remove the remaining contents. This type of storage is for dairy barns.

Solid Manure Storage

Solid manure storage is used where manure dries sufficiently or where enough bedding is added make it a stackable solid. This is a very popular type of storage for turkey growers and for chicken farmers, who have high rise buildings with superior ventilation rates, which dries the manure. Stacking systems for dairy manure also are observed frequently in Minnesota. Problems with flies are reported with stacking methods. The stacks are not usually covered in Minnesota and therefore are subject to rain and snow, adding considerably to the volume that must be handled at the end of the storage period.

Positive and Negative Aspects of Current Storage Practices

Liquid Manure Pits

How do current practices compare to past practices?

The modern reinforced concrete tanks with sufficient capacity for one-year storage are almost always installed in new construction of swine facilities. This contrasts strongly with former practices of shallow pits, which had limited storage capacity. These reinforced concrete tanks also have sufficient strength in the walls to properly withstand the soil and equipment pressures because they are designed by engineers and are installed by properly trained contractors.

The Minnesota State Auditor stated that the MPCA has adequate design standards for structures that store manure (MN State Auditor, 1999). This contrasts with former practice of untrained contractors installing what they thought was correct, with little design provided. An old practice used a clay soil to form the bottom of the tank.

Do current practices meet existing requirements?

Current engineered concrete tanks do meet the storage and water protection requirements. Proper drainage is also supplied to ensure that the tanks do not float. They are adequately sealed and located.

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

The use of reinforced concrete tanks gives the strongest and most leak proof storage. The larger storage volume however may increase the odor emissions since the manure is stored for a longer time than when the pits were smaller. The tanks reduce the amount of rainfall, which dilutes the manure and increases the volume needed to be applied to soil. The location of the large proportion of these tanks beneath buildings imposes additional hazards on the animals and workers in the buildings when they are agitated to remove the manure. As a result of this hazard, many tanks are not adequately agitated and solids accumulate from year to year and reduce the storage space.

Earth Storage Basins

How do current practices compare to past practices?

In the past (1970-1990) there were only a few outside storage basins and most of those were for runoff from beef lots and dairy lots. In the 1990s larger hog operations were built with some outside storage basins. Parker et al. (1999a) reported that seepage had exceeded the 6.1-m sampled depth under an unlined feedlot runoff pond. The seepage also exceeded the allowable Nebraska seepage rate following a rainfall event on a dry bottom pond.

Do current practices meet existing requirements?

A review of current state regulations from 17 states (not including Minnesota) showed a wide range of requirements for limiting seepage from storage basins (Parker, et al., 1999a). They further recommended that a risk based regulatory system be developed to answer the question "how much seepage is too much?"

The Minnesota State Auditor stated that the MPCA is monitoring about a dozen earthen basins constructed since the agency has toughened its standards in 1993 to gather information on the long-term adequacy of these basins. MPCA is also considering alternative ways of addressing concerns about potential leakage from unlined earthen basins installed before the standard were changed (MN State Auditor 1999).

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Outside storage basins really have few positive aspects other than low initial construction costs. Maintenance costs are not minimal and they pose risk of groundwater and odor pollution (Parker, et al., 1999b). The negatives include collecting additional rainwater, increasing odors, reducing the amount of solids that can be recycled and being a hazard to safety of animals and persons.

Above-Ground Manure Tanks

How do current practices compare to past practices?

The above ground tank is a replacement for solid manure storage which had no containment and often was of insufficient size. The limited footprint and open top storage replace a much larger area and reduce the amount of rainfall that mixes with the manure.

Do current practices meet existing requirements?

The above ground tanks are engineered and meet requirements if sized sufficiently. There is protection against groundwater contamination and spillage if proper construction and operational schedules are maintained.

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Above ground storage maximizes the storage volume per perimeter length. The rainfall collected is minimized. The cleaning out process is well mechanized. Sealing is done well and groundwater is protected. The limited and elevated surface layer may hold down the emissions of gases and odors. The manure is hidden in a structure, which is reasonably pleasing to see and thus may reduce complaints from people who pass, by the operation. Due to the head pressure created by having the liquid manure storage above

ground, a leak in the piping at the bottom of the tank can cause the entire storage volume to be released in a very short period of time causing an environmental event. Adequate safeguards and inspections are needed to prevent such occurrences.

Semi-Solid Manure Storage

How do current practices compare to past practices?

The old way of storing semisolid manure outside of barns is much poorer than using the newer methods of semisolid storage. The newer methods provide a method to drain away liquids to separate storage areas and make the whole situation much better for the environment.

Do current practices meet existing requirements?

The newer methods do meet requirements for protection of groundwater. Stacking pads of concrete and structures to control and collect runoff contain the contaminated material and protect the water and soil.

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Separation of liquids and solids make handling much easier and cleaner. The areas create less odors and environmental damage from excess nutrients and runoff into areas where the nutrients can cause damage.

Solid Manure Storage

How do current practices compare to past practices?

The old way of storing solid manure outside of barns on soil or near fields was much poorer than using the newer methods of solid storage. The newer solid slabs lower seepage and reduce potential pollution.

Do current practices meet existing requirements?

The newer methods do meet requirements for protection of groundwater. Stacking pads of concrete and structures to control and collect runoff contain the contaminated material and protect the water and soil.

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Solid storage under roof, screened from view on a sealed floor maximizes the collection of nutrients and reduces the negative impacts of runoff.

Manure Handling

Manure with 20%-25% solids content (75%-80% moisture content) can usually be handled as a solid, i.e. it can be stacked and can be picked up with a fork loader. Liquids need to be drained and the manure dried or bedding added to get solid manure. In the 10%-20% solids content, handling characteristics vary depending on the type of solids present. In this range, the percent solids content does not necessarily define handling characteristics. Manure with 4%-10% solids

content can usually be handled as a liquid, but may need special pumps. Manure with 0%-4% solids content is handled as a liquid with irrigation or flushing consistency. Liquids, which have larger solids settled or filtered out or manure with dilution water added may have 4% or less solids. Manure that can be handled as a liquid are referred to as slurries.

Solid Manure-20% or more solids

Manure with 20% or more solids can usually be handled as a solid. Solid manure characteristics vary with the animal, ration, amount and type of bedding, time of year, and the amount of liquids separated from the solids. Manure collected in a settling basin can contain soil and debris.

Most solid manure spreaders are box-type. Others include flail-type spreaders, dump trucks, earth movers, or wagons. A spreader should distribute manure uniformly. Front-end loaders, scrapers and blades and several mechanical systems transport solid manures but are not usually used for spreading. Box-type spreaders are tractor-pulled or mounted on trucks. Spreader boxes are steel or wood and need to be watertight for road transport. Spreader mechanisms include paddles, flails, and augers. The feed apron, which moves the manure to the spreader, is often variable speed. Some spreaders have moving front-end gates that push the manures to the spreading mechanism.

Flail-type spreaders are tanks with open tops and usually have a shaft mounted near the open top and parallel to the main axis of the tank. Chain flails on the shaft throw the manure out the side of the spreader as the shaft turns. Large spreader capacity reduces the number of trips to the field but can increase soil compaction.

Semi-Solids-4% to 15% Solids

Semi-solids with up to about 15% solids can be pumped. Solids and liquids separate in storage so agitate manure before pumping. Big gun sprinklers can spread manure with high solids content. Pipeline design is similar to that for dilute manure, except that each component is selected to handle more solids. Big guns handle any consistency up to that of thick milk. Manure solids can coat crop leaves, reducing photosynthesis and causing salt burns on leaves. Also, over application of semi-solid manure or manure draining from the pipe when detached can kill the crop in that area. Avoid applying semi-solid manure to a growing crop. If it is necessary to apply manure during crop growth, apply at minimal rates unless fresh water is also applied. For alfalfa, apply after hay cutting. For corn, do not apply when the plant is very young or during silking.

Liquid Manure- <4% solids

Manures with up to about 4% solids can be handled as a liquid. Liquids are spread on fields with tank wagons, or are pumped through large hoses to injectors mounted on toolbars where it is applied below the surface of the soil. Tractors pull these injectors. Fibrous materials, such as bedding, hair, or feed, can hinder pumping. If large quantities are handled, a pipeline may be preferred over tank wagons for transport. Prevent large solids such as ID tags, containers, lids,

teeth, and hair from passing through the pump. Settle out solids if possible. For irrigation, provide a chopper ahead of the pump intake. Required pump capacity is influenced by amount of manures; time, labor, and power source available; labor and equipment costs; and for cropland disposal, the rate at which soil and crops can receive water. A small capacity pump is less expensive but may require more labor.

Liquid manure can be applied with irrigation system. Irrigation equipment land applies manure and also adds water and fertilizer to crops. Improved crop production from the water and the fertilizer value of manure can help pay for the manure land application system. For relatively large amounts of effluents, irrigation systems are economical and labor saving. As with any manure management system, there are potential problems.

- Odor problems can be severe, depending on the manure and management.
- Application of strong manures to crops may adversely affect plant growth or utilization.
- Fine-textured and tight soils may not have enough permeability to receive liquids rapidly.

Irrigation methods used are surface and sprinkler irrigation system. Surface spreading is an effective method of manure disposal. Manure water is delivered to the field through portable or stationary pipe and spread on fields with gated irrigation pipe or through an open ditch with siphon tubes or turnout gates. Surface irrigation is low cost and has low power requirements and few mechanical parts. However, it requires a high degree of management skill, is inflexible with respect to land area, and requires a moderate amount of labor. Surface systems require good design and management to avoid runoff and to get uniform distribution. Do not use them on land with greater than 2% slope. Before attempting surface spreading, contact a soil and water engineer to inspect the site and help you decide. Dissolved nutrients enter the soil with the liquids, but solids tend to settle out or be filtered out by grass near the inlet to the field. More nutrients and somewhat more liquid are absorbed at the high end of the slope.

Sprinklers allow land application on rolling and irregular land. Types of sprinkler systems are hand-move sprinkler, towline, stationary big gun, towed big gun, traveling big gun, center pivot system, sideroll system, and solid set system. Each system has its own advantage and disadvantages. Although initial and operating costs are generally higher for sprinklers than for surface systems, labor requirements are reduced, some systems can be automated, and application can be more uniform. Odors from sprinkled manure can create nuisances. Avoid sprinkling on days with high humidity or when wind blows odors to areas of concern. Select sprinklers and spacing to avoid runoff for the particular soil type, topography, crop, and application time. Select equipment to handle anticipated manure particle sizes with minimum plugging and maintenance. There is also data that suggests that air borne pathogens can also be a problem (NRAES, 1994 and 1996).

Nutrient Losses During Collection, Storage, and Land Application

The percentage of the original manure nutrient content retained in various storage systems by species is summarized in Table 6. The cost:benefit ratio of optimizing retention of manure nutrients under different storage structures or manure handling should be considered when upgrading or adding new facilities.

Bedding and water dilute manure, resulting in less nutrient value per pound. Much nitrogen can be lost to the air as ammonia. Runoff and leaching in open lots can remove nitrogen. There is much less nitrogen loss from compost pits, liquid storage systems, or roofed feeding areas. Nitrogen losses between excretion and land application are presented in Table 7.

Table 6. Percentage of original manure nutrient content retained in various storage systems[a]

	Dairy			Beef			Poultry			Swine			Sheep			Horse		
Method	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Daily spread	80	90	90				65	90	90				75	90	90	75	90	90
Dry + roof	70	90	90				60	90	90				65	90	90	70	90	90
Earthen Storage	55	60	70	65	80	85				60	60	70						
Lagoon /flush	30	40	60	65	80	85	25	40	60	30	40	60						
Open lot	60	70	65	60	70	60				60	70	65	55	70	60	60	70	65
Pits + slats	75	95	95	75	95	95	70	95	95	75	95	95	75	95	95			
Scrape/storage Tank	70	90	90	70	85	90												

Adapted from Moore and Gamroth (1993 - National Data base)

Table 7. Typical losses between excretion and land application adjusted for dilution in the various systems. These values are in addition to land application losses.

System	% Nitrogen lost
Solid	
Daily scrape and haul	15-35
Manure pack	20-40
Open lot	40-60
Deep pit (poultry)	15-35
Liquid	
Anaerobic pit	15-30
Above-ground storage	10-30
Earth storage	20-40
Lagoon	70-80

[a]Adapted from MWPS (1985)

Table 8. Average nitrogen losses by method of application and manure type.

Percent of nitrogen applied that is lost with 4 days of application.

Application method	Type of waste	% Nitrogen lost
Broadcast	Solid	15-30
	Liquid	10-25
Broadcast with immediate cultivation	Solid	1-5
	Liquid	1-5
Knifing	Liquid	0-2
Sprinkler irrigation	Liquid	15-35

[a]Adapted from MWPS (1985)

Phosphorus and potassium losses are negligible except for open lots or storage basins. About 20%-40% of the phosphorus and 30%-50% of the potassium can be lost by runoff and leaching in open lots. However, much of the P and K can be recovered by runoff control systems such as settling basins and holding ponds. Up to 80% of the phosphorus in storage basins can accumulate in bottom sludge and is not applied to land unless the sludge is removed.

Methods of application of manure are: broadcast (top dressed) with plow-down or disking, broadcast without plow-down or disking, knifed (injected under the soil surface)., and Irrigated. The effects of manure application method and type of manure is shown in Table 8.

The greatest nitrogen response follows land application and immediate incorporation into the soil. Plow down solid manure as soon as possible to minimize nitrogen loss and to begin release of nutrients for plant use. Most losses occur in the first 24 hours after application, so incorporate manure into the soil as soon as possible. Injecting, chiseling, or knifing liquids into the soil minimizes odors and nutrient losses to the air and/or to runoff. Nitrogen loss as ammonia from land is greater during dry, warm, windy days than during humid or cold days. Ammonia loss is generally greater during the spring and summer months.

Poultry and veal calf manures are highly alkaline, so ammonia losses are greater than from other manures. It is especially important that poultry and veal calf manure be incorporated into the soil as soon as possible. Uniform application prevents local concentrations of ammonium or inorganic salts that can reduce seed germination and yields. Apply manure as near planting date as possible so more nutrients will be available to plants, especially in areas of high rainfall and with soils in which nitrate is lost by leaching or denitrification. Lowered germination and reduced seedling growth could occur, however, if planting takes place immediately after heavy manure applications because of high salt concentrations near the soil surface.

As an alternative, late fall or winter applications may be desirable because of greater labor availability and better soil trafficability. Even though fall-winter applications may result in a 25%-50% total nitrogen loss (from leaching and denitrification), fall applications allow soil

microorganism's time to more fully decompose manure and release nutrients for the following crop season. This is especially advantageous for solid manure, which contains high levels of organic matter.

Minnesota Producers Using Manure Storage and Handling Systems

The percentages of Minnesota producers using various manure systems are presented in Table 9. The table was developed by a panel from the Department of Biosystems and Agricultural Engineering, University of Minnesota with expertise in manure management systems. The process included a meeting to discuss the various systems and components within the systems. The percentages are represented in a range as this is the opinion of the panel without any scientific or survey data to verify these ranges.

Species of horse, sheep, goat, veal, and duck are not included. Percentages are by production units, not animal numbers. Percentages sum within each major category however may exceed 100% due to multiple systems within a production unit, e.g. outdoor lots with animal shelters which use both liquid and solid manure systems. All blank cells indicate less than one percent.

Manure Management Handling and Storage Trends

The following are manure management handling and storage trends in the last couple of years:

Collection

- Increased dietary refinement to decrease total manure voided and decrease nutrients in the manure.
- Increased use of water saving devices in washing and cleaning to decrease total manure-water output.
- Increased use of deep pits.
- Decreased use of gravity drain and high volume flush systems.
- Increased of solid flooring with increase use of straw bedding.
- Change in feeding systems to reduce feed wastage and to use less water.

Transfer Systems

- Decrease in manure moisture content to reduce cost of hauling for increased hauling distance.

Liquid – Solids Separation

- Increase in handling liquids and solids separately, with the liquids being applied close to the source and the solids being transported further distances from the source.
- Increase opportunity to reduce phosphorus application on near by fields by applying it at a further distance from the source.
- Increased use of separation is limited by flow, separation efficiency, and costs.

Storage

- Increased covered storage either by deep pits under the barn or (naturally or artificially) covering of outdoor storage.

- Increased windbreak and landscaping use.
- Increased storage capacity to meet MPCA requirements and allow more flexibility for land application.

Treatment

- Increased interest in composting and handling as a solid.
- Increased treatment is limited by the additional costs.

Land Application

- Increased injection and incorporation.
- Increased custom (commercial) manure applications.

Change cropping practices to accommodate increased usage of manure and improve timeliness of application.

Table 9. Estimated percentages of Minnesota producers using various manure systems, based on judgement of faculty who are experts in the field. No comprehensive survey of manure storage facilities is available for Minnesota.

	Dairy	Swine	Beef[1/]	Turkey[2/] Broiler	Layer
Collection					
Slotted flooring	3 - 10	60 - 85	1 - 3		>99
Solid floors/manure pack	70 - 90	2 - 10	70 - 80	>99	
Manual scrape	20 - 40	1 - 4			
Automatic scrape	50 - 60	1 - 4			>99
Flushing (high volume)		1 - 4			
Gravity drain		5 - 15			
Pit-recharge		1- 4			
Unpaved lot runoff	20 - 40	1 - 4	70 - 90		
Paved lot runoff	20 - 30	2 - 10	20 - 30		
Transfer system to storage					
Slotted flooring to pit	3 - 10	60 -86	1 - 3		>99
Solid floor/manure pack	70 - 90	10 - 20	70 - 80	>99	
Reception pit and pump	45 - 60	5 - 15			
Gravity drain - pipe	2 - 5	15 - 25			
Gravity drain - surface	50 - 60				
Pressure vessel					
Vacuum tank wagon					
Loader/skid steer	25 - 40			>99	
Liquid - Solids separation					
None	96 - 98	95 - 99	85 - 95	>99	>99
Settling tank		2 - 5			
Settling basin	1 - 2	1 - 2	5 - 15		
Settling channel					
Mechanical separation	1 - 2	1 - 2			
Evaporation					
	Dairy	Swine	Beef	Turkey Broiler	Layer
Storage					
None/Minimal[3/]	20 - 40				
Liquid					
Pits	2 - 8	65 - 85	1 - 3		
Earthen basin	45 - 60	65 - 85	80 - 90		
Above ground	2 - 8	1 - 2			
Semi-solid					
Earthen basin	5 - 15				
Stacking slab					

Table 9. Continued

	Dairy	Swine	Beef[1/]	Turkey[2/] Broiler	Layer
Solid					
Paved/Unpaved lot	45 - 60	10 - 20	80 - 90		
Stacking slab	2 - 8			>99	
Deep pit					>99
Within building	70 - 90	10 - 20	10 - 20	>99	
Treatment					
None	97 - 99	95 - 99	>99	98 - 99	98 - 99
Composting	1 - 2	1 - 2		1 - 2	1 - 2
Aerobic lagoon					
Aeration		1 - 2			
Anaerobic lagoon	1 - 2	1 - 2			
Anaerobic digestion					
Transfer system to application site					
Basin pump	25 - 40	15 - 15	70 - 90		
Gravity drain - pipe					
Liquid tank wagon	25 - 40	70 - 85			
Solid manure spreader	70 - 90	10 - 20	70 - 90	>99	>99
Land application					
Irrigation	1 - 2		3 - 8		
Tanker - surface	25 - 35	20 - 40	1 - 5		
Tanker - surface/incorporation[4/]	5 - 15	5 - 15			
Injection[5/]	15 - 35	30 - 50			
Box spreader - surface	75 - 85	10 - 30		>99	>99
Box spreader - incorporation[4/]	1 - 2				
Runoff infiltration area	1 - 5		1 - 5		
Odor control[6/]					
None	95 - 99	50 - 75	90 - 98	98 - 99	>99
Covered storage	1 - 5	1 - 5			
Biofilter					
Pit additive		15 - 25			
Chemical additive - agitation					
Dietary		5 - 15			
Windbreaks/Landscaping	1 - 5	2 - 10	2 - 10	1 - 2	
Oil spray					

1/ Cow-calf or pasture not included
2/ Turkey on ranges not included
3/ Storage is less than two weeks or called daily haul
4/ Incorporated with four days
5/ Injection or immediate incorporation by tanker or towed hose
6/ Used on a continuous basis

The Economic Liability of Manure Storage and Handling

The Minnesota feedlot ordinance requires every farm with at least 10 animal units to have an operating permit. There are over 40,000 farms requiring a permit, and each will need a land application plan for manure as part of the permitting process (Levins, et al., 1996). The required proper storage, collection, and land application has reduced the economic value of manure. The economic value of manure is assumed to be the value of commercial fertilizer it could replace, minus storage, hauling, and application costs.

Farms need to have sufficient manure storage capacity to allow maximum flexibility in timing manure applications. When storage is inadequate, applications must be made without due consideration to likely losses or other adverse effects, such as soil compaction. Manure costs are largely tied to the costs of storage, which are directly related to storage capacity. As the capacity increases, costs also increase. Application costs increase with distance from the source, as well as total acres covered. This economic pressure (and the typically distasteful nature of manure handling) encourages application of higher manure rates closer to the farmstead. As animal concentrations increase, the distance from the source over which manure must be transported increases. This is the cost that ultimately limits the size of animal operations (Fleming, et al., 1998).

Thus far, agronomically-determined manure application rates generally have been designed to supply nitrogen to the following crop. There is increasing impetus to base the rate on crop phosphorus need, instead, at least for fields where runoff to surface water is a concern, and this typically doubles the amount of land required for manure application. Therefore, economic forces are sometimes at odds with the best environmental strategy.

The dis-economies of scale and disincentives for environmentally sound manure application are particularly problematic for dilute liquid manures, such as storage basin liquids, where large quantities of dilution water must also be transported to the field (Fleming, et al., 1998). Transportation costs are much less of an issue for solid manures where there is less water and thus less weight. Poultry manure, separated solids from dairy manure, and bedded manures such as swine manure from hoop structures all have a relatively high nutrient densities, and can thus be economically transported greater distances. Composting such manures reduces moisture, weight, and volume even more.

Addressing the disincentives to environmentally sound manure management does not come without costs, and the balance between benefits and cost is a major factor in on-farm manure management decisions. The greatest differences among manure management system alternatives are related to costs for manure storage, machinery, fuel, labor, and timeliness of operations (Harrigan, et al., 1996). Some of these costs, manure storages, represent significant capital investments that set the pattern for other manure management decisions, sometimes for a period of several decades, while others are more adaptable to evolving policy and economic incentives.

Example of costs associated with storage structure and storage capacity are presented in Table 10. Based on a summary of data from dairy farms in Wisconsin, (Frame, 1998) concluded that the cost of manure storage construction and barnyard improvements was about $65,000 per farm.

He concluded that this unacceptably high cost was a barrier to farmers moving from daily haul systems.

Table 10. Comparison of costs for manure storage (MN NRCS, 1993, personal communication)

Types of Storage Structure	Approximate cost/1000 gallon of storage capacity[1/]
Unlined (natural) earthen basin	36
Clay-lined earthen basin using clay on site	70
Clay-lined earthen basin using clay from an off-farm borrow site (varies with haul distance)	88
Earthen basin lined with plastic liner (geosynthetic membrane)	76
Earthen basin lined with concrete	88
Above-ground tank constructed with precast concrete	141
Round, above-ground tank constructed of poured in place concrete	163
Above-ground, glass-lined tank	198

1/ Cost estimates based on 50,000 gallon storage capacity. Cost per 1000 gallon will decrease significantly for larger storages.

The lowest cost of manure handling equipment is associated with daily hauling and the highest cost is associated with slurry injection. According to (Harrigan, et al., 1996), the highest net return is associated with short-term manure storage and frequent hauling; the lowest with long-term storage and slurry injection. Compared to slurry injection, net return on the 150-herd cow farm increased about $20, $28, and $78/cow-yr for slurry spreading, irrigation, and daily hauling, respectively. When odor is a concern, injection of the slurry car reduce odors, but increases handling costs (fuel, maintenance, and labor). According to this analysis, fuel use was greatest for slurry injection and the least for daily hauling with a V-tank spreader. Slurry injection and

slurry spreading concentrated labor in the spring and fall, which caused delay in both tillage and planting and led to lower corn yield and higher feed costs. As might be expected, therefore, a recent survey of Minnesota dairy farmers (Russelle, 1999) indicated that most depend on daily or frequent manure hauling as their primary strategy for manure application, while liquid storage systems are of secondary importance.

Nearly 30 years ago, researchers at Cornell University (Casler and LaDue, 1972) concluded that conversion from daily hauling to a 6-month liquid manure slurry storage system would result in increased costs for the farmer, higher odor impacts during manure application, and uncertain reductions in water contamination. They recognized that many of the benefits from such storage systems are public rather than private. This realization has resulted in cost-sharing that is available to farmers from state and federal governments to support construction of manure storage facilities and physical barnyard improvements to prevent runoff.

Although most analyses have concluded that costs of manure storage and handling exceed the economic benefits, some have not. For example, considering dry manure from beef feedlots in Idaho, which involve minimal storage costs (Araji and Stodick, 1990) concluded that the cost of manure application was only 20 to 35% that of commercial fertilizer. Clearly, evaluations must be made on the basis of the livestock involved, storage system being considered, and mode of manure transportation that is available.

VALUE AND ENVIRONMENTAL IMPACTS

Crediting Manure Nutrients: An Asset

As commercial fertilizer has reduced the need for manure, the economic benefit of manure has been increasingly viewed only in terms of the direct benefit associated with the essential nutrients for crop growth. This typically is measured in terms of the fertilizer replacement value. For example, an application of 10 tons of solid beef manure to an acre of land reduces fertilizer nitrogen requirements by about 40 lbs. during the next cropping year, which would save the farmer about $10 per acre at present fertilizer prices, disregarding the cost of manure application. Such a calculation ignores other tangible benefits of manure.

Utilization of manure applied to land is accomplished through microbial conversion of plant residues and wastes into usable crop nutrients. Breakdown of organic nutrient sources takes considerable time with only a fraction of the applied nitrogen being available the first year. Actual mineralization rates are difficult to determine given the fact that this is a biological process that is sensitive to temperature and moisture conditions found in the soil system. Information on nitrogen mineralization rates is needed to accurately determine application rates of organic nutrient sources (Gilmour, et al., 1996). In manure, N is mostly organic and ammonium nitrogen. Organic N is a slow release N source. Ammonium N is equivalent to commercial fertilizer and, except for that lost to the air, can be used by plants in the application year. Organic nitrogen must be converted to inorganic form before plants can use it. Variable amounts of organic nitrogen are released in a plant-available form during the first cropping year

Table 11. Amount of organic nitrogen mineralized (released to crops) during the first cropping season after application of animal manure (MWPS, 1985).

Manure Type	Manure Handling	Mineralization Factor
Swine	Fresh	0.50
	Anaerobic liquid	0.35
	Aerobic liquid	0.30
Beef	Solid without bedding	0.35
	Solid with bedding	0.25
	Anaerobic liquid	0.30
	Aerobic liquid	0.25
Dairy	Solid without bedding	0.35
	Solid with bedding	0.25
	Anaerobic liquid	0.30
	Aerobic liquid	0.25
Sheep	Solid	0.25
Poultry	Deep pit	0.45
	Solid with litter	0.30
	Solid without litter	0.35
Horses	Solid with bedding	0.20

after application (Table 11). Organic N released during the second, third, and fourth cropping years after initial application is usually about 50%, 25%, and 12.5%, respectively of that mineralized during the first cropping season (MWPS, 1985).

Nearly all of the phosphorus and potassium in animal wastes are available for plant use the year of application.

The availability of manure nutrients to crops varies with manure storage and application. For example, nitrogen losses by ammonia volatilization can be large when slurry is not incorporated soon after spreading. Thus, the "book value" for swine manure is 28 lb of nitrogen per thousand gallons of slurry when it is incorporated within three days, but only 22 lb per thousand gallons when it is not.

Crop rotations, addition of organic materials, and presence of legumes can all cause changes in N availability to succeeding crops. It is of utmost importance that the "N credit" (that is, the reduction in N fertilizer required to produce optimum yield) for these effects be determined using the correct method. Most published studies where N credits were determined have been based on a method that does not account for improved yield potential in crop rotations compared with continuous cropping of one species or in manured fields compared with those that do not receive manure.

When this yield advantage is present, the best way to determine true N fertilizer need is to use several rates of N on the crop of interest both with and without the effect one wants to measure. For example, different rates of N fertilizer should be applied to both continuous corn, and corn grown after soybean. The difference in optimum rates is the N credit. The same method can be used with and without application of manure, sewage sludge, or other amendment, and with other crop rotations. At Waseca, corn grown after wheat shows the same effective N benefit as corn grown after wheat with underseeded alfalfa (Randall, 1980). The economic N rate in continuous corn was 173 lb N/acre and was 145 lb N/acre in both rotations with wheat. Thus, the N credits for wheat or wheat plus alfalfa before corn was 28 lb N/acre in that study (Lory, et al., 1995).

Corn rarely responds to fertilizer N the first year after alfalfa at some Minnesota locations and has limited N fertilizer response at others (Lory, et al., 1995). Further analysis of data collected in that research concluded that simple adjustments using an N credit approach may not be accurate and reliable at all Minnesota locations (Lory, et al., 1995). That research concluded by recommending more careful study of N credits under different Minnesota soil and weather conditions. This discussion of N credits is very important, because the risk of leaching or other losses of N increase as fertilizer N rate exceeds that needed for optimum yield.

Robust estimates of N credits for various crop systems are needed to provide environmentally sound recommendations. University of Minnesota recommendations typically are well supported and kept up-to-date by research on crop yield and environmental impact. Special recommendations can be made of particular situations, such as is being done as part of a current LCMR project in southwest Minnesota. It is largely fertilizer dealers and independent consultants on whom Minnesota dairy farmers rely for fertilizer recommendations (Russelle, 1999). The key, then, is to assure that farmers and their advisors use the appropriate recommendations, especially on fields where the environmental impacts of excess nitrate may be large.

Surveys by the Minnesota Department of Agriculture show that farmers typically are applying N fertilizer within 10 to 30 lb N/acre of the University of Minnesota recommendations when their crop rotations are simple soybean and corn (Bruening, 1998). However, fertilizer N applications apparently are much in excess of the University recommendations when rotations are more complex or when livestock manure is being used. Presumably this over-application results when farmers or their advisors (fertilizer dealers, independent consultants, etc.) do not credit manure, legumes and other crops in the rotation for the N they effectively contribute to the system, a recognized problem in many states (Lory, et al., 1995;Peterson and Russelle, 1991).

Nitrogen recovery by plants receiving topdressed (surface-applied and not incorporated) manure slurry is relatively low, primarily because of ammonia volatilization losses. Current guidelines in Minnesota suggest that about 20% of the slurry N applied in this way will be absorbed by a crop (Schmitt and Rehm, 1998b), and this matches recent experimental results with dairy manure slurry on reed canarygrass (Russelle, et al., 1997). These ammonia losses can have significant downwind effects when large concentrations are released or large areas serve as the source. At the same time, losses by other mechanisms, such as leaching, are reduced. Thus, the relative

impact of various pathways of N loss can be assessed in each situation to determine what management is desirable.

By using livestock manure on the fields from which feed was harvested, a variable and often very large fraction of the harvested nutrients are returned to the soil. Thus, manure collection and application helps recycle nutrients on the farm. This recycling helps improve agricultural sustainability.

An interesting contrast is provided by our systems of handling livestock manure and human manure. Livestock manure typically is used to recycle nutrients on cropland, whereas human wastes are not. In municipalities, human wastes are treated, which results in large losses of nitrogen gases. The solid fraction is either landfilled or applied to land near the town and much of the liquid fraction, which contains significant amounts of phosphorus, is disposed of in rivers. In septic tank systems, some nutrients accumulate in the sludge, which generally is landfilled, while those in the liquid fraction infiltrate into a relatively small volume of soil on the property. In terms of potential and likely environmental benefit, then, livestock manure use is considerably more beneficial to sustainable crop production than is our current system of human waste treatment.

This discussion leads to an important concept. Within a farm that produces most of its own livestock feed, manure should not be considered a source of new nutrients, but rather a temporary storage pool for nutrients. Where purchased feeds comprise a large proportion of the livestock diet on a given farm; nutrients in this imported feed will comprise a similarly large proportion of manure nutrients. In this case, manure will contain "new" nutrients for the farm. On a whole farm basis, when nutrient imports (feed, fertilizer, symbiotic N_2 fixation, etc.) exceed exports in products (milk, meat, wool, eggs, hay, etc.), nutrient accumulation or losses, or both, will increase. Manure handling and application play a significant role in managing where and when nutrients are used, and can therefore strongly influence the environmental impacts.

In addition to the obvious economic value, manure also improves the physical and biological soil properties that are important for soil quality and crop production, but it is not as easy to estimate a dollar value for this positive aspect of manure utilization. Research has consistently shown that manure applied at agronomic rates can reduce water runoff and the concentrations of soil and associated pollutants by increasing water infiltration into the soil. In Minnesota, researchers observed that a one-time manure application on a landscape with 12% slope reduced rainfall runoff by 0.4 inch in 1993 and 0.13 inch in 1994, which thereby reduced sediment loss 1.1 and 0.1 ton/acre, in moldboard and ridge till cropping system, respectively (Ginting, et al., 1998). The authors also concluded that when manure was applied with proper residue management, they were effective in minimizing runoff and sediment losses during intense rainfall.

As discussed in other sections of this report, livestock manure provides benefits that are difficult to assess economically. A good example is the improvement in soil quality that accrues with long-term manure addition. However, the main economic value of manure usually is associated with the nutrients it recycles on the farm. Regardless of the advantages obtained in recycling the nutrients in livestock manure by using it on cropland, the costs of manure storage and handling typically outweigh the direct economic benefits of reduced commercial fertilizer requirements.

Manure Nutrient Accountability And Whole-Farm Balance

As animal agriculture faces the increasing intensity of environmental challenges, more emphasis is being placed on reduction of nutrient excretion, utilization of nutrient budgets to account for manure nutrients as an economic asset to an operation, and developing nutrient profiles that contribute to effectively managing whole-farm nutrient balances as presented in Figure 3 (Koelsch and Lesoing, 1998;Chandler, 1996;Coffey, 1996;Hansen, 1996;Powers and Van Horn, 1998;Van Horn, et al., 1996;Rinehart, 1996;Van Horn, et al., 1996; Henry, et al., 1995; Van Horn, et al., 1994).

Factors affecting the whole-farm nutrient budget include nutrient excretion rates, nutrient removal by plants, nutrient binding capacity of the soil, and loss of nutrients in the system (Van Horn, et al., 1996). Controlling nutrient losses are particularly prevalent in the Netherlands where mandated target goals for the next decade have intensified the emphasis to maintain a farm nutrient balance that includes the profiles of energy, N, P K, emission of ammonia, carbon dioxide and methane (De Boer, et al., 1977;Mandersloot, et al., 1993;Tamminga, 1996).

The question of whole-farm nutrient balance does not mean that intensive farming necessarily results in "leaky" conditions. Surveys of 1550 Dutch dairy farms in 1992 showed that the best farms with high milk production had N losses no worse than the farms with poorest balance and low milk production (de Vries, 1994). This De Marke experimental farm in the Netherlands has demonstrated that much improved nutrient cycling is achievable in concert with high milk production, if all aspects of the inputs, losses, and recycling of nutrients are addressed.

Losses still occur on the De Marke farm, but at drastically reduced rates than on commercial dairy farms (de Vries, 1994). Due to inherent and, to some extent, inescapable inefficiencies of the food chain, losses must be expected in systems that are more productive than natural ecosystems (O'Connor, 1974).
Dairy and poultry production has very high nutrient use efficiencies, compared to beef and pork production. For example, milk N produced per unit N consumed is generally between 0.2 and 0.3, whereas the ratio for meat N production is closer to 0.1 or 0.15 (Van Vuuren and Meijs, 1987;Worthington and Danks, 1992). That is to say, 70 to 80% of the N eaten by a high

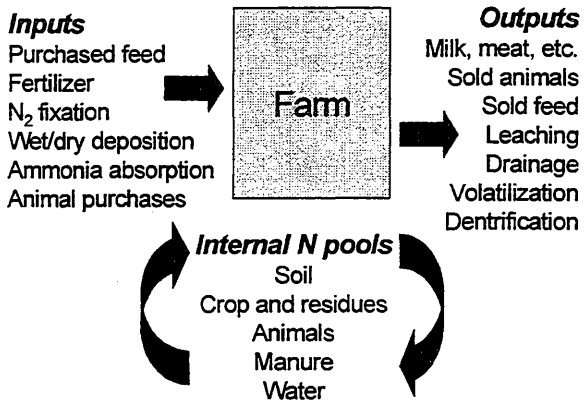

Figure 3. Schematic diagram of whole farm nutrient balance (excluding human waste products and minor transfers).

producing dairy cow is excreted as urine and dung, whereas growing steer excretes about 90%. Adult humans are extremely inefficient in nutrient use, because we excrete about as much as we eat.

Improvements in N use efficiency by dairy cattle can be achieved with nutritional management or ionophores (which selectively suppress bacteria in the rumen that produce ammonia) (Broderick and Shaver, 1994). Dutch researchers suggest that the maximum N use efficiency may be about 0.43 (Van Vuuren and Meijs, 1987), although it is very unlikely such high efficiency could be achieved on farms, due to the wide variety of factors that influence animal productivity, including temperature stress, incomplete feed digestion, variable feed quality, etc. Recent research in Wisconsin has suggested that dairy rations could contain 0.38% P, rather than the currently recommended 0.48% P, which would decrease P excretion in manure by 25 to 30% without reducing milk production or reproductive efficiency (Satter and Wu, 1999).

Thus, it is reasonable to expect that Minnesota dairy farms should be able to achieve acceptable whole-farm balances for these and perhaps other nutrients, with good control of the dairy rations, best use of on-farm crops to limit import (purchase) of supplements, and excellent herd and crop management. This statement is predicated on the availability of sufficient land on which to apply manure.

Phytate is the major storage compound of phosphate in plants. It is poorly available to most monogastric (single stomach) animals, like swine and poultry, and 80 to 90 percent of dietary phytate is excreted in manure. As the result, producers have to add more P to diets of monogastric animals.

Although swine and poultry manure comprises only 18% of total manure in the USA, they account for about one-third of all phosphorus excreted by livestock (Cromwell and Coffey, 1991). In addition, phytate chelates trace nutrients, such as copper and zinc, and reduces their availability (Ravindran, et al., 1995), requiring higher supplementation of these metals in the diets, with higher subsequent excretion.

Two ways of reducing P excretion in monogastric animals are to feed plants with less phytate (for example, low phytate corn grain) or to add phytase to the diet. Phytase is an enzyme that releases phosphate from the phytate molecules. Either approach appears to be effective (Cromwell, et al., 1992;Ertl, et al., 1998).

In livestock operations, the differences between the amount of total feed intake (DM basis) and nutrient composition minus total outputs (amount and composition of milk, meat, eggs, etc weight gain) closely predicts the amount excreted in the urine and feces (Powers and Van Horn, 1998;Van Horn, et al., 1996;Van Horn, et al., 1996). Typically, the feed DM consumed by livestock may be between 60 and 70% digestible, which will result in between 30 and 40% of DM excreted in feces and urine. Predicted total manure (feces and urine) DM excretion for a livestock unit can be estimated by knowing the feed DM intake and estimates for digestibility (Van Horn et al., 1996ab).

A Florida example using an N budget per 2.5-acre units on a dairy operation is shown below (Van Horn et al., 1996):
N-budget:

- INPUTS:
  2.5 acre harvested crops provide 1258 lb N in feed, and 2024 lb N in purchased feed are imported to the farm = total of 3288 lb N, enough to support 10.4 cows

- OUPUT:
  Milk = 970 lb N; New calves born plus their weight gain = 31 lb N; total of 1001 lb N;

- DIFFERENCE (INPUTS - OUTPUTS)
  2287 lb N in the manure

In this system the manure is flushed into a screen separator. The effluent is stored in a storage basin or pond then sprayed on to cropland with irrigation equipment. The solids are used for compost and sold off the farm. Prior to irrigation 158 lb of manure N is lost in composted solids. Forty-eight lb N are volatilized before flushing and 198 lb N volatilized in the storage basin or pond. A total of 82.3% of the original manure N (1882 lb N) will go into the irrigation system. During irrigation 282 lb N are volatilized. Once applied a further 246 lb N are lost in the soil, 51 lb N to the groundwater, but 37 lb of N are gained from rainfall. A total of 1340 lb of manure N can be utilized for crops or 71%. In the same scenario, 96% of the manure P would be returned to the crop fields with only 4% P loss to the compost solids, 2 lb P loss to surface run-off (P environmentally balanced in this case), and 2 lb P gain from rainfall. Ninety-eight percent of total manure K output was accounted for on the irrigation spray fields with 1.3% loss to the compost solids. The cropland received 101 lb of K, 5% of manure K was lost to the ground water and 9 lb K to surface run-off but a 2 lb K gain from rainfall. Over 98% of the manure K was returned to the cropland. Accounting for nutrient losses in Minnesota will be more challenging than in Florida, where it is mandated to document total nutrient flow and this is made easier by use of volume meters on the spray irrigation equipment.

A detailed accounting of nutrient flow was conducted on a Florida grazing dairy operation (Boettcher, 1995). The research found that 23% of the feed N and P was accounted for in milk outputs leaving 77% of feed nutrients excreted. Approximately 24% of manure N and P were excreted in the milking area where 5% of manure N was lost. In the feeding area 28% of the manure N was excreted. The remaining manure N and P were excreted in the pasture and lanes to and from the pasture. A further 45% of the manure N was volatilized but all of the P was available.

Work by (Peterson and Gerrish, 1996) emphasized the importance of designing a cattle grazing system to optimize the distribution of manure nutrients on the pasture and prevent build-up of nutrient concentrations under shade or by water and feeding stations. Placement of water within 600 to 800 ft walking distance of the cattle, design of square paddocks, minimize landscape variation within paddocks, limit time cattle have access to 'comfort' areas and preference for a 12 paddock system were critical criteria. Manure nutrient loss in the pasture access lanes ranged from 13 to 22%.

Table 12. Compositional analyses of manure (feces and urine) by manure storage and handling system on six Waseca County dairy farms, 1997-1998.

	DM	N	P	K	N	P	K
	-------- % DM basis ------				--- lbs/ton* or 1000 gal**		
Farm A: (40 cows tie-stall/summer grazing)							
Manure from barn cleaner	13.0	2.8	.78	1.24	7.3*	2.0	3.2
Farm B: (50 cows tie-stall – partial grazing							
Lagoon from barn and milk house	8.7	5.5	1.0	4.9	40.0**	7.3	35.6
Farm C: (600 cows free stall/flush)							
Flush water (150,000 gal/day)	0.8	11.3	3.8	10.0	7.6**	2.5	6.7
Flush water + manure effluent	1.25	9.6	4.0	6.4	10.0**	4.2	6.7
.Separated solids (to be composted)	25.5	1.7	.47	.67	8.7*	2.4	3.4
Separated liquids to lagoon	1.0	14.0	2.0	10.0	11.7**	1.7	8.4
Farm D: (500 cows free stall/flush)							
1st Stage lagoon	5.2	6.4	1.4	3.3	27.8**	6.1	14.3
2nd Stage lagoon	2.5	8.6	1.6	1.6	17.6**	3.3	3.3
Farm E: (30 cows, tie-stall)							
Lagoon from barn and milk house	2.9	7.2	3.4	1.4	17.6**	8.3	3.4
Farm F: (180 cows free stall/scrape)							
7-day storage pit	21.0	2.5	.61	1.7	10.5*	2.6	7.1

The concepts of nutrient balance is currently being applied in Minnesota at 6 Waseca County dairy farms varying in herd size and manure handling and storage systems (Chester-Jones, 1997). Information on manure composition in storage systems at these farms is presented in Table 12.

Farm A represents a 40-cow tie stall unit where manure is collected from a barn cleaner directly to a manure spreader. Cows are housed inside during the winter and only housed inside during milking throughout the grazing season. Farm B has a 50-cow tie-stall barn where manure is directly pumped to a storage basin (that also holds milk house washings) which is emptied twice a year. Cows are housed inside during the winter and partially grazed from the late spring to early fall. Cows are fed from a feed bunk outside daily. Farm E similarly has a tie-stall barn with manure and milk house washings pumped to a storage basin pumped once per year. The 30 cows in this herd are housed inside year round, but are also fed outside daily.

The other three farms have free stall housing units for their lactating herds. Farm C has a 600-cow free-stall and flush unit. Flush water from a storage basin is pumped to storage tanks. Free-

stall areas are flushed with 150,000 gallons from the storage basin daily. The flush water and manure effluent is pumped into a solid/liquid separator. The liquids return to the storage basin. The solids are stacked on a concrete pad next to the separator where composting process begins. Stacks will be moved into 200 cu yard windrows. After completion of the composting process, the compost is blended with wood chips and used as bedding in the free-stall barn.

Farm D is a 500-cow free stall with a similar flush system but all the flush water and manure effluent are pumped into a primary stage storage basin. The effluent from this storage basin is collected into a secondary stage storage basin used for recycling as flush water. A portion of manure nutrients are recycled continuously through both flush systems. Farm F is a free stall barn that is scraped daily into a short-term storage pit at the end of the barn. The composition of manure in this system closely resembles that of fresh cow manure. Manure is land applied by a side-slinging manure spreader weekly. Storage basins on the other farms are emptied either through an irrigation pipe system or injected beneath the soil surface from a manure tank.

Typical feed, milk, manure, and urine nutrient composition from cows on these 6 farms are summarized in Table 13.

N, P and K Budget

A detailed accountability for nutrient flow was conducted on a Florida grazing dairy operation (Boettcher, 1995). The research found that 23% of the feed N and P was accounted for in milk outputs leaving 77% of feed nutrients excreted. Approximately 24% of manure N and P were excreted in the milking area where 5% of manure N was lost. In the feeding area 28% of the manure N was excreted. The remaining manure N and P were excreted in the pasture and in the lanes leading to and from the pasture. A further 45% of the manure N was volatilized but all of the P was available. For estimating a nutrient budget using concepts previously described, data from 600-cow herd free stall with a flush system (Farm C in Table10) in Waseca County is given below

- INPUTS
  Feed averaged 54 lb of DM/cow daily containing 1.5 lb N, 0.27 lb P, and 0.69 lb K/day.

- OUTPUT
  Milk averaged 68 lb/day contained 0.32 lb N, 0.068 lb P and 0.109 lb K
  Cow body weight gain/day @ 0.2 lb/day which contain 0.002 lb N, 0.001 lb P, and 0.004 lb K;
  TOTAL OUPUT 0.322 lb N, 0.069 lb P, and 0.1094 lb K

- DIFFERENCE (INPUT - OUTPUT)
  Manure nutrients excreted/cow daily = 1.18 lb N, 0.2 lb P, 0.58 lb K
  Manure nutrients excreted /600 cows daily = 708 lb N, 120 lb P, 348 lb K.

Using Florida research, the digestibility of the DM fed to Farm C cows is 65%. Then 35% of DM is excreted (30% in feces and 5% in urine) providing 18.9 lb of manure DM excreted

daily/cow. The manure averaged 83% moisture. Each cow would excrete just over 111 lb of wet manure daily. This excretion rate will change with dietary nutrient concentration, milk production and stage of lactation as shown in Table 5.

The manure from the herd is flushed daily from the free stall barns. The flush water effluent contains 10.2 lb N, 1.8 lb P, and 6.5 lb K/1000 gallons, which is pumped into a solids/liquid separator. The solid manure is piled on a concrete pad next to the separator. This manure averaged 8 lb N, 0.9 lb P, and 2.5 lb K/ton at 74.5% moisture. The liquid effluent returns to a storage basin, which is recycled flush water. The storage basin is pumped twice a year. Over 50% of N, 40% of P, and over 65% of the K is recycled into the flush water storage basin. The solids are composted and blended with wood chips then used for bedding the free stalls. Records of nutrients in harvested crops, land-applied storage basin effluent, and any purchased fertilizer used will be applied to the budget to estimate losses and account for retained nutrients on the farm. The farms used in this project have a high soil fertility base and optimizing the available manure nutrients to maintain the fertility will preclude the necessity of purchasing fertilizers.

Table 13. Compositional analyses of feed, milk, manure and urine averaged across 6 dairy farms in Waseca County, MN representing 1400 cows, 1997-98.[a]

	Dry Matter DM)	CP	N	P	K	Ca	Mg
A. Feed, % DM basis							
Total mixed rations (TMR)	49.0	16.9	2.71	0.47	1.44	0.93	0.29
Pastures (1 farm)	20.0	20.4	3.26	0.48	3.00	0.58	0.22
B. Manure, % DM basis (individual cow composites)							
Confined cows	19.0	15.1	2.41	0.76	0.75	1.90	0.57
Pastured cows	15.5	13.1	2.10	0.86	0.64	2.95	0.74
C. Urine, % as is (Individual cow composites)							
Confined cows	-	4.0	0.62	0.02	0.78	0.002	0.03
Pastured cows	-	2.65	0.41	0.05	0.81	0.001	0.02
D. Milk (Bulk tank composites)	-	3.03	0.47	0.10	0.16	0.14	0.01

[a] Current on-going project; six farms ranging from 30 to 600 cows with varying manure storage and handling facilities; one rotational grazing herd.

The goals of a nutrient budget are to maintain a balance within the limitation of the land base available.

Not Fully Crediting Manure: An Environmental Liability

The negative side of the manure nutrient ledger occurs when manure is over applied, applied at inappropriate times of the year, or unevenly applied. Under these conditions, environmental impacts can be large and the benefit of the nutrients lost for crop growth. The challenges to manage manure so as to maximize the economic benefit and minimize any negative environmental impacts are many. Composition of manure can change during handling and storage and is affected by diet. Therefore, estimating the nutrient content from published values can introduce large errors. A representative sample is necessary at the time of application, but this is difficult to obtain and the analysis may not be available to determine an application rate. However, these analyses will help the farmer determine the appropriate fertilizer rate needed in manured fields.

The next challenge is to get manure uniformly applied. This can be difficult due to applicator limitations, weather conditions, and lapses of time between applications. After manure is applied the amount of nutrients that are in organic forms that need to be released to become available to crops is largely driven by weather (temperature and moisture). In cool dry years crops can run short and in warm wet years there can be an overabundance of nutrients. There can also be release of nutrients in warm autumns or springs when crops are not present to take them up.

Causes of Excessive Manure Application

Excessive application of manure is often due to economic pressures and uncertainties described above. This results in a manure disposal rather than a manure utilization strategy. Also, the advent of economical commercial fertilizers a few decades ago resulted in the trend of less reliance on manure nutrients for meeting crop demand. The use of commercial fertilizers, rather than manure, was appealing to crop producers because the application rate, nutrient density, and application uniformity were perceived to be far superior for commercial fertilizer. On-farm tests confirm that manure application is often quite nonuniform, in part because of equipment limitations and in part due to human error. As a consequence, many producers do not fully credit manure for the nutrients it contributes to their cropping system. As a result, on many integrated livestock and crop farms, there is an excess of nutrients applied to crops because of insufficient reductions in fertilizer nutrient additions on manured fields.

Uncertainty due to weather plays a significant role on lack of manure crediting. Weather can limit timely applications, cause nutrient losses, and reduce nutrient availability to crops. So the uncertainties that farmers face include:

- Am I sure of my rate?
- Am I confident in the nutrient content?
- Is manure applied uniformly?
- Will the weather result in nutrient losses or reduced release?
- Is my storage sufficient to allow optimum timing of my application?

All of these uncertainties result in farmers often reducing the amount of nutrient credit they take from applied manure and in some cases also in over application and environmental degradation.

A combination of short-term manure storage and daily hauling is chosen for many herds due to its low cost (Harrigan, et al., 1996). But when manure is hauled daily, nutrient concentration and uniformity of distribution can be highly variable. Also, delays of manure incorporation can lead to volatilization of N or nutrient loss in runoff water. With this system farmers are often reluctant to reduce commercial fertilizer use because losses are not quantified and they recognize the lack of uniformity in application rate.

The reasons for manure nutrient crediting problems are mainly that too many assumptions were being made that were not true regarding crediting (Schmitt, et al., 1996). These researchers stated that the most important decision manure applicators make is nutrient application rate, which includes knowing the manure application rate, manure nutrient content, and manure nutrient availability index. A comprehensive survey provided strong evidence that very few crop producers had adequate information on their farm to properly credit manure nutrients(Schmitt, et al., 1996).

As a result of improper crediting of manure, excess nutrients on livestock producer's fields have led to numerous environmental concerns. These environmental concerns have recently led to regulatory issues sweeping the state and country, and it is this regulation, either existing or proposed, that is the major driving force behind producers changing their manure nutrient management practices (Schmitt, et al., 1999). These authors also reported that manure testing and application calibration are high educational priorities, yet the most accepted nutrient management strategy being implemented was the development of nutrient management plans.

Nutrient (manure) management plans require each livestock producer to detail--on a field by field (crop by crop) basis--the rate, time, and method of manure application as well as any additional commercial fertilizer that is added to a field. The ultimate objective of each farm's nutrient management plan is to have a set of management practices that meet the agronomic needs of the crop, minimize any environmental liabilities, and provide economic optimization for the whole system.

An article has been written describing a software program developed in Minnesota that meets the overall objectives of nutrient management planning(Schmitt, et al., 1994). An important concept presented in this paper is that there are three major areas of input needed for optimum plans: manure supply, crop nutrient demand in each field, and economic information. While manure supply and economic information are relatively static for an enterprise, the field demand section is somewhat dynamic depending on which crops are selected to be grown in each field and fertilized with manure.

Environmental Liability of Manure

The environmental liability of manure has been associated with degradation of water and air quality. Water degradation is due to influx of manure-derived nutrients, biologically decomposable material, and certain microorganisms. Air quality problems arise due to disagreeable odors and presence of harmful gases. We do not address direct human health impacts due to gases in this section, as this is discussed elsewhere in the GEIS.

Manure has been a liability in several instances because of poor manure application practices, disposal of manure at high application rates, greater concentrations of animals associated with modern livestock production systems, or uncontrolled access of livestock to surface water. The application of manure rates beyond the N and P removal by crops can result in excessively high soil N and P test. Soils in Oklahoma and Texas had high P (85 to 419 ppm Mehlich-3 P) due to application of beef feedlot, poultry, or swine manure (Sharpley, 1996). Repeated application of manure, even at recommended rates for one nutrient, can result in excessive accumulations of other nutrients. The ratio of available nitrogen to phosphorus is often lower in manure than crops require. In addition, because nitrogen can be lost by a numerous pathways, nitrogen losses are often more likely than phosphorus losses. As a result, even at agronomically acceptable manure rates based on crop nitrogen need, excessively high soil phosphorus accumulations can change manure from being a net asset to becoming a net environmental liability.

In addition, with increasing encroachment of suburban development on farms and the development of highly concentrated animal feeding operations, odor has become a widely recognized problem. These water and air quality concerns of manure have resulted in regulations, including the federal Clean Water and Air Acts. However, many scientists now recognize that high soil test levels does not necessarily imply high environmental liability. The question is, "What are the measures for the environmental liability of manure?"

Risk as a Measure of Environmental Liability

The liability of manure to the environment should be considered in terms of risk. The environmental risks from manure management include several types. Much of the press emphasis is on catastrophic/accidental failures, especially large manure spills that kill fish in streams, but there are also impacts from runoff and leaching from manure application to soil that can be more gradual and difficult to detect (Richard and Hinrichs, 1998). Risks related to storage facilities can be minimized by facility design, construction, and management.

Risk of adverse effects on surface water from manure application is related to rate of manure application, thoroughness of incorporation into the soil, slope and soil condition (e.g., water infiltration rate), the rate and intensity of rainfall or snowmelt, proximity to surface water, presence of vegetated buffer strips between the manure soil and surface water, and many other factors. For example, frozen soils allow little water to infiltrate, so the risk of runoff is higher than on non frozen soil, other things being equal. Similarly, properly designed and managed vegetated buffer strips can effectively filter out particulate material in runoff and allow infiltration of some of the dissolved nutrients and suspended microorganisms. On the other hand, unless infiltration is high enough to stop water movement across a vegetated buffer strip, dissolved nutrients are not completely removed, so managing soil nutrient levels in the field is a critical issue affecting risk of surface water impacts.

As with surface runoff, the risk of adverse impacts of manure on ground water are greatly dependent on many variables such as precipitation, geology, landscape, depth to water, and the characteristics of the potential pollutant. Nitrate is highly mobile in soils, whereas phosphorus typically is not. Of course, the environmental risk is not the same over the whole state. The risk

of nitrate entering shallow aquifers is highest in the deep glacial outwash sands in the central part of the state, the fractured limestone aquifers in the southeast, and in shallow aquifers throughout the state, such as those in southwest Minnesota. These risks have been taken into account in developing best management practices recommended for various regions of the state, but need to be considered in each field where manure is to be applied.

Once the soil test is very high, the risk for higher P concentration in water is greater although P loss in water may not be the case. There have been many efforts to relate soil P test with dissolved phosphorus concentration in runoff. In a laboratory study or under rainfall simulation an increase of Mehlich-3 P from 100 to 500 ppm, resulted in increasing dissolved P from 0.2 to 1.9 ppm (Pote, et al., 1996). However, desorption of P is not only dependent on soil P test but also on the duration of contact time between water and the soil and the ratio between water and soil (Sharpley, et al., 1981). Therefore, concentration of dissolved P is greatly dependent on runoff and rainfall intensity. This indicates, that high soil P test did not necessarily means higher dissolved P loss although P concentration in runoff is higher due to higher soil test. The low rainfall runoff from manured soils can cancel out the effects of higher soil P test (Ginting, et al., 1998). Dairy manure application under a chisel plow system did not result in greater molybdate reactive P loss even though concentrations of molybdate reactive P were greater due to incomplete incorporation of manure into soil (Mueller, et al., 1984). These findings emphasize that the hazard of high nutrients is dependent on many variables.

Comparative Risk of Manure and Other Source of Nutrients/Fertility

Water Quality

Inherently, quantity and quality of elements in commercial fertilizer are controlled. In manure however, quality and quantity of elements vary with many factors, such as feed, storage, handling, and many other manure management decisions. Due to its organic nature, manure will have greater environmental risks in term of soluble or particulate organic elements, such as organic nitrogen, organic phosphorus, and oxygen-demanding compounds. Elements in animal feed and organisms from animal digestive tracts caused manure to present a greater risk for water contamination from heavy metal, hormones, and pathogens than commercial fertilizers. Water contamination by manure can occur directly from storage facilities or unprotected animal confinement areas, as a result of land application of stored manure, and as a result of direct deposition on soil or in water by the livestock (Morse, 1996).

As with any other nutrient source, excessive application of commercial fertilizer and manure will increase soil nutrient status, thereby increase risk of losses (King, et al., 1990;Vellidis, et al., 1996). Once the nutrients from both inorganic fertilizer or sources are in the same form and quantity, the risk of losses of nutrient of interest will be the same provided other factors are the same.

Nitrogen Leaching

Nitrate-N leaching from application of commercial fertilizer or manure has generated water quality concerns. There are cases showing that nitrate-N concentrations measured in soil

percolate at 3-ft depth on the 2% slope were higher under commercial fertilizer (8.3 ppm) than 8 ton/acre broiler litter treatments (4.8 ppm) (Wood, et al., 1996).
Nitrate in the subsurface tile drain system is a good indicator that nitrate-N leached is a major concern for groundwater quality. Depending on the amount of water draining, large nitrate-N losses from commercial N fertilizer may occur (Baker and Johnson, 1981;Baker, et al., 1975;Randall, et al., 1997;Randall and Iragavarapu, 1995). In Iowa, averaged across the 4-yr period, mean annual nitrate-N losses were 35 lbs/a (Baker, et al., 1975). Nitrate-N concentrations and losses from continuous corn crops increased with increasing rate of commercial fertilizer N application. Nitrate-N losses were very high when the commercial fertilizer-N application rate exceeded recommendations (Gast, et al., 1978). Annual NO_3-N losses from moldboard plowed continuous corn fertilized with 178 lbs/a N ranged from 1.1 to 156 lbs/a during an 11-yr period in Minnesota (Randall and Iragavarapu, 1995). Even with best management practices, however, nitrate losses can be relatively high, because leaching is the product of the volume of water flowing through the soil and the concentration of nitrate. Minnesota research showed that annual row crop systems (continuous corn or corn/soybean rotation) had much greater losses in tile drainage than did a Conservation Reserve Program planting or alfalfa (Randall, et al., 1997).

Nitrate leaching losses are generally small when fertilizers or manure are applied at recommended times and rates. British researchers found that N-rich manures should not be applied in the fall but should instead be applied in the spring as a top dressing to growing crops otherwise nutrient loss will occur and be more pronounced on coarser textured soils (Smith and B.J. Chambers, 1993). Once the rate exceeds plant demand for high yield, or if application time results in high nitrate supply during times of low crop demand, nitrate losses increase. Some research has shown that over application of poultry manure results in high nitrate in soil solution (Kingery, et al., 1993), groundwater (Adams, et al., 1994), and wells (Ritter and Chirnside, 1982).

Nitrate leaching losses generally are quite low when manure is surface applied to established perennial forages. This is due in part to the higher ammonia volatilization that occurs with surface application, in part to the high nitrogen demand of the crop, and in part to the lack of water movement below the root zone. Perennial crops use water and nitrogen over a longer period than annuals, and therefore nitrate leaching losses are lower than in annual crop systems. This conclusion, of course, is tempered by soil texture. For example, no accumulation of nitrate in a fine textured soil was measured when a grass hay crop received either high rates of manure slurry or nitrogen fertilizer, however, soil water nitrate concentrations did increase on a sandy soil when nitrogen rates of either source exceeded about 200 lb/a (Russelle, et al., 1997).

Phosphorus Leaching

Phosphorus has been considered immobile in soil (Brady, 1984). The most prevalent form of plant-available phosphorus, the phosphate ion, interacts chemically with calcium, iron, and aluminum in soils, and only negligible amounts of P are usually transported to subsurface tile lines (Kladivko, et al., 1991). Phosphorus losses in subsurface tile drainage from soils receiving commercial P fertilizers range widely depending on various soil properties. Average soluble P concentrations were 0.63 ppm during spring to fall and 0.42 ppm during fall to spring on a sandy

soil used for citrus production in Florida (Calvert, 1975). In Ontario, phosphate-phosphorus concentrations and losses from intensively cropped sandy and silty clay soils ranged from 0.015 to 0.072 ppm and 0.03 to 0.27 lb/a, respectively (Miller, 1979). On organic soils in the same study, phosphate-phosphorus concentrations and losses were much higher, ranging from 1to 18ppm and 1.8 to 41 lbs./a, respectively. A 3-yr study on a silty clay soil showed a mean soluble inorganic P concentration of 0.04 ppm and annual losses of 0.39 lb/ac (Bottcher, et al., 1981).

Preferential flow has been cited as greatly affecting P losses in some soils. Phosphate-P concentrations and losses from a clay loam soil with extensive cracking averaged 0.24 ppm and 0.42lb/acre/year or 3% of the total fertilizer P added (Gaynor and Findlay, 1995). In Quebec, total P concentrations ranged from 0.01 to 1.17 ppm in tile drainage with higher P concentrations related to samples taken immediately after extended dry periods when soil cracking could have enhanced preferential flow (Beauchemin, et al., 1998;Sims, et al., 1998)

Research documenting P losses in subsurface tile drainage from soils receiving manure is limited. In New York, annual application of dairy manure at rates of 0, 16, and 89 ton/acre (wet) to a calcareous, glacial till, silt loam soil resulted in 3-year average inorganic P concentration of 0.011, 0.014, and 0.218 ppm, respectively (Hergert, et al., 1981). The initial Olson P soil test was 11 ppm and after 3 year was unchanged with the 16 ton/acre manure rate but was increased to 35 ppm by the 89 ton/acre.

Recent research has indicated that phosphorus losses via leaching are higher with organic phosphorus sources than with inorganic sources (Eghball, et al., 1996). Suspended or dissolved organic phosphorus forms may move through the soil without being influenced by chemical precipitation. Thus, it appears that the risk of phosphorus leaching to ground water or to surface water through tile drains may be somewhat higher with manure than with commercial fertilizer. However, there are little data at present to indicate that these impacts are ecologically significant or are occurring in Minnesota soils.

Leaching of Pathogens

Manure poses a greater risk of pathogen impacts in the environment than commercial fertilizer because manure contains pathogens associated with fecal material. Storage conditions can either increase or decrease viable pathogen concentrations in manure. Coliform bacteria movement through the soil profile and into drainage water has been associated with flow through large pores (macropores), which reduces the soils ability to retain bacteria and viruses (Smith, et al., 1972). Well-structured soils allowed rapid downward movement of coliform bacteria when accompanied by high water addition rates (Smith, et al., 1985).

Rapid downward movement of pathogens associated with manure can occur within hours of manure application. For example, 30- to 900-fold increases in fecal bacterial concentrations in drain tile out flow from a pasture on sandy loam soil occurred within 2 hours of spreading liquid manure (Evans and Owens, 1972). In Ontario, sandy loam, silt loam, and clay loam soils, water quality degradation from bacterial contamination occurred within 20 minutes to 6 hours of liquid manure spreading at 8 of 12 sites (Dean and Foran, 1992). A field that was tilled just prior to manure application had insignificant microbial contamination. Shearing of the macropores by

tillage appeared to limit microbial transport (Dean and Foran, 1992), and may dramatically attenuate bacterial concentrations in leachate water (Smith, et al., 1985). In Kentucky, the potential for ground water contamination by fecal coliform bacteria depended more on soil structure and water flow than the mortality rate within 2 months after a manure application (Smith, et al., 1985). Thus, the risk of pathogen impacts on ground water that manure application poses is strongly site-dependent, and clearly related to soil structure and disturbance.

Nitrogen in Runoff Water

Soil nitrogen from both commercial fertilizer and manure is subject to loss in runoff water. Runoff losses of nitrogen are lower when manure is incorporated in the soil, applied at lower rates, applied at proper timing. In a simulated rainfall runoff study 7 days after fertilizer and manure application, the concentration of nitrate-N, ammonium-N, total N, were higher from plots that received inorganic fertilizer than those receiving manure (Edwards and Daniel, 1994). Poultry litter application increased mean concentrations of total N in runoff during the following 16 weeks in both no-till (15.4 ppm) and tilled treatments (16.7ppm)(Heathman, et al., 1995). More important in terms of aquatic life is the concentration of ammonium-N. A study evaluated the effects of fertilizer rate, hog manure rate and time of application on ammonium-N losses in surface runoff. Plots receiving chemical fertilizer plus hog manure had a significant increase in ammonium-N losses as compared with the plots receiving fertilizer only (Gangbazo, et al., 1995). Due to the fall manure effect, NH4+-N loads increased by three-fold after the first year, 1.46 times between the first and the second year, and 1.14 times between the second and the third year for corn when compared with the treatment that received only fertilizer.

Phosphorus in Runoff Water

Phosphorus is a primary nutrient that limits growth of undesirable aquatic plants in lakes, so phosphorus runoff has long been a topic of concern in Minnesota. Concern over phosphorus losses from commercial fertilizer or manure is primarily related to off-site transport of surface runoff, erosion and associated phosphorus-enriched sediment entering streams and lakes. Livestock operations can have a significant effect on total phosphorus runoff. Streams in watersheds with high livestock population had a 50-fold total phosphorus loss compared to forested watersheds (Duda and Finan, 1983).

The concentration of phosphate-phosphorus and total phosphorus of plots receiving inorganic P fertilizer can be higher than the plots that received manure (Edwards and Daniel, 1994). Phosphorus concentrations in runoff from fields that have been recently fertilized with commercial fertilizer and manure are often very high and decrease with time (Edwards and Daniel, 1994). The longer inorganic phosphorus is in contact with soil, the more likely it will form compounds that are less soluble, and become essentially immobile.(Shreve, et al., 1995)

Due to phosphorus immobility in the soil and lack of incorporation manure application results in accumulation of phosphorus at the soil surface (Ginting, et al., 1998;Kingery, et al., 1993). There have been many efforts to relate soil phosphorus test levels with dissolved phosphorus concentrations in runoff. In one study, an increase of Mehlich-3 phosphorus (one of many

typical soil test methods used in the USA) from 100 to 500 ppm, resulted in dissolved phosphorus increasing from 0.2 to 1.9 ppm (Pote, et al., 1996). Poultry litter application increased concentrations of total phosphorus in runoff during the 16-week study with no-till (5.8 ppm) and tilled treatments (6.1 ppm) (Heathman, et al., 1995). However, desorption of phosphorus is not only dependent on soil phosphorus test, but also on the duration of contact time between water and soil and on the ratio between water and soil(Sharpley, et al., 1981). Therefore, concentration of dissolved phosphorus is greatly dependent on runoff and rainfall intensity. High soil phosphorus tests do not necessarily mean higher dissolved phosphorus losses. Because manuring can improve water infiltration rates, low rainfall runoff from manured soils can cancel out the effects of higher soil phosphorus test (Ginting, et al., 1998;Mueller, et al., 1984).

These interacting effects have been combined recently into a phosphorus risk index, which is being promoted in some states (Lemunyon and R.G. Gilbert, 1993). This index takes into account the soil phosphorus test, slope, proximity to surface water, and all the other relevant management and site characteristics to produce a numerical index that indicates risk of surface water damage. Thus, a flat field with very high soil test phosphorus may have a low risk index, because water runoff is unlikely, unless it is quite near to surface water. Land Conservation personnel from Trempealeau County, Wisconsin, indicate that farmers apparently understand and accept this index, which is being used to develop manure management plans on those farms.

Carbon in Runoff Water

Soluble and particulate organic constituents in manure or sewage sludge results in greater risk loss of carbon in surface water quality than commercial fertilizer. Loss of carbon will increase chemical oxygen demand and biological oxygen demand of water, reducing oxygen for fish and other aquatic organisms. In a rainfall simulation study, highest concentrations of chemical oxygen demand (COD) occurred in runoff from plots treated with poultry litter (Edwards and Daniel, 1994). In a different rainfall simulation study, concentration and loss of chemical oxygen demand in runoff was higher from poultry littered plots (428 ppm, 36 lb/acre) compared to N fertilized plots (88 ppm, 14 lb/acre) (Nichols, et al., 1994).

Pathogens in Runoff Water

Manure poses a greater risk of pathogen impacts on surface water than commercial fertilizer because manure contains pathogens associated with fecal material. Poultry manure contains pathogens related to human diseases (Bhattacharya and J.C. Taylor, 1975;Fontenot and Webb Jr, 1975;McCaskey and Anthony, 1979). Poultry manure application on pasture increased the amount of fecal coliform in runoff water (Giddens and Barnet, 1980). In a watershed in eastern Nebraska, variation of fecal bacteria has been related to livestock management and manure handling practices (Baxter-Potter and W.W. Gilliland, 1988). Virus has also been reported in poultry litter (Sims and D.C. Wolf, 1994). Due to virus small size and weak interaction with clay and organic matter, virus can be potentially leached through soil, into ground water, and surface water. Bacteria leached to less extent due to its larger sizes and its interaction with soil particles (Angle, 1994).

The pathogenic hazard of manure and sewage sludge is greatly dependent on the persistence of pathogens in soil. The approximate survival time of pathogens in soil (Kowal, 1986) is:

- fecal coliform ranged 8 – 55 days
- Enterovirus ranged 70-170 days
- Poliovirus ranged 70-90 days
- Helminth eggs >1000 days,

Using source tracing techniques based on differences in antibiotic resistance of bacteria in manure from different types of livestock, the relative contribution of different livestock to bacteria in streams is separated. See Section on *Comparison of Causes of Impaired Rivers and Streams for Various Land Uses* in the Water Resources report for more description.

Animal manure contains substances that protect virus from inactivation, so viruses may persist for prolonged periods of time if stored under non-aerated conditions. At times of land application, this may lead to environmental contamination with pathogens (Pesaro, et al., 1995). On the other hand, the persistence of hepatitis A virus was inactivated more rapidly in the presence of cattle manure slurry and with swine manure slurry (Deng and Cliver, 1995). Sewage sludge may need decontamination prior to agricultural use by raising pH (Ghiglietti, et al., 1997). Treating sewage sludge with lime increases pH and exothermic reactions, which further reduces pathogens (Sloan and Basta, 1995). Treated biosolids can be safely applied to land with minimal off-side impacts to surface waters (Harris-Pierce R.L., et al., 1995). Would similar treatment of livestock manure be economic and effective? There clearly is a need for more research on the presence, pathogenicity, persistence, impact, and management of microorganisms in livestock manure.

Heavy metals

Like sewage sludge, manure poses a risk to soil and water contamination with heavy metals. The poultry industry adds compounds with as arsenic, cobalt, copper, iron, manganese, selenium, and zinc to poultry feed (Tufft and Nockels, 1991). Copper has been used as a growth promoting additive in pig diets (Braude and Hosking, 1975;Prince, et al., 1979). Chromium is used for growing-finishing pigs (Page, et al., 1993) and zinc at the pharmacological level is used to improve pig performance (Hahn and Baker, 1993). Swine fed with 250 ppm copper produced manure containing 61 ppm copper (Brumm and Sutton, 1979). Application of poultry manure resulted in elevated levels of Cu and Zn in soils (Kingery, et al., 1993).

Metal uptake by plants is dependent on solubility and exchangeability of the element. Plant available heavy metals that may be contained in the waste need to be determined (Berti and L.W. Jacobs, 1996). Solubility and exchangeability of calcium, magnesium, iron and manganese in soils treated with sewage sludge were not significantly different from those treated with cowpea green manure or chicken manure (Li, et al., 1997). Heavy metals such as copper could function as a bactericide in soil. Addition of sludge with low or high content of heavy metals (chromium, silver, copper, mercury, and lead) and organic pollutants reduced atmospheric nitrogen fixation activity (Martensson and Torstensson, 1996).

Other Aspects

Sewage sludge may result in phytotoxicity to germination and seedling growth, although some researchers have shown otherwise (Warman and Termeer, 1996). Application of composted cow manure or activated sewage sludge also resulted in significant increases of grubs (Green June beetles) in 1 of 2 years studied (Potter, et al., 1996).

Air Quality

Manure poses greater risk for air pollution than commercial fertilizer, especially with regard to volatile organic substances and odor. Air quality concerns related with manure are the volatilization of ammonia, volatile organic compounds, and reactive organic compounds from decomposition of manure and bedding (Morse, 1996). Other gasses produced from manure include sulfur compounds, methane, and nitrous oxide (Kuroda, et al., 1996).

Odors can be generated on livestock production farms from three major source areas: production facilities; manure treatment systems; and fields where manure is applied (Westerman and Zhang, 1997). Under anaerobic conditions, bacteria break down the manure into simple organic acids and finally produce methane, other gases, and foul smelling odors (Day and Funk, 1998). From a swine production facilities, 40 organic compound were identified in liquid and gas samples, of which 27 volatile organic compounds were confirmed to contribute to decreased air quality in the vicinity of the facility (Zahn, et al., 1997).

Odors and noxious gases can be a major problem during land application of stored manure. Storage method and presence of a cover, animal diet, application method, weather conditions, and other factors affect the concentration and dispersion of gases. The odor issue is treated in much more detail in the Manure and Odor Topic area.

Maximize the Positive and Minimize the Negative Impacts of Manure

Improving Livestock Manure Storage and Treatment Facilities

A treatment system is designed and operated for biodegradation — converting organic matter (feed, bedding, and body byproducts) in animal manure to more stable end products.

Anaerobic Lagoons

In Minnesota, true lagoons are not common. Earth basins (which are storages, not lagoons) are more common for swine, dairy, and beef operations even those using flushing and recirculation.

Anaerobic lagoons handle high loading rates but give off some septic odors. Well designed and managed lagoons have a musty odor. Foul odors indicate malfunction. Aeration of the top few inches of a lagoon may start aerobic conditions and reduce odors but can be costly and difficult.

Mineral buildup, resulting from water evaporation leaving dissolved salts behind, requires periodic dilution and pumping. Water from roof drains and other sources are often added to a lagoon.

Anaerobic lagoons liquefy and break down manure solids, but not all manures added are completely degradable. Sludge accumulation depends on management, environment, manure characteristics, and loading rate. After about 2 years, sludge buildup rate in a properly functioning lagoon may decrease. Because complete treatment is not practical, the sludge is periodically pumped or drained to cropland. Enough land area must be available to land apply lagoon effluent and sludge.

Methane can be produced during anaerobic digestion. This process converts the biodegradable organic portion of animal manure into biogas (a combination of methane and carbon dioxide). The remaining semi-solid is relatively odor free but still contains all the nitrogen, phosphorus, and potassium originally present in the animal manure. However, half of the nitrogen can be lost after 72 days of storage in a holding pond. The solid portion of the semi-solid can be separated and used as bedding.

Anaerobic digestion is a stable and reliable process, as long as the digester is loaded daily with a uniform quantity of manure, digester temperature does not fluctuate widely, and antibiotics in the manure do not slow biological activity. Major problems with digestors include manure handling, pumping, grinding, mixing, and screening miscellaneous debris. Gas leakage (methane is explosive at 5%-15% in air) and pipe and valve corrosion have also been problems. To reduce these problems, obtain competent engineering design and purchase quality materials.

Advantages

- In addition to labor savings from removing liquid manure from buildings, labor can also be saved by using irrigation to dispose of liquids.
- Long storage times permit pumping flexibility while bacteria break down solids.
- The high degree of stabilization can reduce odors during spreading.
- High nitrogen reduction is an advantage if manure used must be on small areas.

Disadvantages

- Odors are produced if environmental or management changes reduce biological activity lagoons are sensitive to sudden changes in temperature and loading rates.
- Where winter water temperatures are near or below freezing, lagoons experience spring and fall turnover (bottom water rises and top water drops). After a winter of little bacterial action due to low temperatures, odorous material from the lagoon bottom rises to the surface. Higher spring water temperatures increase microbial action, and foul odors are generated during the bacterial buildup stages.
- Because higher temperatures improve manure decomposition, anaerobic lagoons work best in summer and in areas without cold winters.
- Fertilizer value reduction is a disadvantage if lagoon effluent is used to fertilize crops. Up to 80% of the nitrogen is lost in a lagoon. Phosphorous may precipitate to the bottom but can be recovered when sludge is removed.

Aerobic Systems

The aerobic treatment process requires that free oxygen be made available to microorganisms in the manure through mechanical or natural aeration. The systems available to producers are naturally aerated lagoons, mechanically aerated lagoons, oxidation ditches and composting.

Advantages

The major advantages of aerobic treatment systems are:

- Relatively odor-free operation.
- Fast rate of biological growth.
- Rapid adjustment to changes in loading and temperature.
- Elevated temperatures are not required.

Disadvantages:

- Oxygen is required.
- High production of biological sludge.
- Relatively high space, maintenance, management and energy requirements for artificial oxygenation.
- Shallow depths require large surface area.

Currently, the aerobic process is considered uneconomical for livestock operations. But with the advantage of odor control, aeration may become more popular.

Composting

Composting is a biological process in which organic matter (volatile solids) is degraded to a relatively stable humus-like material. Composting reduces manure volume. A study showed that approximately 50% of the carbon was lost from microbial respiration, which contributed to the overall volume reduction associated with composting (Eghball, et al., 1997). Manure composting can be either anaerobic or aerobic, but modern composting is usually limited to aerobic systems.

Objectives of composting are to:

- Stabilize putrescible organic matter.
- Kill pathogens and weed seeds.
- Conserve the nitrogen, phosphorus, potash, and resistant organic matter found in the raw material.
- Produce uniform, sterile, and relatively dry end produce, which free from odors.
- Conduct the process free from insects, rodents, and odors, and as inexpensively and dependably as possible.
- Produce a valuable fertilizer and soil conditioner.

Composting is a biological process, so environmental factors influence organism activity and determine the speed and extent of the composting cycle. The most important factors are material particle size, moisture content, aeration, temperature, and initial carbon-nitrogen ratio. Ideally,

the smaller particles, the greater the surface area, and the more access for the degrading organisms. Particle size may need to be reduced by grinding, such as crop residues like corn stalks.

The moisture content for optimum composting is 50%-60%, depending on particle size and aeration. If aeration is maintained, the moisture content can be above 60%. At high moisture content, voids fill up with liquids, and aeration is hindered. Low moisture levels retard or stop microbial activity, although some composting occurs with moisture as low as 25%.

If adequate aeration can be maintained despite high moisture content, fresh animal manure can be composted directly because of favorable particle size. Over-aeration has no advantage and tends to reduce temperatures. Aeration can be accomplished by forced air or turning.

High rate composting in a large rotating drum is another common method. Forced air is supplied to drums up to 12' in diameter and 8' long. The material rolls in these drums for 2 to 10 days.

High temperatures are sustained long enough in most operations to destroy pathogens, weed seeds, and insect eggs and larvae. Generally, the interiors of compost piles reach these elevated temperatures but not the outer surfaces. Turning the pile mixes the two areas.

Composting also depends on microbe food and nutrient supplies. Mineral content of livestock manures is usually adequate. Carbon is an energy source, and with nitrogen also builds protoplasm. More carbon than nitrogen is required, but activity decreases with too much carbon. The proportion of carbon to nitrogen is the C/N ratio. A C/N ratio of 30:1 is about optimum for rapid composting. With C/N ratios lower than 20, nitrogen is lost during composting and escapes as ammonia. In animal manure, the C/N ratio is usually 10-15:1. Composting animal manure with bedding or other plant wastes, or with municipal wastes containing large amounts of paper, has been successful. If the pile does not reheat after turning, the process is complete. Finished compost is dark brown to black in color, practically insoluble in water, has a slightly earthy to musty odor, and has a loose friable texture.

Composting, though sometimes expensive, degrades organic material to inert humus with some fertilizer value. Usually composted livestock manure contains 0.5% nitrogen, 0.4% phosphorus, and 0.2% potassium. While not rich in fertilizer value, the material is odorless, sterile, and weed free. Adding compost improves soil moisture retention of light soils and pore volume of heavy soils. Compost-improved soils have a relatively stable structure and are erosion resistant.

Addressing Constraints and Strategies in Sustainable Manure Management

If manure nutrients are to be more efficiently used in agricultural crop production, some or all of the constraints must be addressed. Table 14 summarizes those constraints and suggests some possible remedies (Richard, 1998).

The challenges of specialization and scale in livestock production become a constraint when individual livestock farms are unable to economically utilize the nutrients in their manure. However, these same challenges can be transformed into opportunities. Concentrated sources of manure tend to generate environmental, social, or political problems, which often help clarify for producers the need to create and market manure products for off-farm uses. There are also economies of scale in some of the treatment and processing technologies, which reduce the costs of those technologies for larger operations. Groups of smaller farms can also achieve similar economies of scale by cooperative manure management efforts, as currently occurs in the U.S.A.

Nutrient density is a particular problem when liquid manure must be hauled over a distance. For highly dilute systems, pipeline delivery via umbilical cords or buried lines reduces application costs considerably. Nutrient concentration can also be increased through design of collection systems, by minimizing use of flush water in liquid systems and bedding in solid manure handling systems. A particularly effective nutrient concentration technique for swine manure is the fecal-urine separation developed in Japan, that concentrates 55% of the N and 95% of the P in the fecal matter, which represents only 27% of the total mass (Person, 1997). Further

Table 14. Constraints and strategies to increase sustainable manure management.

Constraints	Strategies
Specialization	Promote integrated crop and livestock farming.
	Market manure products to specialized crop farmers.
Scale	Decentralize livestock production facilities.
	Utilize scale (for large farms or aggregations of smaller farms) to capitalize manure treatment and processing facilities.
Low nutrient density	Concentrate nutrients using solid manure collection, liquid/solid separation, composting, drying and/or pelletization.
	Install pipelines for efficient transport of liquid manure.
Spatial variability	Homogenize during processing, treatment, and application.
Temporal variability	Stabilize nutrients in organic forms using composting, anaerobic digestion, drying and/or pelletization.
	Characterize bioavailability for different processes and products.
Application variability	Develop improved application technologies.

Source: (Richard, 1998)

concentration of nutrients in this and more conventional solid manure collection systems, along with homogenization to promote uniformity and stabilization to facilitate storage and handling can be accomplished through such established technologies as composting and pelletization.

These later approaches, while they facilitate efficient nutrient utilization on an integrated crop and livestock farm, they can also provide an attractive way to market manure from livestock farms to specialized crop farms or even non-agricultural markets. Compost is already being marketed this way by a number of facilities. The value of this product-as a fertilizer and soil amendment for horticulture-is well established. Specially processed compost is now also being used as a pesticide substitute, providing plant pathogen suppression equal or better than chemical pesticides for several common soil borne diseases (Hoitink and Fahy, 1986;Hoitink and Grebus, 1994), while compost extracts are being used for foliar fungal disease control (Brinton, et al., 1996;Weltzhien, 1992).

Composting has proven very attractive for livestock producers for a variety of reasons, including the ready availability of proven technology (Richard, 1992;Richard and Walker, 1990), the high value and ready acceptance of the product, and the ease of adaptation to many different sizes and types of livestock operation (Rynk, et al., 1992). The primary disadvantage to traditional batch composting is the high cost of a dry, carbonaceous bulking amendment, such as sawdust or straw, to absorb excess moisture present in the manure. Liquid - solid separation technologies can aid with this problem, particularly with dairy and cattle manures where the solids fraction has a relatively large particle size (Zhang and Westerman, 1997). Bio-drying systems use the heat generated by composting to allow sequential additions of manure, effectively recycling the bulking amendment for multiple batches of manure (Richard, 1998;Richard and Choi, 1996).

The other potential concern with composting is the possibility of market saturation, as the high price currently received for the product may drop as many more compost production facilities are built. Market development, especially for such added value characteristics as pathogen suppression, will prove important for this technology's future success.

Another option for turning manure into a marketable product is through drying, with or without pelletization. Pelletization has seen increasing use in the U.S.A. for sewage sludge, and has received good farmer acceptance. In the Netherlands, where pollution from excess manure nutrients is also a serious concern, a government initiated program is pelletizing manure for both domestic and export markets (Voorburg, 1993, cited in (Gassman and Bouzaher, 1995). Pellets are easy to store and can be applied with fertilizer equipment. The disadvantages to this method are the high energy costs associated with drying the manure, and the need for large centralized facilities to achieve economies of scale.

Research, Development, and Demonstration

To further minimize the negative impacts of manure storage, handling, and storage, further research, development and demonstration are necessary. Some research aspects are:

- Research dietary manipulation to reduce total mass and nutrients (increased retention) and odor control or adjustments.

- Determine sulfur mass balance where inputs could be reduced in order to reduce hydrogen sulfide emissions.
- Develop handling and separation methods to reduce phosphorus in the manure
- Research seepage from storage units including concrete and earthen basins and both liquid and solid storage units.
- Test effects of tile placement around concrete and earthen storage units and their longevity, sizing, effectiveness, and construction techniques.
- Develop low cost treatment system for reducing biological oxygen demand/chemical oxygen demand and/or odor control.
- Develop storage agitation techniques to increase the uniformity of manure for land application
- Develop easy calibration methods for land application equipment
- Develop land application equipment with more uniform application to decrease the volume.
- Determine nutrient availability during the first cropping season after application and the amount carried over to next cropping season.
- Research effects of surface tile inlets on manure applied land on stream and river quality.
- Develop systems for fly control.
- Develop alternative manure management systems.

Alternative Uses for Manure

While recycling manure nutrients via crop production makes a great deal of sense; an even more efficient strategy can be to process the manure directly into animal feed. The nutrient content of manure has been shown to be 3 to 10 times more valuable as animal feed than as plant nutrients. While the ability of ruminants to utilize non-protein nitrogen gives them an advantage over other livestock (Smith and Wheeler, 1979) (Zinn, et al., 1996), refeeding has also been successful with poultry and swine (Day, et al., 1980;McCaskey, 1995). The principal concern with refeeding has historically been animal health concerns, but the use of drying, ensiling, heat treatment, and chemical treatment have all been effective at eliminating disease transmission (McCaskey and Anthony, 1979). However, the costs of processing combined with lower nutrient values from some processing approaches (such as drying and heat treatment) have limited the application of this strategy primarily to the refeeding of poultry manure and litter to poultry and ruminants (Hauck, 1995). Further discussion of manure use as a livestock feed can be found in Section on the *Use of Processed Manure as Feed* of the Animal Health Report.

A somewhat less direct means of converting manure into high protein human foods is through the use of aquaculture and fish ponds. Waste treatment in ponds has been an established practice for centuries in parts of Asia and are also currently found in Europe and North America (Edwards, 1980;Polprasert, 1989). Fish have a high feed efficiency ratio and with proper design the biological treatment processes in ponds can effectively address most odor and water quality issues, although pathogen survival and transmission can still be a concern with untreated manure (Polprasert, 1989).

The other important product that can be derived from livestock manure using currently available technology is energy. Anaerobic digestion converts much of the energy in manure to methane gas, which can be burned for space and process heating and/or converted into electricity with an engine generator (Badger, et al., 1995;Hashimoto and Chen, 1981;1989). In addition to the recoverable energy produced, anaerobic digestion also reduces the odor content of the manure. While anaerobic digestion has been demonstrated as effective with a wide variety of manures throughout the world, the relatively high capital costs and management skills required have limited its application. Because anaerobic digestion converts manure solids to gas, the moisture content of the manure increases during digestion. On farms where land application of digester effluent is constrained by limits on land availability, liquid-solid separation followed by further treatment of both the liquid and solid streams would probably be required.

While the previously described approaches to livestock manure management are available today, there is a number of other promising strategies that should be considered for the future. Of particular interest are those that use applied biotechnology to generate value-added products from manure. Composting and anaerobic digestion are two current examples of this approach, and in both cases advances in processing efficiency and product value are likely benefits from additional research. While composting biologically utilizes the energy in manure for drying, minimizing or eliminating the need for liquid treatment and disposal, anaerobic digestion biologically converts that energy into a combustible gas. In the future we may see manure converted into even more valuable products, including proteins for animal feed through algal or other microbial conversion processes (Calvert, 1979;Hauck, 1995;1989), and enzymatic conversions to alcohol or other chemical feedstock Spellman (1994). While such systems may seem difficult to imagine today, with future research the concentrated energy and nutrients found in livestock manure are certain to be seen as a valuable resource rather than a waste.

Sharing Cost and Technical Support

Reduction of environmental risk from manure could be achieved by increasing incentives for farmers to better utilize their manure. This would include cost sharing for improving storage and handling facilities as well as developing and implementing good nutrient utilization plans. These plans should include identifying the necessary cropped area for environmentally sound utilization based on the amount of manure and crop sequence anticipated. Manure management has the potential to impact Minnesota crop production in many different ways. Probably the greatest manure management decision for livestock producers is which field or crop will receive the manure. Manure rates are generally determined by regulations, although a producer's ability to implement rate recommendations will be constrained by both equipment and technology. Manure application methods and timing are primarily logistical decisions based on what equipment is available and the length of storage capacity on a farm. Thus, deciding which crop will receive manure and then choosing the appropriate application rate is paramount. Agronomic, environmental, economic, and logistical issues all enter into the decision process.

Cropping Systems

Typical crops in Minnesota, such as corn, soybean, alfalfa, and perennial grasses, provide different benefits and liabilities in determining the best manure management plan for a farm.

Manure has traditionally been considered to be best utilized with corn. Corn has the greatest nitrogen recommendation of crops commonly grown in Minnesota and therefore seemingly presents the greatest economical advantage for replacing commercial fertilizer with manure. Survey research indicated that over 80% of all swine manure was applied to corn (Schmitt, et al., 1996). However, as the environmental issues increase, along with the evidence of manure being strongly under-credited, the justification of exclusively targeting corn is weakening. On a crop removal basis, legume crops in Minnesota, like alfalfa, remove significantly more nitrogen and similar amounts of other nutrients than corn. Applying manure for legumes can be considered an environmental safeguard when the manure is properly managed.

Amount of N, P and K removed by various crops are given in Table 15. When only grain is removed, many nutrients are left in the residues but are temporarily tied up in them and are not readily available. Estimate nutrient requirements for one crop year by assuming complete crop removal. Manure nutrients especially nitrogen are utilized more efficiently by grasses and cereals than by legumes. Legumes get most of their nitrogen from the air, so additional nitrogen is not usually needed.

Research provided agronomic and environmental evidence to the feasibility of applying manure for alfalfa (Schmitt, et al., 1994). Although some farmers report excellent results with applying manure slurry to established alfalfa, most dairy farmers avoid this for a variety of reasons, including the potential for stand damage (Schmitt, et al., 1999). The optimum manure application time is prior to seeding of alfalfa (Schmitt, et al., 1994). This application time minimized the foliage "burn" potential associated with topdress applications and places the immobile nutrients into the topsoil for more efficient use by the plant. Significant amounts of nitrogen can be removed with alfalfa and, more importantly, the plant compensates its nitrogen fixation amounts by removing more of its nitrogen from the soil when soil nitrogen is present. Interestingly, the forage yields of manured alfalfa resulted in yields greater than established fertilizer response curves would have predicted, thus, the benefits of applying manure extend beyond the nutrient additions. Similar results were also independently measured in Wisconsin research (Kelling and Schmitt, 1996).

While applying manure for alfalfa resulted in encouraging agronomic and acceptable environmental findings, many livestock producers in a corn-soybean rotation were curious if similar results would occur by adding manure before soybean. The principles of manure for soybean parallels that of manure for alfalfa, and the research results were very similar. Schmidt and colleagues investigated manure effects for soybean and measured increased soil nitrogen removal compared to corn, increased seed yields compared to unlimited fertilizer treatments, and better residue management in applying manure into corn residue for the following soybean crop. Downside risks included increased lodging and a more favorable environment for disease incidence if the causal organisms are already present in a field.

Another major crop grown in Minnesota is grass hay. Again, as we search for alternative cropland to apply manure, grass hay was determined to be a viable alternative, especially for producers forced into summer applications of manure due to storage restrictions. We selected reed canarygrass as the most ideal grass for manure applications due to its yield potential, ability to grow under wet or dry soil conditions, its tolerance to salt burn with topdressed fertilizer, and

its persistence in the field. These results confirmed that manure applications to a grass crop could be an excellent environmental and agronomic choice. Crop yields are enhanced with manure compared to unlimited fertilizer applications. This grass persists well, even under very high application rates of manure, and the nitrogen removal rates are more than twice as great as corn, thus providing a good crop for recycling of nutrients. Other grass species may provide similar results, but earlier work in Minnesota indicated that reed canarygrass was the best choice for nutrient removal and persistence.

Thus, there are a number of opportunities to use manure nutrients efficiently on a variety of crops. Farmers and their advisors need to be aware of the options they have in selecting fields for manure application.

Table 15. Amount of nutrient removal for various crops. Values are for the total above-ground portion of the plants (MWPS, 1985).

Crop	Yield	N	P_2O_5	K_2O
		----------lb/acre----------		
Corn	80 bu	121	42	77
	100 bu	160	60	120
	150 bu	185	80	215
	180 bu	240	100	240
Corn Silage	16 tons	130	45	102
	32 tons	200	80	245
Soybeans	30 bu	123	32	52
	40 bu	180	45	80
	50 bu	257	48	120
	60 bu	336	65	145
Grain sorghum	4 tons	250	90	200
Wheat	40 bu	70	40	50
	60 bu	125	50	110
	80 bu	186	54	162
Oats	80 bu	75	35	95
	100 bu	150	55	150
Barley	65 bu	74	32	63
	100 bu	150	55	159
Alfalfa	4 tons	180	40	180
	8 tons	450	80	480
Orchardgrass	6 tons	300	100	375
Bromegrass	5 tons	166	66	254
Tall fescue	3.5 tons	135	65	185
Bluegrass	3 tons	200	55	180
Coastal Bermuda Grass	4 tons	225	40	160
	10 tons	535	145	410
Clover-grass	4.5 tons	185	60	175
	6 tons	300	90	360
Sugar beets	30 tons	275	85	550
Rice	2.25 tons	110	45	110
	3.5 tons	112	60	168
Timothy	4 tons	150	55	250
Pangola grass	12 tons	299	108	430
Sorghum-Sudan grass	8 tons	319	122	467

INVENTORY OF NUTRIENT SOURCE AND SOIL LEVEL

The Capacity of A Cropping System To Retain And Remove Nutrients

The nitrogen, phosphorus, zinc, and copper are all nutrient elements found in animal manures that have the potential to cause environmental degradation. Also arsenic, a non-nutrient toxic element, is found in some animal manures at concentrations that have raised concern. Soils have the capacity to retain a quantity of these elements and crops can rapidly remove very significant quantities of N and P. Thus in agricultural systems the negative environmental impacts of these elements are minimal if the quantity of these elements applied in manure does not exceed the capacity of crop uptake and the ability of soil retention. The capacity of a unit of land to safely handle the manure from a given number of animals can be calculated using the data for uptake and retention of the element of concern.

Nitrogen

In Minnesota the capacity of a field to safely utilize manure is defined by best management practices recommendations using an estimation of the nitrogen needs of the crop (Schmitt, et al., 1999). The "Crediting Manure Nutrients: An Asset" section of this document describes in detail how a farmer can estimate available N in any particular form an animal manure. With this information and information on the N inputs and outputs in a livestock system it is possible to calculate an N budget and estimate the carrying capacity of a cropping system for N.

Nitrogen Leaching to Ground Water

When excessive rates of manure N or commercial fertilizer N are applied to soils, leaching of nitrate-N into ground water may occur on sensitive soils. At soil temperatures greater than 50° F, ammonium N in manure is rapidly converted by soil microbes to nitrate. Organic N is first converted to ammonium by several types of soil organisms, and then to nitrate (O'Leary, et al., 1989). Nitrate is not retained by the soil particles and the nitrate in excess of that taken up by plants or that lost by denitrification can move with soil water into ground water. This was discussed in detail in the Economic Liability of Manure section.

Even under natural conditions, some nitrate leaches into ground water, but under conditions of long-term applications of high levels of manure or inorganic fertilizer N, nitrate can increase in ground water to values exceeding the US Public Health Service drinking water standard of 10 ppm N. When excessive nitrate leaches into ground water, then the "carrying capacity" then can be said to be exceeded.

Another threat of manure N is the ammonium N in runoff water. Runoff from freshly manured soils can contain elevated ammonium N,. This common in the first runoff event following application, especially when the manure is not incorporated into the soil (Wall and Johnson, 1996)

Comparison of Manure and Commercial Fertilizer as N Sources

When manure is applied based on best management practices for determining the quantity of manure, application timing, and application method, leaching of nitrate might be expected to be less from manure than from inorganic fertilizers. This is because the organic N in manure is a slow release source that supplies N to a crop while the crop is growing. Research results, however, suggest that difference between manure and inorganic N sources may not be great.

Results of a study near Waseca showed similar nitrate leaching from liquid dairy manure and inorganic N on corn when manure N was applied using standard methods for estimating N availability. In another study with liquid dairy manure in Goodhue County, nitrate leaching was higher in corn plots with anhydrous ammonia than with liquid dairy manure (Joshi, et al., 1991). Turkey manure applied to sandy loam soils in central Minnesota resulted in similar nitrate leaching compared to inorganic fertilizer applied at similar rates of available N (Malzer, et al., 1992;Nathan, et al., 1992). Tile line water nitrate concentrations under corn in a silty-clay loam soil in Nashua, Iowa, were higher for swine manure plots than inorganic N plots (Kanwar, et al., 1995).

The variability in these results is likely due to the difficulty in estimating the availability of N in manure and in occasional lack in synchrony between N release and crop demand (Sims, 1987). However, in general, nitrate losses to ground water from manure plots are similar to those from inorganic fertilizer. This means that over application of manure N can create as severe a problem as over application of inorganic N, but also that with appropriate management manure is no worse than inorganic fertilizer in terms of nitrate leaching losses. It is very difficult to apportion the sources of nitrate in ground water. Although isotopic tracer techniques have been used (see the Water Resources report), scientific consensus on the reliability of these methods is lacking.

Calculation of Carrying Capacity for N.

When carrying capacity is considered on a broader scale than application of manure to a field or a plot, the ratio of animals to the land available for manure application must be considered. Budget calculations of animal system inputs, outputs, and losses can be useful in defining a maximum environmentally safe ratio of animals to cropland area. Figure 4 shows a N nutrient budget calculation for a dairy system in southeastern USA, with a cropping system that included rye silage, corn silage, and bermudagrass. In this system a ratio of 4.2 animals per acre did not exceed the carrying capacity for N (Van Horn, et al., 1996). This calculation considered all possible N inputs to the system, even the small amount added in rainfall, and all possible losses (although some pathways were only roughly estimated).

In this system, 30% of the N fed to the cows leaves the farm in the milk and 16% is lost to the air through ammonium volatilization from the manure. Ammonia losses are high in large part because liquid manure was applied using a spray irrigation. The system required that purchased feed comprising more than 60% of the N be fed to the cows to make up for N losses, the N sold in the milk, and N storage in soil organic matter.

With repeated application of manure, soil organic matter can increase (see discussion in the Soil Quality report). Because soil organic matter typically contains more that 3% N, this results in accumulation of soil N in forms that are much less available to plants than the organic N in manure. In an N-balanced system, application of manure P will generally exceed that removed by the crops, and soil test P will increase.

Little information is available on the nutrient budgets for the various livestock systems in Minnesota, although Dr. Chester-Jones at the Southern Research and Outreach Center in Waseca

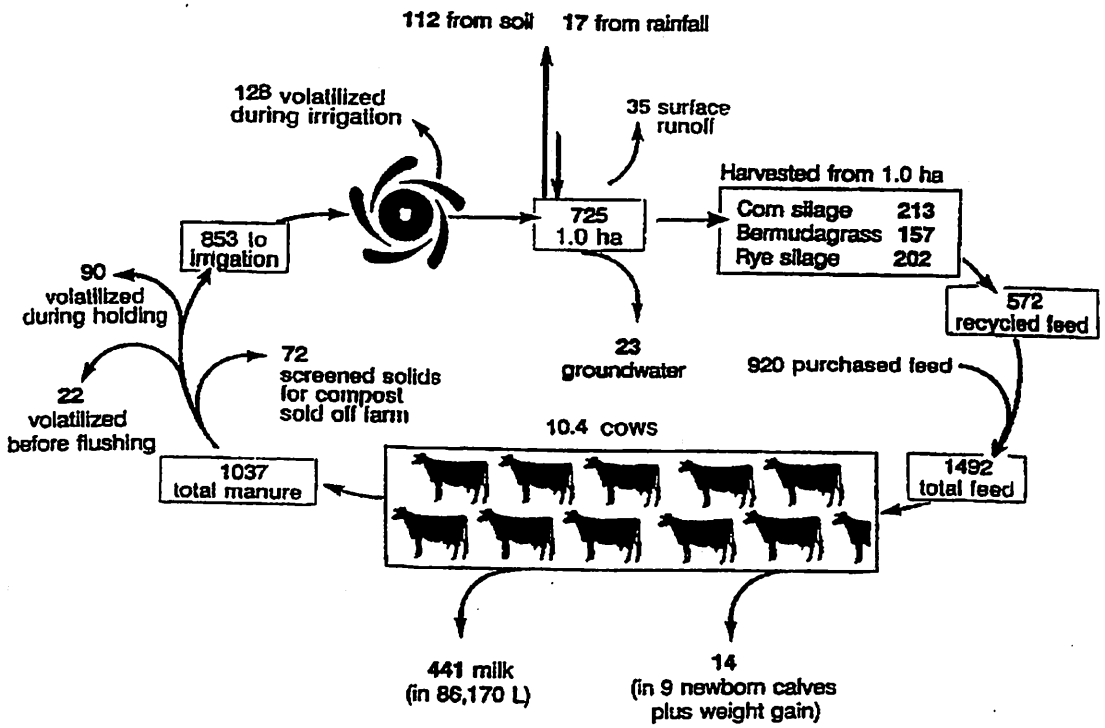

Figure 4. The N nutrient budget for one hectare (2.5 acres) for an N-balanced dairy system in southeastern USA (Van Horn, et al., 1996)

is currently collecting this information on six farms in the south central region of the state (discussed in Section on Manure Nutrient Accountability).

In calculations of carrying capacity, knowledge of the distribution of the crops grown is important. Soybeans and alfalfa are legumes and obtain much of their N from the air, so nitrogen fertilizers are not applied to these crops. The available N in the soil after an alfalfa crop is such that the following corn crop usually needs little or no additional N. The N needs for a small grain crop are much less that corn. In a typical soybean/corn rotation, common to much of southern Minnesota, the carrying capacity for N would usually be calculated using only the corn acreage. Where alfalfa is in the cropping system, the acres of corn grown in the year after alfalfa would be excluded. Recent research, however, has shown that manure can be used as a P and K source for alfalfa and soybeans, thereby extending the carrying capacity in cropping systems containing these legumes. When manure, or fertilizer, N is applied to a soil, these legumes

obtain much less N from the air, and instead take up manure or fertilizer N (Schmitt, et al., 1994;Lamb, et al., 1995). This is discussed in more detail in the "Nutrient Sources Section" below.

Potassium:

Potassium is a nutrient element that is found in high concentration in manure. Crops need potassium and manure is a good source of this nutrient. Potassium, however, is not an element that causes environmental problems at the levels it is applied in manure. As stated earlier in this report, there are increasing concerns about animal health problems associated with high soil test K levels due to manure and fertilizer, so this element is coming under increased scrutiny

Phosphorus

Phosphorus in strongly retained by soil particles and unlike nitrate-N it does not readily move with in soil water. However, excess P in surface soils can result in negative environmental impacts when P dissolves from P rich soils and moves by erosion into surface waters.

Also in soils that do not strongly retain P long-term heavy applications of manure can result in elevated P in shallow ground water.

Retention of P by Soils

An important parameter in determining the environmental fate of P is the ability of a soil to strongly retain P. The terms retention and sorption are often used as synonyms for the process of removal of phosphorus from soil water by soil or soil constituents (Wild, 1950). Phosphorus sorption is a function of the amount soil clay and the quantity of calcium carbonate (the mineral in limestone). The type of clay, soil pH, and the quantity of soil organic matter also influence sorption. Soil clay and other soil minerals retain P in a number of ways. Phosphate ions can be adsorbed to some extent on the edges of clay particles and on the surfaces of calcium carbonate, iron oxide and aluminum oxide minerals. Another means of P retention is the formation of compounds of iron, aluminum and calcium. In most Minnesota soils this is mostly due to calcium. In general, fine textured soils (that is clays and clay loams) have a much greater capacity to retain P than course textured soils (that is sands).

When manure is a applied on the soil surface, retention by soil particles is minimal and P can run off into surface waters. The poultry industry in some area is beginning to add alum to litter to acidify the litter and reduce ammonia volatilization, which also can decreases P runoff by almost 90% (Shreve, et al., 1995). Alum also decreases the runoff losses of, arsenic and heavy metals (Moore Jr., et al., 1998).

Phosphorus adsorption capacity of the soils can be estimated by standard laboratory methods. When manure P additions are greater than crop removal, the P adsorption capacity of a soil is partially satisfied and laboratory measures of P sorption decrease. After three years of application of swine storage basin effluent at the rate supplying 28 and 208 lb/acre of P, the sorption capacity of the surface horizon of a sandy soil was 234 ppm where 28 lb/acre of P was

applied. However, the P sorption capacity of the soil in plots that received the higher rate of P was only 71 ppm (Reddy, et al., 1980). This means that the soil receiving high rates of manure application was approaching the limit of its capacity to retrain P. Field studies in Oklahoma indicate that long-term manure application reduced the P sorption in the top 2 inches of 12 soils from 354 to 174 ppm (Sims, et al., 1998). Phosphorus sorption capacity of many agricultural fields with a history of manure application in Sussex County Delaware, the site of highly concentrated poultry production, was lower than the non-manured field borders (Mozaffari and Sims, 1994). Similar trends have been reported in other areas where land application of animal manure is extensively practiced (Breeuwsma, et al., 1995;Simard, et al., 1995) (Kingery, et al., 1994). These studies indicate, not surprisingly, that long-term application of animal manure reduces the capacity of soils to retain additional P.

In estimating the capacity of a soil to retain P with sufficient strength to avoid environmental degradation laboratory determination of total P sorption capacity is not sufficient. As more P is adsorbed P becomes more available for plant uptake, more available for dissolving in surface runoff and leaching into ground water, and more available for the promotion of algae growth when soil particles are moved by erosion into surface waters. In the Netherlands a value of 25% of the total sorption capacity has been defined as a critical level that should not be exceeded (Sharpley, et al., 1996).

While some very broad based generalizations can be made about the relative P sorption capacity of agricultural soils in Minnesota, actual quantitative information on individual soils is virtually non existent. However, two research projects at the University of Minnesota are currently working to determine the P sorption capacity of a wide range of Minnesota soils

Can P Leach to Ground Water?

Although P is considered to be quite immobile in soils, additions of very large quantities of manure or fertilizer P can sufficiently saturate the P sorption capacity to result in some leaching. This can result in elevated P concentrations in shallow ground water. The 25 % critical value for sorption capacity in the Netherlands was defined by the need to minimize the potential of P to leach into shallow ground water (Sharpley, et al., 1996). Because manure has organic forms of P that are not necessarily retained as strongly as the inorganic P in commercial fertilizers the P in manure many be somewhat more mobile in some soils than inorganic fertilizer P.

Some leaching of P was seen in Nebraska in a calcareous soil (containing natural limestone) receiving 43 years of solid beef manure or commercial fertilizer. In this experiment, the addition of excess P resulted in an increase of Olsen soil test P in the surface soil to about 125 ppm, a very high value (see below for a discussion of soil test P). In soil that did not receive manure, little fertilizer P moved beneath 3.5 feet. In the soils receiving nearly equal phosphorus amounts as manure, P moved to greater depths. Possible explanations for the difference were that phosphorus from manure moved in organic forms, or that chemical reactions occurred with compounds in the manure that may have enhanced solubility (Eghball, et al., 1996). Thus long-term application with heavy loading of manure can result in leaching of phosphorus.

A study of the results of 30 years of heavy application of hog manure to soils with a low capacity for sorption of P shows that heavy manure applications can threaten P pollution in shallow ground water. In a sandy loam soil that has a seasonal water table at one meter depth (3,3 ft) researchers found that in more that half the surface soils sorbed P was greater than 50% of the saturation capacity. At a few the 256 sites sampled the soil from 0.9 meter depth contained sorbed P at greater than 30% saturation of the sorption capacity. This presents a threat of excess soluble P in the ground water (De Smet, et al., 1996)

Research on manure-amended soils in Minnesota and other locations demonstrates that long-term application of animal manure can increase available P in subsurface horizons. Researchers at Waseca incorporated dairy manure for three years on a Webster clay loam soil. Before manure application, soil test P in the surface soils was 30 ppm, but after three years of manure application at very high rates (total of 343 ton/acre of dry manure) soil test P in the surface soil rose to 415 ppm (Randall and Iragavarapu, 1999). At the end of the study soil test P in the subsurface horizon (12-24") was three times higher than in non-manured land.

In another study in Minnesota based on disposal rates of solid dairy cattle manure, no P movement was seen passed the 2- foot depth. The manure was applied to a Webster clay loam soil with an initial soil test phosphorus level of 30 ppm (Bray). It increased soil test values by 9 and 14 times in the surface soil (Randall, et al., 1975). In a more recent study, dairy manure and commercial fertilizer were applied as N sources for 4 years, at agronomic rates, in continuous corn. After 4 years soil test phosphorus was in the surface soil was 43 ppm (Bray) in the soil receiving manure and 26 ppm where inorganic fertilizer had been applied. Losses of phosphorus in subsurface tile drainage were low (Randall and Iragavarapu, 1999).

Thus, application of manure at rates that exceed the capacity of soil to retain P from can present a threat to shallow ground water. However, research on the better agricultural soils of Minnesota that have not been subjected to long-term manure application, suggests that with manure application at agronomic rates little or no P leaching will be observed.

Setting Environmental Critical Values for Soil Test P

The concept of soil test phosphorus level is a universally accepted method to estimate plant available phosphorus. Each soil test method uses a different extraction solution and the correlation tables for plant response to soil test values vary with the test procedures (Table 16). Although the values from soil test procedures are in units of ppm these units do not directly compute to the quantity of plant available P. The soil test values are really just index values that have been correlated with plant response. Soil test phosphorus values for optimal crop production have been identified as a range of available soil phosphorus at which crop response to additional phosphorus fertilizer no longer produces an economic yield benefit. For most crops, application of fertilizer or manure P is recommended for all soil test results less than the very high values in Table 16.

Table 16. Soil test phosphorus calibration for three commonly used test procedures.(Rehm et al 1998; University of Oklahoma, 1999)

P- level	Bray	Olsen	Mehlich-3
	----------ppm----------		
Very low	0-5	0-3	0-10
Low	6-10	4-7	10-20
Medium	11-15	8-11	20-40
High	16-20	12-15	40-65
Very high	21+	16+	65+

Although soil test phosphorus methods were not meant as estimates of the amount of phosphorus that may potentially be transported with surface runoff or erosion, some states have recommended critical values that if exceeded define unacceptable environmental risk (Table 17). Alabama, Arkansas, Colorado Delaware, Ohio, Mississippi Texas and Utah have established single critical values for P management recommendations that if exceeded require elimination or severe limitation of all sources of P. Indiana, Kansas, Oklahoma, Maine, Michigan and Wisconsin have set 2 or more environmentally critical levels that call for a scaled reduction in P inputs. In Oklahoma test values on the range of 30 to 130 ppm call for a 50% reduction in P rate on slopes in excess of 8%. A values in the range of 130 to 200 ppm a 50% reduction of P inputs on all soils is recommended and at greater than 200 ppm, the P addition should not exceed crop removal. In Michigan, test values in the range of 75 to 150 ppm call for additions of P not to exceed crop removal. At soil test values in excess of 150 ppm no P should be added. In Wisconsin values of 75 to 150 ppm call for planting of P-demanding crops and reduction in P application rates and at test values of greater than 150 ppm, manure should not be added (Sharpley, 1996). In Wisconsin, State regulations are tied to cost share programs.

The use of soil test values for determination of the environmental risk of soil P has been criticized for being too simplistic. Soil test values obtained for predicting potential crop nutrient needs are not necessarily good predictors of phosphorus moving into surface waters. Runoff volume and erosion are critically important components affecting soil phosphorus loss. A comprehensive integrated approach in determining potential phosphorus loss should include soil test phosphorus values and potential phosphorus losses due to runoff and erosion, generally referred to as the P risk index approach (Sharpley, 1996). Clearly, promulgation of any guidelines or regulations involves political decisions, and these issues are discussed in the report on the Role of Government.

Tempealeau County in Wisconsin has developed a phosphorus index that ranks fields for the potential for P to run off the field and reach a water body. The index incorporates soil test P but in addition includes: distance from a stream, infiltration/erodibility rates, how often manure is applied, fertilizer application rate, method of fertilizer application, and the rate of manure P. The calculated index values resulted in 4 possible recommendations varying form application of

Table 17. Soil test phosphorus level management guidelines from seven states.

State	Critical Value
Alabama	250 ppm (Mehlich 3)
Arkansas	150 ppm (Mehlich 3)
Colorado	100 ppm (Olsen)
Delaware	120 ppm (Mehlich 1)
Indiana	150/200 (Mehlich 3)
Kansas	100/150/200 (Bray 1)
Ohio	150 ppm (Bray 1)
Oklahoma	30/130/200 ppm (Mehlich 3)
Maine	40/100 ppm (modified Morgan)
Michigan	75/150 ppm (Bray 1)
Mississippi	144 (Lancaster P)
Texas	200 ppm (Bray 1)
Utah	100 ppm (Olsen)
Wisconsin	75/150 ppm (Bray 1)

Adapted from (Sharpley, 1996, Lory and Scharf, 1999)

manure to meet N needs of the crop to no application of manure (Frame, 1999, personal communication).

Calculation of Carrying Capacity for P

Manure application at disposal rates or agronomic rates designed to meet the N needs of crop result in a build up of soil phosphorus levels. If a soil already has sufficient P for maximum crop production, maintenance of crop productivity only requires addition of P sufficient to replace the P removed by the crop. Calculation of the P balance for the southeastern USA dairy system (Figure 5) showed that restricting manure P additions to crop removal rates reduced the carrying capacity to 2.2 animals per acre (Van Horn, et al., 1996). This is about one-half the value when manure is applied at rates sufficient to supply the N needs of the crops. Major differences between N and P are that the losses of P from the system are very small and essentially all the P is available for crop uptake. Also, when organic matter builds up in soil in response to repeated manure additions the accumulation of organic N is much greater than organic P. In soil organic matter, the N to P ratio is about 10, whereas in many manures the ratio is about 2 (poultry litter often has a ratio of 1). In a P-balanced livestock/cropping system, inorganic N would be needed for the production of corn and grasses.

Phosphorus budget data are not yet available for Minnesota farms. However, some understanding of the difference in the response of soils in Minnesota to P inputs at crop removal rates vs. inputs in excess of crop removal rates can be gained from the results of a long-term study of inorganic P applications at Waseca and Morris. In this study, increases in phosphorus test levels over 12 years of fertilizer application were measured in a corn/soybean cropping system. During the next 8 years, decline rates in phosphorus and potassium soil test levels were measured. Average annual additions of 22 lb/acre of P (P_2O_5 x 0.44 = P), resulted in only a slight increase on soil test P (Figure 6). This is approximately the crop removal rate. Average annual additions of 44 lb/acre of P resulted in an increase of about 35 ppm Bray soil test units after 12 years. This increase resulted from addition of about 290 lb/acre of P, in excess of crop uptake. The researchers concluded that soil test phosphorus levels maintained at 18 to 20 ppm, with an annual application of 20 to 25 lb P/acre/year (crop removal rate), would be best for optimum profitability for corn and soybeans in southwest and south central Minnesota. The results indicate that producers with very high soil test phosphorus levels (Table 16) could eliminate phosphorus application and use soil testing to monitor phosphorus draw-down (Randall, et al., 1997). Although this study did not include manure as a treatment, the concepts are similar when interpreting soil P fertilization with manure. Soils testing very high in phosphorus due to long-term or over application of livestock manure would require no additional phosphorus.

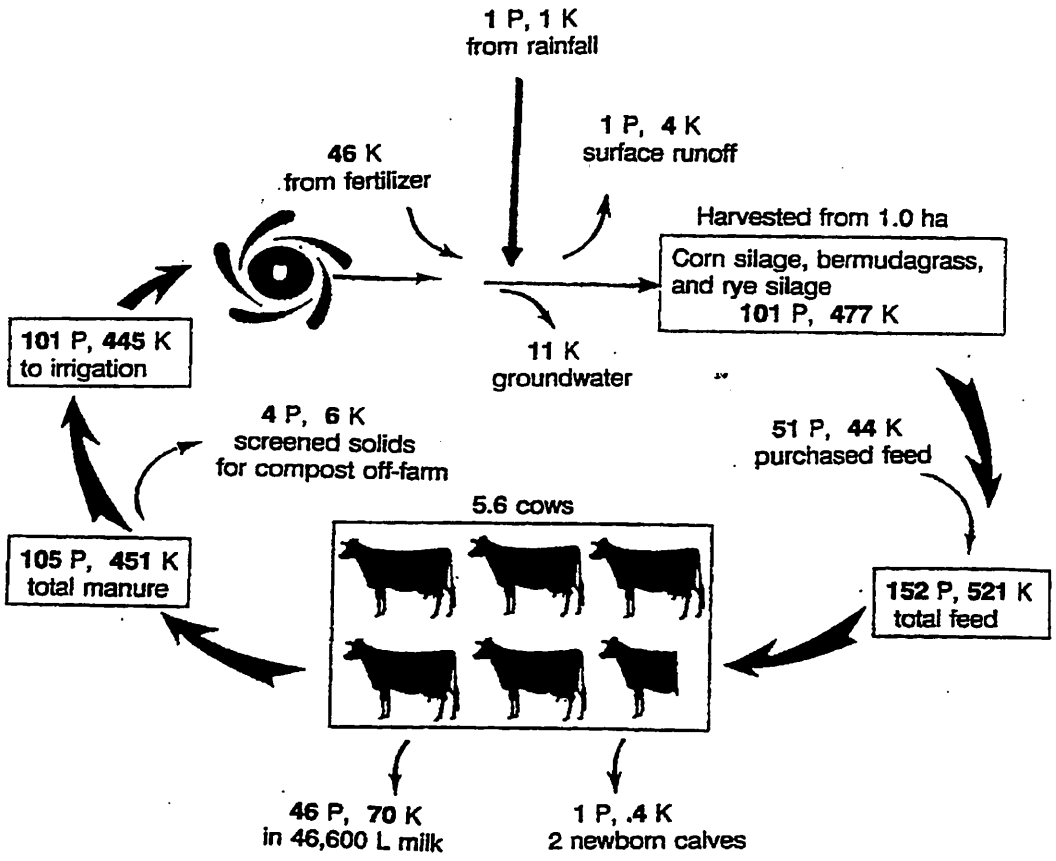

Figure 5 The P nutrient budget for one hectare (2.5 acres) for an N balanced dairy system in southeastern USA (Van Horn, et al., 1996)

The definition of P carrying capacity of a soil/cropping system depends on the P soil test value, soil type, and crops grown. At low soil test P, phosphorus is not necessarily a factor in calculating carrying capacity. Rather carrying capacity can be defined by the crop need for N. At higher P test values the carrying capacity might logically be defined by crop P removal rates. Michigan sets a critical Bray soil test P value of 75 ppm to trigger a recommendation of P addition not to exceed crop removal. At still higher soil test P some states have chosen to recommend no manure or commercial fertilizer P application (Table 17). The increase in soil test P with addition of a given quantity of manure (or inorganic P) is a function of the P sorption capacity of a soil. Thus, the increase in soil test P with a given addition of manure or inorganic P is greater in sandy soils than in clayey soils and clayey soil can be said to have a greater capacity to retain added P.

One new way to increase P retention in manure-amended soils is to add alum, an industrial byproduct, to the manure. This approach has been championed by Patrick Moore (USDA-ARS in Arkansas) for use in poultry production. Poultry litter contains significantly greater amounts of soluble P than other manures and fertilizer. Soluble P was reduced significantly by application of alum and by composting (Chaubey, et al., 1995).

Alum added to poultry litter was effective at reducing soluble P from over 2,000 ppm P to 467 ppm P for an addition of 0.1 lb alum/lb litter and to 111 ppm P for an addition of 0.2 lb alum/lb litter (Shreve, et al., 1996). Amended poultry litter was then incubated with soil for up to 100 days. Soluble P concentrations in soil incubated at pH 7 for less than one day were 15 or 9 ppm P for the 0.1 or 0.2 lb alum rate, respectively. Much larger reductions in soluble P were attained by incubating litter in soil for as many as 100 days.

Soluble P levels in runoff from a silt loam soil receiving alum-amended poultry litter were 87%

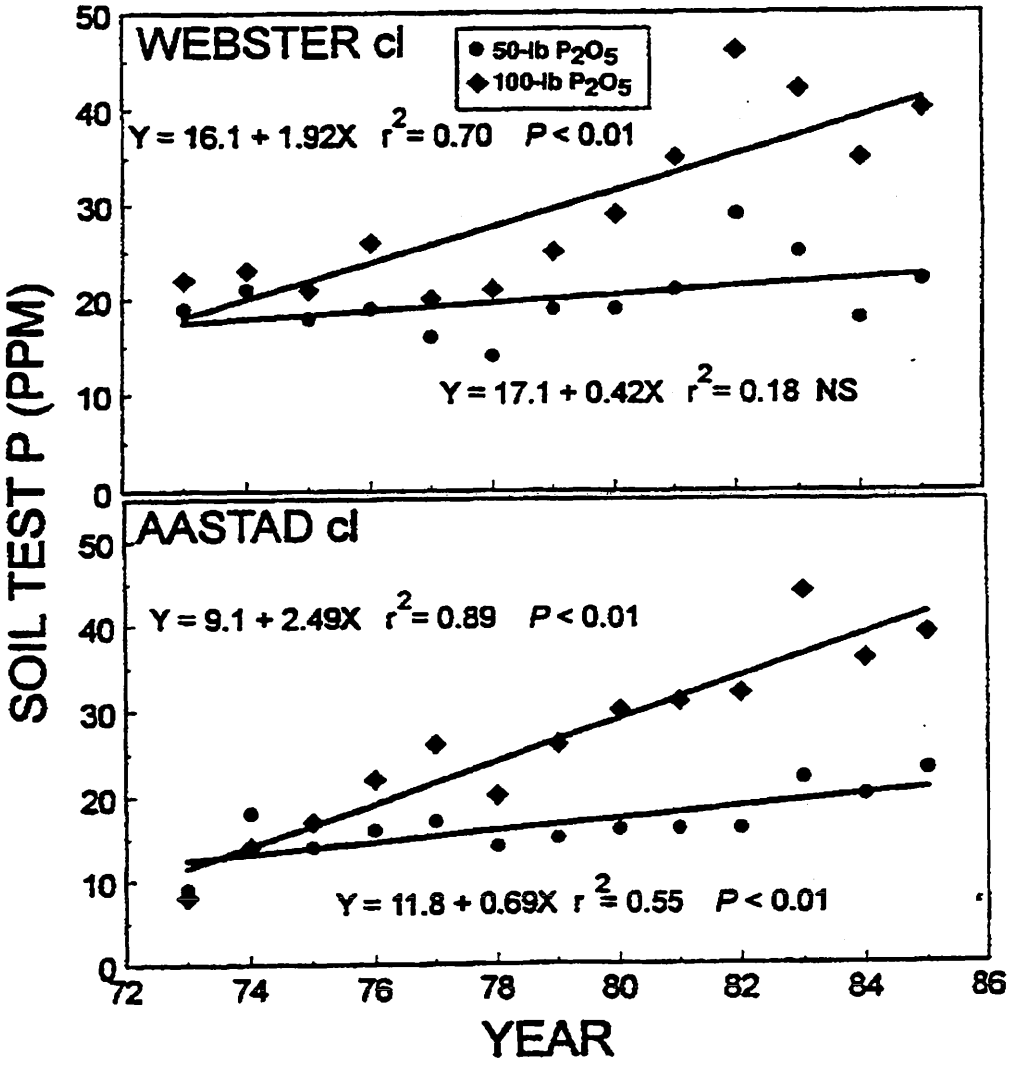

Figure 6. Comparison of the change in Bray soil test P with long–term addition of commercial fertilizer P at a rate that is slightly greater than crop removal with a rate greatly in excess of crop removal. The Webster soil is at the Southern Experiment Station at Waseca and the Aarstad soil is at the West Central Experiment Station at Morris. The P_2O_5 values can be converted to P by multiplying by 0.44.

lower than levels from soil receiving amended litter without alum (Shreve, et al., 1995). Runoff loads of soluble P and total P with the alum-amended litter were reduced by over 80%.

Addition of alum to poultry litter decreases the fecal coliform levels in runoff from manured fescue plots from 63,000 to 12,000 CFU/100 mL (Moore, 1998). In comparison, plots receiving no manure had from 1,500 to 1,700 CFU/100 mL in runoff. Additions of alum also decreased runoff concentrations of arsenic, copper, iron, and zinc associated with the soluble organic carbon fraction of runoff.

Both alum and ferrous sulfate amendments to manure can significantly reduce ammonia volatilization from poultry litter ((Moore, et al., 1996). This has very positive benefits to worker and poultry health. Moore (1998, personal communication) has found no increases in soluble aluminum in soil treated with alum. Because addition of alum to poultry litter increases the availability of N to crops, reduces heavy metal runoff, improves human and poultry health, and decreases the solubility and loss of P, it promises to be an important tool in improving the environmental sustainability of poultry production.

Zinc, Copper, and Arsenic

Zinc, copper, and arsenic are added to animal feeds to improve animal health. Zinc and copper elements are added as anti-microbial compounds that increase weight gain. Both elements are essential nutrients that are required for plant and animals health. At higher concentrations, however, they can be toxic. Four arsenic-containing compounds has been common in the diets of broilers, turkeys, and laying hens (Fontenot, 1981).

We could not find data for As in manure in Minnesota. A mean value for poultry manure reported in 1981 was 40 ppm (Fontenot, 1981). This may not be greatly different from current concentrations in poultry manure. Recently researchers in Arkansas reported a value of 43 ppm Arsanilic acid and 3-nitro-4-hydroxyphenylarsonic acid (3-nitro) are excreted largely unchanged with as much as 88% of ingested 3-nitro occurring in the broiler excreta, according to (Fontenot, 1981). However, poultry diets have changed since then and the arsenic content of animal diets is more restricted now.

Arsenic Retention in Soils

Arsenate is a non nutrient toxic element that in soil behaves very much like phosphate. For example, arsenic retention in soil increases with increasing clay content and with increasing Fe and Al mineral content. The arsenic retention capacity of the soils of Minnesota has not been studied.

Copper and Zinc Retention and Response to Manure Additions

Copper (Cu) and zinc (Zn) are retained tightly by soil particles and do not readily move through soils with water. These elements are retained by a number of processes, including sorption by iron, manganese, and aluminum oxides, and strong bonding with soil organic matter. In a study

involving sewage sludge, researchers found that copper adsorption in a soil was always greater than zinc adsorption , particularly in the surface soil. The researchers reported that copper sorption increased with increasing organic matter whereas zinc sorption was dependent on clay content (Eulalia-de-Mesquita, et al., 1993). Just as the solid organic matter in soils retains Cu, the mobility of Cu in soil water can be increased due to soluble organic matter. In a laboratory study, strong interaction of Cu with the dissolved organic matter in a swine manure slurry helped keep Cu in solution. The researchers suggested that association with dissolved organic matter is a possible factor in movement of Cu though soils after swine slurry application (Giusquiani, et al., 1998).

Soil test levels for copper increase after long applications of manure from animals fed with diets high in added Cu. Four years of application of 180 t/ha of liquid swine manure (wet weight) from animals fed with a ration containing 250 ppm added Cu substantially increased soil test Cu. However, little effect was observed in corn tissue Cu concentration (Sutton, et al., 1983). Bouldin and Klausner (1998) stated that long-term applications (10 years) of pig manure to corn at agronomic rates could increase soil Cu levels by a factor of 2 to 10 times.

Eight years of application of copper sulfate or Cu-enriched swine manure on three soils in Virginia greatly increased the soil test Cu, but did not increase corn tissue Cu concentrations or adversely affect corn production. It this study the total Cu added was as much as 300 lb/acre as copper sulfate and 250 in Cu enriched manure. The manure contained up to 1,550 ppm Cu and was produced by pigs fed diets with an average of 251 ppm Cu. The authors reported large increases in soil test Cu in the surface soils, but very little increase in subsoil Cu even in the fine sandy loam soil. Thus, little, if any, Cu was transported into the subsoil (Payne, et al., 1988). A follow up study was conducted on the same plots after eleven years of manure applications. The main finding of that study was that the capacity of the soils for sorption of Cu, in a laboratory test, was actually increased with application of high Cu manure (Zhu, et al., 1991). The increased sorption capacity was due to an increase in organic matter content after manure addition.

EPA Sewage Sludge Limits for Copper, Arsenic, and Zinc

Because few data are available from manure studies that are useful for estimation of limits for application of manure Cu and Zn to soils, it is necessary to look to the body of knowledge available for sewage sludge application to soil. The USEPA in 1993 established the 503 sewage sludge rules which set limits on the concentration of toxic elements in sludge (Table 18) and on quantity that can be applied over the life-time of the site (Table 19). It is unlikely that any manure would violate the ceiling concentration limits but with very long-term application, the loading limits could be exceeded.

If elemental concentrations are known and an application rate is assumed, the time for exceeding the EPA lifetime loading rates can be calculated. For average heavy metal contents of manure at manure applications of 10 to 12 tons/acre and assuming 30-40% moisture in the manure, the limits would not be exceeded for cadmium in 169 years, zinc in 388 years, copper in 660 years, and lead in 40,000 years (Sweeten, 1993). With poultry manure, arsenic (As) may be more limiting than the metals. A similar calculation for arsenic as above, assuming a 40 ppm dry

weight As concentration (Fontenot, 1981), suggests the loading limit for As would be exceeded in about 110 years.

CURRENT LEVEL OF P, Zn, and Cu

Soil Testing in Minnesota

Due to the diversity in soil properties and varying solubility of different nutrients, a number of chemical extractants have been developed to measure plant available nutrients in different regions. As an example, soil testing laboratories across the USA use at least five different chemical extractants for measuring plant available P. Each method is most suited to the region in which it is being utilized. Soil tests are also offered for K.

Because Minnesota is a large state with diverse soils, two different soil P extractants are used. The Bray-P1 method is used to measure plant available P in soils with pH lower than 7.4 and the Olsen method is used for soils with higher pH. Soils with Bray-P1 value lower than 5 ppm or an Olsen P value of less than 3 ppm are considered low in P and application of P fertilizer has a high probability of increasing crop yield (Rehm, et al., 1994). Table 16 shows current University of Minnesota interpretations for various soil P levels.

Table 18. EPA 503 Ceiling concentration for metals in sewage sludge.

Element	ppm
Arsenic	75
Cadmium	85
Copper	4,300
Lead	840
Mercury	57
Molybdenum	75
Nickel	420
Selenium	100
Zinc	7,500

Table 19. EPA 503 cumulative pollutant loading rates for metals

Element	LOADING RATE (LB/ACRE)
Arsenic	37
Cadmium	35
Copper	1,340
Lead	268
Mercury	15
Molybdenum	-
Nickel	375
Selenium	89
Zinc	2,500

A number of private soil testing laboratories provide soil analysis services, as does the University of Minnesota Research Analytical Laboratory. Because most farmers rely on their fertilizer dealer or crop consultant to provide fertilizer recommendations, the vast majority of soil tests are performed by private laboratories associated with those companies.

In addition to K and P, the University of Minnesota Research Analytical Laboratory offers soil testing services for available Ca, Mg, and metals such as iron, copper, and zinc. Soil test for recommendations for Cu are available for soils with very high (more than 80%) organic matter (Histosols). Using DTPA it is also possible to test for manganese, chromium, cadmium, nickel, and lead. However, in Minnesota no agronomic interpretation is made for the soil test results for Mn, Cr, Cd, Ni, and Pb. Historically, the role of agronomic interpretation of soil test data has been to assess the potential nutrient deficiencies and most agricultural soils in Minnesota contain adequate levels of Cu, Mn, Fe, and zinc (Rehm, et al., 1994). A more complete discussion on

fertilizer recommendations for agronomic and horticultural crops in Minnesota is provided by (Rehm, et al., 1994) and (Rosen and Eliason, 1996).

How the Data Were Collected

In 1991 to 1993, 69% of the soil samples tested by the University of Minnesota Research Analytical Laboratory had soil test P values greater than 21 ppm and 38% of the samples had exchangeable K levels greater than 120 ppm (Munter, 1994, as cited in (Randall, et al., 1997). Other than that reference, there are no published summaries available on current levels of nutrients and metals in agricultural soils of Minnesota. Some raw data exist in the electronic archives of the University of Minnesota Research Analytical Laboratory, but data from private laboratories was not available in an electronic format or could not be converted to a format easily compatible with our statistical software for this project. We have summarized the data from the archives of the University of Minnesota Research Analytical Laboratory. To obtain a more representative sample, the data from last five years were (1994-1998) were included in the statistical analysis. The soil test values are from commercial farms only.

Presented in the APPENDIX section (Appendix Table 1) are the data for soil extractable P (Bray-P1 or Olsen method) and DTPA-extractable copper and zinc. The number of samples tested from each county, means, and standard deviations by the county are listed there. The data base contained about 24,000 observations for the Bray method, 3,670 observations for the Olsen method, 1, 970 observations for copper, and 568 observations for zinc. This is a very small subsample. An additional 10,000 soil samples from farms in western Minnesota were analyzed by the North Dakota State University Laboratory during 1993-1998. Unfortunately, the format of that data was not compatible with our data base.

Because private laboratories perform the vast majority of soil test analysis, and soil samples from certain areas of Minnesota are often sent to the public laboratories in the adjacent states, the readers are cautioned that these data do not represent an unbiased sample of all Minnesota farmland. Consequently, the interpretations and conclusions in this report *must* be considered tentative.

Summary of Soil Test Results from University of Minnesota Archives

The distribution of soil test P by Bray or Olsen method for different counties in Minnesota is presented in Figures 7 and 8. To avoid biased results due to low sample numbers, we present the data only for those counties where 100 or more samples had been analyzed by the University of Minnesota Research Analytical Laboratory. As a result, data for some counties are not mapped and are designated as 'insufficient data.' Readers interested in means for any specific county should refer to the appendix, but should not rely on that average as being definitive.

There was a wide range of variation in available phosphorus across the state. Mean soil test phosphorus values for various counties across the state ranged 6 to 65 and 5 to 38 ppm as measured by Bray and Olsen methods, respectively. The median Bray and Olsen soil test phosphorus for various counties across the state were 28 and 19 ppm, respectively. The mean value for Bray soil test P for several counties in central Minnesota ranged from 41 to 63 ppm.

These values are generally lower than seen in Wisconsin. The soil test laboratory at the University of Wisconsin has published summaries of soil test data for 1968 to 1994. These data include the University data plus the certified private laboratories in the state. The data show that the state mean for Bray P has increased from 34 for 1968-73 to 50 for 1990-94. The 1990-94 data show one county with a mean value of more that 150 ppm and 4 counties with mean values in the range of 75-150 (Combs, 1995); (Combs, et al., 1996)

Although the University of Minnesota data base had insufficient samples for many western Minnesota counties, data from North Dakota State University indicated that in general phosphorus levels in these soils were lower than in central Minnesota. This is not surprising, because many western Minnesota soils are calcareous and can tie up large amounts of phosphorus.

A few counties were selected that represented different areas of the state (Table 20). These results show that there are large numbers of fields that have excessive soil test P levels. We do not know if these high P tests are related to manure application. Stearns County generally leads other counties in milk and cattle, producing about one ninth of all milk in Minnesota and having about 70,000 adult bovines. Manure production in this county is quite high (see Water Quality report). In contrast, lower numbers of excessive soil P tests in Rock and Waseca counties probably reflects the high P-fixing capacity of their soils.

The mean, standard deviation, and the total number of samples tested for DTPA extractable (plant available) copper and zinc from all counties is presented in Table 21. There was a large variability in extractable copper and zinc in soils across the state as suggested by standard deviations that were more than twice as large as the mean. This indicates that the distribution of data likely was skewed, rather than being symmetrically bell-shaped. Therefore, the median probably better represents the central tendency of the data, that is, the median better represents what the typical soil in Minnesota contains.

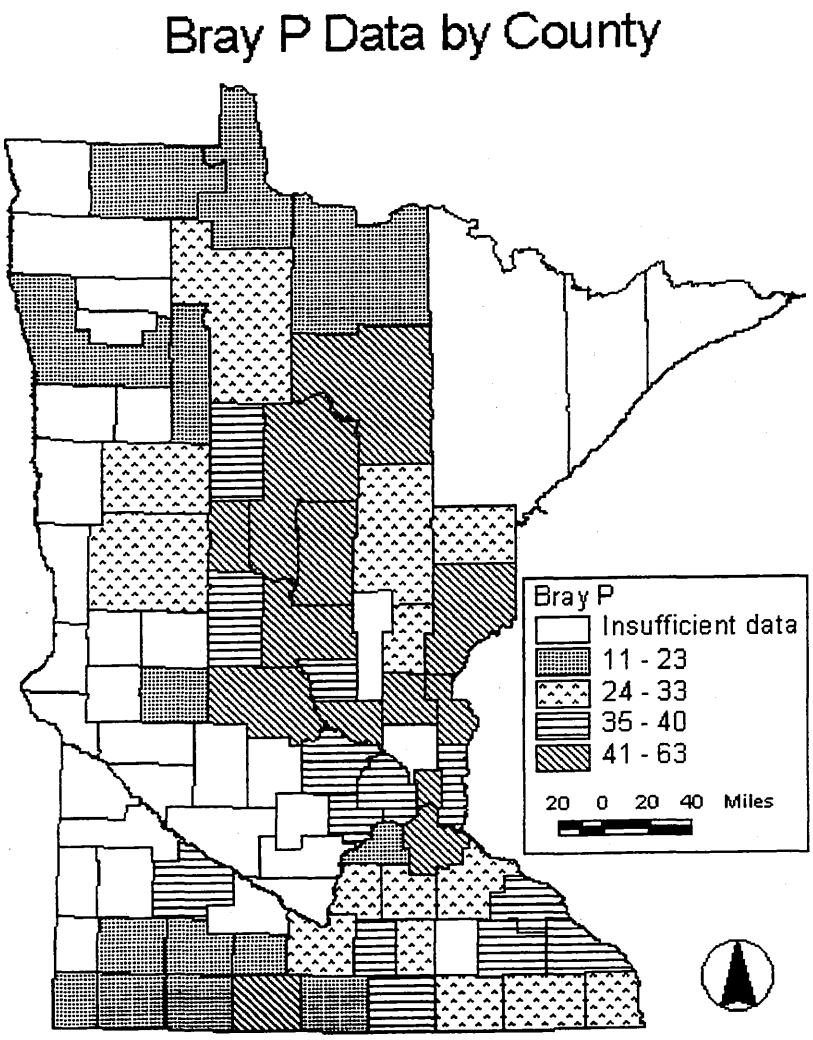

Figure 7. Mean soil Bray-P for Minnesota counties based on the University of Minnesota Research Analytical Laboratory database (1994-1998). Counties where less than 100 samples had been analyzed are categorized as "insufficient data".

With the exception of a few soils, most counties had an average soil test copper below 2.5 ppm and the median soil test copper of 0.7 ppm. In general, the critical level for DTPA extractable copper is 0.12 to 2.5 ppm (Sims and Johnson, 1991). In another words, crops grown on soils that have soils that have a DTPA extractable copper levels of less than 0.1 to 2.5 ppm may benefit from copper fertilization. However, crops in Minnesota usually do not show increased yield with copper application, except on organic soils (Rehm et al., 1994).

The median zinc soil test value for various counties across the state was 2 ppm. The critical range for DTPA extractable zinc is reported to be between 0.2 to 2 ppm (Sims and Johnson,

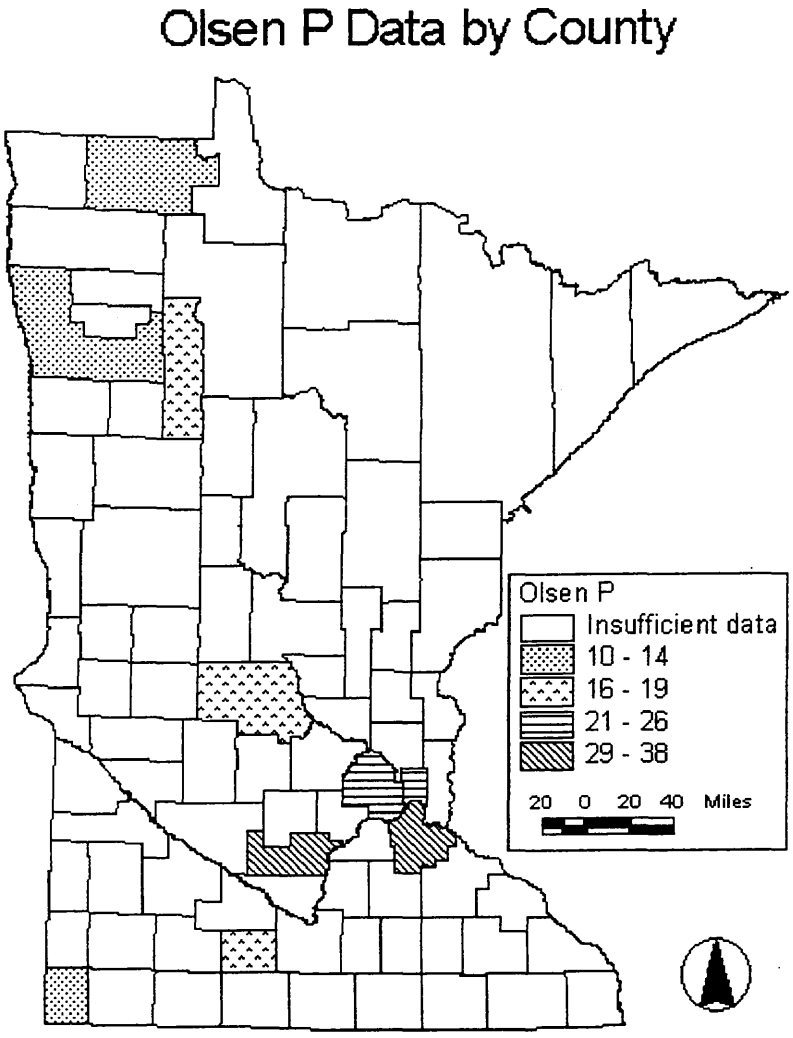

Figure 8. Mean soil Olsen-P for Minnesota counties based on the University of Minnesota Research Analytical Laboratory database (1994-1998). Counties where less than 100 samples had been analyzed are categorized as "insufficient data".

1991), but in Minnesota, crops typically do not respond to zinc addition at soil test levels greater than 0.75 ppm (Rehm et al., 1994).

The data base does not suggest significant accumulation of copper and zinc in agricultural soils of Minnesota. A more definitive evaluation of the current levels of phosphorus, copper, and zinc in agricultural soils of Minnesota requires detailed statistical analysis of considerably larger data bases from neighboring states and many private soil testing laboratories.

Table 20 Distribution of Bray P in selected counties of Minnesota.

County	No. of samples	Percentage of samples testing greater than		
		75 ppm	150 ppm	200 ppm
Dakota	1,103	18	5	4
Rock	914	3	-	-
Stearns	855	25	8	6
Waseca	400	13	1.5	< 1
Washington	1,165	14	< 1	-

Table 21. DTPA-extractable copper and zinc in Minnesota soils, calculated from the University of Minnesota Research Analytical Laboratory data base for 1994-1998.

Element	Number of samples	Median	Mean	Std. Dev.
		-------- ppm --------		
Copper	568	0.7	2.1	4.0
Zinc	1,974	2.0	3.5	9.6

Implications of Soil Test Results

The Minnesota database provides a reference point for evaluation of current levels of available nutrients and metals in agricultural soils of the state. However, manure-amended soils are not separated from non-manured soils. In a 1996 survey of Minnesota dairy farmers, (Russelle, 1999) found that nearly 80% of respondents reported soil test P levels greater than 20 ppm. The overall median of these reports was 40 ppm, but the median was twice as high for Alfisols than for Mollisols. This may be due to differences in manure and fertilizer management, to soil characteristics, or to a combination of factors. The finding that soil nutrient levels are high or excessive on some contemporary farms in Minnesota reflects findings in other states.

Nutrients accumulated to excessive levels in manure-amended soils can potentially be transported by runoff or leaching into surface and/or ground waters and impair water quality. Accumulation of excessive amounts of metals increases the potential for metal uptake by plants

and subsequent biological magnification through the food chain. Knowledge of current levels of nutrients and potential pollutants in manure-amended soils of Minnesota will identify problem areas that may pose a risk to environmental quality.

Such information can be used to gain insight into long-term nutrient supplying capacity of agricultural soils in Minnesota. Long-term research at Waseca and Morris, Minnesota showed that soil test P levels declined by less than 2.7 ppm/year on high-testing soils with continuous corn production and no additional P fertilizer (Randall, et al., 1997). Field research on high P soils in other states indicated that it required 16 years of continuous cropping in a high P soil (100 ppm) to decrease soil test P to 20 ppm (McCollum, 1991) (Sims and D.C. Wolf, 1994).

Quantification Of Statewide Nutrient Inputs From Various Sources

Table 22 presented in this section provides an estimate of total state–wide nutrients inputs from a number of inorganic and organic sources. However, it does not represent the amount of plant available nutrients. Missing are estimate of nutrient loss and fate during the storage, pretreatment, and handling of manure, and calculations of feed purchased from outside the state. In addition, livestock manure and soil nitrogen should be considered temporary storage pools for nitrogen that entered the state through other pathways.

It is also important to remember that not all nutrients will be retained in the soil. Understanding the pathways and factors of nutrient losses will assist all persons associated with land application to use agronomic rates and apply as close to plant uptake as possible.

A WORD OF CAUTION

Quantification of the nutrient input into any agro-ecosystem is very much dependent on the assumptions used in developing that particular nutrient budget. For example, the National Research Council developed a state by state nutrient budget for the entire USA using data from 1987 (National Research Council, 1993). For the state of Minnesota, they reported N fertilizer sale of 580,000 tons, recoverable manure N of 79,800 tons (we are reporting the estimated amount of manure excreted in 1997), and an equivalent to 242,000 tons of N from crop residue. Therefore, any nutrient budget should be evaluated with careful consideration of underlying assumptions and potential limitations involved. In the table below, many of the assumptions used in the calculations are listed as footnotes for each calculation. We do not present these as proportions of total input due to the tentative and confounded nature of these estimates. Further discussion can be found in the Water Quality section.

TABLE 22. Sources of nutrients and the assumptions used in developing the table.

NOTE: Nitrogen contribution by some of the processes quantified in this table are mutually exclusive. Consequently, summing up the amount of nitrogen produced by all various sources provides an overestimation of the total amount of nitrogen. Also nitrogen transformations in the soil such as denitrification and immobilization has not been quantified due to the complexity of the issue.

Nutrient source	Nitrogen	Phosphorus	Potassium
	US tons		
Animal manure excretion [a]	245,000	66,000	154,000
Commercial fertilizer [b]	730,000	131,000	264,000
Soybean credit [c]	123,000	-	-
Hay credit[d]	36,000	-	-
Soil residual credit[e]	129,000		
Organic matter mineralization [f]	946,000		
Sewage sludge [g]	1,400	640	
Atmospheric deposition [h]	134,000		

[a] Manure nutrient values were estimated using cattle, hog, chicken broiler, and turkey inventories and average nutrient content of manures from (Schmitt and Rehm, 1998a;Schmitt and Rehm, 1998b;Schmitt and Rehm, 1998c). The numbers do not take into account the nutrient losses during the storage. Significant amounts of nitrogen can be lost during storage, principally due to ammonia volatilization. However, research indicated that much of the volatilized ammonia will be reabsorbed by vegetation, soil, and surface water within several miles of the source.

[b] 1996 fertilizer sale data. We assumed fertilizer purchase in Minnesota was applied in the state.

[c] Soybean credits were computed using a recommended fertilizer credit of 40 lb/acre on soybean acreage, which is the standard value used in Fertilizer Recommendations for Agronomic Crops in Minnesota by (Rehm, et al., 1994).

[d] Hay credits were computed using 100 lb/ac on 1/3 of hay acreage (assuming 1/3 of acreage in a 3-year rotation is plowed down). This is a standard fertilizer recommendation credit used in Fertilizer Recommendations for Agronomic Crops in Minnesota by (Rehm, et al., 1994) for alfalfa stands averaging 2-3 plants per square foot.

[e] Residual soil N credits were computed using 50 lb/acre from wheat and corn cropland acreage in counties where a soil N test is recommended. This is the soil nitrate-N generated by soil organic matter mineralization and other processes that is carried over from the previous crop.

[f] Organic matter mineralization was computed using 20 lb/acre on fertilized cropland acreage, based on two percent mineralization of organic matter nitrogen per year and using county averages of soil organic matter concentration.

[g] (Stark, 1999, personal communication). These values are for the amount of total N and P that are land applied. The amount of nutrients available for potential plant uptake will depend on the rate of mineralization of these nutrients.

[h] Atmospheric deposition data from (Montgomery, 1991). This data does not include dry deposition estimates, which are typically equal to wet deposition (Krupa, 1999, personal communication), nor redeposition of locally derived ammonia (Burkart and James, 1999).

PART V. CURRENT RESEARCH

Current Research Interview Sheet

Investigators: Larry J. Cihacek
Institution or Affiliation: North Dakota State University
Title of Study: Restoration of productivity in eroded fields with manure additions
Funding Agency: USDA
Duration of Study:1990-2000
Objectives: To evaluate how effective manure is in restoring productivity of eroded soils.
Key Words: manure, erosion, soils, productivity
Location (or Locations) of Study: North Dakota
Type (or types) of Soil Used:
Climate: semiarid
Approach: Manure is being applied to eroded soils and compared to non manured soils with commercial fertilizer. Soil quality is being assessed by measuring water stable aggregates and organic carbon by depth.
Progress:
Potential Implications: A quantitative value for manure as a soil remediation treatment can be identified.

Current Research Interview Sheet

Investigators: Daniel Ginting, John F. Moncrief, and Satish C. Gupta
Institution or Affiliation: University of Minnesota
Title of Study: Losses of pollutants to surface tile inlets on a landscape scale using a paired watershed technique
Funding Agency: LCMR, MDA, and USDA
Duration of Study:1996-2000
Objectives: To evaluate the effect of conservation tillage and manure application on profitability and pollutant losses to surface tile inlets on a landscape scale.
Key Words: tillage, conservation, manure, pollutants, drainage, surface inlet, tile
Location (or Locations) of Study: South Central Minnesota
Type (or types) of Soil Used: Spicer and Medilia clay loams
Climate: South Central MN
Approach: A paired watershed approach is being used to estimate the effect of conservation tillage and manure application on runoff losses of N, P, and oxygen demanding materials into surface tile inlets. Each watershed is about 130 acres in size and drains to a surface tile inlet. The flow is monitored with a bidirectional sensor and grab samples taken with an automated sampler.
Progress: The baseline period has been completed. The treatment period will begin in the fall of 1999.
Potential Implications: Most of the data evaluating losses are from small runoff plots. This study is unique in that it is on a large scale and quantitatively estimates the losses into surface tile inlets.

Current Research Interview Sheet

Investigators: Thomas L. Richard, Cynthia C. Cambardella, and Thomas E. Loynachan
Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, National Soil Tilth Laboratory USDA, and Department of Agronomy Iowa State University respectively
Title of Study: Surface and subsurface drainage tile pollutant losses with integration of manure into conservation tillage systems
Funding Agency: Leopold Center for Sustainable Agriculture
Duration of Study: Objectives: This study will address swine manure nitrogen dynamics as influenced by the composting process and land application of the compost product.
Key Words: swine, manure, compost, nitrogen, biofilter
Location (or Locations) of Study: Iowa
Type (or types) of Soil Used:
Climate: Iowa
Approach: Typical rates of nitrogen loss from hoop manure compost will be measured, and two management strategies to conserve nitrogen during the composting process will be evaluated: 1) the addition of topsoil to the mixture to provide extra exchange sites for nitrogen, and 2) the application of a layer of stabilized compost on top of the pile as a "biofilter" to trap ammonia in the exhaust gas stream. Incubation studies will be used to measure C and N mineralization of these composts after they are applied to soil.
Progress:
Potential Implications: The goal is to help farmers develop compost products that synchronize nitrogen release and crop-uptake and improve the overall quality of the soil.

Current Research Interview Sheet

Investigators: Thomas L. Richard, Cynthia C. Cambardella, Matt Liebman, and Derrick N. Exner
Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, National Soil Tilth Laboratory USDA, Department of Agronomy Iowa State University, and Iowa State University Extension Service respectively
Title of Study: Optimizing Swine Hoop Manure Management for Soil Quality and Crop System Performance
Funding Agency: Leopold Center for Sustainable Agriculture
Duration of Study:
Objectives: This study will evaluate the impact of alternative hoop manure management strategies on soil quality and cropping system performance.
Key Words: hoop barn, soil quality, cropping system
Location (or Locations) of Study: Iowa
Type (or types) of Soil Used:
Climate: Iowa
Approach: Alternatives to be tested include both fall and spring applications of composted or bedded manure in a corn-soybean rotation. The study will include both replicated plot studies at an ISU research farm (on-station) and field trials with members of Practical Farmers of Iowa (on-farm). The on-station experiments will allow large numbers of well controlled replicated plots and detailed measurement of soil and crop effects, while the on-farm experiments will evaluate a wider range of soil, manure, and crop management practices and help define the range of possible outcomes.
Potential Implications: The on-farm research also provides us with the opportunity to gain data on labor, equipment, and management tradeoffs, which farmers will ultimately balance against agronomic impacts in deciding which strategy to pursue.

Current Research Interview Sheet

Investigators: Thomas L. Richard and C. Clare Hinrichs
Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, Department of Sociology Iowa State University
Title of Study: Socio-economic and Environmental Dimensions of Swine Manure Management Decisions
Funding Agency: Leopold Center for Sustainable Agriculture
Duration of Study:
Objectives: This study is investigating farmer attitudes toward and decision-making about manure management systems.
Key Words:
Location (or Locations) of Study: Iowa
Type (or types) of Soil Used:
Climate: Iowa
Approach: Farmers using a wide variety of systems are being interviewed in two different watersheds to better understand their views on the advantages and disadvantages of different systems, their perspectives on how manure management fits into their overall farming operation, and assessing how concerns about environmental protection influence their decisions and actions.
Potential Implications:

Current Research Interview Sheet

Investigators: Matt Liebman and Thomas L. Richard
Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, Department of Sociology Iowa State University
Title of Study: Soil Amendment Effects on Crop–Weed Interactions
Funding Agency: Leopold Center for Sustainable Agriculture
Duration of Study:
Objectives: In this project, we will examine how substitution of composted swine hoop house manure for synthetic fertilizer affects corn and weeds common in Iowa corn fields.
Key Words:
Location (or Locations) of Study: Iowa
Type (or types) of Soil Used:
Climate: Iowa
Approach: Maintenance of soil fertility and effective regulation of weed populations are critical components of productive cropping systems. Although manure can serve as a means moving weed seeds back onto fields, composting kills many seeds. Previous work by the principal investigators also indicates that increased reliance on organic soil amendments rather than synthetic fertilizer can improve crop performance and reduce weed growth and competitive ability, due to changes in soil biochemistry and microbiology. We will test whether this is true for corn production in Iowa.
Potential Implications:

Current Research Interview Sheet

Investigators: M.P. Russelle, B. Shaw, J.F.S. Lamb
Institution or Affiliation: USDA-ARS at Univ. of Minnesota, Univ. Wisconsin
Title of Study: Preventing ground water nitrate impacts from abandoned barnyards using N_2-fixing and non-N_2-fixing alfalfa
Funding Agency: ARS In-house funds, WI DNR
Duration of Study: 3 years
Objectives: Determine whether non-N_2-fixing is as effective as normal alfalfa in preventing ground water nitrate impacts after a feedlot is abandoned.
Key Words: barnyard remediation, ground water nitrate
Location (or Locations) of Study: Portage Co., WI
Type (or types) of Soil Used: Sandy loam
Climate: Moist subhumid
Approach: We planted large plots (100 X 200 feet) of alfalfa, determined spatial variability in topsoil N and soil profile inorganic N, are measuring plant response, and have installed multi-port wells to monitor up-gradient and down-gradient ground water nitrate at several depths.
Progress: Experiment was begun in 1998
Potential Implications: Use of non-N_2-fixing alfalfa may provide a more effective means of removing nitrate from soil that has received high rates of livestock manure.
Publications: None

Current Research Interview Sheet

Investigators: M.P. Russelle, B. Shaw, D. Undersander
Institution or Affiliation: USDA-ARS at Univ. of Minnesota, Univ. Wisconsin
Title of Study: Improved pasture management on sandy soils to prevent ground water impacts
Funding Agency: ARS In-house funds, various WI sources
Duration of Study: 3 years
Objectives: Determine ground water impacts of current pasture management and improved practices for intensive rotational grazing.
Key Words: pasture, ground water nitrate
Location (or Locations) of Study: Waupaca Co., WI
Type (or types) of Soil Used: Sandy loams
Climate: Moist subhumid
Approach: We have installed multi-port wells to monitor up-gradient and down-gradient ground water nitrate at several depths in three pastures. Plant and soil samples are being taken to monitor N status. After background conditions are assessed, one-half of each paddock will receive improved practices, as jointly defined by the farmers and researchers.
Progress: Experiment was begun in 1998
Potential Implications: Although leaching losses of nitrate under pastures are very small on fine-textured soils in the North Central Region, we suspect losses may be high on sandy soils. Improved management techniques may help improve the environmental sustainability of grazing on these soils.
Publications: None

Current Research Interview Sheet

Investigators: M.P. Russelle, R. Leep
Institution or Affiliation: USDA-ARS at Univ. MN, Michigan State U.
Title of Study: Nitrate leaching losses under N-fertilized grass and grass-legume pastures on shallow, loamy soils.
Funding Agency: ARS In-house funds, U. MI In-house funds
Duration of Study: 3 years
Objectives: Determine the relative risk of nitrate leaching loss in grazed pastures that differ in source of N input (symbiotic N_2 fixation vs. N fertilizer).
Key Words: pastures, nitrate leaching
Location (or Locations) of Study: Kellogg Biological Research Station, MI
Type (or types) of Soil Used: Loam
Climate: Humid
Approach: In established pastures grazed by beef cattle, we have imposed treatments of split N fertilizer applications versus interseeded legumes and grass. Suction cup samplers were installed to monitor soil solution nitrate concentrations at several locations in each paddock. Plant and soil samples are being taken to monitor N status.
Progress: Experiment was begun in 1998
Potential Implications: Although leaching losses of nitrate under pastures are often very small on fine-textured soils in the North Central Region, use of fertilizer N to boost pasture production may increase leaching losses. Results will help us formulate recommendations for grazers in the region.
Publications: None

Current Research Interview Sheet

Investigators: M.P. Russelle, R. Kanneganti, R. Walgenbach
Institution or Affiliation: USDA-ARS at Univ. MN, US Dairy Forage Res. Ctr.
Title of Study: Fertilizer N rate and nitrate leaching losses under intensively grazed pasture and mowed forage on fine-texture soil.
Funding Agency: ARS In-house funds
Duration of Study: 3 years
Objectives: Determine the relative risk of nitrate leaching loss in grazed pastures that differ in amount of fertilizer N input.
Key Words: pastures, nitrate leaching
Location (or Locations) of Study: Prairie du Sac, WI
Type (or types) of Soil Used: Clay loam
Climate: Moist subhumid
Approach: In established pastures grazed by dairy cows, we have imposed treatments of split N fertilizer application rates (up to 600 kg N/ha). Drainage lysimeters are used to measure nitrate leaching losses, and plant and soil samples are taken to monitor N status.
Progress: Experiment was begun in 1997 and will be completed in spring 2000.
Potential Implications: Leaching losses of nitrate under pastures were small and similar to mowed forage when fertilizer N rates were low on fine-textured soils in the North Central Region. Our results indicate that fertilizer N rates should be lower on pasture than on mowed forage to keep leaching losses low.
Publications: None

Current Research Interview Sheet

Investigators: M.P. Russelle, J.F.S. Lamb
Institution or Affiliation: USDA-ARS at Univ. of Minnesota
Title of Study: Does root system architecture alter phosphorus uptake from soils with high P availability?
Funding Agency: ARS In-house funds
Duration of Study: 3 years
Objectives: Determine whether alfalfa populations selected for divergent root system architectures differ in P uptake.
Key Words: Phytoremediation, root systems
Location (or Locations) of Study: Rosemount and Becker, MN
Type (or types) of Soil Used: Silt loam and loamy sand
Climate: Moist subhumid
Approach: Four germplasms of alfalfa that had been selected for differences in root systems (number of fine roots, dominance of tap root, etc.) were planted at the two locations in plots with two P rates. Herbage dry mass and P content are being measured at each harvest.
Progress: Experiment was begun in 1997 and will be completed in fall 1999.
Potential Implications: Many fields in livestock farms have very high soil test P levels and new ways of decreasing those levels are needed to reduce the risk of P runoff to surface water. High-yielding alfalfas with root systems adapted for P uptake may provide a new tool to achieve both goals.
Publications: None

Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle
Institution or Affiliation: USDA-ARS at Univ. of Minnesota
Title of Study: Improved salinity tolerance in alfalfa
Funding Agency: ARS In-house funds
Duration of Study: 5 years
Objectives: Develop alfalfa for improved salinity tolerance to reduce damage by topdressed manure and food processing wastewater.
Key Words: alfalfa, salinity tolerance
Location (or Locations) of Study: Rosemount and Becker, MN
Type (or types) of Soil Used: Silt loam and loamy sand
Climate: Moist subhumid
Approach: Established stands of alfalfa are exposed to drip irrigation water mixed to achieve high electrical conductivity. This water is used as a surrogate for liquid manure or food processing wastewater. Plants best able to tolerate the stress are selected and crossed to produce improved germplasm.
Progress: Experiment was begun in 1998.
Potential Implications: Farmers and food processors need options for in-season application of waste products. Alfalfa has high potential to utilize applied N, P, and K, but is not tolerant of highly saline wastes. Improved alfalfas would provide an economic and environmentally beneficial way of reusing the nutrients in these wastes to produce high-quality livestock feed.
Publications: None

Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle
Institution or Affiliation: USDA-ARS at Univ. of Minnesota
Title of Study: Improved root extension rate in alfalfa
Funding Agency: ARS In-house funds
Duration of Study: 5 years
Objectives: Develop alfalfa for faster root growth rate.
Key Words: alfalfa, root growth
Location (or Locations) of Study: Rosemount, MN
Type (or types) of Soil Used: Silt loam
Climate: Moist subhumid
Approach: Established stands of alfalfa are selected based on how quickly they reach a given soil depth. Plants with fastest root length extension are selected and crossed to produce improved germplasm.
Progress: Experiment was begun in 1996.
Potential Implications: Alfalfa has the capacity to produce extremely deep roots and current varieties grow between 4 and 6 feet per season. To make alfalfa better able to capture mobile pollutants in the soil before they reach ground water, varieties with faster root length extension are needed.
Publications: Meyers, L.L., M.P. Russelle, and J.F.S. Lamb. 1996. Fluridone reveals root elongation differences among alfalfa germplasms. Agronomy Journal 88:67-72.
Lamb, J.F.S., M.P. Russelle, K.I. Henjum, L.L. Meyers, and D.K. Barnes. 1998. Selection for root elongation rate in alfalfa. Agronomy Abstracts. p. 80.

Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle
Institution or Affiliation: USDA-ARS at Univ. of Minnesota
Title of Study: Altering nitrate uptake by N_2 fixing alfalfa
Funding Agency: ARS In-house funds
Duration of Study:5 years
Objectives: Develop alfalfa for either better or poorer nitrate uptake.
Key Words: alfalfa, nitrate uptake
Location (or Locations) of Study: Rosemount and Becker, MN
Type (or types) of Soil Used: Silt loam and sandy loam
Climate: Moist subhumid
Approach: Established stands of alfalfa are selected based on how much bromide they contain. Bromide is an excellent analog for nitrate and provides an inexpensive way to select N_2-fixing plants for nitrate uptake.
Progress: Experiment was begun in 1996.
Potential Implications: Alfalfa absorbs N from the soil and fixes it from the atmosphere. New germplasm that has improved nitrate uptake could be used in phytoremediation of contaminated sites. On the other hand, germplasm that has poorer nitrate uptake may be less competitive with grass forages, reducing the need for N fertilizer.
Publications: Magarian, D.M., M.P. Russelle, J.F.S. Lamb,. And J.M. Blumenthal. 1998. Bromide as a tracer for nitrate-N uptake in alfalfa herbage. Agronomy Journal 90:651-657.

Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle
Institution or Affiliation: USDA-ARS at Univ. of Minnesota
Title of Study: Development of new non-N_2-fixing alfalfas
Funding Agency: ARS In-house funds
Duration of Study: 5 years
Objectives: Develop non-N_2-fixing alfalfa to clean up soils with excessive nitrate and to prevent nitrate leaching from manure and waste products.
Key Words: alfalfa, ineffectively nodulated
Location (or Locations) of Study: Greenhouse
Type (or types) of Soil Used: Sand
Climate: Controlled
Approach: Non-N_2-fixing alfalfas are crossed with alfalfas adapted to different regions of the USA. Progeny that are nonfixing but high yielding under high N supply are selected, recrossed with the adapted parents, and selected again.
Progress: Experiment was begun in 1996, seed increases begin in 1999.
Potential Implications: Non-N_2-fixing alfalfa has very high nitrate uptake capacity and effectively removes nitrate from subsoils at nitrate-impacted sites. These germplasms will be useful in preventing nitrate leaching where high rates of N-containing waste products, such as livestock manure, are applied.
Publications: None

Current Research Interview Sheet

Investigators: Michael A. Schmitt and Gyles W. Randall
Institution or Affiliation: University of Minnesota
Title of Study: Agronomic Feasibility of Growing Low-Phytate Corn
Funding Agency: Pioneer Hi-Bred, International, MN Corn Growers, MN Pork Producers
Duration of Study: Through the 2000 growing season
Objectives: Evaluate the consistency and range in plant P uptake, phytate-P concentration, and grain yield as affected by soil P levels (from manure histories) and fertilizer P applications in corn hybrids that contain normal and high available P (low phytate) quality characteristics.
Key Words: Phytate, Manure, Phosphorus, Corn
Location (or Locations) of Study: Rochester, Waseca, Rosemount, MN
Type (or types) of Soil Used: Webster Clay loam
Climate: Southwestern MN
Approach: Field research plots are being/have been/will be established at three locations in southern Minnesota. The effect of manure history, which would create varying soil P test level differences, and fertilizer P application rates are being measured for their impact on regular and low-phytate lines of two established corn hybrids for the Upper Midwest. For each of these four corn lines (two hybrids x available P levels), grain and stover dry matter yields and grain and stover concentrations were measured, which could then provide plant uptake and crop removal information.
Progress: Based on initial field data from the study evaluating corn hybrids, corn that has the trait for low-phytate has the potential for being an important component of whole farm nutrient management planning. The low-phytate hybrids yielded slightly less than the standard lines. Yields of all corn increased as the amount of previously applied manure increased, even though sufficient N was applied with commercial fertilizer and P and K soil test indicated a low probability of yield response based on these nutrients. The inclusion of the low-phytate trait did not affect the grain or stover P concentrations, thus the plants were not compensating for a change in P form with a change in P quantities. Fertilizer P, or any P fertilizer interactions, did not significantly affect any of the measured parameters.
Potential Implications: This project shows the potential for reducing the phosphorus load of manure rather than just better management of existing manure's phosphorus load. There is great potential in today's niche corn marketing systems to success in using low-phytate corn hybrids to better manage phosphorus in agriculture.

Current Research Interview Sheet

Investigators: Michael A. Schmitt, Gyles W. Randall, Jeff S. Strock, and Neil C. Hansen
Institution or Affiliation: University of Minnesota
Title of Study: Manure Application Rate and Placement Effects on Crop Phosphorus Use Efficiency and Soil Phosphorus Build-Up
Funding Agency: USDA
Duration of Study: 1999-2009
Objectives: Project objectives include: 1) evaluating the effects of manure placement on crop P use efficiencies and stratification of soil test P; 2) quantifying the effect of manure rates on soil P build-up /drawdown rates; and 3) determining effect of tillage system on crop P use efficiencies when manure is a source of nutrients.
Key Words: Manure, Phosphorus, Tillage
Location (or Locations) of Study: Lamberton, MN
Type (or types) of Soil Used: Webster Clay loam
Climate: Southwestern MN
Approach: Within a corn-soybean rotation, manure and/or fertilizer treatments would be applied preceding the corn. Three P rates, two methods of application (broadcast and subsurface banding), two P sources (manure and fertilizer) will be applied to plot areas. Corn and soybeans will be grown under a conventional tillage system and a pseudo no-till system where the only tillage is that done by the manure/fertilizer application equipment. Phosphorus uptake and removal quantities as well as grain/stover yield will be measured annually. Soil P tests will be measured every other year.
Progress: Initial set of treatments were all applied in the fall of 1998 and corn was planted in spring of 1999. No measurements have been made yet.
Potential Implications: The implications from this experiment are critical. The uniqueness of this study is that the plot area is on the Elwell Agro-Ecology farm that has never had commercial fertilizer applied to it. The soil P test is approximately 3 ppm, thus, the dynamics of P additions from these two sources and methods should be very distinct.

Current Research Interview Sheet

Investigators: Bruce Montgomery, Mike A. Schmitt, Mike P. Russelle
Institution or Affiliation: MN Department of Agriculture, University of Minnesota, and USDA Agricultural Research Service
Title of Study: Improved Agricultural Systems Overlying Sensitive Aquifers in Southwestern Minnesota
Funding Agency: LCMR
Duration of Study: 1999-2001
Objectives: Objectives include: 1) assessment of current N best management practices (BMPs), including organic N crediting and overall N rates; 2) creation of special situation BMPs guidelines for the area; and 3) implementation of the new BMPs.
Key Words: Nitrates, Manure, Nitrogen, Crop Systems
Location (or Locations) of Study: Lincoln and Pipestone counties
Type (or types) of Soil Used:
Climate: Southwestern MN
Approach: sites will be identified that will be planted to corn in the following growing season, but may have different previous crops (i.e. soybean, alfalfa, grass hay) grown in this area of the state. With different previous crops as a backdrop, a series of fall nutrient management practices will be imposed. We are planning on applying fertilizer N at two dates in the fall; one near October 1 (this would represent an earlier-than-currently recommended date); the other near October 28 (representing the recommended date). A series of N rates (0-200 lb N/acre/yr.) would be used. At one of the fall dates, a series of manure rates would also be applied using broadcast and injected methods of application, which would provide a range of N availabilities as well as a range of crop responses. The following spring, a set of fertilizer and manure treatments would be applied as a benchmark basis for all the fall treatments.
Progress: Project will start later in 1999.
Potential Implications: Implications specifically will provide N management recommendations for crop/livestock producers that have very shallow aquifers in their fields. The effect of time on N cycle transformations is much more critical when the water table is a 5 feet rather than one hundred or more feet.

Current Research Interview Sheet

Investigators: Jeffrey S. Strock
Institution or Affiliation: University of Minnesota
Title of Study: Manure management effect on surface and subsurface nitrogen and phosphorus transport to surface water
Funding Agency: Start-up funds
Duration of Study: Three years
Objectives: The objective of the proposed research is to evaluate the relationship of manure application rate and vegetative riparian buffers to reduce N and P losses from agricultural land.
Key Words: Swine manure; runoff; erosion; leaching; nitrogen; phosphorus; riparian buffer
Location (or Locations) of Study: Lake Shetek, Murray County, Minnesota
Type (or types) of Soil Used: Barnes loam, 3 to 6 percent slopes
Climate: Warm humid summers, cold winters, 25 inch average annual precipitation.
Approach: Runoff plots 36-ft by 10-ft will be situated on a slope and liquid swine manure will be applied to the soil at three rates. Surface and subsurface transport of N and P will be measured using a combination of methods. Surface erosion and runoff water will be collected with automated water samplers and analyzed for N and P. This will be done for all naturally occurring erosion and runoff events for three years. Nitrogen and phosphorous leaching will be monitored using soil sampling and shallow piezometers installed between the lake and the experimental plots.
Progress: Plots will be established at the beginning of the 1999 cropping season. Sample analysis and data summary will occur as the project progresses. The final sampling period will be fall 2001 and results are expected to be in publication format at that time.
Potential Implications: Multiple precipitation events will allow for the characterization of N and P losses from erosion, runoff, and leaching as a function of manure application rate. These relationships will then be used to determine what combination of tillage practice and manure application rate that would minimize P loss. Understanding these relationships is critical in recommending environmentally sound management guidelines.
Publications: Results will be presented to the Lake Shetek Watershed Clean Water Partnership Resource Committee and published in a refereed professional journal.
Other Comments:

PART VI. RECOMMENDATION FOR ADDITIONAL RESEARCH

MANURE RESEARCH ADDRESSING ENVIRONMENTAL CONSIDERATIONS

We need to quantify benefits of manure in addition to nutrient content, including erosion control, increased water holding capacity, and in the case of composts, weed control and disease suppression. Research has shown that manure from ruminants properly managed can reduce sediment and total P losses while still providing increased soil fertility levels and increased crop yields. This needs to be evaluated for swine and poultry manure sources. The economic value of these additional benefits needs to be part of farmers' decision making processes.

This research will identify benefits of manure that increase its value and enhance its utilization potential and provide data that support manure utilization strategies offering a win/win scenario (reduced environmental impact and increased profitability).

Evaluate the extent to which nitrate leaching and phosphorus runoff losses from Minnesota animal agriculture can be reduced.

There are several management strategies that can be used to reduce nitrate leaching and P runoff losses in Minnesota cropping systems, including choice of crop, fertilizer, and manure management, crop management, irrigation management, pasture management, etc. These will be evaluated with a computer simulation and geographic information system approach. "Ground Truth" data needs to also be collected to verify model results.

The product of this research will be maps of selected high risk areas showing predicted nitrogen and phosphorus losses under current and various improved management scenarios, and a summary of the findings. This analysis will help policymakers evaluate the likely potential impacts of proposed regulations or guidelines and changes in farmer behavior.

Characterize and evaluate whole-farm nutrient balances for different classes of livestock.

Farms will be selected to represent the range of conditions in Minnesota with respect to size, intensity, manure handling, reliance on purchased feed, soil texture and landscape characteristics, etc. of livestock operations. This effort will include consideration of nutrient distribution within individual farms to identify imbalances.

Results from this research will help define the current situation regarding nutrient balance and fate on Minnesota livestock operations. For policymakers, the research will provide thorough on-farm data on which to base their decisions regarding regulations.

Development of initial P application guidelines to protect surface water quality.

As described in the literature review, there are a number of states and counties that are adopting guidelines or regulations on P application. There is considerable disagreement about the soil test levels to invoke and the approach to incorporating them into a rational, understandable, and effective system. This work will involve determining current status of soil test P in Minnesota, evaluating soils for their P holding capacity and other characteristics, and modifying the P risk index approach using Minnesota conditions.

This research will produce a P risk index that can be evaluated by state and county agencies and other stakeholders.

What is the best management of surface tile inlets to minimize entry of pollutants from manure application? The primary strategy for reducing losses of manure derived pollutants into surface tile inlets is to keep them in place (?) on the fields with use of tillage and other conservation systems. A secondary measure is treatment at the inlet with vegetative buffer strips and/or various sand or gravel filters. There are very few references in the literature that have evaluated these options both from crop production and environmental perspectives.

Winter application of manure is still necessary for a large number of Minnesota farmers. What is the impact of winter application on runoff losses from snowmelt and rainfall runoff? Published literature on this topic is inconclusive as to the environmental hazard of winter spreading. Alternate strategies of manure application need to be evaluated : in the late fall before snow, in winter on snow, in the spring before planting, and daily or weekly spreading.

Determine the metal content by livestock species and investigate metal transport in soil systems.

Poultry and swine are sometimes fed antibiotic compounds that contain copper and arsenic. These and other micronutrient elements are a concern on landscapes that have long histories of manure application. Do manures in Minnesota conform to 'book' values in terms of metal concentration? A survey of current practices, manure analyses from across the state, and soil samples on sites with long manure histories, will determine if this is a concern in Minnesota.

MANURE RESEARCH ADDRESSING CROP PRODUCTION CONSIDERATIONS

Manure is a poor competitor with synthetic fertilizers on the basis of cost per pound of nutrient applied, and this fundamental fact goes a long way toward explaining the view in some cases that manure is a waste and not a resource. To enhance its value as a resource will require:

Better assessment of the nutrient release patterns for different types of manure (age, species, C/N ratio, etc.) applied at different times of the year in different cropping systems under varying climatic and soil conditions.

Synchronicity of nutrient release with crop demand is critical, and may best be achieved by blending synthetic fertilizers with manures. How, at what rates, and when should such combinations be applied?

Application uniformity is notoriously bad. Application variability of plus or minus 30% logically translates into over application by 30% for many manure types. We need new application equipment designed to evenly and efficiently distribute manure.

Variability is also a problem in the manure itself. Methods that homogenize the manure are one approach, while another would be real-time nutrient analysis coupled with a precision application system, which needs to be evaluated.

How much is the transportability of manure enhanced by dewatering and composting? One of the major diseconomies of manure management is the high water content. For several decades much of the published research has been with liquid systems, for which the costs of application typically exceed the benefits within a radius of less than 2 miles. Solid and especially composted manures can be transported considerably farther (12-20 miles) economically, and perhaps farther as additional manure benefits become quantified.

Are chemical treatment approaches viable for liquid manures in Minnesota?
Little is known about ways to reduce the environmental and human health hazard from liquid manures, whereas solid manures can be composted or treated with chemicals to achieve these goals. For example, alum appears to be a highly effective additive to poultry litter, and has multiple environmental, human health, and animal health benefits. This research will investigate whether any of several likely additives or composting can reduce phosphate solubility, ammonia volatilization, and pathogen survival in liquid manures.

PART VII. SUMMARY OF REVIEW AND COMMENTS

Response to Outside Reviewers Comments

Our responses to external reviewers are written in italic.

Our outside reviewers were chosen due to their prominence in the field of manure and nutrient management. They all are nationally recognized leaders in this field. All have published extensively in peer reviewed research journals and have teaching assignments in this area of study. We appreciate their comments.

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Response to Dr. William E. Jokela

1. General comments on the report (i.e. is the information and data in the document complete, accurate and understandable)

Overall, information is complete, accurate, and understandable. See comments under #4 for some suggestions for improved organization and clarity and other changes. The authors have done an excellent, comprehensive job, especially considering the severe time constraints. There are noticeable differences in style, format, and sometimes thoroughness among the different sections of the report, which, I'm sure, reflects the lack of time to coordinate and review among the different subgroups of authors.

2. Did the document adequately address the original questions as presented in the GEIS Scoping document (and provided with the reviewer form)?

All scoping questions were adequately addressed within the limitations referred to in the Critique of the questions (Section 1). See comments in #4 and some general comments below:
Questions 1 and 5.
Adequate presentation but some parts could use increased depth and/or comparison of methods.
Question 2.
Well done. Comparative energy use and geography/geology not always fully covered.
Questions 3 and 4. See comments in #4.
Excellent, especially considering the difficulty of the task and, in some cases, the limitations of data sources.

3. Is there additional information that should be gathered or additional questions that should be posed and answered to address this topic issue for the animal agriculture GEIS.

Only those addressed by the authors in their introductory Critique and within the various sections.

4. Additional Comments

Note: LC = left column; RC = right column

1. Critique...

Good discussion of questions and limitations of response
p. 1. LC: ..."collective opinion of faculty..." What about NRCS staff, who do much of the manure storage design?
p. 2. LC: "The most sensitive..." All refers to leaching. What about P and surface loss?

Insufficient time didn't allow for NRCS input. Text has been altered to address surface loss concerns.

2. Manure Storage and Handling

p. 4. LC: Clarify: "percentages of recoverable manure..." that were actually recovered.

Text altered to clarify

Table 1. Using English units, lb, rather than kg would be more familiar to the lay, nonscientific audience. Numbers stay the same anyway. (lb/1000lb animal mass). Not sure what to do with gram.

Since this table includes density and standard deviation data conversion to English units is difficult. Conversion factors for means are presented.

Table 1 and Table 2. Note that manure production for lactating dairy cattle varies greatly with milk production level of the herd (as noted in Table 3 for different stages of lactation).

This is described in detail in the text. Table 1 and 3 of reviewed draft have been changed to Table 3 and 5 in the final report.

Table 3. More clearly define headings, e.g. stages or periods in lactation: 0-30, 31-70, etc. (I think this is what is intended.)

Table has been altered to Table 5 in the final report and clarified.

Manure Storage

I suggest a reorganization of this section (especially 2.3.5), as follows:

a) Define all the storage designs briefly in one section, including type of manure stored, type of spreader used, etc. A table might be useful to summarize this information.
b) Describe each separate storage design individually, as was done in the present document.
c) Respond to each of the scoping questions. Include a discussion of all storage designs together for each question. This would provide a more integrated answer for each question and would allow comparison of the different methods. This is especially important for the third question, "Which storage maximizes...?"

We agree and have reorganized text. Manure storage section has been altered to section IV.1.4. in the new draft. In this reorganization, definition can be found in the added "glossary section, III.9.". Section IV.1.4.4. is added to discuss positive and negative aspects of storage systems together as suggested by reviewers.

Other specifics:

Some reference to the NRCS Field Office Technical Guide would seem appropriate since they are in the business of designing manure storage systems.

We agree

p. 11. RC: "Conventional" spreaders, or equipment, needs to defined. Does it mean "box-spreader" or something else? This occurs throughout this section (e.g. p. 19).
p. 11 and elsewhere: Include some reference to commonness of storage or other features to give context to the discussion, i.e. how important is it in MN. Example: 2.3.2. Cover. No indication that it is on only 1-5% of manure systems (Table 7).

We have removed the word conventional because the convention is different for various forms of manure.

p. 12. 2.3.3. Volume. Does this really refer to length of time of storage? Specify.

This heading has been eliminated and the content was added to the introduction of "Manure Storage" section to include storage time.

p. 13. LC: Are county extension personnel really qualified to do site evaluation for manure storage? This is generally the role of NRCS.

We feel that extension personnel also can make useful site evaluations.

p. 16. RC: term "lagoon". Need to check with whoever used the term "lagoon" in a later section (p. 39 and Table 10).

Terminology is now consistent

p. 20-21. 2.3.5.3. Solid manure storage. This section is very sketchy compared to other storage methods. This is especially apparent in answers to the three questions.

We would say this section is more succinct and there are less solid storage systems to describe.

2.3 Manure Handling. (p. 21-23)

Good explanation of handling methods relative to manure type, but some questions/suggestions:
a) The categories appear to leave out manure of 15-20% solids. What category is it?

MWPS defines this as "in this range, the percent solids content does not necessarily define handling characteristics". ASAE give four ranges of liquid, slurry, semi-solid, and solid with a considerable overlap in moisture content. For the range of 15-20%, this would be semi-solid for poultry and swine, in transition for beef, and solid for dairy.

b) The term "liquid manure" is commonly used to refer to any manure that is handled in liquid, or slurry, form, not limited to less than 4% solids.

We agree and using sprinkler irrigation for application is described for the semisolid category but only after components for this type of manure is available.

c) Include discussion/definition of "slurry". It is another common term (especially in Europe) and is used in a later section of this report (e.g. p. 30).

Added text to clarify.

d) p. 23. Important to note another disadvantage of sprinklers – airborne transport of bacteria. This has been documented in Quebec (and elsewhere I'm sure), and Quebec has limited (or maybe eliminated?) irrigation of manure for this reason. Reference: Denis Cote, personal communication (e-mail: denis.cote@agr.gouv.qc.ca)

Additional references from NRAES (Northeast Regional Agricultural Engineering Service), the NE equivalent of MWPS (Coop Ext, Riley-Robb Hall, Ithaca, NY):
Animal Agriculture and the Environment, NRAES-96; Liquid Manure Application Systems, NRAES-79; Liquid Manure Application Systems Design Manual, NRAES-89.

Added citations and text where appropriate.

2.4 Nutrient Losses...

p. 24 and Table 4. "P and K losses are negligible..." 30-40% losses for earthen storage does not seem negligible, and also seems too high.

Table 4 has been renumbered as Table 6 in this final report. This is not actual loss but settling.

p. 25. LC: "The greatest **N** response..." (vs. nutrient)

Changed text.

2.6 Minnesota producers...

Table 7. % with various systems...
Good to see this table, even with the qualification of the unscientific source. I was surprised to see the low %, especially 1-2% for dairy, for Tanker – surface/incorporation. Also, injection: 35-35?

Changed number to correct typo.

2.8 Economic liability...

Table 8. Comparison of costs...
Since costs decrease with larger storages, I would include numbers based on larger storage. Based on data in Table 2, a 50,000 gallon storage would be adequate for 10 Holstein cows for one-year's manure (not including dilution water).

We would have to consult with the original source to do so

3. Crediting manure...

This section is well written and quite thorough.

p. 32. RC: Elaborate more on the concept of manure N in two pools – organic and ammonium, especially as in related to management possibilities.

We have done so in the introduction.

Reference for organic N release in 2, 3, and 4th year?
p. 33, LC, top: Reference?

Reference has been included.

p. 33. RC: More emphasis on the effect of manure incorporation on reducing ammonia loss. This is an important aspect of manure nutrient utilization that farmers have some control over. Several references give more specific estimates of N loss/utilization depending on time of incorporation after manure spreading. Examples: NY/Cornell (Klausner. 1995. Nutrient Management... Cornell Univ. 95CUWFP1); Pennsylvania (Beegle. 1998. Soil fertility management. *In* The Penn State agronomy guide. 6M1198NVO); Vermont (Jokela et al.. 1998. Nutrient recommendations for field crops... Br 1390. Univ. of Vermont;).

We have added this discussion

4. Manure nutrient accountability and whole-farm balance

Additional useful references on whole-farm nutrient balance: Klausner. 1995. Nutrient Management... Cornell Univ. 95CUWFP1; Magdoff et al. 1998. Nutrient Management: More Than an On-Farm Priority. Northeast SARE, Univ. of Vermont; Magdoff et al. 1997. Nutrient cycling, transformations, and flows... Advances in Agronomy (Vol. 60), Academic Press.

p. 36. LC: "Factors affecting..." Include Inputs in the list (as in Fig. 1).
p. 37. RC: "Phytate is... purely available..." Does this mean "fully, or 100%, available"?
This is a typo and should read poorly available.

p. 38. RC: Florida dairy example. Too much data in text; use table or graphic.

There's about the same numbers in text as in other examples. with more time a table could be developed here.

p. 38-42. Florida and Waseca, MN, dairy examples have too much data and detail and not enough summarizing of the main points. Condense greatly and/or summarize in table or graphic form. As I see it, the main points in whole-farm nutrient budgeting are: a) the input and output

components that make up the N, P, and K budgets and their relative importance; b) the % exported from farm, retained, and lost to environment for different systems; c) what management changes the farmer can make to improve the budget.

We have expanded the discussion on this study

5. Not fully crediting manure...

p. 45. Include more specifics about nutrient management planning and it's importance in both economic and environmental aspects of nutrient management.

Expanded discussion.

6. Environmental liability...

6.2.1. Water quality.
Good review of a range of water quality impacts of manure nutrients, including comparison with fertilizer.
6.2.2 Air quality (and health)
Include discussion of air-borne transport of pathogens, especially by irrigation application methods.

Already have, see above

7. Maximize the positive...

p. 58. 7.3 Research...
"To further maximize the negative impacts of manure storage..." ?? What is really intended here?

Typo, should be minimize

p. 59. LC: "Develop land application equipment to decrease volume...." This is confusing to me.

Reworded to make clearer

7.6 Cropping systems
p. 62. Table 13. Nutrient removal for crops. These figures are correctly copied from the source, but I think there are some problems, especially for corn and corn silage. A 180-bu corn grain crop is approximately equivalent to a 32-ton silage crop, but corn harvested for silage will, of course, remove a much greater amount of nutrients – twice the N and P and several times the K. However, Table 13 shows greater amounts of nutrient removal from the grain-harvested crop.

The heading states "total above ground portion of the plants". similar corn yields should result in similar uptake.

8. Capacity of a cropping system...

p. 69. and Table 14. Critical levels for soil test P. I don't see any interpretation of Minnesota's soil test P that indicates what level is considered the critical level for crop production. This would be useful for much of the discussion that follows.

Text added to clarify.

p. 69 text and Table 15. Soil test P level management guidelines... Use of the term "critical value" or level in the discussion and table heading need to be clarified. Critical Value typically refers to the point at which there is no economic agronomic response, but here it is also used for management restriction levels.

We now use the term "environmentally critical values".

p. 74. LC (top): "increase in soil test P..." Aluminum extracted in the same extractant used for P has correlated well with change in soil test P with P additions (Magdoff et al., 1999. Comparison of phosphorus soil test extractants... Soil Sci. Soc. Am. J. 62 (In Press); Jokela et a.l. 1998. Improved phosphorus recommendations.... Comm. Soil. Sci. Plant Anal. 29:1739-1749).

They use a different p test in Vermont and have quite different soils. these references do not apply to Minnesota

9. Total amount and proportion of plant nutrients from various sources applied to Minnesota soils

This section is a serious attempt at a very difficult task. It reflects a considerable amount of work. (I think there may be more detail than needed on symbiotic N fixation for the intended audience.) Some interpretation of Table 20 would be useful, including elaboration of the note at the top of the table.

This is a proposed research project.

Citations and References

Check form of citations listed in text, e.g. p. 30, RC, l. 3 (Frame, 1998).

Missing in Reference List (not complete list)
p. 4. NRCS (1995)
p. 12. Goodrich, 1999
p. 31, Table 8. MSCS, 1993.
p. 65. Randall et al., 1994.

Citation from is due to a problem with Procite® database we created, and has been corrected. Reference list is complete.

Response to Dr. Tommy C. Daniel

Generally, the Committee has done a good job of reviewing the subject area and producing a document that is understandable by a diverse audience.

While the Critique of Scoping Document Study Question attempts to summarize the findings, the statements are far too general to provide any clear leadership or direction. For example, from a technical standpoint, if year-long storage is needed to solve the environmental as well as the production aspects of manure handling, the authors should so state. How these facilities would be paid for is another question, but if that is the technical solution, then it should be stated and the group would the have a point to start working from on the economics. This is the most important section and should be the strongest and most definitive. This section needs work.

The points in this section have been made clearer.

This document makes little reference to best management practices (BMPs) and it is assumed that this aspect is covered in another section. However, this section is concerned with build up of P in soils and proper nutrient management planning is the key to preventing this from happening. Fortunately, Minnesota is not experiencing elevated soil P levels in the very excessive range (300 ppm Bray P 1) and the best BMP to address this issue is to prevent it from happening. A phased in threshold soil P level as part of the nutrient management plan is one way to ensure that from happening.

The BMP section has been expanded. development of an environmentally critical soil p level for Minnesota is proposed.

Generally, the document did a good job of describing the mobility of P in both surface water and through the vadose zone; however, on page 67 under section 8.3, the document reverts back to the previous thinking that P is insoluble and that soils are an infinite sink for P.

Verbiage added to clarify that we do not believe soil is an infinite sink

The issue of agriculture and water quality will be with us for a long time and, undoubtedly, the assessment process will uncover unanswered technical questions that can only be addressed through an applied research effort. Provisions should be made to ensure that this much needed research be an inherent part of the process.

We agree.

Response to Dr. Robert L. Mikkelsen

As you requested, I have reviewed the Literature Review addressing Manure and Crop Nutrients. Overall, the review has carefully documented the important considerations related to proper manure management. It reflects a great deal of effort to synthesize a large body of research and practical experience accumulated over many years. Many of the document authors are leading national authorities in this area of study.
It is written at an appropriate level for the intended audience.

Due to the short period of time allowed for the review, I have only included a few comments that may be useful for your consideration: One of the difficulties in using organic nutrient sources is estimating the residual/carryover value of the added material. This concept is only given brief mention (pg. 32) relative to organic N. Additional description of this phenomenon would help educate the readers about the difficulty in obtaining accurate estimates of this value and the long-term significance.

Added additional description.

It is mentioned that "phytate is purely available to most monogastric animals" (pg. 37). This needs to be corrected.

This is a typo purely should be poorly.

Advantages and disadvantages of various manure treatments and handling options are listed. However, no disadvantages of COMPOSTING are given. To be consistent (and fair), the limitations and disadvantages of this treatment/handling option should be listed too.

The text that describes disadvantages of composting is found on pages J-69 and J-70.

The specific soil P extractant used to develop Fig 4 (pg. 73) needs to be clearly identified. (I think it's Bray). It is impossible to fully interpret the data without this detail (also, is it AASTAD or AARSTAD? (it's spelled both ways on Fig. 4)
Corrections made in test.

Numerous spelling and formatting errors should be corrected. Additionally, I did not check all the references, but many inconsistencies and errors still exist.

This has been corrected.

This document should be useful as you enter into the next phase of this project- identifying research knowledge gaps. You have made an excellent start at summarizing a complex subject. I hope that this process will lead to valuable contributions to our understanding of manure and nutrient management. Please contact me if I can be of additional assistance in the process. I would be pleased to receive a final draft of the document when it becomes available.

Thank you for your interest and time we appreciate your input.

Response to the CAC Comments on the DRAFT Report June 14, 1999

Round bullets are Citizens Advisory Committee comments and the arrows with paragraphs in italic are responses.

1. **Actual Systems/Practices**
   - Can more information be given about actual numbers/percentages of various systems now in use in Minnesota? If there is a "data gap", so state.

There is a decided gap about the actual numbers and percentages of various systems in use in Minnesota because no one had done surveys or kept track of construction.

- Are under barn pits common and what are their environmental benefits and risks?

Under barn pits are very common in Minnesota. For swine under barn pits have been the predominant storage constructed in the last four years and has been popular prior to that time. For dairy and beef they are less popular. Turkeys have no under barn pits. Poultry have some depending on the age of the buildings.

Environmentally under barn pits are a benefit to protecting groundwater because they are well constructed and watertight. From a human and animal safety point of view (risks to human and animal health) they are less beneficial than above ground tanks since the gases are kept in close proximity to the animals and workers. Less runoff water and rainwater is contaminated when under barn pits are used compared to aboveground tanks and outside detention ponds. The least risky storage situation is a covered concrete tank outside of the barn.

- Can more information be added regarding actual land application practices now in use in Minnesota?

- Number of earthen basins?

Data are lacking on the number of earthen basins in Minnesota. The number on swine operations is not increasing at this time. They are still being constructed for dairy operations.

- Frequency of emptying pits?

Most pits are emptied when they reach the full point or above. Planning is needed to move the emptying time to strategic times of the year when it makes most sense to empty the pits. Planning cropping systems to make more efficient use of the nutrients and to place a higher priority on using the nutrients should be studied. Crop rotations and better use of government programs to use the nutrients may be possible.

2. Fertilizer vs. Manure

- Need more comparison of manure to fertilizer (see page 71).

The table referred to estimates the amounts of various nutrient sources in Minnesota including sewage sludge, commercial fertilizer, atmospheric deposition, etc. This table doesn't allow for a monetary comparison due to the confounding described in the text. Direct monetary comparisons of commercial fertilizer and manure can be found in section 3.

- Discuss direct dollar savings by using manure instead of fertilizer and the cost of failing to do soil testing.

Direct dollar saving from using manure is a function of the nutrient content minus the storage and application costs. Examples of storage and handling costs are found in Table 10. As is explained in section IV.1.6 (text and tables 6, 7, and 8) the fertilizer value has to take into account losses in storage and handling which is variable depending on the particular system. The values in these tables can be used to estimate fertilizer value for various systems based on the current fertilizer prices.

3. Health/Safety

- Does anaerobic storage of manure increase its environmental risks?

Anaerobic storage and the accompanying digestion create volatile gases and odors, which are not beneficial to health. Hydrogen sulfide, mercaptans, ammonia are just a few of the approximately 200 compounds that have been identified in anaerobic storage systems. These increase the risk to humans and animals. Methane is a serious greenhouse gas and this is also produced in significant quantities. Landfills which are also producers of methane gas are now having to control the methane and not release it to the atmosphere.

- Safe handling measures.

Manure needs to be handled so those nutrients are not released to the environment in incorrect quantities nor in inappropriate places. Proper hazard analysis and control point analysis need to be applied so that the environment is protected.

4. Use of Phosphorus Limits

- How did other states set phosphorus limits and are they relevant to Minnesota?
- What would be an appropriate limit for Minnesota?
- Clarify if other states' limits are regulation or guidelines.

We have enlarged the discussion of how other states are approaching the question of defining fields where P applications are restricted by guideline or regulation. Many states are considering new guidelines or regulations and may adopt them in the near future, thus the situation nationally is quite dynamic.

In our judgement based on present knowledge, no scientifically-sound statewide or soil-specific limit for P can be set for Minnesota that relies on soil test P alone. Although there are differences of opinion at present, we expect that a more reasonable approach to setting P limits in Minnesota will be to modify the 'P risk index' approach for conditions in our state. This approach was suggested by NRCS several years ago and has been tested under relatively few conditions in the USA since then. Establishment of a P risk index is complicated, as it involves site-specific landscape, soil, climate, and surface water considerations. Although implementation is more complicated than using soil test P level alone, the P risk index approach is scientifically defensible. Conducting the necessary research and formulating a draft P risk index (or indexes for various areas of the state) is among our high priority recommendations.

Clearly, the establishment of guidelines or regulations on P application is a role of government and we expect that their report will cover aspects of this issue.

5. Role of Enzymes

- Discuss use of phytase enzyme for nutritional purposes in swine and poultry and its implications for manure.
- Cross reference animal health.

The role of phytase in making P stored in plant phytate has been added to the report and is cross referenced to the Animal Health report.

6. "Old" vs. "New"

- Clarify context or restate that old facilities are more threatening then new facilities.

New facilities have met stronger environmental criteria than older facilities. Many of the older units may be improperly located and have been allowed to continue in potentially hazardous locations since they have not been brought under the new regulations.

- Can result in localized problem.
- Advice given by agricultural engineers in past, present and future.

This was in discussion only and was not part of report.

7. Definitions/Clarification

- Isotope testing of water?

With respect to isotope testing of water to determine sources of nitrate, two studies were cited in the report on Water Resources (section 6.1.4). These references concluded that isotopes of either nitrogen or boron could be used to differentiate sources. Not all scientists

agree with the use of nitrogen isotopes, as there is a tremendous range of enrichment in various N sources in the environment. Use of boron isotopes for this purpose has not been subject to much scientific scrutiny, but may prove to be an acceptable method.

- (Page 51) minimize rather than maximize.

The word 'maximize' was changed to 'minimize' on the former page 51 —thank you.

- (Page 51) manure as feed.

The topic of manure as feed has been discussed at length in the Animal Health report and this is now cross referenced to Section G of that report.

- Nutrient sources – clarify sources percentages (Q4).

The table on nutrient sources in Minnesota (Table 22) is expressed as tons per year and, although calculation of percentages for each 'source' would appear easy, it is not. Readers must understand that animal manure and soil organic matter are not 'new' sources of nutrients, but simply temporary storage pools for nutrients brought in by other means. In addition, a major nutrient addition to the state, that is, livestock feed and supplements purchased from outside the state, has not been included, because this data is not available. On individual livestock farms, purchased feed and supplements can be the largest source of both nitrogen and phosphorus. Given these and the other uncertainties discussed in table footnotes and associated text, expressing nutrient inputs to the state of Minnesota in terms of percentages would be misleading and inaccurate.

8. Cross Referencing

Water (ex: manure storage, manure vs. commercial fertilizer, cumulative ground water impact under earthen basins).
Role of government (ex: tax on commercial fertilizer, required nutrient management plans, phosphorus limits).
Air/odor.
Human health.

Cross referencing has been added where appropriate

9. Report

What about recommendations for additional research?

Research Recommendations have been added to the report.

- Cross referencing.

Cross referencing has been addressed in 4,5,7, and 8 above.

- Inconsistencies regarding "lagoons" compared to Water Report.

As defined in our report in Section 2.3.5.1.2 Earth Storage Basins A lagoon is an earthen facility for the biological treatment of wastewater. It can be aerobic, artificially aerated, anaerobic or facultative depending on the loading rate, design and type of organisms present (ASAE, 1998). To be more precise in our treatment of the topic we chose to use the term earthen storage basins to describe this method of storage where appropriate. In the Water topic area report the team chose to report whatever term was used in the paper being cited, even if it was technically incorrect.

- More "meticulous" citation of sources

This comment was in large part made due to confusion about our introduction, which describes common storage and handling systems in Minnesota. This is in direct response to Scoping document question 1. This section was offered as a back ground piece for the non farming readers. It is not research and therefore doesn't require citation. Some of the definitions were taken out of a 1985 publication written by 12 north central US states including Minnesota, which was cited at the beginning of the section. We have added a better description of this publication and explanation of its use. These storage and handling systems have not changed appreciably since 1985.

This comment may also refer to the numbers present after some citations. This is a result of a compatibility problem with ProCite and Word software.

- Page 25 could make Table 10 a footnote to emphasize #'s are expert opinions not facts.

Footnote added to table 8. The table was developed by a panel from the Department of Biosystems and Agricultural Engineering, University of Minnesota with expertise in manure management systems. Note that numbers will not add to 100% because sequential storage exists and individual locations often have multiple modes of storage.

PART VIII. REFERENCES

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APPENDIX

Appendix. Table 1. Current levels of phosphorus, zinc, and copper in Minnesota agricultural soils based on the information from University of Minnesota Research Analytical Laboratory. Note that due to limited number of samples this may not be a true a representation of the typical soil test levels.

County	Bray P			Olsen P			Zinc			Copper		
	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.
		--- ppm ---			---- ppm ----			---- ppm ----			----- ppm -----	
Aitkin	296	29	26	20	23	14	20	4.1	5.2	17	1.1	1.2
Becker	111	33	27	18	16	14	5	3.2	1.4	4	0.5	0.1
Beltrami	613	30	27	55	15	14	14	7.7	7.4	14	2.4	6.3
Benton	625	39	26	9	29	16	32	2.7	4.3	12	1.1	1.2
Big Stone	21	21	13	10	20	12	1	1.3	.	0	-	-
Blue Earth	183	33	27	8	26	19	2	51	69.2	2	14.8	17.6
Brown	17	58	39	2	10	4	1	0.5	.	0	.	.
Carlton	622	27	27	24	24	16	16	2.2	2.9	4	0.6	0.3
Carver	136	36	29	29	24	17	3	2	1.1	2	0.8	0.3
Cass	220	43	27	7	22	14	3	0.8	0.4	0	.	.
Chippewa	38	59	34	6	30	22	0	.	.	0	.	.
Chisago	496	45	28	57	31	16	37	2.3	2.1	19	0.8	0.3
lay	15	37	40	8	11	2	6	0.4	0	0	.	.
Clearwater	441	22	17	119	16	10	51	6.8	5.7	45	3.5	4.8
Cook	2	6	7	1	10	.	0	.	.	0	.	.
Cottonwood	248	15	12	54	13	9	161	6	18.7	0	.	.
Crow Wing	285	48	31	3	13	3	7	2.3	3.2	2	0.2	0.1
Dakota	1,094	56	82	111	38	18	35	3.5	3.9	23	1.7	2.4
Dodge	81	25	20	16	31	13	10	2.4	1.1	0	.	.
Douglas	90	16	16	26	13	10	10	1.6	1.4	1	0.5	.
Faribault	272	21	17	62	15	11	27	2	1.3	7	1.3	0.2
Fillmore	340	33	26	23	29	16	4	1.3	0.3	3	0.6	0.2
Freeborn	265	40	29	21	16	10	12	5.1	6.3	0	.	.
Goodhue	803	28	21	69	23	14	40	1	0.8	7	0.6	0.2
Grant	2	65	50	1	23	.	0	.	.	0	.	.
Hennepin	572	36	38	120	21	13	15	3	2.6	5	1.0	0.5
Houston	751	32	24	52	25	14	13	1.8	1.7	3	0.7	0.1
Hubbard	304	36	22	4	21	10	10	1.5	0.7	6	0.3	0.1
Isanti	416	51	28	21	27	14	17	1.4	2.5	9	0.7	0.4
Itasca	692	48	34	39	22	14	24	5	7	24	1.2	1.1
Jackson	297	21	17	57	13	7	135	4	15.4	0	.	.
Kanabec	461	29	23	3	27	17	23	2.3	2.6	4	2.2	2.6
Kandiyohi	12	31	39	5	5	7	1	1	.	0	.	.
Kittson	64	21	24	57	16	14	0	.	.	0	.	.
ıoochiching	165	16	19	23	10	10	11	5.2	5.4	5	0.3	0.3
Lac Qui Parle	29	12	9	15	8	5	11	1.8	1.6	0	.	.

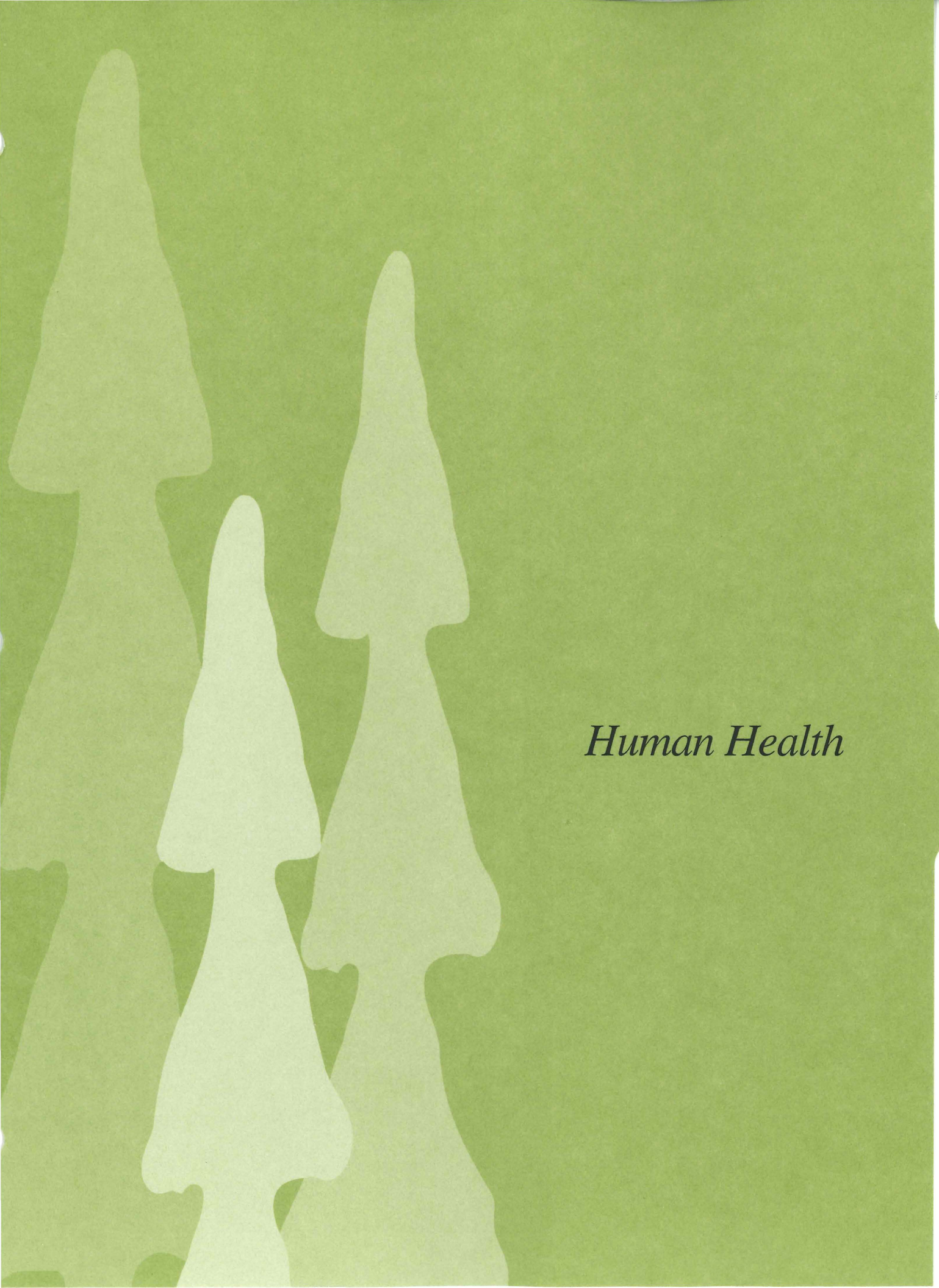
Appendix Table 1. Continued

County	Bray P			Olsen P			Zinc			Copper		
	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.
		--- ppm ---			---- ppm ----			---- ppm ----			----- ppm -----	
Lake	65	29	30	8	38	16	11	16	17.2	11	8.5	12.1
Lake of Woods	127	17	17	66	15	9	2	1.1	0.1	2	1.1	0.2
Le Sueur	152	25	23	7	26	15	1	1.5	.	0	.	.
Lincoln	24	11	10	11	9	7	10	0.9	0.3	0	.	.
Lyon	35	20	30	25	13	13	10	10.8	31.3	6	0.9	0.2
Mahnomen	91	20	22	76	15	12	4	3	1.2	0	.	.
Marshall	82	17	15	28	9	4	12	1.4	2.3	3	0.1	0
Martin	198	42	36	72	31	19	6	1	0.6	5	0.9	0.2
Mc Leod	40	14	21	34	14	13	0	.	.	0	.	.
Meeker	32	45	33	11	28	18	5	4.1	1.9	0	.	.
Mille Lacs	54	28	23	0	.	.	0	.	.	0	.	.
Morrison	795	45	28	36	31	14	34	2.3	2	5	1.0	0.9
Mower	425	26	19	8	31	15	22	1.4	0.6	3	0.6	0.3
Murray	108	20	16	31	19	12	65	2.7	12.3	7	1.7	0.6
Nicollet	99	22	19	16	13	7	3	1.7	0.4	0	.	.
Nobles	145	11	10	41	9	7	54	1.1	0.9	1	1.2	.
Norman	7	21	13	7	10	5	7	0.8	1	1	0.4	.
Olmsted	387	35	27	11	26	14	7	1.2	1.1	5	0.8	0.3
Otter Tail	259	24	20	73	12	9	24	1.7	0.6	3	0.5	0.1
Pennington	94	14	15	62	13	10	1	1	.	1	1.1	.
Pine	508	47	52	6	35	42	10	16.2	33.8	2	0.7	0.2
Pipestone	67	19	20	6	7	2	42	0.8	0.5	0	.	.
Polk	409	16	16	233	14	11	98	4.7	4.5	56	2.4	2.9
Pope	101	16	16	14	17	15	13	2.4	2.8	2	0.7	0.1
Ramsey	303	56	40	108	26	17	11	4.4	4.3	8	0.9	0.7
Red Lake	85	10	18	75	8	11	4	2.6	1.7	4	5.0	3.6
Redwood	133	38	29	19	17	10	12	1.3	0.6	0	.	.
Renville	26	25	25	13	20	15	7	1.5	0.8	0	.	.
Rice	229	33	24	16	15	14	11	1.6	1.1	3	1.1	0.1
Rock	910	15	15	117	10	10	152	1.3	1.5	25	4.0	5.2
Roseau	253	17	16	178	12	9	28	11.3	7.4	28	1.8	2.4
Scott	128	23	23	44	23	15	4	2	1	1	0.7	.
Sherburne	335	48	34	26	28	12	17	2.2	1.9	12	0.4	0.2
Sibley	94	41	33	31	29	16	2	1.1	0.3	0	.	.
St. Louis	919	31	33	99	19	17	58	4.1	5.6	30	2.4	5.5
Stearns	853	63	70	127	33	19	43	3.3	8.6	10	3.4	6.6
Steele	120	27	22	35	28	14	12	5.2	8.6	1	1.2	.
Stevens	67	14	18	60	15	12	6	2.3	1.2	1	1.4	.
Swift	16	17	14	4	16	8	1	1.6	.	1	2.0	.
Todd	264	40	26	10	29	15	12	1.5	0.7	2	0.5	0.1

Appendix Table 1. Continued

County	Bray P			Olsen P			Zinc			Copper		
	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.	Freq.	Mean	Std. Dev.
		--- ppm ---			---- ppm ----			---- ppm ----			----- ppm -----	
Traverse	3	18	6	1	10	.	0	.	.	0	.	.
Wabasha	143	36	25	34	34	15	4	2	0.4	1	1.0	.
Wadena	353	41	23	5	16	6	18	2.6	2.9	5	1.1	0.9
Waseca	399	37	36	40	22	20	42	1.7	1.1	9	1.0	0.2
Washington	1,165	39	31	85	34	18	38	3.8	7.6	16	2.2	3.9
Watonwan	318	23	17	284	18	10	152	1.7	1	1	1.3	.
Wilkin	4	9	9	4	6	3	0	.	.	0	.	.
Winona	438	39	30	50	33	15	18	2.7	2	13	5.0	4.7
Wright	362	38	37	21	22	16	34	5.2	13.6	23	2.9	6.9
Yellow Medicine	80	8	7	33	8	4	11	1.8	0.7	0	.	.

Freq. is the number of samples tested in each county.



Human Health

K

Generic Environmental Impact Statement on Animal Agriculture:

A Summary of the Literature Related to the Effects of Animal Agriculture on Human Health (K)

Prepared for the Environmental Quality Board

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Executive Summary

Animal agriculture can have a variety of both positive and negative impacts on human health through occupational exposure, other environmental exposures, and exposures through consuming the product. Many of the environmental exposures are addressed in other sections of the GEIS literature review. The present report looks at human health concerns through occupational, direct environmental, and consumer pathways.

While human health risks can be associated with different types of animal production systems, it is difficult to make direct comparisons between systems. Most of the human health literature reviewed was not explicit about the type of production system studied. There are countless variations of animal production systems, making all but general classifications of systems nearly impossible in a project of this scope. In addition, there is a preponderance of research focused on confinement production systems and very little research focused on outdoor, alternative, and other types of systems. This report reflects that focus on confinement systems. For these reasons, there is little information contained in this report that compares the human health effects of different types of animal production systems. Unfortunately, this leaves key systems-level questions, especially important in the search to prevent or mitigate human health risks in animal agriculture, unanswered.

For workers in the industry, there are various airborne exposures and other workplace hazards such as traumatic injuries. For neighbors there are air-, water-, soil-, and fly-borne exposures. For consumers of the product, there are environmental health threats associated with contaminated foods and potentially negative nutritional effects. For other consumers, there are exposures from microbial contamination that affect other foods and water supplies, including possible exposure to antibiotic resistant pathogens.

There are several regulations aimed at protecting human health, including those related to animal production (antimicrobial use, airborne emissions, disease control, worker safety) and those related to animal products processing and sale. While there are few worker safety regulations focusing exclusively on agriculture, existing OSHA regulations apply to animal production in many cases and can also serve as a guideline for employers to develop their own safety practices. The effectiveness of food and meat inspection regulations cannot be measured directly and indirect measures, such as prevalence of food-borne disease, are questionable.

Production agriculture is the nation's second most dangerous industry with the greatest number of injuries occurring on beef, hog, and sheep operations. Working in confinement operations presents a number of health and safety risks to the employee, such as traumatic injury, hearing loss, dermatologic conditions and possible zoonotic infections. Prevention of injuries can be accomplished through engineering (facilities design), providing guards on moving machinery, wearing gloves, and education.

Two of the most significant human health issues are antibiotic (antimicrobial) resistance and antibiotic residues. Concern about the increasing resistance in bacteria that are relevant in human diseases has been a controversy for decades but only recently has there developed some clear indication that animal feeding practices are involved. It has been clearly established that some animal pathogens, which are resistant to antimicrobial agents, including antibiotics, are transmitted to humans. These are called zoonotic pathogens. Five recent published studies have demonstrated the link between antimicrobial use in food animals and the transfer of resistant Campylobacter to human patients, including a very recent study in Minnesota.

Antibiotic residues in food are a problem of much less significance than the development of resistant strains of pathogens in living animals. This is due to the mandatory residue testing of meat and milk and educational efforts by USDA and the livestock industries. Further improvement is possible by increasing voluntary residue avoidance programs on the farm.

There is concern about the human health risks associated with steroid implants and Bovine Somatotropin used in animal production. However, they have not been clearly substantiated.

Substantial scientific literature exists that human health is adversely affected by the transmission of a number of toxic and noxious agents via the air. Large animal production units are a source of air transmission of toxic and noxious agents, such as gases, dust, odors, and biogenic particles. Those generated within animal and poultry confinement facilities can adversely affect health of people working in those environments and potentially the health of people living or working near such facilities. Acute health effects are particularly common and frequently involve the respiratory system. Some chemicals have been documented to cause fatalities such as hydrogen sulfide in manure pits. The effects of odors are potentially serious and include loss of appetite, poor respiration, nausea, vomiting and mental distress.

Water-, soil-, and fly-borne pathogens and nutrients are also a concern. Pathogens may be transmitted to humans from animal wastes through contaminated surface drinking water supplies, contaminated ground water supplies, or direct contact with contaminated environment e.g., recreational use of water. Some incidents of human disease attributable to contact with livestock waste have been reported. Water-borne nitrate represents a health risk to infants under the age of six months, because it can cause an acute and potentially fatal condition called methemoglobinemia. Insects, especially flies, are a potential vehicle for the transmission of human disease from manure, dead animal carcasses, and other animal wastes. Escherichia coli (E. coli), Salmonella spp. and Campylobacter jejuni are candidates for transmission by flies. However, the literature on this subject is ambivalent. More research is needed to determine the extent to which fly-borne microorganisms are transmitted to humans and cause illness, and on the control of flies in farming.

A wide variety of food-borne disease organisms exist in animal products. Many of these newly emerging diseases have a significant impact on human health (including "external" impacts on people who are not eating the food that was responsible for the pathogens in the environment)

and economic impact on the livestock industry. Children, pregnant women, the elderly, and the immunocompromised are most likely to develop severe symptoms and serious consequences. An extremely large literature exists but the development of "emerging pathogens," newer microorganisms that account for a rapidly escalating number of cases of human illnesses, indicates that knowledge gaps are likely to be constantly appearing as organisms alter characteristics. More information is needed on management practices, pre-cooking, probiotics, and impact of antimicrobial agents. Consumer education regarding the proper cooking, storage and handling of animal products and all foods is still necessary.

Animal products do make positive contributions to human health by providing essential nutrients. Consumption of animal products has been statistically associated through epidemiological studies with increased mortality and morbidity in Western populations. However, controlled laboratory studies designed to analyze these statistical associations have not been able to identify any causative mechanism and thus have not been able to validate these statistical associations.

In terms of which segments of the population are most susceptible to health problems related to animal agriculture, for occupational injuries it is obviously farm workers, especially those who are new and untrained. For airborne contaminants, workers and neighbors are most at risk where geographical factors increase their exposure. For food borne microbial diseases, the young, elderly and immunocomprimised are the most likely to develop severe symptoms and serious consequences. They are also potentially most vulnerable to pathogens transmitted by water, soil, and flies; and to resistant strains.

Critique of the Scoping Document Study Questions

Scoping Document Study Questions as Published

1. What are the current regulations and routine practices in place in Minnesota and other places related to animal agriculture production that are aimed at the protection of human health? What is known about the use of these practices, or in the case of regulation, what is known about compliance? What is known about the effectiveness of the regulations and practices?

2. What are the human health effects and associated risks of different types of animal agriculture giving consideration to:

- 2.a. use of antibiotics, heavy metals, and other chemicals in livestock production;
- 2.b. transmission of gases, dust, odors and pathogens and nutrients through the air, water and soil;
- 2.c. transmission of disease and sickness via manure, flies, dead animal carcasses and other animal waste bi-products
- 2.d. transmission of disease and sickness through consumption of animal products;
- 2.e. safety and wholesomeness of the food supply?

3. How do these human health effects and associated risks vary by segment of the population including: workers, neighbors, animal product consumers, the elderly, the ill, pregnant women and young children?

4. How do the human health effects vary by species, operation, system type, management, geography, and concentration of livestock facilities?

5. What monitoring techniques, modeling approaches, and standards are available and in use in Minnesota as well as other places to detect and measure for the existence of these human health effects and how can we judge the validity of each?

6. What are the current and potentially available prevention and mitigation measures that are available to producers, workers and neighbors for addressing these effects and to what extent are these effective?

Critique of and Suggestions for Study Questions

Changes to Study Questions

The scoping questions do not address occupational injury as a human health effect of animal production. This is an important area of study where there are major human health impacts. Therefore, an additional question was added on occupational injury.

Scoping document questions 2.b. (transmission of gases, dust, odors and pathogens and nutrients through the air, water and soil) and 2.c. (transmission of disease and sickness via manure, flies, dead animal carcasses and other animal waste bi-products) contained overlapping areas of information. Therefore, a portion of question 2.b. was incorporated into 2.c. These questions are now redefined as:

Question 2.b. - Transmission of Gases, Dust, Odors, and Pathogens through the Air

Question 2.c. - Transmission of Sickness and Disease via Water, Soil, and Flies from Manure, Dead Animal Carcasses, and Other Animal Wastes

With regard to scoping document question 2.e. (safety and wholesomeness of the food supply), safety and wholesomeness are very similar terms and do not address nutrition. Safety was included with the food-borne disease sections, and wholesomeness was re-classified into "nutritional wholesomeness." Therefore, scoping document question 2.e. is now "Nutritional Wholesomeness of Animal Products."

Alterations in Report Organization

In order to improve the organization and readability of this report, two organizational changes were made:

Questions 3, 4, 5, and 6 were incorporated into questions 2.a. through 2.e. They are clearly labeled as such both in the text and in the Table of Contents for easy reference. Consequently, former questions 3 through 6 have been deleted as separate questions.

The order of the questions was changed to reflect the shift in focus from occupational health effects, to environmental health effects, to consumer health effects. The new order of the questions is:

Question 2.a. - Occupational Injury

Question 2.b. - Transmission of Gases, Dust, Odors, and Pathogens through the Air

Question 2.c. - Transmission of Disease and Sickness via Water, Soil, and Flies from Manure, Dead Animal Carcasses, and Other Animal Wastes

Question 2.d. - Transmission of Disease and Sickness through Consumption of Animal Products

Question 2.e. - Antibiotics, Heavy Metals, and Other Chemicals

Question 2.f. - Nutritional Wholesomeness of Animal Products

General Comments and Suggestions

Involving some scientists from the relevant areas would have been useful by:

- Accelerating the formulation of the questions, which would have allowed more time for the review to be done.
- There would be clear, non-overlapping questions.
- The terminology would be more accurate and clear.

Current Regulations and Current Practices

- Question is impossible to adequately research given the resources

Human Health Effects of Animal Agriculture

- Antibiotics, Heavy Metals, and Other Chemicals
  - Heavy metals-does this include trace minerals?
  - The term chemical is meaningless in the context (see Primer on Toxicology)

Critical Review of Information Sources

Question 1 - Current Regulations and Routine Practices Related to Animal Agriculture Production Aimed at the Protection of Human Health

Issues of Concern: Many regulations and practices exist that are related to animal agriculture. In a general sense, they can be divided into four main areas: animal production, animal transport, animal products processing, and animal products sale. Because of the broad nature of these questions, it is difficult to narrow the focus to a few concise issues. However, when thinking about protecting human health, it is most relevant to look at those issues related to animal production, and the processing and sale of animal products, or in other words, meat safety. Consequently, this section will focus on issues of regulation and practices related to those two areas. For point of comparison, it will also briefly discuss regulations and practices in nations other than the U.S.

CURRENT REGULATIONS AND PRACTICES RELATED TO ANIMAL PRODUCTION

Current Regulations and Practices Related to Antimicrobial Use

USDA/FSIS conducts mandatory residue testing of meat and milk prior to further processing. There are also intensive educational efforts by USDA and the livestock industries (mostly as result of quality assurance programs for e.g. pork, dairy, poultry, etc. on a national or state basis) on antimicrobial use.

Current Regulations and Practices Related to Airborne Emissions

Odor and Hydrogen Sulfide State Standards

Federal, state and some local governments regulate ambient concentrations of specific gases and dust. See the Air Quality and Odor report, GEIS topic III. H., for detailed summaries of various state hydrogen sulfide and odor standards.

Ambient Dust Emissions

Ambient dust is regulated by the U.S. Environmental Protection Agency (EPA) under the National Ambient Air Quality Standard (NAAQS) (EPA, 1998c). Emissions from large beef cattle feedlots in Texas and California are regulated (Sweeten and others, 1998).

Current Regulations and Practices Related to Disease Control

In spite of the potential for transmission of diseases to humans by animal production, little regulation is practiced. However, some regulation does occur related to animal production and much closely related information is found in the Animal Health report, GEIS topic IV.L., starting with section B. These regulations are important in that by protecting the health and well being of

non-human animals, human health is also served.

Current Regulations and Practices Related to Worker Safety

Enforcement methods involve mandatory regulations to prevent injuries or illness. These regulations may be internal in terms of policies and procedures developed by the employer, or external regulations enacted through the Occupational Safety and Health Act (OSHA) (Occupational Safety and Health Act, 1970). Coverage of the federal OSHA, which is provided through a state approved plan in 38 states, does not extend to all farming operations. Certain farms are protected from federal OSHA enforcement of rules, regulations, standards or orders under the Act, as stated in the Department of the Interior and Related Agencies Appropriations Act , 1996: funds appropriated for OSHA may not be "expended to prescribe, issue, administer, or enforce any standard, rule, regulation, or order under the OSH Act of 1970 which is applicable to any person who is engaged in a farming operation which does not maintain a temporary labor camp and employs ten or fewer employees" (Department of the Interior and Related Agencies Appropriations Act 1996; and OSHA 1993).

Some state plans have also adopted standards applicable to agriculture. For example, Minnesota hog production facilities with greater than ten employees are covered by the Occupational Safety and Health Standards for Agriculture, 1975 adopted by Minnesota OSHA (OSHA, 1975). The 1928 standards cover agriculture-specific regulations and list the General Industry standards from OSHA 1910 which are applicable to agricultural operations. In addition, agricultural operations are covered under the general industry standards of the Minnesota Rules (Lorentz, P., personal communication, December 29, 1997; and Minnesota Rules, 1973).

Enforcement methods of prevention are also used to protect workers. Labor regulations in some states include confined space regulations, which apply to manure pits; and Right to Know legislation, which requires employees to be made aware of hazardous substances they may be exposed to and the dangers associated with them. These regulations often apply to operations with more than ten employees and require employers to have a written plan enforced which addresses methods of compliance, including measurement of contaminants, safety procedures, employee training and record keeping (Minnesota Rules, 1984 and 1988). The term "employee" refers to all paid employees, except immediate family members, working in operations owned by an individual, family or partnership. Immediate family members are only counted as employees if they are paid for working in operations that are incorporated, including family corporations. This definition corresponds with state and federal employee health and safety regulations (OSHA, 1993).

The OSHA respiratory protection standard does not apply to agricultural operations, but could be used as a guide in developing a respiratory protection program and is considered an accepted standard of minimal protection (OSHA, 1975).

The OSHA Occupational Noise Exposure standard specifies that workers should not be exposed to 100 decibels for more than two hours daily, and 110 decibels for not more than one-half hour

(Hearing Conservation Amendment, 1983). Though the OSHA Occupational Noise Exposure standard (Hearing Conservation Amendment, 1983) does not apply to agriculture operations, this federal standard does offer guidance to employers for prevention methods and is considered an accepted standard of minimal protection (Shutske, J., personal communication, February 9, 1998).

In addition to procedures and guidelines developed by the employer, there are state and federal regulations regarding injury prevention for which the operator employing more than ten employees must comply. For example, the Minnesota Workplace Accident and Injury Reduction Program (AWAIR) requires Minnesota operations to have a written work place accident and injury reduction program promoting safe and healthful working conditions (Minnesota Rules, 1990; and Minnesota Statues, 1973). The federal Machine Guarding Standard was developed to protect agricultural workers from hazards associated with moving machinery parts on farm equipment (Occupational Safety and Health Standards for Agriculture, 1975). This regulation requires the employer to: provide employee instruction on proper use and repair of machinery; protect employees from coming into contact with hazards of moving machinery parts through guarding, including guarding of power take-offs, and all mesh or nip-points of power driven gears; and prevent accidental application of electrical power to equipment. Hog production facilities using tractors must also comply with the federal Roll-over Protection Standard, requiring specific safety features on tractors manufactured after October 25, 1976 (Occupational Safety and Health Standards for Agriculture, 1975).

Minnesota employers, including those in agriculture operations, must also record and report occupational injuries and illnesses that occur (Minnesota Rules, 1978). The purpose of this regulation is to develop information regarding the cause and prevention of occupational injuries and illnesses. Reporting, using the OSHA 200 log or an equivalent, must be made of occupational injuries and illnesses that meet the OSHA definition of recordable injuries and illnesses.

Farm employers must carry workers' compensation insurance which provides compensation to qualified employees who have a work related injury or illness. Some state workers' compensation laws designate amount of cash wages as a condition for qualification under the law, i.e. Minnesota Workers Compensation (Minnesota Statues, 1953) -- $8,000 in cash wages in the previous year, or less than the statewide average annual wage if the employer has a liability policy. Reporting of work related injuries and illnesses may also be required by completing a report of injury form. Employers can manage their workers' compensation costs by reducing work related injuries or illnesses in their operation to below the industry average (Garry, 1990).

What is Known about the Use, Compliance, and Effectiveness of Regulations and Practices Related to Animal Production

Use, Compliance, and Effectiveness of Worker Safety Regulations and Practices

Tripp et al. (1998) conducted a survey of pork producer employers in Minnesota and North Carolina to determine their needs related to worker safety and health and to document their

knowledge of and compliance with key worker health and safety regulations. The survey found that employers in both states were very interested in receiving additional education and training on a variety of topics including such items as animal handling safety; first aid; safe performance of veterinary procedures; prevention of back injuries; and, respiratory protection. The top three worker health and safety problems that had been experienced by the operators surveyed (and their employees) included cuts, neck/back strains, and needle sticks.

Another issue that is growing in importance is workers compensation insurance, required for hired workers in larger livestock operations. A total of 54% of the operations surveyed did carry workers compensation for employees. More than one-fifth of the respondents reported that workers comp insurance rates were increasing slightly to rapidly (a reflection of higher rates of injury among workers).

More than half of all hog producers (53.2%) reported no planned safety training, 41.8% provided planned safety training, and 5% did not respond. At least one planned safety training event was provided at orientation, monthly, bi-monthly, semi-annually or annually. In operations with more than ten employees 76.9% reported planned safety training and 23.1% did not. In all operations, planned safety training was provided most often on use of respiratory protection, performing veterinary procedures safely, safe operation and servicing of equipment, and working with manure storage systems safely. In operations with more than ten employees, planned safety training was most often provided on use of respiratory protection, performing veterinary procedures safely, and use of hearing protection.

Hog producers were asked to report personal protective equipment provided (at no cost to the employee). Two strap dust masks were provided by 70.9% of all operations. A total of 69.2% of operations with more than ten employees provided two strap dust masks. One strap dust masks were provided by 64.6% of all operations and 92.3% of operations with more than ten employees. Supplied air respirators were provided by 5.1% of all operations, but not provided by any operations with more than ten employees. Hearing protection and gloves were provided by 69.6% and 87.3% of all operations, respectively. In operations with more than ten employees, 92.3% provided hearing protection and all (100%) provided gloves.

When asked if protective guards or shields on moving machinery parts were in place, 62.0% of all operations and 53.8% of operations with more than ten employees reported that all machinery parts had guards or shields. Twenty-seven percent of all operations and 30.8% of operations with more than ten employees reported most machinery parts had guards or shields. When asked if methods of preventing a person from starting equipment or machinery while another person was repairing it were in place, an affirmative response was reported by 72.2% of all operations and 84.6% of operations with more than ten employees.

Of the 43 operations providing workers' compensation insurance, 41.8% were aware of the safety inspection and consultation service available by the insurer and 61.1% who were aware of the service had used the service in the past.

Hog producers were asked if they had a plan in place and enforced or being developed in relation to occupational health and safety regulations. Of the operations with more than ten employees, 84.6% had a written plan in place, enforced or under development for the machine guarding standard and the reporting and recording of work injuries and illnesses. A total of 76.9% reported a plan for hazard communication, and 69.2% reported a plan for the confined space entry and for roll-over protective structures. Minnesota has its own permit-required confined space entry regulation that is applicable and has been enforced on farms in the state with 11 or more employees. In addition, 76.9% had a plan in place, enforced or under development for the respiratory protection standard, which agricultural operations in most states are not legally required to comply with except by way of OSHA's "general duty" clause.

Of operations with more than ten employees, 45.4% hog producers reported using the OSHA 200 log, and for the 43 operations reporting workers' compensation insurance, 51.2% used the First Report of Injury form required by insurers following an injury.

CURRENT REGULATIONS AND PRACTICES RELATED TO MEAT SAFETY

HACCP and GMPs

Numerous references are made in this report to HACCP and GMPs and some explanation of these terms is appropriate.

HACCP is a methodical and systematic application of the appropriate science and technology to plan, control and document the safe production of foods. HACCP is a systems approach to food safety management and decision making about a product and its manufacturing process, the identification of hazards and the selection of points and measures for control. GMPs are the minimum sanitary and processing requirements to ensure production of wholesome food. GMPs provide basics in food safety, but have several weaknesses that are then picked up with the use of HACCP. GMPs are too broad to address plant-to-plant-specific hazards; all GMPs are afforded equal weight; no consideration of non-compliance posing a health risk; and do not require record keeping, monitoring of hazard controls or establishment of deviation limitations and corrective actions. Both HACCP and GMPs have been applied to processing of food with great success in terms of reducing risks to the consumer. These same principles are applicable to the farm as well and this is strongly suggested in this document.

As international trade increases, the safety issue will also increase as safety is a convenient trade barrier. Therefore, it is likely that large processors will demand some production safety standards be implemented by producers. The potential use of HACCP and GMPs on farms and its more extensive use in processing plants would aid attempts at producing a safer supply of animal food products.

What is Known about the Use, Compliance, and Effectiveness of Regulations and Practices Related to Meat Safety

The FDA and USDA are the highest authorities dealing with food and meat inspection and regulation. However, there are serious gaps of knowledge concerning effectiveness and compliance of all such programs; their effectiveness cannot be directly measured and the indirect measures, such as prevalence of food-borne disease are suspect, as discussed earlier.

Though the food supply of the U.S. is often considered one of the safest in the world, food safety improvements are still needed. Several arguments can be presented in support of this statement. First, food-borne disease remains a significant cause of mortality and economic burden in the U.S. Second, due to continual exposure to media reports of food-borne disease outbreaks and food product recalls, consumers are increasingly demanding higher quality and safer foods. Third, expanded global trade links the U.S. to food safety developments in other countries. Countries that develop systems that produce safer foods will use this for market advantage, and food safety and quality is likely to become a barrier to market access. Fourth, recent identification of emerging pathogens and development of antibiotic resistance in food-borne pathogens indicate a failure of current methods of monitoring and control to deal with these problems, especially those resulting from healthy-appearing animals.

This topic is discussed in several places in this Human Health report. For more information, look specifically at:
Question 2.d. Transmission of disease and sickness through consumption of animal products
Question 2.e. Antimicrobial residues and resistance

It is generally believed that the prevalence of food-borne disease is higher than reported because oftentimes the patient misdiagnoses or simply does not want to take the time and trouble to report an illness.

REGULATIONS IN MINNESOTA AND THE U.S. COMPARED TO OTHER NATIONS

The United States, Australia, New Zealand, Canada and Sweden probably are among the best countries in terms of meat inspection program effectiveness but these types of comparisons are nearly impossible to make accurately according to Minnesota researchers (Pullen et al., 1999).

Some information from European Union (EU) regulations are useful in terms of knowing what the global competition is doing to protect animals, farm workers and the citizens near animal facilities. European regulations regarding livestock includes directives that are valid for all EU members, but need to be set into power by each member state with slight modifications to address country specifics being allowed.

As an example, the Directive for the minimum housing and management conditions for swine, which resulted in Germany in the revision of the old "Schweinehaltungsverordnung" (Ordinance

on how to keep pigs) into "Schweinehaltungshygieneverordnung" (Ordinance of the hygiene when rearing pigs), was issued on June 7, 1999 and has been in power since June 12, 1999. This regulation prescribes in detail how buildings are constructed to rear pigs, which management systems are required, and which concentration of adverse gases are allowed. Here is just one example of these benchmarks: 20 ppm ammonia is the maximum that is allowed in a swine barn (to compare the maximum working concentration for people is 50 ppm). The reason why it is lower for pigs than for people is that pigs live their entire life in this barn; people work only 8 hours in the same atmosphere and can protect themselves if necessary. The transportation of pigs, the veterinary care and many other aspects are specified.

Such EU-directives and their corresponding member state ordinances exist for all livestock species. Any person who keeps pigs for professional reasons is responsible to know this ordinance and can be legally sued if he or she does not comply (Anonymous, 1999).

In general, the rationale for this type of regulation is based on concerns for the following: the well-being of animals, the well-being of farmers and the public, the fact that healthy animals are less likely to suffer disease conditions and such animals are less likely to transmit such diseases into the environment.

Conclusions

- **Regulations aimed at protecting human health include those related to animal production (antimicrobial use, airborne emissions, disease control, worker safety) and animal products processing and sale.**
- **While there are few worker safety regulations focusing exclusively on agriculture, existing OSHA regulations apply to animal production in many cases and can also serve as a guideline for employers.**
- **The effectiveness of food and meat inspection regulations cannot be measured directly and indirect measures, such as prevalence of food-borne disease, are questionable.**

Question 2 - What are the Human Health Effects and Associated Risks of Different Types of Animal Agriculture for the Following:

QUESTION 2.A. - OCCUPATIONAL INJURY

Issues of Concern: Production agriculture remains the nation's second most dangerous industry, with a death rate exceeded only by the mining industry (National Safety Council, 1998 Accident Facts). Several documents indicate that livestock producers and employees who have direct contact with animals have a relatively high rate of traumatic injury. A study conducted by the National Institute for Occupational Safety and Health (Myers, 1998) found that the greatest number of farm-work injuries occurred on beef, hog, and sheep operations (36.5%), followed by cash grain operations (23.1%), dairy operations (14.6%), and other field crop operations (11.9%).

Employees of animal confinement systems have regular close contact with animals during feeding, cleaning, medicating, performing veterinary procedures, and transporting the animals. This close contact puts workers in hog confinement buildings at risk of exposure to biologic, chemical and physical agents (Christianson et al., 1990).

Health Effects: Occupational Injury

Working in confinement operations presents a number of health and safety risks to the employee. Health effects include acute and chronic respiratory problems, traumatic injury, hearing loss, dermatologic conditions and possible zoonotic infections.

For information on respiratory problems, see Question 2.b. - Transmission of Gases, Dust, Odors, and Pathogens through the Air. Much of the literature review information provided in this section on worker health and safety issues was extracted from a Journal of Agromedicine article in press by Tripp, Olson, and Shutske (Tripp, R, Olson, D, Shutske, J, Schermann, M. 1999. Health and safety issues in hog production. Journal of Agromedicine (in press).)

Traumatic Injuries

There is limited literature regarding injuries in swine confinement facilities. Two studies are discussed here. The first study was done using First Report of Injury forms over a thirty-nine month period. These forms do not differentiate between minor and severe injuries (Gordon and Rhodes, 1993). The study was done in a birth-to-market operation in the midwestern United States which produced approximately 5,700 swine each week. The second study is of acute and chronic trauma in hog farmers in Ontario, Canada (Holness and Nethercott, 1995a). Results were obtained from respondents completing a self-administered questionnaire regarding accidents and injuries over the previous three years.

Gordon and Rhodes found the injury incidence to average 52 injuries per 100 employee years, with the range being 32 to 65 per 100 employee years (Gordon and Rhodes, 1993). The most

common type of injury was bruising, which accounted for 18.6% of the injuries. This was followed by strains and sprains (15.2%) and needle stick injuries (10.4%), which occur most often in the hand, followed by the leg and arm. Other injuries reported in descending order include cuts, back injury, eye irritation, burns, rash, allergy, bite, fracture, and fall.

Holness and Nethercott reported that 21% of respondents experienced an accident, with the lower and upper extremities, and back most often affected (Holness and Nethercott, 1995a). Bruising was reported by 51% of the respondents. Backache and sore knees were the most frequently reported chronic injuries, with 71% and 36% reporting these respectively.

The mechanisms of injury affect various body parts. Holness and Nethercott found falls to be the most frequent mechanism of injury (33%) followed by lifting (23%) (Holness and Nethercott, 1995a). Falls were associated with foot and chest injuries, while lifting was associated with back injuries. Other mechanisms associated with injuries include machinery cut, hit, and crush. When the injury was an amputation, the hand was most often involved (80%). Machinery was the only mechanism significantly associated with these amputations (Holness and Nethercott, 1995a).

A number of veterinary type procedures are performed on new piglets including vaccinating, clipping teeth and tail docking with hand-held cutters, and castration with a curved scalpel blade. As the pigs grow they must be monitored for illness and injected with antibiotics when needed. Syringes and needles are multi-dose, hence they are not changed between injections (Gordon and Rhodes, 1993). Performing these tasks while handling and holding the animals presents opportunities for needle sticks, bruising, cuts and bites (Christianson et al., 1990; Gordon and Rhodes, 1993; and Barnham, 1988). In addition, if high pressure injection systems are used, there can be risk of serious injury if the worker unintentionally self injects the vaccine (Couzens and Burke, 1995).

Noise Induced Hearing Loss

Though there is little in the literature regarding noise induced hearing loss in swine confinement workers, the potential exists. Squealing pigs can produce high frequency noise levels at 100 to 110 dBA (Christianson et al., 1990). A case report in Denmark found a pig breeder who was regularly exposed to noise to have a considerable bilateral sensorineural hearing loss (Kristensen and Gimsing, 1988). This breeder had been exposed to noise levels between 95 and 104 dBA for 45 minutes twice daily during feedings. In addition, the constant noise level in a room housing the system for grinding and mixing feed was found to be 88 dBA, and that of a high-pressure cleaner to be 98 dBA, reaching 105 dBA when directed towards steel surfaces on the floor (Kristensen and Gimsing, 1988).

Dermatological Conditions

Skin conditions are associated with medications administered to the animals. Two cases are reported in the literature, both involving the administration of medications. One reports a six month history of severe dermatitis of the thumb and fingers, with the nails ridged and cuticles lost (Burge and Bransbury, 1994). This pig farmer had been administering oral doses of the

antibiotic furazolidone to newborn piglets using a pump dispenser, where there was contact with the fingers. The second report is a piglet dealer presenting with a two year history of recurrent scaly lichenified eczema of face, neck, hands and forearms which was aggravated by sun (Brasch et al., 1991). This condition was found to be associated with regular intra-muscular injections of azaperone, a sedative given to piglets before transport. Some spillage of the medication is common, contaminating the hands and other areas touched by the hands, since the farmer was not using gloves (Brasch et al., 1991).

Zoonotic Infections

Zoonotic infections can be transmitted to humans while working with animals. The literature is limited documenting these infections in swine farm workers. A majority (83%) of the thirty reports of meningitis caused by *Streptococcus suis* in the Netherlands between 1968 and 1984 were found in individuals working in the pork industry (Arends and Zanen, 1988). *Microsporum nanum*, a dermatophyte was reported in three human cases of pig farmers; two developed inflammatory *tinea faciei* and one developed *tinea cruris* (Roller and Westblom, 1986). This organism is most frequently associated with ringworm in pigs and with rashes in human infections. Pig farmers have also been found to have elevated antibodies to *Yersinia enterocolitica* serotypes common to swine and toxoplasma, though there has not been documented evidence of illness (Seuri and Granfors, 1992; and Seuri and Koskela, 1992).

Pig farmers may be exposed to a variety of medications administered directly to the animals or through animal feed. They may also be exposed to organisms carried by the animals through airborne routes or by direct contact (Brasch et al., 1991; and Arends and Zanen, 1988).

Variation by Segment of the Population: Occupational Injury

Obviously, the segment of the population most affected by occupational injuries are animal production workers. However, limited information is available in the literature on differences between workers. One report said that older farmers report fewer accidents and bruising, and increased arthritis other than in the back and knees. Gordon and Rhodes found one-third of needle sticks occur in the first month of employment and over half occur during the first six months (Gordon and Rhodes, 1993). This is compared to other types of injuries where 32% occur during the same six month time period (Gordon and Rhodes, 1993).

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Occupational Injury

Confinement operations have a number of environmental factors that contribute to health and safety risks including increased animal density, mechanized feeding systems, slotted flooring which facilitates waste handling, and reductions in air exchange to minimize heating needs. Increased reporting of injuries and bruising are associated with facilities which market larger numbers of hogs and with employees who spend a greater number of hours with the animals. In terms of the stages of hog development, those with breeding operations tend to have increased bruising while those limited to finishing have decreased bruising (Holness and Nethercott, 1995a).

Monitoring Techniques, Modeling Approaches, and Standards: Occupational Injury

Minnesota employers, including those in agriculture operations, must record and report occupational injuries and illnesses that occur (Minnesota Rules, 1978). The purpose of this regulation is to develop information regarding the cause and prevention of occupational injuries and illnesses. Reporting, using the OSHA 200 log or an equivalent, must be made of occupational injuries and illnesses that meet the OSHA definition of recordable injuries and illnesses.

Prevention and Mitigation Measures: Occupational Injury

Traumatic Injuries

Engineering methods for the prevention of employee injuries are directed at those agents or tasks associated with the injuries. The literature is limited in establishing links between specific agents or tasks and injuries in swine confinement operations, but some prevention methods can be applied from other areas of agriculture and industries.

Handling large animals presents many situations where there is potential for injury to employees. The principal weapon of the pig is its teeth, being very sharp and as the pig grows, having very strong jaws (Fowler, 1995). Pigs generally do not herd but there can be a mob reaction when handling an individual pig. Hogs also tend to be stubborn and will resist efforts to move them in a certain direction (Fowler, 1995). Engineering methods of prevention include designing facilities that take animal behavior and the necessary worker tasks into account, thus creating a safer environment for moving the animals and caring for them. Such design features will consider safe walkways for the animals and workers; allowing adequate space to prevent situations where the worker may be caught between the animals and structures; and reduction of pinch points that the worker is exposed (Fraser and Broom, 1990; and Grandin, 1993). Operations carrying workers' compensation insurance can obtain assistance in assessing the safety of the work environment through safety consultation services offered by their insurer (Mattsfield, W., personal communication, 1996).

Since machinery is identified as a leading cause of farm injuries, providing guards on moving parts of machinery, and keeping machinery in good repair are methods of prevention (Gordon and Rhodes, 1993).

Educational methods for prevention include instruction on: animal handling and holding techniques; animal behavior and learning to anticipate it; and how to safely perform procedures with the animals, in particular avoiding bite injuries (Fraser and Broom, 1990). Results obtained by Gordon and Rhodes showed that one third of needle stick injuries occurred in the first month of employment, and 62% occurred during the first six months of employment (Gordon and Rhodes, 1993). Other injuries are more equally distributed between short-term and long-term employees, suggesting these injuries may be prevented through instruction and training in animal handling and injection technique (Gordon and Rhodes, 1993).

Noise Induced Hearing Loss

Engineering methods, such as automatic feeding systems which do not require the worker to be present, can be used to contain the noise (Kristensen and Gimsing, 1988; and Hearing Conservation Amendment, 1983). Education of employees consists of providing information regarding the hazards associated with noise exposure and teaching them to avoid hazards when possible, and encouraging their use of hearing protection when in high noise areas. Employers can develop internal operation requirements regarding employee use of hearing protection in documented high noise areas, using the Occupational Noise Exposure standard as a guide (Hearing Conservation Amendment, 1983).

Dermatological Conditions and Zoonotic Infections

Exposure to medications and organisms can be reduced by the use of gloves (Brasch et al., 1991). Education includes informing employees of the risks associated with exposure to medications and organisms, symptoms they may experience and the importance of reporting dermatologic and other systemic conditions (Minnesota Statutes, 1973).

Conclusions:

- **Production agriculture is the nation's second most dangerous industry with the greatest number of injuries occurring on beef, hog, and sheep operations.**
- **Working in confinement operations presents a number of health and safety risks to the employee, such as traumatic injury, hearing loss, dermatologic conditions and possible zoonotic infections.**
- **Prevention of injuries can be accomplished through engineering (facilities design), providing guards on moving machinery, wearing gloves, and education.**

QUESTION 2.B. - TRANSMISSION OF GASES, DUST, ODORS, AND PATHOGENS THROUGH THE AIR

Issues of Concern: Large, intensive confinement facilities represent potentially a special case of airborne agents that are problematic but also potentially the most controllable. Airborne toxic agents generated within animal and poultry confinement facilities can have direct, adverse health effects for people working in those environments. In addition, if these facilities emit substantial quantities of such agents into the atmosphere, there is a possibility that the health of people living or working near such facilities might also be affected.

Of particular concern are the gases and airborne particles, including microbial organisms (bacteria and bacterial toxins, fungi, viruses, and mites), that are generated inside the facilities. These livestock production environments create complex mixtures of toxic airborne hazards, some of which may act synergistically to cause health effects.

Human Health Effects: Airborne Contaminants

Airborne contaminants within and emissions from animal facilities include gases, particulates or dust, odors, and biogenic particles which include pathogens (bacteria, viruses, bacterial toxins, fungi and mites) and a host of microbial byproducts such as endotoxins and glucans. Individually and combined they have potential direct and indirect impacts on human and animal health.

The potential direct impact on human health can be:

- Physical impairment of the biological/mechanical defense mechanisms by dust and irritant gases such as ammonia and hydrogen sulfide (e.g. damage to the respiratory epithelium of the airways, including dysfunction of the cilia that transport mucus and foreign bodies out of the upper respiratory tract) and damage to the goblet cells, changing the functional capacity of the mucus that normally flows on the surface of the airways to trap and transport out foreign material.

- Chemical irritation of the upper respiratory tract lining by gases (e.g. damage of the epithelial barriers to inflammatory substances, respiratory bacterial or viral pathogens; decreased cilia function and increased inflammation of the airways involving increased cellular infiltration and release of inflammatory mediators).

- Immunological sensitizing to allergens (e.g. organic dust particles such as feed ingredients, fungi, animal epidermal scales, and mites).

- Infection with bacteria or viruses that have a pathogenic potential for the human respiratory tract (e.g. Influenza-A-Virus, *Streptococcus, Staphylococcus, Pasteurella, Salmonella, Leptospirosis, Cryptosporidiasis, Giardia, and Haemophilus*) and toxins from the organism *pfiesteria.*

The potential indirect impact on human health can be:

- Gaseous emissions such as NH_3, washed down by precipitation, can contribute to the nitrogen content of ground and surface waters that are used for drinking water.

- Zoonotic bacteria emitted from livestock and poultry facilities may contribute to an increased population of these same microorganisms in the ecosystem (such dust-borne, non-respiratory, bacteria pose hardly any direct risk to human health, even to passers-by near animal houses).

- Bacteria from animal excretions (emitted via exhaust air) that contain genetic determinants for antimicrobial resistance can contribute to an increase of bacterial resistance in the ecosystem but the risk is unknown and needs further study.

The following discussion focuses on the major toxic agents present in animal and poultry confinement facilities, and the principal human health effects associated with exposures to these hazards. Much of the literature review information provided in this section on worker health and safety issues was extracted from a Journal of Agromedicine article in press by Tripp, Olson, and Shutske (Tripp, R, Olson, D, Shutske, J, Schermann, M. 1999. Health and safety issues in hog production. Journal of Agromedicine (in press).) For more information on air emissions from animal agriculture, see the Air Quality and Odor report, GEIS topic III. H., question 1.

Gases

Human Health Effects: Gases

Gases can affect human health in at least two ways. Some gases are irritants to the respiratory system. In the environment of animal facilities, these gases combine with dust and can have an additive or synergistic effect (Reynolds and others, 1994; Donham and Cumro, 1999b). Other gases result in asphyxia, or the impairment of oxygenation of vital tissues. For these agents, the lungs serve as a route of uptake into the circulation leading to health effects in other organ systems. Asphyxia is an important health concern for workers in livestock confinement facilities. Hydrogen sulfide, carbon dioxide, carbon monoxide, and methane, in sufficiently high concentrations, can all decrease the fraction of oxygen in inspired air and lead to low oxygen levels in the blood that may be sufficient to cause unconsciousness or even death.

Anaerobic decomposition occurring in manure storage systems produces a combination of gases made up of approximately 60% methane and 40% carbon dioxide, with trace amounts of ammonia, hydrogen sulfide and other odorous compounds (Feddes and Barber, 1995). Of these gases, hydrogen sulfide and methane have the greatest likelihood of causing asphyxiation.

O'Neill and Phillips (O'Neill and Phillips, 1992) conducted a literature review of the odorous chemicals detected in and around livestock facilities or livestock wastes, which identified 168 different compounds. The most commonly reported compounds in the literature review were volatile fatty acids (acetic, propionic, butanoic, and pentanoic), phenol, p-cresol, and ammonia.

Some of these compounds have been identified as respiratory tract, skin, or eye irritants. Table 1 lists those gas compounds that have some acute or chronic health value associated with them, either from the Minnesota Department of Health, or from the California EPA or the US EPA.

EPA inhalation reference concentrations (RFCs) can be used to estimate a level of environmental exposure at or below which no adverse effect is expected to occur. The RFC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population that is likely to be without appreciable risk of effects during a lifetime. In general, the incidence of human disease or the type of effects that chemical exposures have on humans cannot be predicted. This is due to the numerous uncertainties involved in risk assessment, those associated with extrapolations from animal data to humans and from high experimental doses to lower exposures. The organs affected and the type of adverse effect resulting from chemical exposure may differ between study animals and humans. In addition, many factors besides exposure to a chemical influence the occurrence and extent of human disease (EPA, 1999).

Table 1- Volatile organic compounds and gases identified in livestock wastes with documented subchronic, chronic, or acute health values (O'Neill and Phillips, 1992).

Compound (names)	**Minnesota's Proposed Inhalation Health Risk Values (µg/m3)** **Chronic**	**Sub-Chronic**	**US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects**	**California's EPA Acute REL (µg/m3) and Toxicologic Endpoints**	**EPA Hazardous Air Pollutant Listing**
Acetaldehyde ethanal	5				yes
Acetone dimethylketone (2-)propanone			not avail.[1]		
Acetophenone acetylbenzene methylphenyl-ketone			not avail.[1]		yes
Acrolein 2-propenal acrylaldehyde		0.07	0.02 squamous metaplasia and neutrophilic infiltration of nasal epithelium	$1.9*10^{-1}$ eye irritation	yes
Ammonia	80		100	$3.2*10^{3}$ eye and respiratory irritation	
Benzaldehyde Benzenecarbonal			not avail.[1]		
Benzene	1		not avail.[1]	$1.3*10^{3}$ reproductive developmental	yes
Bis(2-ethylhexyl) phthalate					yes

Table 1- Volatile organic compounds and gases identified in livestock wastes with documented subchronic, chronic, or acute health values (O'Neill and Phillips, 1992).

Compound (names)	**Minnesota's Proposed Inhalation Health Risk Values (µg/m3)** **Chronic**	**Sub-Chronic**	**US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects**	**California's EPA Acute REL (µg/m3) and Toxicologic Endpoints**	**EPA Hazardous Air Pollutant Listing**
Carbon disulphinde	700		700 peripheral nervous system dysfunction	$6.2*10^3$ reproductive developmental	yes
Carbonylsulphide carbon oxysulphide					yes
Chloroform Trichloromethane			not avail. [1]	$1.5*10^2$ reproductive developmental	yes
Crotonaldehyde 2-butenal			not avail. [1]		
Ethyl acetate acetic acid ethyl ester			not avail. [1]		
Formaldehyde methanal	0.8		not avail. [1]	$9.4*10^1$ eye irritation	yes
Formic acid methanoic acid			not avail. [1]		
Hexane					yes
Hydrazine	0.002		not avail. [1]		yes

Table 1- Volatile organic compounds and gases identified in livestock wastes with documented subchronic, chronic, or acute health values (O'Neill and Phillips, 1992).

Compound (names)	**Minnesota's Proposed Inhalation Health Risk Values (µg/m3)**		**US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects**	**California's EPA Acute REL (µg/m3) and Toxicologic Endpoints**	**EPA Hazardous Air Pollutant Listing**
	Chronic	**Sub-Chronic**			
Hydrogen sulphide		10	1 inflammation of the nasal mucosa	$4.2*10^1$ respiratory irritation	
Isobutyl alcohol 2-methyl-1-propanol			not avail. [1]		
Methanol methyl alcohol			not avail. [1]	$2.8*10^4$ CNS[4]-mild	yes
2-methoxyethanol methyl cellosolve methyl glycol		50	20 testicular effects		
Naphthalene	.1		3 nasal effects: hyperplasia and mataplasia in respiratory and olfactory epithelium, respectively		yes
Phenol carbolic acid benzenol hydroxybenzene				$5.8*10^3$ eye and respiratory irritation	yes
Pyridine azine			not avail. [1]		
Sulphur dioxide				$6.6*10^2$ respiratory irritation	

Table 1- Volatile organic compounds and gases identified in livestock wastes with documented subchronic, chronic, or acute health values (O'Neill and Phillips, 1992).

Compound (names)	**Minnesota's Proposed Inhalation Health Risk Values (µg/m3)**		**US EPA's Chronic Inhalation RfC's (µg/m3) and Critical Effects**	**California's EPA Acute REL (µg/m3) and Toxicologic Endpoints**	**EPA Hazardous Air Pollutant Listing**
	Chronic	**Sub-Chronic**			
Toluene	400		400 neurological effect	$3.7*10^4$ CNS-mild eye and respiratory irritation	yes
Triethylamine		70	7	$2.8*10^3$ CNS-mild, eye irritation	yes
Xylene Dimethylbenzene (isomer not specified)			not avail. [1]	$2.2*10^4$ eye and respiratory irritation	yes

Ammonia

Ammonia (NH_3) gas is a potent respiratory irritant associated with manure and storage handling systems. High levels of NH_3 are found particularly with solid manure systems (Feddes and Barber, 1995). Ammonia is generated by the metabolic breakdown of urea and uric acid present in animal and avian excreta, and by the use of quaternary ammonium compounds as sterilizing agents. This highly water-soluble gas is retained in undisturbed liquid manure and on flooring surfaces where scraper systems are used. Concentrations increase significantly from summer to winter in response to decreased ventilation to maintain internal temperatures in the colder weather (Crook et al., 1991).

Ammonia can damage cilia in the respiratory tract, leading to impaired clearance of particles deposited in the airways, and can stimulate hyperplasia and hypertrophy of goblet cells and mucous glands with resulting phlegm production. Among individuals with increased airway reactivity, ammonia can cause reflex airway narrowing via direct stimulation of nerve endings in the airways. NH_3 is a highly irritating gas, causing progressively worse inflammation of mucous membranes at levels of 100 ppm and above (Hurst, 1995). Ammonia exposure above 2,500 ppm can be fatal, and above 5,000 ppm is rapidly fatal (Hurst, 1995). In vapor form, ammonia is captured in the upper respiratory tract. Due to the irritating nature of ammonia, serious health problems are rarely seen because workers remove themselves from high exposures (Preller et al., 1995).

Hydrogen sulfide

Hydrogen sulfide (H_2S) is a potent asphyxiant found in livestock confinement facilities. It is a colorless and moderately water soluble gas with a density of approximately 1.19 relative to air, and is the most toxic (Hurst, 1995). H_2S is flammable, and can be explosive with the right mixture of oxygen. Due to its physical nature, H_2S can remain trapped in gas pockets and released when the manure slurry is agitated. There is potential for high concentrations of the gas to be rapidly released during pit maintenance and emptying procedures. Hydrogen sulfide has a characteristic "rotten egg" odor detectable at concentrations less than 1 ppm; however at approximately 150 ppm the gas produces olfactory paralysis which results in an inability to detect its odor and which gives a worker who believes the exposure has subsided a false sense of security.

Hydrogen sulfide acts in the same way as hydrogen cyanide by blocking the use of oxygen inside living cells. Starved of oxygen, critical tissues such as the brain and heart muscle simply stop functioning, and death can occur within 20 seconds.

At low concentrations, H_2S acts as an irritant to mucous membranes, causing ocular and airway irritation at 20 ppm, with watering eyes and cough (Hurst, 1995). As the concentration increases, a chemical pneumonia or bronchitis may develop, followed by pulmonary edema and central nervous system depression at 250 ppm. At 500 ppm, nausea, unconsciousness and death are possible in thirty minutes. Concentrations over 700 ppm are more rapidly fatal due to paralysis of the respiratory center in the brain stem. The threshold limit value (TLV) established for H_2S is 10

ppm (American Conference of Governmental Hygienists, 1994). Numerous livestock and human deaths have been reported as a result of exposure to H_2S during agitation of manure slurry or upon entering a manure pit (Donham et al., 1982; Hagley and South, 1983; and Osbern and Crapo, 1981), including fatalities each year in Minnesota among farmers and their families.

Successful treatment of hydrogen sulfide poisoning usually results in complete reversal of the effects. Removal of the individual from the contaminated environment, the administration of oxygen, and emergency treatment with intravenous sodium nitrate or an inhalation of amyl nitrate may revive a person who may be unconscious but still breathing. Hall and Rumack (1997) report some success with sodium nitrate but suggest that much more research needs to be done. Slow drip intravenous administration of sodium nitrate, if begun very quickly, may help the victim (Kerns and Kirk, 1998). Prolonged unconsciousness or the absence of breathing at the time the victim is found is a grave prognostic sign and, even if revived, the individual may suffer permanent brain damage.

Methane

Methane (CH_4) has little toxicity but can be dangerously explosive in concentrations greater than five%, which may occur with poor ventilation or in manure head spaces during agitation (Feddes and Barber, 1995; and Hurst, 1995). This colorless gas has no odor, is not very water soluble, has a relative density of about 0.5, and is highly flammable. Due to methane's low density and solubility, it is released constantly into the air. As the concentration of CH_4 rises, the oxygen concentration decreases resulting in hypoxia in workers and animals (Hurst, 1995). Hypoxia causes confusion and may cause death depending on the concentration of oxygen available and length of exposure.

Carbon Dioxide

Carbon dioxide (CO_2) is of concern as elevated levels may lead to hypoxia in humans. Carbon dioxide is produced primarily from the exhalation of the animals, but is also a product of manure degradation. CO_2 is a colorless, odorless gas with a relative density of 1.53, and is highly water soluble (Hurst, 1995). This non-flammable gas has low direct toxicity but displaces oxygen, leading to hypoxia. Studies have shown a significant correlation between CO_2 and lung function as related to forced expiratory flow at 75% vital capacity (FEF_{75}) (Donham et al. 1988) and between exposure to CO_2 and phlegm production (Zejda et al., 1994).

Carbon Monoxide

Carbon monoxide (CO) is of concern as elevated levels may lead to hypoxia in humans. CO is also a colorless, odorless, non-irritating gas produced during manure degradation, but at very low concentrations (Hurst, 1995). When significant levels of CO are present, the source is often the back-drafting of exhaust from heaters or other internal combustion engines (Feddes and Barber, 1995; and Hurst 1995). When CO is inhaled, it binds rapidly and avidly with hemoglobin, occupying the same site as oxygen, and resulting in hypoxia.

Variation by Segment of the Population: Gases

Health Effects on Facility Workers: Gases

Seven fatalities have been reported since 1992 in Minnesota from exposure to gases during agitation and transfer of manure in or near storage tanks or pits.

Health Effects on Neighbors and other Community Members: Gases

In a Terre Haute Indiana study (U.S. Public Health Service, 1964), concentrations of hydrogen sulfide ranged from 22 to 300 ppb and were sufficient to cause public complaints and discomfort and paint blackening of lead-based paint. While Terre Haute, Indiana, had many potential sources of odorous air pollutants, the most probable source, which caused the public complaints and discomfort, was a 35-acre lagoon used for the biodegradation of organic industrial waste. Many public complaints were generated about odors, health effects, and property damage. Main symptoms reported were nausea, loss of sleep and abrupt awakening, shortness of breath, and headache. Few citizens sought medical attention. In the opinion of the medical observers, the hydrogen sulfide and other odorous materials were the likely cause of the symptoms.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Gases

Variation by operation, system type, and management

The information presented above focused on animal and poultry confinement systems. For more information on the variation in gas emissions by operation, system type, and management, see the Air Quality and Odor report, GEIS topic III. H., question 3.

Variation by Species

Groot-Koerkamp et al. (Groot Koerkamp and others, 1998) reported mean and maximum ammonia concentrations in cattle, pig, and poultry houses in northern Europe. Mean ammonia concentrations ranged from 0.3 to 30 parts per million (ppm). The maximum concentrations ranged from 1.7 to 73 ppm. The data indicates that health risks would be greater due to ammonia in the pig and poultry buildings than in the cattle buildings.

Swine

One study found Ammonia concentrations in pig buildings in Minnesota were less than 30 ppm averaging only 10-15 ppm (Jacobson and others, 1996). A study by Donham and Popendorf found levels of NH_3 in twenty-one confinement buildings to be near or exceeding the threshold limit value (TLV), with a mean level of 34 ppm. A relationship was found between the amount of NH_3 and type of building (Donham and Popendorf, 1985). Farrowing buildings had the highest mean amount of NH_3 (42 ppm), followed by nurseries (39 ppm) and finishing buildings (20 ppm). A more recent prospective study by Donham et al. showed mean levels of NH_3 to be less than the TLV, ranging from 5.2 ppm to 6.7 ppm (Donham et al., 1995). Higher levels of NH_3 in the farrowing units may be due to a greater production of waste per cubic foot of animal space and the warmer environmental temperatures needed to raise the young animals (Donham and Popendorf, 1985).

Turkeys
Ammonia levels in turkey grower barns in Minnesota were higher in the fall and winter season compared to the spring and summer (Mulhausen and others, 1987). Seasonal average values ranged from 10 to 35 ppm. Mean ammonia concentrations in turkey buildings ranged from 1.9 ppm in brooder barns in the summer to 46.2 ppm in grower barns with hens in the winter (Reynolds and others, 1994).

Concentrations of carbon monoxide, hydrogen sulfide, nitrogen dioxide, and methane in turkey grower barns were below detectable levels (Mulhausen and others, 1987). Mean sulfur dioxide concentrations in turkey barns ranged from 0.13 to 0.36 ppm (Reynolds and others, 1994).

Chickens
Ammonia concentrations in three broiler barns in North Carolina had average concentrations around 25 ppm ranging from 6 to 75 ppm. Carbon dioxide concentrations ranged from 500 to 1,000 ppm. Carbon monoxide, hydrogen sulfide, nitrogen dioxide, oxides of nitrogen (NOx), methane, mercaptan, formaldehyde, and hydrocarbons concentrations were all below the detection limits of the detector tubes used (Jones and others, 1984).

Monitoring Techniques, Modeling Approaches, and Standards: Gases
Standards
MidWest Plan Service (MidWest Plan Service, 1990) lists TWA concentrations for NH_3 at 25 ppm and for H_2S at 10 ppm. However, Donham and Cumro (Donham and Cumro, 1999a; Donham and Cumro, 1999b) have shown synergistic effects between ammonia and dust and suggest an ammonia TWA threshold limit of 7 ppm inside livestock and poultry facilities. Other gases like carbon dioxide (CO_2) and carbon monoxide (CO) have TWA levels of 5,000 ppm and 50 ppm, respectively. Methane (CH_4) has a safety consideration because of possible explosiveness at 30,000 ppm (MidWest Plan Service, 1990).

Monitoring and Modeling
For information on monitoring, measuring, and modeling emissions see the Air Quality and Odor report, GEIS topic III. H., question 5.

Prevention and Mitigation Measures: Gases
The Air Quality and Odor report, GEIS topic III. H. question 4, describes several mitigation and emission control technologies.

Summary: Gases
Ammonia and hydrogen sulfide were the most commonly monitored gases in animal buildings. Concentrations varied widely and depend on animal species, housing, and manure handling. Research evidence strongly suggests that ammonia and dust have synergistic effects. Researchers are suggesting TWA threshold limits for workers in livestock and poultry facilities. Most other gases have not been found at levels of concern.

Dust

Human Health Effects: Dust

Dusts in and around animal facilities include bits of feed, dried skin, hair or feathers, dried feces, and soil particles (Koon and others, 1963; Anderson and others, 1966; Curtis and others, 1975a; Alegro and others, 1972; Sweeten and others, 1998; Sweeten and others, 1998). Feed was found to be the primary component of the dust (Curtis and others, 1975b; Heber and others, 1988).

There is the possibility of dust acting as a vehicle for NH_3 deposition in the lungs, carrying it into the smaller, more sensitive parts of the pulmonary system (Preller et al., 1995; and Donham et al., 1986). This may explain results obtained by Preller et al. which showed an inverse association between lung function results and exposure to ammonia gas. Other studies have also shown decrements in lung function in response to exposure to NH_3, namely a decrease in forced expiratory volume in one second, or FEV_1 (Reynolds et al., 1996) and in FEF_{75} (Donham et al., 1988). Zejda et al. also found correlations between exposure to NH_3, cough, and chronic bronchitis (Zejda et al., 1994).

Airborne dust in swine confinement facilities is organic in nature with numerous components having been identified. These components include feed, dried feces and urine, swine dander, pollen, grains, insect parts, and mineral ash; feed and fecal components compose the bulk of particles collected (Donham et al., 1986). In addition to NH_3, other airborne substances include endotoxins, molds and bacteria which may also attach to larger dust particles (Feddes and Barber, 1995). These microorganisms consist primarily of gram-positive bacteria with much lower amounts of gram-negative bacteria and fungi (Crook et al., 1991; and Donham et al., 1986).

Dust particles settle in different regions of the respiratory system depending on their size. Those particles with a mass median aerodynamic diameter greater than 10 microns are deposited mainly in the upper respiratory tract, particles of 3-10 microns are deposited mainly in the major airways of the lower respiratory tract, and respirable particles, those less than three microns, largely deposit in the lung parenchyma.

Numerous studies have reported dust concentrations in animal buildings. Mean inhalable dust levels in various cattle, swine, and poultry buildings in Europe ranged from 0.22 to 4.58 mg/m^3 (Takai and others, 1998). Inhalable dust represents the dust inhaled through a human's nose and mouth (Mark and Vincent, 1986). Mean respirable dust concentrations ranged from 0.09 to 0.64 mg/m^3 (Takai and others, 1998). Respirable dust represents the dust that can penetrate deeply into the respiratory tract and lungs.

Variation by Segment of the Population: Dust

Effects on Facility Worker Health: Airborne Dust

Airborne dust is suspected as the major cause of chronic worker health symptoms (Rylander and others, 1989). Work-related symptoms include nasal and eye irritation, cough, chest tightness, wheeze, and phlegm, all reflecting mucous membrane irritation (Crook et al., 1991; and Donham

et al., 1995). Zejda et al. found exposure to respirable dust correlated with the symptoms of phlegm and wheeze (Zejda et al., 1994).

Effects on Community Health: Airborne Dust

Dust from animal facilities and feed mills can contribute to the ambient dust levels. Emissions from large beef cattle feedlots in Texas and California are regulated (Sweeten and others, 1998). Dust mitigation methods are used to reduce emissions from these sources. Ambient dust is regulated by the U.S. Environmental Protection Agency (EPA) under the National Ambient Air Quality Standard (NAAQS) (EPA, 1998c). No research was found reporting on the health effects of ambient dust concentrations downwind of animal facilities in the Midwest or Minnesota. This might be a topic for future research.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Dust

Variation by operation, system type, and management

The information presented above focused on animal and poultry confinement systems. For more information on the variation in gas emissions by operation, system type, and management, see the Air Quality and Odor report, GEIS topic III. H., question 3.

Variation by Species

Turkeys

Total dust concentrations in turkey barns in Minnesota ranged from 0.4 to 13.8 mg/m^3 across two studies (Mulhausen and others, 1987; Reynolds and others, 1994). Concentrations were highest in the winter. Respirable dust concentrations ranged from 0.1 to 2.6 mg/m^3 (Reynolds and others, 1994).

Chickens

Total dust concentrations in broiler barns in North Carolina ranged from 0.02 to 11 mg/m^3 (Jones and others, 1984). Respirable dust levels ranged from 0.02 to 0.62 mg/m^3. Bird age, litter age, and animal activity were factors (Jones and others, 1984).

Total and respirable dust concentrations in caged layer barns in Sweden were comparable or less than those in barns without cages (alternative housing) (Martensson, 1995). Total dust concentrations in the conventional caged layer barns ranged from 1.3 to 2.7 mg/m^3 while respirable dust concentrations ranged from 0.08 to 1.04 mg/m^3. Corresponding total and respirable dust concentrations in the alternative barns ranged from 2.6 to 4.1 mg/m^3 and 0.08 to 1.13 mg/m^3, respectively.

Horses

Total dust concentrations in an Italian horse stable ranged from 0.26 to 10.82 mg/m^3 with a mean concentration of 1.95 mg/m^3. Respirable dust concentrations ranged from 0.03 to 1.46 mg/m^3 with a mean of 0.38 mg/m^3 (Navarotto and others, 1994).

Swine

A significantly greater proportion of swine farmers report nasal and eye irritation, cough, chest tightness, wheeze, and phlegm as compared to farmers raising other types of livestock or only crops (Carvalheiro et al., 1995; and Zhou et al., 1991). Swine workers report respiratory illness more frequently than controls, including frequent chest colds, pneumonia, and work absence due to respiratory illness (Donham et al., 1988).

Research in swine buildings indicates that total dust concentrations are higher in finishing barns than either nursery or gestation barns. Donham and others (1986) reported mean total mass dust concentrations to be 3.2 mg/m^3 in farrowing units, 5.2 mg/m^3 in nursery units, and 15.3 mg/m^3 in finishing buildings. The respirable fractions were 20%, 13.4%, and 12.4% of the total dust in the farrowing, nursery, and finishing buildings, respectively. Maghirang, Puma, et al. (Maghirang and others, 1997) reported a mean total dust concentration of 0.72 mg/m^3, ranging from 0.12 to 2.14 mg/m^3 in a test swine nursery. The respirable fraction ranged from 2 to 30% of the total dust, with an overall mean of 11%.

Total dust levels on average, are lowest in farrowing buildings (3.2 mg/m^3) followed by grower/nursery units (5.2 mg/m^3) and finishing units (15.3 mg/m^3) (Donham et al., 1986). These results differ from the concentrations estimated by Preller et al., showing farrowing units to have higher concentrations of dust (Preller et al., 1995). Donham et al. found farrowing units to have a greater proportion of particles of respirable size, followed by the nursery and finishing buildings respectively (Donham et al., 1986). Feed dust and swine dander particles were found to be larger in size, and therefore more likely to deposit in the upper respiratory tract and airways, while particles of fecal origin were found in all of the size ranges, and made up the majority of respirable particles (Donham et al., 1986).

A number of factors contribute to higher dust levels in swine confinement facilities: stocking density, the age of animals, the feeding system and type of feed (pellet, meal, or loose), hygiene practices, building design, humidity and ventilation (Crook et al., 1991; and Takai et al., 1998). Operations using floor feeding or restricted feeding systems have higher levels of dust (Crook et al., 1991; and Holness et al., 1987). Pellet feed is less dusty than dry meal or loose feed and operations where feed is ground indoors have higher levels of dust (Crook et al., 1991; Holness et al., 1987; and Donham et al., 1986). Dust concentrations in pig buildings increase from summer to winter, due to colder temperatures and the decrease in ventilation in order to conserve heat (Crook et al., 1991; Donham et al., 1986; and Takai et al., 1998).

Monitoring Techniques, Modeling Approaches, and Standards: Dust

Standards

Time-weighted average (TWA) total and respirable dust exposure thresholds of 2.4 mg/m^3 and 0.16 mg/m^3, respectively for workers in livestock and poultry facilities have been suggested (Donham and others, 1989; Donham and others, 1995; Reynolds and others, 1996; Donham and Cumro, 1999a). Time-weighted average threshold limits are based on an eight hour work-day and a 40-hour work week and apply to workers, not the public in the surrounding area.

Monitoring and modeling
A discussion of monitoring and modeling dust emissions can be found in the Air Quality and Odor report, GEIS topic III. H., question 5.

Prevention and Mitigation Measures: Dust
Worker health can be mitigated using dust respirators or masks. Studies report reduced incidence of common respiratory symptoms and substantial respiratory protection (Iversen and Takai, 1990; Hellickson and others, 1989; Barber and others, 1999; Senthilselvan and others, 1999). Also see the Air Quality and Odor report, GEIS topic III. H. question 4, on mitigation and emission control technologies for dust.

Summary: Dust
Dust concentrations in animal facilities can vary widely. Sampling techniques (i.e., aerial versus personal) and building conditions vary widely making direct comparison very difficult. They depend on many management and animal factors. Aerial and personal sampling techniques differ and will give different results. The results indicate that animal buildings can be quite dusty and generally depend on numerous factors including ventilating rate, humidity level, litter use and condition, animal density and activity level, feed form and content, feeding system, amount of cleaning, and other management practices. Dust in animal facilities can be a major contributor to worker health symptoms. Researchers have suggested time weighted average limits for total and respirable dust for workers in livestock and poultry. Respirators and masks can provide substantial respiratory protection.

Odors
Human Health Effects: Odors
Several studies have investigated the health effect of ambient odors downwind of industrial and agricultural sources. Shukla (Shukla, 1991) stated that the immediate physiological stresses produced by odors can cause loss of appetite and food rejections, low water consumption, poor respiration, nausea, and even vomiting and mental distress. In extreme cases, offensive odors can lead to deterioration of personal and community well-being, interfere with human relations, deter population growth, and lower its socio-economic status (Shukla, 1991).

Shusterman et al. (Shusterman and others, 1991) reported on three studies which were conducted in California regarding odor and health complaints. The odorants identified in each of the studies were reduced sulfur gases and compounds with odor thresholds three to four times lower than thresholds that cause respiratory irritation or systemic toxicity. These studies found great variability at when different people in the community could detect odors. Females were more sensitive, while elderly and smokers were less sensitive to smells. The study notes that these differences are important when the community responds to odor abatement measures. It also found that repeated exposure to an odor resulted in enhanced odor recognition and detection. Most symptoms reported by individuals were acute in onset, self-limiting in duration, and subjective, making it difficult or impossible to substantiate objectively (Shusterman and others, 1991).

Shusterman et al. (Shusterman and others, 1991) also presented theories as to why the body may respond to odor. He sets them out in various categories.

- Relationship between Odor Detection and Acute Toxicity: Acute odor-related symptoms could and do occur without toxic exposures. For example, symptoms reporting of sulfur gases begin at levels that barely exceed their odor threshold.
- Innate Odor Aversion: A built-in mechanism for all people to react to pleasant and unpleasant odors. Even babies respond predictably.
- Innate Pheromonal Phenomena: Odors trigger some hormonal responses in animals. Still under study with humans.
- Odor-related Exacerbation of Underlying Conditions: One pre-existing medical condition that may coincide the hyper susceptibility to odors is bronchial asthma. Pre-existing psychological conditions might cause some individuals to respond more to odors.
- Odor-related Aversive Conditioning: After a traumatic exposure, some people report symptoms in response to low-level exposures. While initial symptoms occurred with traumatic exposure, subsequent attacks and symptoms occurred both with and without odor triggers.
- Odor-related, Stress-induced Illness: Persons who believe the odor source is a toxic risk have more symptoms and psychological distress when exposed to odors. This was shown to be the most important variable in people's response to odor.
- Mass Psychogenic Illness: Clusters of people experience similar symptoms. Odors frequently play an important role in causing alarm. Not usually seen in a community setting.
- Recall Bias: This can occur when an adverse health outcome, the publicity surrounding an environmental issue or odor perception, affects the accuracy of recall for a particular symptom.

Knasko (Knasko, 1993) reported on the effects of intermittent bursts of pleasant, unpleasant, and no odor on human task performance, mood and perceived health. Odors did not influence any of these measures; however, subjects who had been exposed to the malodors reported retrospectively that they thought the odors had a negative effect on all of these factors (Knasko, 1993).

Retrospective symptom prevalence data, collected from over 2000 adult respondents living near three different hazardous waste sites, were analyzed with respect to both self-reported environmental worry and frequency of perceiving environmental (particularly petrochemical) odors (Shusterman and others, 1991). Significant positive relationships were observed between the prevalence of several symptoms (headache, nausea, eye and throat irritation) and both frequency of odor perception and degree of worry. Headaches for example, showed a prevalence odds ratio of 5.0 comparing respondents who reported noticing no such odors and 10.8 comparing those who described themselves as very worried versus not worried about environmental conditions in their neighborhood. Potential explanations for these observations are presented, including the possibility that odors serve as a sensory cue for the manifestation of stress-related illness (or heightened awareness of the underlying symptoms) among individuals concerned about the quality of their neighborhood environment.

Cavalini (Cavalini, 1994) noted that with regard to general health complaints, it was found that when exposed to (industrial) odorant concentrations, some people are annoyed and of these people, only some report general health complaints. Exposure in itself does not directly cause general health complaints. Annoyance is the intervening variable between exposure and general health complaints. A possible explanation for the relation between annoyance by malodor and general health complaints might be found in the personality and attitudes of the exposed individual. Cavalini (Cavalini, 1994) found confirmation for the appraisal hypothesis, i.e., the extent to which individuals regard malodor as threatening is positively related to odor annoyance.

Odors have also been reported to affect cognitive performance (Lorig, 1992; Ludvigson and Rottman, 1989) and physiological responses including heart rate and electroencephalographic patterns (Lorig, 1989; Lorig and others, 1991; Lorig and Robers, 1990; Lorig and others, 1993; Lorig and Schwartz, 1988; Manley, 1993). Learning (via conditioning) may also play a role in the psychological and physical effects from odors. Conditioned aversions to odors are documented in the scientific literature (Dyck and others, 1990; Goodwin and others, 1992; Hunt and others, 1993; Meachum and Bernstein, 1992; Murua and Molina, 1990; von Kluge and Brush, 1992).

Odorant molecules contained in emissions from hog farms may cause nasal and respiratory irritation (Bundy, 1992; Cometto-Muniz and Cain, 1991; Donham, 1990; Miner, 1980; Blaha, 1999). Nasal irritation has been shown to elevate adrenaline (Allison and Powis, 1976) which may contribute to feelings of anger and tension. The volatile organic compounds (VOCs) responsible for odors may also be absorbed directly by the body (into the bloodstream and fat stores) via gas exchange in the lungs. Many VOCs that are inhaled into the lungs are known to reach blood and adipose tissue. Persons who have absorbed odorants through the lungs can sometimes smell the odor for hours after exposure due to slow release of the odorants from the bloodstream into expired air activating the olfactory receptors. Volatile organic compounds are well known to be eliminated in breath after exposure (Raymer and others, 1991; Wallace and others, 1991), and methods for measuring VOCs in breath have been described as abnormal smell functioning.

Variation by Segment of the Population: Odor

Health Effects on Facility Workers: Odor

There is nothing in the literature on the health effects of odor on facility workers. This is presumably because the environmental health research has focused on the effects of individual compounds (such as gases) rather than on odors.

Health Effects on Asthmatics: Odor

Odors are an important cause of worsening of asthma. From a practical standpoint, sensitive asthmatic patients should be advised to eliminate odors from their environment as much as possible (Shim and Williams, 1986). Shim and Williams (Shim and Williams, 1986) reported that many patients complain that some odors worsen their asthma. Perfume and cologne are two of the most frequently mentioned offenders. Four patients with a history of worsening asthma on

exposure to cologne underwent challenge with cologne, and their pulmonary function was tested before, during, and after the exposure. Forced expiratory volume in one-second declined 18 to 58% below the baseline period during the 10-minute exposure and gradually increased in the next 20 minutes. Saline placebo pretreatment did not affect the response to subsequent challenge. A survey of 60 asthmatic patients revealed a history of respiratory symptoms in 57 of them on exposure to one or more common odors.

Health Effects on Neighbors and Other Community Members: Odor
Odor complaints have been reported to be most frequent among new, large, or recently expanded animal facilities that are located near existing residences or shopping areas (Miner, 1980; Sweeten and Miner, 1993).

A Michigan study (Warner and others, 1990) was designed to assess the impact of a 50,000 animal swine-growing facility as an odor source and potential health problem. In parallel with the measurement of odor intensity, the Michigan Department of Public Health conducted a health survey to obtain information regarding the pervasiveness of the odor in the community and its possible health implications. Citizens' complaints reported included physical symptoms such as breathing difficulties, burning sensations in the nose and throat, nausea and vomiting, and headaches. A survey of residents within 0.5 miles of the center of the facility (58 households / 89 persons) and those between 0.5 and 1.25 miles away (176 households / 225 persons) resulted in response rates of 55% and 49%, respectively. The authors concluded the following: "These responses contained complaints of symptoms attributable to the swine facility. As with any population, symptoms as general as those which relate to complaints as noted are difficult to correlate to specific health problems. However, the clear excess of complaints stands as a fact of record. Perhaps further study is needed to surface a better understanding of individual health effects and symptoms as these relate to perception of odor." "Information is not provided on the type of complaints nor was there any report on frequency of symptoms or whether they differed by proximity to the farm" (Warner and others, 1990).

From 1984 to the mid-90s, a large scale and long-term epidemiological study on the frequency of respiratory disease in children comparing rural and urban areas was conducted in Germany by the German Medical Association. The results showed that in the rural areas a non-significant higher proportion of allergic disease in children was recorded; however, no conclusions on any causal relation to livestock operations could be drawn, since there were too many confounding factors (Blaha, 1999).

Schiffman et al. (Schiffman and others, 1995) evaluated forty-four individuals living near hog operations and forty-four control subjects in North Carolina. These two groups were matched on the basis of age, gender, race, and educational level. Compared to controls, the experimental group had statistically significant increases in tension, depression, anger, fatigue, and confusion scores from the standardized Profile of Moods State Questionnaire. Schiffman deemed these findings consistent with other previous studies where odors of varying hedonic properties have been found to affect mood (Baron, 1990; Ehrlichman and Bastone, 1992; Rotton, 1983;

Schiffman and others, 1994a; Schiffman and others, 1994b; Blaha, 1999; Winneke and Kastka, 1977). Schiffman states that the mood alteration could be caused by "a) the unpleasantness of the sensory quality of the odor; b) the intermittent nature of the stimulus; c) learned (via conditioning) aversions to the odor, and are well documented in the scientific literature; d) potential neural stimulation of immune responses via detect neural connections between odor centers in the brain and lymphoid tissue; e) direct physical effects from molecules in the plume including nasal and respiratory irritation; f) possible chemosensory disorders; and g) unpleasant thoughts associated with the odor."

Thu et al. (Thu and others, 1997) reported on the association of health effects with exposures to environmental odors from animal operations. The study collected mental and physical health information by personal interviews from a small random sample of 18 residents living within two miles of a 4,000-sow operation in Iowa. Data was compared to that collected from a demographically comparable sample of 18 rural residents living in an area with minimal livestock production. The results of the comparison indicated that "neighbors of the large-scale swine operation reported experiencing significantly higher rates than the controls of four clusters of symptoms that are known to represent toxic or inflammatory effects on the respiratory tract. These clusters of symptoms have been well documented among swine confinement workers." The specific symptoms reported are quite similar to the list of symptoms reported by hog farm workers: cough, increased sputum production, shortness of breath, chest tightness, wheezing, nausea, dizziness, headaches, runny nose, scratchy throat, burning eyes, muscle aches and pains, skin rash, and fever. Among the control group in this study, symptoms of skin rash, muscle aches, and fever were more frequently reported. There was no difference in the frequency of reported symptoms and distance from the swine facility. This study found that neighbors did not suffer higher rates of psychological health effects, such as depression or anxiety, when compared to controls. Thu et al. (Thu and others, 1997) also states that all responders felt the owner of the farm was creating social and class divisions within that community.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Odor

Variation by operation, system type, and management

The information presented above focused on animal and poultry confinement systems.

Variation by Species

A recent study (Wing and Wolf, 1999) was prompted by the rapid expansion of intensive hog productions in North Carolina. Residents of three rural communities were surveyed, one community in the vicinity of a 6000-head hog operation, one community in the vicinity of two intensive cattle operations, and a third rural agricultural community where residents lived at least two miles from livestock operations that use liquid waste management systems. The average number of episodes of most symptoms was similar in the three communities with the exception of respiratory, gastrointestinal, and mucous membrane problems. The study found "a number of symptoms that have previously been reported to be elevated among persons occupationally exposed in swine confinement houses were elevated among residents of the hog community

compared to the community with no livestock operations. In particular, headache, runny nose, sore throat, excessive coughing, diarrhea, and burning eyes were reported more frequently in the hog community. Members of the cattle community did not report similar elevations, nor did they report reduced quality of life. The quality of life measures concerning opening of windows and ability to go outdoors even in nice weather showed a large excess in the hog community." Long-term physical and mental health impacts of reduced quality of life could not be investigated in this study.

For additional information on variation in odor emissions by system type, see the Air Quality and Odor report, GEIS topic III. H., question 3.

Monitoring Techniques, Modeling Approaches, and Standards: Odors
For information on odor measurement technologies and methods, see the Air Quality and Odor report, GEIS topic III. H., question 5.

Prevention and Mitigation Measures: Odors
For information on odor mitigation and control technologies, see the Air Quality and Odor report, GEIS topic III. H., question 4.

Biogenic Particles
Human Health Effects: Biogenic Particles
Airborne biogenic particles include bacteria, viruses, fungi spores, amoebae, algae, pollen, plant parts, insect parts and wastes, endotoxins and mycotoxins. Endotoxins are naturally occurring substances in the cell walls of gram negative bacteria that are released when the microorganisms die. Mycotoxins are toxins produced by fungi. Researchers have reported biogenic concentrations for bacteria, fungi and endotoxins in animal buildings. Microbial sources include the animals, bedding, feed, manure or exterior (outside) sources.

The inhalable airborne particles present in these environments come from microbial, vegetable, animal, and avian origins. A key component of these aerosols is endotoxin which is derived from the cell walls of gram-negative bacteria that grow readily in the excreted feces and urine of livestock and heavily contaminate animal and poultry facilities (Clark and Rylander, 1983; Donham et al., 1986; Reynolds et al., 1994). Experimental studies in laboratory animals have confirmed that the direct instillation of endotoxin into the lungs causes airway and parenchymal lung changes (Milton et al., 1990).

Various allergens become airborne and are capable of causing sensitization of the upper and lower respiratory tracts (Brady J; Dalphin et al., 1998; Iversen 1997; Mauny et al., 1997; Vohlonen et al., 1987). Such aeroallergens occur almost exclusively in or on the surface of inhalable particles. Allergic reactions can be caused by a wide variety of agents, including proteins from animal dander or feathers, from urinary and fecal proteins, from vegetable matter in bedding and feed materials, and from molds and other microbial flora in the environment. Asthma and allergic rhinitis occur commonly among livestock confinement workers (Dalphin et

al., 1998; Donham et al., 1989; Iversen 1997; Mauny et al., 1997; Noorhassim et al., 1995; Terho, 1990; Vohlonen et al., 1987; Wilhelmson et al., 1989).

Variation by Segment of the Population: Biogenic Particles

Health Effects on Facility Workers: Biogenic Particles

Zejda et al. found exposure to endotoxin correlated significantly with chronic cough, and marginally with chronic bronchitis (Zejda et al., 1994). After adjusting for smoking, chronic cough and chronic bronchitis were associated significantly with airborne concentration of endotoxin (Zejda et al., 1994).

Some researchers have noticed episodes of organic dust toxic syndrome (ODTS) in animal facilities workers (33% of workers), mainly during high dust exposure times like sorting or moving animals and during power washing of the building interior. These situations may be related to inhaling endotoxins from aerosolized gram negative bacteria (Rylander and others, 1989). Donham et al. (Donham and others, 1988) found endotoxin levels to be significantly related to the one-second forced expiratory volume (FEV1) and the forced expiratory phase at 25-75% lung volume (FEV25-50) of swine workers in a dose dependent way. Donham and Cumro (Donham and Cumro, 1999a) suggest TWA threshold concentrations of 614 EU/m^3 for total endotoxin and 0.35 EU/m^3 for respirable endotoxin.

Health Effects on Neighbors and other Community Members: Biogenic Particles

A few researchers have considered the effects of biogenic emissions from animal facilities and their potential as a respiratory health hazard and disease transmission to other animals (Bohm and Hartung, 1994; Homes and others, 1996; Seedorf and others, 1998). Some of the research on animals, especially pigs, may be useful in terms of learning what occurs in humans.

Local topography, weather, emission rates and source characteristics will effect potential transmission (Seedorf and others, 1998). Measurements at one swine facility found total bacteria concentrations decreased dramatically between inside and outside a swine facility. Concentrations were higher than background levels at 200 m but not at 300 m downwind of a swine facility (Homes and others, 1996).

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Biogenic Particles

Variation by operation, system type, and management

The information presented above focused on animal and poultry confinement systems. There is limited research information on microbial populations as affected by feed type, animal activity, bedding type and management, manure handling system, stocking density, air temperature, and relative humidity. Bedding provides environmental conditions appropriate for bacterial growth and fungal spores (Beran, 1991). Populations change with bedding use. Fungi populations in fresh and used litter in broiler houses had different species populations. *Aspergillus* spp. and *Scopulariopsis brevicaulis* were predominant in the litter after one cycle of birds (Dennis and Gee, 1973). Research reported by Jones et al. (1984) for broiler farms in North Carolina

indicated airborne fungal counts were an order of magnitude higher in a house with fresh litter compared to a flock housed on old litter (same age birds).

Airborne endotoxin concentrations were measured in cattle, pig, and poultry buildings in Europe (Seedorf and others, 1998). Mean inhalable endotoxin concentrations ranged from 11.8 to 786 nanograms/m^3 (ng/m^3). Mean respirable endotoxin concentrations ranged from 0.6 to 72 ng/m^3. In general both inhalable and respirable concentrations were higher in poultry buildings than pig buildings and lowest in cattle buildings. Generally daytime concentrations were higher than nighttime concentrations.

Seedorf et al. (Seedorf and others, 1998) measured airborne microorganism concentrations in animal buildings, mostly in Germany. The highest mean bacterial concentrations were measured in broiler buildings where the mean concentration was 6.43 logarithm of colony-forming-units per cubic meter of air (log cfu/m^3). Mean bacterial concentrations in layer and pig houses ranged from 4 to slightly over 5 log cfu/m^3. Mean bacterial concentrations in cattle barns were generally slightly over 4 log cfu/m^3. Mean daytime Enterobacteriaceae concentrations ranged from 3.2 to 4.5 log cfu/m^3. Mean daytime fungi concentrations were 3.8 for cattle, 3.7 for pigs, and 4.0 for poultry log cfu/m^3, respectively with similar values for nighttime (Seedorf and others, 1998).

Variation by Species

Poultry

Hartung (Hartung, 1994) noted some generalities in a review regarding airborne microbes in poultry buildings. Airborne microorganisms found in poultry buildings, as in most livestock facilities include: staphylococci, streptococci, pseudomonas, E. coli/Enterobacter, fungi, molds and yeasts. Of the fungi, several different species were found – some of which considered to be allergenic (*Penicillium, Aspergillus, Cladosporium, and Alternaria*) (Hartung, 1994).

Airborne bacteria concentrations in three broiler barns in North Carolina were around 150,000 cfu/m^3 (Jones and others, 1984). Fungi concentrations were 10,000 cfu/m^3. Endotoxin concentrations ranged from 0.77 to 61 ng/m^3 in the total dust samples and from 0.71 to 15 ng/m^3 in the respirable dust.

Because methods of microbial determination (i.e., bacteria and/or fungi) and differentiation (i.e., fungi species), sampling times and sites differed between studies, there may be limited value in reported quantities of airborne particulates as absolute values. For instance, three papers reported widely varying airborne microbial concentrations in egg layer houses for layers in cages: range of 360 to 3781 CFAs per liter of air (Hartung, 1994); range of 17 to 5860 cfus per liter of air (Muller, 1987); and, range of total bacteria of 290,000 to 680,000 cfus per cubic meter (Clark and Rylander, 1983).

The effects of independent variables can be assessed when measurements are taken using the same standard procedures for specific comparison purposes. For instance, the type of poultry and housing shows an effect on airborne microorganism concentrations. (Hartung, 1994) indicated

that airborne microorganisms in houses with chicken layers on litter (bedding) had approximately 5 times the concentrations compared to chicken layers in cages, perhaps reflecting the difference in hen activity and contributions of the litter material.

In the Midwest, season had a significant affect on airborne microorganisms in turkey houses. (Mulhausen and others, 1987) found that airborne *Aspergillus* concentrations in a turkey barn in Minnesota never exceeded 73 cfu/m^3, which was less than background levels found in two ambient air studies (Calvo and others, 1980; Jones and Cookson, 1983). Reynolds et al. (Reynolds and others, 1994) found mean bacteria concentrations in turkey barns ranged from 300,000 to 38,700,000 cfu/m^3. Higher levels of bacteria, approximately 5 fold, (Debey and others, 1995) and higher levels of *Aspergillus*, approximately 3.5 fold (Janni and others, 1985) were found in rearing facilities in the winter compared to summer. The large difference is most likely due to ventilation rates targeted toward keeping barns warm in the winter and heat removal in the summer time.

Monitoring Techniques, Modeling Approaches, and Standards: Biogenic Particles
For information on monitoring, measuring and modeling biogenic particles emissions, see the Air Quality and Odor report, GEIS topic III. H., question 5.

Prevention and Mitigation Measures: Biogenic Particles
For information on mitigation and emission control technologies for biogenic particles, see the Air Quality and Odor report, GEIS topic III. H., question 4.

Summary: Biogenic Particles
Biogenic particles are a broad class of organic particulates including bacteria, fungi, and endotoxins. Concentrations differ depending on animal species, manure system and management, bedding use, feed form and quality, feeding system, animal activity, and management. Measurement techniques vary making direct comparison between studies very difficult. Endotoxins can reduce respiratory capacity and researchers have suggested threshold limits for workers in livestock and poultry facilities.

Variation by Segment of the Population: Airborne Contaminants

The following is a summary on variation in health effects by segment of the population for all airborne contaminants combined. For more detailed information on the variation in health effects by segment of the population for each airborne contaminant, see "Variation by Segment of the Population" for each airborne contaminant above.

Facility Workers
The increasing use of intensive livestock-management systems presents a number of risks to the respiratory health of the workers. Air contaminants present in confined animal housing include carbon dioxide, carbon monoxide, bioaerosols, airborne dust particles and manure gases consisting of ammonia, hydrogen sulfide, methane and other odorous compounds (Feddes and

Barber, 1995). Acute effects, ranging from impaired status of consciousness to death, arise from exposure to asphyxiates such as hydrogen sulfide, methane, carbon monoxide and carbon dioxide (Donham et al., 1977; and Hurst, 1995). Subacute and chronic respiratory effects, such as symptoms of airway irritation, and small decrements in lung function, appear to be associated primarily with exposures to ammonia, dust particulate and bioaerosols (Zejda et al., 1994).

The health of people working in animal housing facilities, especially in swine and poultry units, has become a concern to the producers, health officials, and researchers. Chronic respiratory problems for workers in these environments are common including symptoms such as cough, sputum production, chest tightness, shortness of breath, and wheezing due to the airborne dust, gases, and other particulates (Donham, 1989). Acute worker health and safety concerns also exist during short-term events like manure pit agitation that can result in large emissions of toxic gases like hydrogen sulfide. Seven fatalities have been reported since 1992 in Minnesota from exposure to these gases during the agitation and transfer of manure in or near storage tanks or pits.

A number of studies have found workers in intensive animal facilities with a high prevalence of respiratory health problems (Patni and Clarke, 1991; Iversen and Takai, 1990; Hellickson and others, 1989; Zejda and others, 1994). Most of these studies were done in pig barns but several (Hellickson and others, 1989; Nicolai and Janni, 1998a) were carried out in poultry (turkey) facilities. Assessment was done by measuring the reduction in lung function of animal facility workers (Iversen and Takai, 1990). Patni and Clarke (1991) compared to non-exposed people. Lung function also decreased as workers became older (Hellickson and others, 1989).

When compared to unexposed controls, swine confinement workers have been shown to have a greater prevalence of respiratory symptoms, such as cough, shortness of breath, wheezing, chronic bronchitis, and decrements in lung function (Donham et al., 1988; Crook et al., 1991; and Holness et al., 1987). Agents associated with these effects include ammonia, bioaerosols, and airborne dust composed of a complex mixture of substances. Schwartz et al. found swine confinement workers to have far greater exposure to total dust and endotoxin as compared to neighboring farmers not involved in swine confinement farming (Schwartz et al., 1995). These results are supported by findings of Holness et al. as well (Holness et al., 1987).

Several studies compared the health or respiratory function between workers in pig facilities and those on farms without swine and workers not associated with farms. A number of studies reported a higher frequency of respiratory symptoms, more colds, wheezing, coughing, and pneumonia in swine workers than in other farm workers not exposed to pig barn environments (Donham and others, 1984; Holness and others, 1987; Vohlonen and others, 1987; Dosman and others, 1987; Wilhelmson and others, 1989).

Numerous clinical and epidemiological studies of confinement farmers in the dairy, swine, and poultry industries have shown an excess of acute and chronic respiratory disorders among workers exposed to high dust levels and various toxic gases.

Acute health effects are particularly common. These are manifested mainly by symptoms of respiratory irritation (cough, phlegm production, and frequent wheezing), upper respiratory and eye irritation, acute decreases in lung function during the work period, and increased rates of upper and lower respiratory infections (Donham et al., 1984b, 1987, 1989; Dosman et al., 1988; Holness et al., 1987; Iversen et al., 1989; Iversen and Pederson, 1990; Iversen and Takai, 1990; Reynolds et al., 1994; Terho, 1990; Vohlonen et al., 1987; Wilhelmson et al., 1989). The rates of allergic disorders (asthma, rhinitis) are increased also among farmers in animal and poultry confinement facilities (Amishima et al., 1995; Donham et al., 1984b; Iversen et al., 1989; Noorhassim et al., 1995; Prior et al., 1996; van Hage-Hamsten et al., 1985; Vogelzang et al., 1997; Wilhelmson et al.,1989).

In the few longitudinal studies to date, livestock confinement workers have shown increased rates of cough, phlegm, and wheezing, as well as an accelerated loss in lung function consistent with the development of chronic airflow obstruction (Dalphin et al., 1998; Iversen 1997; Mauny et al., 1997; Vohlonen et al., 1987). Some studies have shown that chronic airflow obstruction may be accompanied by increased bronchial reactivity, suggesting an "asthmatic" component to the airway obstruction (Amishima et al., 1995; Iversen et al., 1989; Vogelzang et al., 1997).

In addition to the acute and chronic airway effects, workers in livestock confinement facilities can develop acute febrile illnesses. The most common variant is a self-limiting condition in which people complain of high fever, chills, dry cough, and muscle aches and pains. This condition resembles a bad case of the flu and has been termed the "organic dust toxic syndrome" (ODTS). The causative agent(s) for ODTS have not been identified but probably include cellular components of bacteria or fungi. This is thought not to be an allergic reaction but rather an acute, massive response of white cells to the presence of large amounts of the toxic material in the lungs. People with ODTS have usually been exposed to very high dust levels that are heavily contaminated with microbial organisms. A similar disorder has been described in workers handling sewage sludge.

A similar but much less common condition is "farmer's lung" (Lutsky et al., 1984). Originally described in farmers breathing dust from moldy hay, this disorder resembles an episode of pneumonia: the individual appears ill with a high fever and a high white cell count in the blood, and there may be shadows on the chest X-ray that suggest an infectious or inflammatory process. The condition is a lymphocyte-mediated immunologic reaction to specific molds *(Thermophilic actinomyces and Micropolyspora faeni),* that can lead to lung fibrosis and respiratory failure if repeated exposures occur. Workers in livestock confinement facilities may experience similar problems, and could develop lung fibrosis, if they inhale the same molds.

To summarize the effects on the lungs, the predominant findings from studies of workers in animal and poultry confinement facilities are thus acute and chronic airway irritation, and the development of chronic airway obstruction over time. Where exposures have been measured, it appears that the risks of adverse health effects are related mainly to exposure levels of airborne particles (Clark and Rylander, 1983; Donham et al., 1986, 1989; Holness et al., 1987; Reynolds

et al., 1995; Vogelzang et al., 1997). To date the exposure-response relationships have not been well defined, and considerable uncertainty exists about what might constitute a "safe" level of exposure to dust and gases in livestock confinement facilities. It is apparent from available data, however, that respiratory health problems occur among workers in large and small confinement facilities, and that these problems relate primarily to the levels of aerosols and gases present.

Senthilselvan et al. conducting a four year longitudinal study, reported swine confinement workers (n=217) had the largest annual rate decline in lung function as compared to grain farmers (n=218) and nonfarming controls (n=179) (Senthilselvan et al., 1997a). After controlling for age, height, smoking, and baseline pulmonary function, swine confinement workers had an excess annual decline of 26.1mL in FEV1 (p=0.0005), 33.5 mL in FVC (p=0.0002), and 42.0 mL/s in forced expiratory flow between 25% and 75% of FVC (FEF25-75%) (p=0.02) over nonfarming control subjects. Findings suggest that swine confinement workers are prone to accelerated yearly losses in lung function with a risk for future development of chronic air flow limitation.

Lung function decrements across a work shift are associated with endotoxin levels (Zejda et al, 1994; Donham et al., 1988; Holness et al., 1987; and Schwartz et al., 1995) and there is evidence of a dose-response relationship (Donham et al., 1988; and Reynolds et al., 1996). Disinfection of buildings or compartments is done when the area is emptied prior to getting ready for the next group of animals. Disinfection procedures which take more than ten minutes are significantly associated with decreased lung function (Preller et al., 1995). This result was not attributable to the type of disinfectant or procedures, quantities of disinfectant used in a year, or differences in the exposures to dust, endotoxins, or ammonia. It was hypothesized that there may be an association with the level of ambient exposure concentration (Preller et al., 1995).

Respiratory symptoms reported by workers are associated with pig handling, such as weighing, ear tagging, teeth cutting and injections; barn work in general; and the milling and mixing of feed (Crook et al., 1991; Holness et al., 1987; and Preller et al., 1995). Workers experience exposure of greater duration in pig handling activities and feeding as they spend a greater amount of time doing these activities (Preller et al., 1995). Preller et al. found that workers spend more time in farrowing buildings (Preller et al., 1995). Smokers consistently report respiratory symptoms more frequently than non-smokers (Donham et al., 1988; and Donham et al., 1995) and show greater decrements in lung function parameters (Donham et al., 1984a).

Neighbors and Others

Airborne gases, dust, odors, and biogenic particles can negatively impact human health. There are a number of research reports documenting that neighbors of large swine facilities experience higher incidences of health symptoms than comparable rural residences near minimal livestock production. Similar studies around other animal production facilities are limited. Clearly more research is needed to relate emissions from animal facilities to airborne concentrations and the health effects on individuals living near animal production facilities.

In terms of air-borne toxicants, the following groups exhibit heightened susceptibility:
1) people with pre-existing lung or heart disease
2) children (who are generally more likely to develop allergies than adults, and therefore may have more problems with asthma, hay fever, and rashes.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Airborne Contaminants

Airborne contaminants can vary by animal species, system type, and management. For detailed information on these variations, see "Variation by Species, Operation, System Type, Management, Geography, and Concentration" under each airborne contaminant above.

Monitoring Techniques, Modeling Approaches, and Standards: Airborne Contaminants

Some of the airborne contaminants have standards that have been suggested. For more information, refer to "Monitoring Techniques, Modeling Approaches, and Standards" for each airborne contaminant above.

Prevention and Mitigation Measures: Airborne Contaminants

Prevention of respiratory health problems requires decreasing environmental hazards and increasing employee awareness of the hazards. Engineering and management practices are directed at decreasing the levels of gases, dust and bioaerosols in the air, either by decreasing their production or removing them once they are in the air. These include:

- Lower animal stocking densities to reduce airborne dust and bioaerosols (Feddes and Barber, 1995; and Donham et al., 1995)
- Feeding systems enclosed as much as possible to decrease the amount of dust discharged into the building (Feddes and Barber, 1995; and Donham et al., 1995)
- Delivery of feed into covered feeders rather than dropping it to the floor (Feddes and Barber, 1995; and Donham et al., 1995)
- Feeders designed to allow animals easy access to the feed (Feddes and Barber, 1995; and Donham et al., 1995)
- Ventilation systems to exhaust toxic gases from the building and manure pits, including a warning system in the case of failure (Feddes and Barber, 1995; and Donham et al., 1995)
- Heating units kept clean, vented and functioning properly; and systematic washing inside buildings with power sprayers to reduce the amount of dried materials which create airborne dust, microorganisms and gases (Feddes and Barber, 1995; and Donham et al., 1995)
- Oil sprinkled in barn to reduce dust, endotoxin, ammonia, and hydrogen sulfide levels (Zhang et al., 1998; and Senthilselvan et al., 1997b)

- Use of pelleted feed rather than dry mash to lower dust creation (Feddes and Barber, 1995; and Donham et al., 1995)

- Provide approved dust masks, or other respiratory protective equipment for employees to be used during tasks where elevated exposures may occur, such as feeding and animal handling (Feddes and Barber, 1995; and Donham et al., 1995; and Bono et al., 1998)

Educational methods for prevention of respiratory health problems are directed at increasing the employees awareness of the hazards they face in this environment and encouraging employees to practice protective behaviors. Included is education on the specific risks, potential health problems, symptoms which may develop and methods of protection. A prevention program based on education and industrial hygiene consultation has shown to be effective in improving producer knowledge of health and safety risks, and shifting attitudes towards protecting themselves and their employees (Gjerde et al., 1991). In a study by Gjerde et al. producers received six home-study modules and were invited to participate in evening sessions on respirator use and gas measurement (Gjerde et al., 1991). The intervention was effective in increasing knowledge, changing attitudes, and motivating workers to have building heaters inspected and serviced, wear a respirator when working, and to measure some gas levels.

Employees should also be instructed to avoid being in the confinement unit during feeding and to use respiratory protective equipment (RPE) unless they can be assured the concentrations of air contaminants are below recommended limits (Feddes and Barber, 1995; and Donham, 1995). In high concentrations of dust or gases, a half-mask cartridge respirator or air helmet may be needed (Donham, 1995).

Some studies reported that swine confinement workers wore respirators more frequently when compared to non-confinement workers, with those who spent more time feeding and grinding feed wearing RPE more often (Donham et al., 1984a; and Holness and Nethercott, 1995b). A Minnesota survey, however, found that 51% of farmers working with grain use RPE always or most of the time and only 18% of those working in confinement barns and 1% of those working in manure pits reported using RPE (Lexan et al., 1994). This survey also found 47% of those working in confinement barns and 94% of those working in manure pits reported never using RPE.

Studies have shown that employees will use RPE for different reasons, some using RPE for prevention of symptoms, others using RPE after having experienced respiratory symptoms (Holness and Nethercott, 1995b; and Zejda et al., 1993). Those using RPE for prevention had significantly fewer respiratory symptoms and better lung function when compared to those using RPE for current symptoms or for non-users (Zejda et al., 1993).

For further information on mitigation and emission control technologies for airborne contaminants, see the Air Quality and Odor report, GEIS topic III.H., question 4.

Conclusions:

- **Substantial scientific literature exists that human health is adversely affected by the transmission of a number of toxic and noxious agents via the air.**
- **Large animal production units are a source of air transmission of toxic and noxious agents, such as gases, dust, odors, and biogenic particles.**
- **Confinement housing systems are associated with human health being adversely affected by air-transmission of toxic and noxious agents.**

QUESTION 2.C. - TRANSMISSION OF DISEASE AND SICKNESS VIA WATER, SOIL, AND FLIES FROM MANURE, DEAD ANIMAL CARCASSES, AND OTHER ANIMAL WASTES

Water- and Soil-borne Pathogens

Issues of Concern: Water may be a vehicle for transmission of bacteria and viruses of human and animal origin to both humans and animals. Most studies on waterborne transmission of disease are primarily concerned with water contamination with human viruses. However, under certain conditions, water contaminated with animal viruses may pose a hazard to not only animals but also humans (Kalter, 1986).

Human Health Effects: Water- and Soil-borne Pathogens

Animal manure may contain bacteria, protozoa, and viruses which can cause disease in humans. These include Salmonella sp., Escherichia coli, Leptospira interrogans, Listeria monocytogenes, Campylobacter jejuni, Histoplasma capsulatum, Cryptosporidium parvum, Giardia lamblia, and viruses such as adenovirus, enteroviruses, reoviruses, and rotaviruses. Information about the specific human health effects of these pathogens is contained in this report in question 2.d., Transmission of Disease and Sickness through Consumption of Animal Products.

These pathogens may be transmitted to humans through contaminated surface drinking water supplies, contaminated ground water supplies, or direct contact with contaminated environment e.g., recreational use of water.

Some incidents of human disease attributable to contact with livestock waste have been reported. Stanley et al. (1998) isolated Campylobacter jejuni from groundwater in the Arnside area of Cambria. Some of the strains isolated were of the same biotype as the ones from a dairy farm situated within the hydrological catchment of the polluted spring indicating that the groundwater was a vehicle for bacterial transmission. In a study of a farmworker community in Zimbabwe, Campylobacter spp. were common in chicken feces but not in houseflies or household stored drinking water (Simango and Rukure, 1991) indicating that chickens were the main potential source of Campylobacter in the homes of farmworkers.

In a longitudinal study of four dairy farms, it was suggested that E. coli O157:H7 was disseminated from a common source on these farms and that this strain could persist in the herd for up to 2 years (Shere et al., 1998). In a Russian study, Gordeiko and Pushkareva (1990) detected Yersinia in 25.4% of water samples taken from wells situated in the zone of irrigation with sewage water from a swine-breeding complex. Conversely, no Yersinia was isolated from wells that were remote from the irrigation zone. They also established an epidemiological relationship between a case of Yersinia infection and the use of infected well water.

Prokopcakova and Pospisil (1984) conducted serological surveys for leptospirosis in rodents, cattle and humans in the vicinity of two large water reservoirs in Eastern Slovakia. Sera from 243 rodents, 168 cattle, and 876 humans were examined; 8.2%, 7.7%, and 3.2%, respectively were

positive. The presence of antibodies to the same Leptospira serovar in humans, cattle and rodents indicated the existence of close contact among humans and animals with the possibility of acquiring water-borne infection in recreation zones. An epidemic of hemorrhagic fever caused by Leptospira was reported in rural Nicaragua following heavy flooding. A case-control study revealed that the illness was associated with walking in creeks, having household rodents, or owning dogs with titers of $\geq$1:400 to Leptospira. Leptospira spp. were isolated from case-patients and from potential animal reservoirs. Most likely, this epidemic resulted from exposure to flood waters contaminated with urine from infected animals, particularly dogs.

Five boys from a small town in rural Illinois developed leptospirosis after swimming in a small pond. Leptospira interrogans serovar grippotyphosa was isolated from urine of 2 cases and from pond water. A high seroprevalence for L. grippotyphosa was also found in animals near the pond indirectly suggesting the transmission of the organism from area animals to humans.

Rhodococcus coprophilus and associated actinomycetes were isolated consistently from feces of farm animals, poultry reared in proximity to farm animals and wastewater polluted with animal fecal wastes but not from samples of human feces. The fecal coliform to fecal streptococci ratio could not distinguish between human and animal fecal samples but R. coprophilus to Actinomyces ratio could (Mara and Oragui, 1981). Introduction of organic farming practices on a farm in south-west England was responsible for the introduction of environmental mycobacteria on that farm. The change in the profile of environmental mycobacteria has important implications for the immunological priming of humans and animals (Donoghue et al., 1997).

A marked peak in human cases of cryptosporidiosis was noticed in the Sheffield area in 1986. Epidemiological investigations suggested a waterborne outbreak of cryptosporidiosis, the possible source of which was cattle on a farm adjacent to the reservoir complex (Rush et al., 1990). In another study, 249 surface water samples were tested for parasites in 2 adjacent British Columbia, Canada, watersheds: the Black Mountain Irrigation District (BMID) and the Vernon Irrigation District (VID) both of which serve rural agricultural communities active in cattle ranching. Giardia cysts were not detected in the raw water samples collected from lake sources at the headwaters of both watersheds but were found in 100% and 97% of water samples at BMID and VID intakes, respectively. Significantly higher levels ($P < 0.05$) of Giardia cysts were found at the BMID intake than at the VID intake probably because cattle have access to creeks in the BMID watershed, whereas access is restricted in the VID watershed. Peak concentrations of both parasites coincided with calving activity. Fecal samples from cattle were positive in both watersheds: 10% in the BMID and 50% in the VID watersheds. No fecal sample was positive for Cryptosporidium. Thus, the differences in patterns of parasite contamination and cattle management practices may contribute to the unique watershed characteristics although they may be topographically similar and geographically adjacent (Ong et al., 1996).

Bates et al (1994) isolated vancomycin-resistant Enterococcus faecium (VRE) from raw sewage, farm animals and uncooked chickens. Two ribotyping patterns were found among isolates from

animals and sewage and those from clinical sources. A blood and a urine isolate from separate hospital patients and porcine isolates shared the same ribotyping pattern and a stool isolate from a patient in the community and sewage isolates shared another pattern. This led them to suggest that animals might serve as a reservoir of VRE. We would like to suggest that humans may also serve as the source of organisms for animals.

Table 2 shows the relative risks of bacterial diseases that can be transmitted between humans and animal via water.

Table 2. Relative risks of bacterial transmission between humans and animals via water.

Bacteria	Disease	Level of risk
Clostridium tetani	Tetanus	Low Risk
Brucella melitensis	Brucellosis	Low Risk
Bacillus antracis	Anthrax	Low Risk
Erysipelas rhusiopathiae	Erysipelosis	Low Risk
Leptospira spp.	Leptospirosis	Medium Risk
Yersinia enterocolitica	Yersiniosis	High Risk
Salmonella spp.	Salmonellosis	High Risk
Mycobacterium tuberculosis	Tuberculosis	High Risk
Atypical mycobacteria	Mycobacterial infections	High Risk
Escherichia coli	Colibacillosis	High Risk
Campylobacter jejuni	Campylobacteriosis	High Risk
Listeria monocytogenes	Listeriosis	High Risk

Some studies show negligible effects of animal manure on human health. During routine examination of bathing areas near North Sea in Germany, Salmonella contamination was detected for the first time in 1988. To define the source of contamination, strains isolated from seawater and rivers were studied by molecular marker methods. The plasmid profile and antibiotic resistance patterns excluded the surrounding cattle industry as a source (Graeber et al., 1995). The presence of Salmonella in North Sea coastal water did not correlate with the presence of fecal indicator bacteria (Tobias and Heinemeyer, 1994). Also, Salmonella from agricultural sources proved to be irrelevant in this study.

Jones et al. (1980) examined 882 samples of settled sewage, sewage sludges and final effluents from eight sewage treatment plants. Of these samples, 68% were positive for Salmonella.

Isolation frequencies from settled sewage, raw sludge, and anaerobically digested sludge were 85%, 87%, and 96%, respectively. Fewer isolations were made from final effluent (24%) and processed sludges (58%). Samples usually contained less than 200 salmonellae/100 mL. They argued that such low concentrations should not lead to disease in animals if suitable grazing restrictions are followed.

Smeltzer *et al.* (1979) spread cattle manure on experimental plots at the rate of 54 tons/ac/yr. The manure was applied to 2 plots at 6-monthly intervals while a further 2 plots received monthly applications. Samples of manure soil, run-off and groundwaters were examined for bacteria. Comparison of the bacterial counts from samples from the test plots to those of the control plots showed that no change occurred in the levels of coliforms or faecal coliforms over the 3 years of manure application. One hundred and fifty-seven isolations of Salmonella were made from the soil and water samples, but only 51 could be attributed to manure. No difference was observed in the effects of different application frequencies.

Escherichia coli serotype O157:H7 has become a major foodborne pathogen for the young and the elderly. The association of non-bovine products with outbreaks suggests that other vehicles of transmission may exist for this pathogen (Feng, 1995). Remote, supposedly pristine water samples have been found to be contaminated with Giardia cysts in the Yukon (Roach et al., 1993).

Certain assumptions can be made regarding the transmission of animal viruses through water:

1. Large numbers of viruses are excreted in infected animal feces. In fact, enteroviruses have been found in all animal species that have been extensively studied. These animal viruses can gain entrance to streams, lakes and other bodies of water via land application of animal wastes or by direct contamination from pastures and feedlots. Constant fecal contamination of open water in pastures and washings of pens and closed lots are important in this respect. Wastes from abattoirs and dairy operations may also be important (Malherbe *et al.*, 1967).

2. If virus-contaminated water becomes immediately accessible to susceptible individuals (which may be humans or other animals), viruses may induce active infections.

3. It should be realized that this problem may not exist in areas where treatment of water supplies in adequate. However, a vast majority of Earth's population is dependent upon water supply of unknown purity. In many parts of the world, humans and other animals use the same water holes and streams as primary source of water.

4. It has also been known that certain viruses produce a benign disease in their natural hosts but may cause cancer or be even fatal in other animal species. For example, adenoviruses of monkeys and mice are considered oncogenic in hamsters. Similarly, pseudorabies, a herpesvirus of pigs, produces mild disease in adult pigs but is fatal in cattle, dogs, and rabbits.

5. Any virus excreted in feces and urine is potentially capable of being a waterborne disease and farm animals are known to excrete a variety of viruses in their feces. Many of these agents are pathogenic in farm livestock and some may also be transmissible to humans. In one study, Grew *et al.* (1970) was able to detect animal viruses in rural farm families in Costa Rica. Derbyshire (1976) isolated animal enteroviruses from soil, surface run-off and surface water on farms in Ontario where liquid pig manure was routinely used on land. And, these viruses were isolated as long as 8 days after the manure was spread.

6. To establish virus-contaminated water as a significant link in the epidemiology of animal virus disease, it is necessary to study the factors affecting virus survival in water under natural conditions. Few studies are available that have addressed these issues. Derbyshire (1976) compared several techniques for the concentration of porcine enteroviruses from water and liquid manure. Using some of these techniques, he isolated animal viruses from 17 of 22 samples of swine fattening house and from one of 6 sow farrowing houses.

An extensive discussion of pathogens in animal manure and the potential human health risks can be found in the Water report, GEIS topic III. G., question 4.

Variation by Segment of the Population: Water- and Soil-borne Pathogens
It has been estimated that by the year 2010 (barely a decade from now) approximately 20% of the human population will be classified as particularly "vulnerable" to health effects of pathogens and chemical pollutants. "Vulnerable" segments of the population will include infants and the elderly, and all those people whose immune systems are compromised. The latter group includes persons undergoing cancer therapy; organ transplant patients (who must remain on anti-rejection medications); as well as those who have the human immunodeficiency virus (HIV), which causes AIDS (acquired immunodeficiency syndrome). This is a serious and sobering prediction. It means that one in every five persons will be particularly vulnerable; that at least one person in most families will have a particular vulnerability to potential health hazards.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Water- and Soil-borne Pathogens
A discussion of the variation of water-borne contaminants by species, system type, geography and concentration can be found in the Water report, GEIS topic III. G., question 6.

Monitoring Techniques, Modeling Approaches, and Standards: Water- and Soil-borne Pathogens
A discussion of regulations, monitoring, and standards for water-borne pathogens can be found in the Water report, GEIS topic III. G., question 4.

Prevention and Mitigation Measures: Water- and Soil-borne Pathogens
Information on preventing water pollution such as water-borne pathogens is presented in the Water report, GEIS topic III. G., question 7.

Nutrients Transmitted through Water and Soil

Human Health Effects: Water- and Soil-borne Nutrients

Nitrate is a common contaminant found in many wells in Minnesota. Nitrate represents a health risk to infants under the age of six months, because it can cause an acute and potentially fatal condition called methemoglobinemia. (This is the so-called blue baby syndrome because the oxygen in an infants system is removed from the blood in a biochemical reaction involving the nitrate; thus they appear to be suffocating.) Some researchers have even suggested that nitrate may also play a role in the development of some cancers. However, several studies involving nitrate and cancer over the past two decades have ended with ambiguous results. Therefore, we must conclude at this time that, to the best of our knowledge, there is no clear evidence that nitrate ingestion results in an increased cancer risk. Obviously, more work needs to be done to provide a definitive answer to whether there is any relationship of nitrate to cancer.

An extensive discussion of nutrients transmitted through water and the associated human health risks can be found in the Water report, GEIS topic III. G., question 4. A discussion of nutrients in the soil can be found in the Soil report, GEIS topic III. I. Detailed information on nutrients transmitted through water and soil can also be found in the Manure and Crop Nutrients report, GEIS topic III. J.

Variation by Segment of the Population: Water- and Soil-borne Nutrients

Infants, and pregnant and nursing mothers are those most affected by nitrates, as described above.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Water- and Soil-borne Nutrients

A discussion of the variation of water-borne contaminants by species, system type, geography and concentration can be found in the Water report, GEIS topic III. G., question 6.

Monitoring Techniques, Modeling Approaches, and Standards: Water- and Soil-borne Nutrients

A discussion of regulations, monitoring, and standards for water-borne nutrients can be found in the Water report, GEIS topic III. G., question 4.

Prevention and Mitigation Measures: Water- and Soil-borne Nutrients

Information on best management practices and mitigation technologies to prevent against water pollution such as nutrients can be found in the Water report, GEIS topic III. G., question 7.

Fly-borne Disease

Issues of Concern: Dead animals, animal wastes, and manure are reservoirs for agents that can be transmitted to humans via various vectors and cause human disease. Flies are a common transmission vehicle or vector, present on or around animal agricultural facilities. There is a paucity of data dealing with dead animal carcasses and by-products. However, a number of studies have been completed on flies and their potential role in disease transmission. A key issue

is to quantify the degree to which fly-borne transmission of pathogens to humans occurs with human illness as a result.

Human Health Effects: Fly-Borne Disease

A variety of microorganisms can cause foodborne illness if consumed in human food. Among the many causes, three groups of bacteria are particularly prominent in animal feces, especially those of livestock and poultry. *Escherichia coli* commonly occurs in the gastrointestinal tract of many animals and some are pathogenic such as *Escherichia coli* O157:H7, as well as *Salmonella* spp. and *Campylobacter jejuni* that occur in poultry. For a case of enteric disease to occur, any of these potentially pathogenic bacteria must be transmitted or vectored from a reservoir somewhere in the environment to human food. It is well established that many different fecal-oral transmission routes are possible; notable ones involve food handlers, some eggshells, and steps in the slaughtering and packaging processes. Transmission by those routes is reviewed in question 2.d. of this report, Transmission of Disease and Sickness through Consumption of Animal Products.

This section summarizes what is known about mechanical transmission by the kinds of flies that inhabit filthy habitats. This topic was recently reviewed by Olsen (1998). Interested readers should consult that source for additional details. This is a key reference and will be provided. Important flies are house flies, *Musca domestica*, and blow flies (family Calliphoridae). House flies breed in moist organic matter, including manure, soiled animal bedding and spoiled animal feeds around confined hogs, cattle, horses, and poultry. Blow flies breed in media that are richer in nitrogen, such as dead animal carcasses, improperly disposed slaughter wastes, and egg enriched poultry manure (for more information see the Air Quality and Odor report, GEIS Topic III.H.). A central question is whether animal agriculture affects the risk of fly-borne outbreaks of enteric diseases, and how that risk might vary with different animal species, housing styles, animal densities and farm sizes.

Evidence Incriminating Flies as Mechanical Vectors

Three approaches have been used to study fly-borne transmission of enteric pathogens. The first and oldest approach is epidemiological, where evidence was sought to associate observed outbreaks of disease with flies. Second, intervention studies have sought to demonstrate importance of flies by experimentally controlling flies and observing a reduction in the incidence of disease. Finally, laboratory studies have considered components of the transmission process: Can a chosen fly acquire a pathogen by walking or feeding on a contaminated substrate? Can the acquired pathogen remain viable on or in the fly? Can the contaminated fly effectively inoculate a clean substrate with the retained pathogens? All three of these events must occur if transmission is to occur.

Epidemiological Studies

Older literature. Greenberg (1973) reviewed much of the epidemiological evidence that incriminates flies as mechanical vectors. While many studies have been reported from urban public health or military contexts, seven studies have been concerned directly with pathogens and

flies associated with domesticated animals. *Salmonella typhimurium* was isolated from the bodies of trapped house flies, as well as ill turkeys, snakes and cats on the same premises in the southeastern US (McNeil and Hinshaw 1944). Similarly, *S. choleraesius* was isolated from captured house flies associated with pigs in Russia (Ostashev 1956), *S. carrau* and *S. typhimurium* were isolated from house flies around pigs in Uruguay (Hormaeche et al. 1944), and 12 types of *Salmonella* were isolated from house flies and blow flies around a Mexican slaughterhouse (Greenberg and Bornstein 1963).

More recently, Berndtson *et al.* (1996) isolated *Campylobacter* from flies netted in anterooms of barns containing positive broiler flocks in Sweden. Urban and Broce (1998) isolated *Salmonella* and three other kinds of bacteria from 43% of house flies and blow flies netted around dog kennels in Kansas, where meat from a neighboring rendering plant was the main food for the dogs. And most recently, Iwasa *et al.* (1999) isolated the enterotoxic *E. coli* O157:H7 from 1.6% of house flies netted directly from cattle manure piles at 1 of 4 dairy farms in Hokkaido, Japan. Collectively, these studies demonstrate that varying percentages of flies netted around animals and their manures can harbor isolatable loads of potentially pathogenic bacteria. These studies do not, however, demonstrate unambiguously that the contaminated flies were numerically important in the epidemiology of human disease, either at the subject premises or in the surrounding landscape.

Work in progress. There are two ongoing studies of flies and foodborne illness around large caged-layer facilities in Ohio and Minnesota. The Ohio Department of Health (ODH) has been studying house fly abundance and foodborne illness around a 2.5 million bird caged-layer facility in Hardin county (Winpisinger-Slay and Berry 1998, Winpisinger-Slay and Berry 1999). In 1997, fly traps placed at increasing distances from the facility indicated that house fly densities diminished exponentially with distance from the subject facility. Fly densities were greatest on site, but densities declined to less than 10% a mile or more in all directions.

To see if the flies at the facility were contaminated with *Salmonella* sp. or *Campylobacter* sp., staff of ODH netted flies from manure in the facility's barns. Flies were also netted from manure at two dairies in neighboring counties, both of which had histories of infection with *S. cerro* (Winpisinger-Slay and Berry 1998). Pathogenic bacteria were isolated from flies at one of the dairies, but not at the second dairy or at the caged-layer facility. The authors concluded that their isolation procedure was capable of detecting bacteria, but further work would be needed to more fully assess the extent of contamination in the flies at the subject facility, and at points elsewhere in the surrounding landscape.

A second aspect of the same project in Ohio examined the hypothesis that incidence of diarrheal disease was greater among people living near the caged-layer facility in Hardin County than living elsewhere in the state. The authors did not describe other possible sources of flies in any of the counties. Incidence of physician diagnosed *Salmonella* and *Campylobacter* infections in 1998 were 6.6 and 9.6 cases, respectively, per 100,000 people in the county. In contrast, there were 13.8 and 9.8 cases, respectively, statewide. Thus, case rates in the same county as the

subject facility were actually *lower* than in the state overall. Active surveillance among residents at specified distances from identified fly and pathogen sources will be required before an association between disease and animal confinement facilities can be more critically assessed.

Minnesota's Department of Health (MDH) has taken a different approach to a similar problem (Anonymous, 1999). In response to community complaints around a 2-million bird facility in the center of Renville County, a telephone survey of 100 randomly chosen households in the county was conducted in late 1998. Callers asked how many people in the household had diarrhea in the preceding 5 months, when fly-borne transmission would have been most likely. If diarrhea was reported, follow-up questions were asked about symptom history, medication and other possible exposures. Residents were also asked to rate peak fly abundance during the same 5-month period, using a 0-10 point subjective scale. The report did not consider other possible sources of flies in the survey area. Nevertheless, analysis revealed no associations among incidence of diarrhea, perceived fly abundance, and distance from the subject facility.

As was done in Ohio, case rates of physician diagnosed *Salmonella* and *Campylobacter* infections in Minnesota in 1996 and 1997 were analyzed to see if case rates (per 100,000 people) were greater near the subject facility. The rate in Renville County was 8.5 cases—actually *lower* than in 3 of 4 neighboring counties. Interestingly, the annual rate in the five Minnesota counties was 14.8, approximately half of Ohio's statewide rate of 23.6. In summary, MDH's telephone survey and analysis of case reports both failed to detect an association of diarrheal disease (and putative fly-borne transmission) with the subject caged-layer facility.

Intervention Studies

No studies of this kind have involved animal agriculture directly, but a classic experiment was conducted in Hidalgo County in southern Texas in the late 1940s (Watt and Lindsay 1948). The study assessed the value of community-wide fly control in a high morbidity area for reducing acute diarrheal disease, specifically salmonellosis and shigellosis. The latter disease is caused by *Shigella* spp, a group of bacteria that occur exclusively in the gut and feces of humans and other primates—but not domesticated animals.

Intervention consisted of intensive spraying with DDT in five towns; another four towns were left untreated for reference. After 20 months, treatment in the first group of towns was discontinued, and treatment in the second group was initiated for another three months. Surveyors canvassed all nine towns to assess the incidence of diarrhea and dysentery, collected stool samples, took rectal swabs from children under 10 yr. of age, and examined the county's mortality records to assess death rates from enteric disease. Fly control substantially reduced abundance of house flies and other species, reduced frequency of *Shigella* isolates, and reduced infant mortality attributed to diarrhea. Isolates of *Salmonella* were less affected by fly control, indicating flies were more important in the spread of *Shigella* than of *Salmonella.*
The authors concluded, "a significant reduction in the amount of infection, disease and death resulted from the degree of control established." They further cautioned, however, that, "something more basic [than community-wide insecticidal control], particularly the elimination

of man-made breeding places, must be done if the full effect of fly control on disease is to be brought about."

A more recent study evaluated the value of fly control around isolated military training camps in the desert of Israel (Cohen *et al.* 1991). The study involved two camps with chronic histories of diarrhea among trainees. In a prospective crossover design, workers instated intensive use of traps and insecticidal fly baits for 11 weeks to control latrine breeding house flies at one camp, and then switched fly control to the second camp. The same routine was repeated, but with camp order reversed in a second year. Fly counts in the camps' mess tents were 64% lower when the camps were being treated. Concomitantly, clinic visits dropped by 42%, diagnosed cases of shigellosis dropped by 85%, and seroconversions to *Shigella* and to enterotoxic *E. coli* dropped by 76% and 57%, respectively. As in the Texas study, reductions of fly abundance by more than half caused concurrent declines in transmission of enteric pathogens among the trainees, presumably by reducing spread of the bacteria from latrines to food in the camps' mess tents.

These two intervention studies (among many other less rigorous studies reviewed in Greenberg [1973]) demonstrate that reductions in abundance of house flies and presumably other kinds of filth flies caused a reduction in the spread of enteric pathogens. It follows, therefore, that increases in fly abundance could increase spread of disease, provided a reservoir of the pathogen is available, susceptible human populations are effectively exposed to the flies, and flies are sufficiently abundant and contaminated to deposit infectious loads of bacteria on human food.

Laboratory Studies of Components of Transmission

All the different kinds of filth flies begin life as an egg laid in the species' breeding medium. After hatching, the larva feeds on bacteria and other products in the medium, grows and molts twice before becoming a non-feeding pupa in the same medium. Between each transition, the insect sheds its old integument (skin) and forms a new one. Finally the adult fly emerges from the pupa and disperses in the surrounding habitat in search of water, food and mates. Many experimental studies have considered how potentially pathogenic bacteria can be acquired and persist on or inside the insect as it develops through its life cycle. An enormous volume of literature dating back to the early 1900's exists on this topic, and Greenberg (1973) reviewed much of the early work.

Acquisition. Pathogens in the medium, including *E. coli*, *Salmonella* spp. and *Campylobacter* spp., contaminate the larva's external integument and are ingested into its GI tract. Once ingested, the pathogenic bacteria do not multiply inside the insect; rather, they are confined to the gut where they are digested or otherwise eliminated by competition with other non-pathogenic bacteria. Most interestingly, most gut inhabiting bacteria are eliminated during the process of molting to the pupa, and the emerging adult flies are internally and externally sterile. Sterility is temporary, though, because the new fly can be quickly contaminated on the outside as it walks over the substrate from which it emerged. Contamination probably occurs with all kinds of bacteria that may be present in the larval medium, whether benign or infectious to animals and humans.

Once the fly becomes mobile and is able to take wing, it can acquire further loads of bacteria by landing, walking and feeding on new substrates, as demonstrated with *Salmonella typhimurium* mice and houseflies in small cages (Ostrolenk and Welch 1942). Flies are adept at finding droplets containing water, sugar and protein directly on living animals (including humans) and on surrounding debris such as feces, soiled bedding, animal food and carcasses. In the process, feeding flies can acquire bacteria on their tarsi, on their mouthparts, and in their digestive tracts. Microbes can also be acquired from other contaminated flies. As with contaminants of the larvae, the largest loads of contaminants of all kinds are probably acquired from feeding substrates. Fortunately, none of the bacterial causes of enteric disease in humans effectively replicate in the flies.

Retention. The vast majority of acquired bacteria are eliminated from the outside of the insect within the first few hours, through grooming, desiccation on the dry integument, UV radiation in the outdoor environment, and physical dislodgement during flight. The most recent study of retention of microbes by house flies (Tan et al. 1997) showed that particles of a simian rotavirus were eliminated from flies within 1 hour of initial acquisition, and most were shed during their first flight after acquisition or when the insects first landed on their next substrate. As occurs with larvae, bacteria ingested by adult flies are eliminated through digestion, competition, or passage out the fly's rectum. Retention times in the gut range from hours to days—not much longer than occurs with inert particles.

Inoculation. The three main routes of inoculation are likely from tarsi onto landing substrates, from mouthparts onto feeding substrates, and from fly feces to anything in the fly's environment. The amount of inoculum is directly proportional to the load of bacteria present on the fly's tarsi and mouthparts. During feeding, house flies and blow flies expel contents of their crops, which can be laden with up to 10^8 bacteria. Similarly, bacteria in fly feces will be deposited wherever flies spend more than a few seconds. The characteristic fly specks that are evidence of fly presence are actually a mixture of fly vomit and feces, and at time of deposition can contain thousands of bacteria. The fate of those bacteria depends on the nature of the substrate. If dry, they probably die within hours, with exception of *Salmonella* that are long lived in dry environments. If the bacteria are inoculated into a human food that supports bacterial growth and multiplication, then the inoculum left by a fly could multiply many times before being ingested by humans.

Variation by Segment of the Population: Fly-Borne Disease

Risk is obviously greatest around human habitations where feces, flies and food are all in close proximity. The segments of the population most vulnerable to fly-borne disease would be the same as for food-borne disease, namely children, pregnant women, the elderly, and other immuno-compromised people as described in Question 2.d. of this report, Transmission of Disease and Sickness through Consumption of Animal Products.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Fly-Borne Disease

A central question is whether animal agriculture affects the risk of fly-borne outbreaks of enteric diseases, and how that risk might vary with different animal species, housing styles, animal densities and farm sizes. Information on fly populations by species and facility type can be found in the Air Quality and Odor report, GEIS topic III. H., questions 1 and 3 (insects).

Monitoring and Modeling Techniques, Validation and Evaluation: Fly-Borne Disease

A variety of methods involving traps and spot cards are used by entomological researchers, integrated pest management consultants, and public health officials to assess the density (per unit area) of flies in a given environment. Those methods were reviewed in the Air Quality and Odor report, GEIS Topic III. H. However, none of the available methods is practical for assessing rates of fly contamination with specific pathogenic bacteria. Isolations reported above were done in the context of specific studies, and it does not appear that pathogen monitoring is done routinely anywhere. A computer model for house fly populations has been developed (Wilhoit *et al.*, 1991), but it is not suitable in present form to monitor or predict the vector potential of flies associated with animal agriculture (or any other human enterprise).

Prevention and Mitigation Measures: Fly-Borne Disease

It is prudent that managers of animal facilities of all kinds and sizes work vigilantly to minimize fly production on their premises.

Knowledge Gaps and Researchable Topics: Fly-Borne Disease

The evidence reviewed previously (and much more omitted for sake of brevity) has led to the basic tenet in public health that filth fly populations pose an unacceptable risk for transmission of enteric diseases. Risk is obviously greatest around human habitations where feces, flies and food are all in close proximity. Risk becomes progressively lower where feces and flies become increasingly unavailable.

It remains to be demonstrated that fly populations emanating from agricultural sources such as manure, carcasses or other organic debris at livestock or poultry facilities are or could contribute materially to the incidence of enteric disease in populations of workers at those facilities, or in residents in neighboring communities. As progressively larger animal agriculture enterprises have emerged in the Upper Midwest, a corresponding increase in human disease has yet to be identified. Rather, outbreaks of foodborne illness that have achieved notoriety have been traced to direct routes of transmission from farms to humans through the chain of food processing and distribution. Nonetheless, it is prudent that managers of animal facilities of all kinds and sizes work vigilantly to minimize fly production on their premises.

Evidence in the published literature and reports of ongoing studies indicate that in some circumstances, isolatable loads of potentially pathogenic bacteria can occur on filth flies netted directly from animals or their manure. However, it is not clear that contamination rates on flies would be the same among flies that have dispersed epidemiologically significant distances from

such sources. This issue will require much more effort than has been invested to date. Similarly, analysis of reported case rates by county, as has been done in Ohio and Minnesota, may be at a spatial scale that is too aggregated to detect elevated case rates within a mile or two of putative animal reservoirs on the landscape. Active surveillance among households at known distances from presumed reservoirs will be required, but given the overall low rate of cases in general, it will be difficult and expensive to detect a spatial pattern, if one exists at all.

Conclusions:

- **Pathogens may be transmitted to humans from animal wastes through contaminated surface drinking water supplies, contaminated ground water supplies, or direct contact with contaminated environment e.g., recreational use of water.**
- **Some incidents of human disease attributable to contact with livestock waste have been reported.**
- **Water-borne nitrate represents a health risk to infants under the age of six months, because it can cause an acute and potentially fatal condition called methemoglobinemia.**
- **Flies carry a wide variety of human pathogens.**
- **More research is needed to determine the extent to which fly-borne microorganisms are transmitted to humans and cause illness.**

QUESTION 2.D. - TRANSMISSION OF DISEASE AND SICKNESS THROUGH CONSUMPTION OF ANIMAL PRODUCTS.

Issues of concern: There are three main issues of concern in terms of foodborne disease caused by animal products. A key issue is how to reduce the number of pathogens routinely found on animal products and subsequently the prevalence of foodborne disease in Minnesota. A second issue is how can such a reduction be accomplished in an economically feasible manner: improvements in health of animals on the farm, irradiation of products and pre-cooking or pasteurization of products. A third issue is how do different systems of agriculture impact the level of contamination by pathogenic microorganisms?

This area of research is one of the most thoroughly studied areas in the entire human health document. Nevertheless, gaps in knowledge remain, if for no other reason then the organisms can mutate and develop resistance to antimicrobials, as discussed in question 2.e. of this report. Therefore, in this section, a detailed review of human pathogens transmitted by food is presented. Animal products represent important, but not the only, vectors for these pathogens. Much (though not all) of the transmission through other vectors can also be traced back to animal agriculture, however, either through contamination of other food by contact with the contaminated animal food, food-handling person-to-person transmission after infection from animal food, or through manure (e.g., Ackers 1998).

Human Health Effects: Food-borne Disease

Salmonella

Salmonella are facultative anaerobic gram-negative bacteria. They are members of the family *Enterobacteriaceae,* and included are many pathogenic species *like S. typhimurium, S. enteriditis, S. pullorum, S. dublin, S. gallinarum, S. indiana, S. javiana*, and *S. arizonae* (D'Aoust, 1997). Infection by *Salmonella* can cause enteric (typhoid) fever, uncomplicated enterocolitis and systemic infections. Enteric fever is characterized by diarrhea, fever, abdominal pain, and headache. In many cases, the silent persistence of *Salmonella* in the gastrointestinal tract can lead to chronic conditions such as reactive arthritis or Reiter's syndrome. *Salmonella* is an ubiquitous organism in nature (Varnam and Evans, 1991) and can be isolated from multiple sources, including animals and animal products.

Human Incidence

Salmonella is the human foodborne pathogen with the greatest estimated economic burden of human foodborne disease, and, as the focus of the current HACCP monitoring program by the USDA-FSIS in slaughter plants (USDA-FSIS, 1999), is a primary target for on-farm interventions. This pathogen infects approximately 3 million people and is responsible for more than 3,000 deaths, every year. According to the FoodNet surveillance network, the average incidence of *Salmonella* infections was 13.9/100,000 population (FoodNet, 1998) The number of reported outbreaks related to food consumption contaminated by *Salmonella* can be more than 100 in a single year in the U. S. (Bean et al., 1998).

Salmonellosis is caused by a variety of plant and animal products, but the majority of cases are related to the consumption of foods from animal origin. Outbreaks of *Salmonella enteritis* are typically related to the consumption of poultry and egg products, but pork, beef and dairy products are also frequently implicated in cases with *Salmonella* (D'Aoust, 1997). One of the largest outbreaks of *Salmonella enteritis* occurred in Minnesota in 1994 when a batch of ice cream mix was transported in an unsanitized truck that had previously been used to transport raw eggs (Hennessy et al., 1996). In this case more than 220,000 people were infected. In humans, the number of isolates of *S. enteriditis* increased almost 10-fold from 1976 to 1995 in the U. S. (Hogue et al., 1997b) and consumption of eggs was the primary risk factor.

Foods of Animal Origin as a Source of *Salmonella*

A variety of animal species are reservoirs of infection, including cattle, swine, and poultry. Information from the NAHMS 1996 national dairy study indicates at least 28% of dairy operations have milk cows shedding *Salmonella* at any point in time, with about a 5% milk cow fecal shedding prevalence (Wells et al., 1998). There is evidence of clustering of *Salmonella* on certain dairy operations.

Salmonella enteriditis is endemic in poultry and egg products because this pathogen is a normal inhabitant of the gastrointestinal and reproductive tracts of fowl species (Suzuki, 1994). This pathogen is able to infect many different organs of chickens and *Salmonella* is easily transmitted to forming eggs by the oviduct tissues colonized by this pathogen (Keller et al., 1995). *Salmonella* cells are typically found at the eggshell, but this bacterium can easily penetrate the egg shell (Miyamoto et al., 1998).

It has been estimated that approximately 1 egg in 10,000 is typically contaminated with *Salmonella* (D'Aoust, 1997). Recent surveys reported that *S. enteriditis* was detected in 19% of unpasteurized eggs in different regions of the country, with the highest prevalence in the Northern states with more than 40% of flocks infected (Hogue et al. 1997a). The flock prevalence was 45% overall, but the prevalence in the Northern region was as much as 64%. Most egg-associated Salmonellosis are caused by the consumption of raw eggs, poorly cooked eggs or mayonnaise made with unpasteurized eggs (Mackenzie et al.,1998). Because *Salmonella* has been detected in more than 35% of raw chicken (Arumugaswamy et al., 1995), the consumption of undercooked pieces and cross contamination of other foods can lead to infection.

Salmonella is also a normal inhabitant of the gastrointestinal tract of pigs (Rajkowski et al., 1998) and under the current practices the incidence of positive animals is 50-60% (Berends et al., 1998). However, a recent study reported no positive samples among 932 carcasses (Miller et al., 1997). In pork products this problem is enhanced by cross contamination at the processing plant (Berends et al., 1998). Similarly to chicken products, the consumption of poorly cooked pork meat poses a great risk.

Vehicles of Transmission

The majority of *Salmonella* contamination of meat products occurs at slaughter when intestinal

contents contaminate carcasses (Varnam and Evans, 1991). The current farm practice of recycling of offal and inedible raw materials into animal feeds has perpetuated the presence of *Salmonella* in chicken and pork products (D'Aoust, 1997; Hapapuro et al., 1997). *Salmonella* can also be transmitted from manure to other products like milk, fruits and vegetables (Buzby et al., 1996). Despite the fact that recent reports indicated that *Salmonella* can be transmitted between flocks through air (Gast et al., 1998; Lever and Williams, 1996) there is no evidence for airborne human infection. Water contaminated with manure or soil can also cause Salmonellosis (Angulo et al., 1997; CDC, 1998).

Methods to Reduce Contamination

Salmonella can be controlled, but not eradicated on dairy operations. For both host and non-host adapted serotypes, control measures include simultaneously removing carrier cows, improving sanitation (reduce environmental burden of cow feces, avoid use of recycled flush water, contamination of feeds with manure), pest control (birds and rodents), and by addressing feed-borne *Salmonella* (Smith et al., 1992). An approach for dairy cattle using identification and removal of *Salmonella* infection sources, and adoption of quality assurance programs to assure use of this process, seems more promising than a test and cull approach.

Improvement in sanitary conditions, utilization of HACCP systems, cooking, pasteurization, and irradiation are effective methods to prevent and reduce the consumption of contaminated foods, but some technologies have been developed to control contamination at the farm level. Vaccination of hens has shown promising results, but they are not commercially available, yet (Curtiss and Hassan, 1996; Hassan and Curtiss, 1996; Holt et al., 1996; Zhao et al., 1995). Nisbet and colleagues developed a competitive exclusion system by preventing *Salmonella* colonization using a mixture of probiotic bacteria (Hume et al., 1998). This already available commercial method can reduce the mortality of chicks caused by *S. gallinarum* (Nisbet et al., 1998). Use of chemicals to prevent colonization or to wash poultry carcasses have also been used, with limited results (Breen et al, 1997; Hwang and Beuchat, 1995; Line, 1998).

Campylobacter

The two species of *Campylobacter* responsible for food borne diseases are *C. jejuni* and *C. coli*, and they are the second predominant etiologic agent of bacterial diarrhea in humans (Altekruse et al., 1999). *Campylobacter* are gram-negative bacteria that do not survive well in the environment and do not cause illness in animals (Nachamkin, 1997). The typical symptoms of campylobacteriosis include watery diarrhea, abdominal pain and fever (Varnam and Evans, 1991). Prolonged illness and relapses are observed in 10% of patients (Buzby et al., 1996), extraintestinal infections and sequela can occur in 2%, but death by campylobacteriosis is very unusual (less than 0.05%) (Nachamkin, 1997).

Human Incidence

Campylobacter infects approximately 1.5 million people and costs the American economy $1 billion per year. In addition, it is responsible for an average of 6 major outbreaks per year in the U.S. (Bean et al., 1998; Buzby et al., 1996) Campylobacteriosis is probably the major cause of

foodborne infections not related to outbreaks and it is estimated that they account for as much as 14% of the total human diarrheal diseases (FoodNet, 1998). In 1998, the estimated overall incidence of campylobacteriosis was 19.7cases/100,000 population. A variety of foods are implicated in infections by *Campylobacter*, but most cases of *C. jejuni* are related to poultry products and the majority of infections by *C. coli* can be traced to pork products. *Campylobacter* is associated with the development of a secondary complication, Gaullain-Barré Syndrome.

Incidence in Foods of Animal Origin

A wide variety of wild and domestic animals serve as reservoirs of *Campylobacter* that normally colonize their gastrointestinal tract (Angulo, 1997). The foods that have been implicated in outbreaks are milk, poultry and red meat (Varnam and Evans, 1991). A relatively large number of outbreaks are water-borne, because this pathogen has the ability to survive in water in an infectious state (Nachamkin, 1997). In poultry products, the incidence of detection in carcasses increases during the summer months (Willis and Murray, 1997) and this incidence is linked to the seasonality of human infections (Bean et al., 1998). More than 40% of poultry products can be contaminated with *Campylobacter* (Atabay and Corry, 1997) and in recent years the proportion of strains resistant to quinolone antibiotics has significantly increased (Atanassova and Ring, 1998; Bowler et al., 1996). From a subset of the NAHMS 1996 national dairy study herds tested using a PCR test, 100% of herds tested had positive cows with an individual milk cow prevalence of 43%. *Campylobacter* is considered an emerging foodborne pathogen (Altekruse, 1999). Whether this "emergence" is linked to modern husbandry practices or is due to the improvement in detection methods, remains to be elucidated.

Vehicles of Transmission

Similar to *Salmonella*, *Campylobacter* contaminates foods by exposure to intestinal contents or manure (Nachamkin, 1997). Fruits and vegetables have also been cause of infection by contact with manure (Buzby et al., 1996). Water is an important vehicle for campylobacteriosis because this pathogen can remain dormant in a non-culturable state (Altekruse et al., 1998). Despite the fact that *Campylobacter* appears to be widespread in birds, the number of cases related to egg consumption is very low (Bean et al., 1998).

Methods to Reduce Contamination

The measures currently tested to reduce the incidence of *Campylobacter* in poultry products are directed to improve sanitary and farm practices and to increase the resistance to colonization (Buiker and Urlings, 1991). Competitive exclusion is a potential solution but it is still in the experimental stage (Stern and Meinersmann, 1989). As for *Salmonella*, irradiation is a potential solution to treat unprocessed meats (Thayer, 1995). Ecology of *C. jejuni* on-farm has not been well studied, though would be expected to relate to fecal hygiene. Effectiveness of on-farm control measures has not been shown.

Escherichia coli O157:H7

Escherichia coli is a facultative anaerobic bacterium that is normally found in the mammalian gastrointestinal tract. *E. coli* was considered an innocuous communal organism, but in recent

years many strains capable of developing infection have been isolated (Nataro and Kaper, 1998). Most pathogenic *E. coli* cause diarrhea and some infect the urinary tract. Enteropathogenic *E. coli* (EPEC) is responsible for infantile enteritis and enterotoxigenic *E. coli* (ETEC) is the cause of "travelers' diarrhea." Enterohemorrhagic *E. coli* (EHEC) strains are the major etiologic agent of hemorrhagic colitis and *E. coli* O157:H7 has been linked to numerous outbreaks.

The typical symptoms of infection by O157:H7 are abdominal cramps, bloody diarrhea and, rarely, vomiting (Su and Brandt, 1995). These symptoms normally develop within 2 to 8 days and 6% of patients develop two serious complications: hemolytic uremic syndrome (HUS) in children and Thrombocytopenic Thrombotic Purpura (TTP) in the elderly. The case fatality rate is 0.06% of infected individuals.

Human Incidence

Isolation of *Escherichia coli* O157:H7 from human patients has been reported in more than 20 countries, but incidence of hemorrhagic colitis and HUS caused by this bacteria is highly variable (O'Brian and Kaper, 1998). The United States, United Kingdom and Canada have the highest infection rates with more than 6 cases per 100,000 people (Mead and Griffin, 1998). In continental Europe some outbreaks have been described, but overall public health hazard remains relatively low. O157:H7 has also been detected in Australia, but the major cause of hemorrhagic colitis outbreaks is another EHEC strain, O111:H$^-$. Among developing countries, Argentina appears to have the highest incidence of HUS in the world. The low incidence of EHEC infections in less developed countries might be due to the gain of immunological protection against EPEC infections during childhood, diagnostic limitations and dietary factors.

According to recent epidemiological estimates, *E. coli* O157:H7 causes approximately 40,000 infections and 250 deaths in the United States each year (Buzby et al. 1996). During the 1980's, the incidence of reported outbreaks was less than 5 per year, but the number of outbreaks increased after 1993 to more than 20 every year. In the past decade, infections caused by *E. coli* accounted for less than 0.5% of total foodborne illnesses (Bean et al., 1998), but new figures suggest that *E. coli* O157:H7 incidence is only surpassed by *Campylobacter* and *Salmonella* infections in some states (FoodNet, 1998). Between 1982 and 1996, a total of 139 outbreaks were distributed among 36 states, but they were concentrated among Minnesota, Washington, Oregon and New York with 17, 14, 12 and 12 outbreaks, respectively (USDA/APHIS, 1997). Recent data from the FoodNet confirmed that Minnesota has one of the highest incidence rates of the country (6 cases/100,000 population). Although the rates are not as high as *Campylobacter* and *Salmonella* infections, *E. coli* O157:H7 incidence is economically significant due to illness, hospitalization, and case fatalities.

Incidence in Foods of Animal Origin

The incidence of *E. coli* O157:H7 in foods seems to be highly dependent on the sensitivity of the detection method employed. Several surveys of beef products found a relatively high level of contamination by shiga-toxin-producing *Escherichia coli* (greater than 15%), but the fraction of

those positive for O157:H7 was very low (less than 2%) (Armstrong, et al., 1996; Mechie et al., 1997). Doyle and Schoeni (1987) reported that 3.7 and 5% of the beef samples were contaminated with O157:H7 in different locations. The USDA's National Microbiological Monitoring Program found only 0.1% of the samples surveyed tested positive for *E. coli* O157:H7 (USDA/APHIS, 1997). The prevalence of strain O157:H7 in produce has not been studied in detail, but this pathogen has been detected in cantaloupe, potatoes, radish sprouts, alfalfa sprouts, cabbage, celery and coriander (Besser et al., 1993; Griffin, 1998; USDA/APHIS, 1997). Ground beef remains the most common source for infection.

E. coli O157 remains a difficult enigma. Cattle are considered the primary reservoir of human infection, though other species including dogs, horses, flies, and birds have cultured positive (Hancock et al., 1998). From the NAHMS 1996 national dairy study, 24% of dairy herds had at least one culture-positive milk cow, with a milk cow prevalence of about 1% (Wells et al., 1998). These estimates are consistent with those from the NAHMS 1995 national feedlot study (63% of feedlots, with higher sampling per feedlot, and 1% of fecal samples). Typical duration of shedding is short.

The source of transmission for a large number of outbreaks has been confirmed to be cattle asymptomatically infected with *E. coli* O157:H7 (Rajkowski, et al. 1998). The contamination of meat-related outbreaks has been clearly identified to occur when carcasses are infected by feces or intestinal contents (Meng and Doyle, 1998; USDA/APHIS, 1997) and at the milking parlor in outbreaks associated with dairy products (Morgan, 1993). In outbreaks caused by vegetables and apple juice, the point of contamination occurred when previously spread cattle manure came in contact with produce (Besser, et al., 1993; Mechie et al., 1997). Direct transmission from cattle to humans has also been documented (Armstrong et al., 1996).

Because cattle are a natural reservoir of *E. coli* O157:H7, more than 30 surveys have been conducted in the U. S., U.K and Europe to determine the prevalence of this pathogen in feces of bovine populations. Herd prevalence between 22% and 100% indicated that *E. coli* O157:H7 is widespread in both beef and dairy cattle, but the prevalence appears to be highly variable within herds (Armstrong et al., 1996; USDA/APHIS, 1997). The median percentage of *E. coli* positive animals within herds calculated from those studies was 1.7 %, and the range varied from 0 in four cases to 63% in a recent report (Jackson et al., 1998). Even in herds implicated in outbreaks the prevalence was quite variable (Armstrong et al., 1996).

Pigs do not normally harbor *E. coli* O157:H7 in their intestines and no outbreak has been directly linked to consumption of pork meat. In a large survey conducted by the USDA's National Animal Health Monitoring System in 1995 (Bush, 1996), no evidence of fecal shedding of *E. coli* O157:H7 in pigs could be found, and Chapman et al. (Chapman et al., 1997) reported a 0.4% prevalence. However, *E. coli* O157:H7 has been detected in pork meat and carcasses, likely due to cross-contamination from beef. Doyle and Schoeni (1987) isolated this bacterium from 1.5% of fresh retail pork meats, and in a survey at slaughterhouses, 14% of the cattle carcasses tested positive for O157 serotype.

Recent studies have shown that the transmission of *E. coli* O157:H7 from cattle to other animal species can occur. Hancock and coworkers (Hancock et al., 1998) isolated this pathogen from the feces of horses, dogs and flies in dairy farms. Strain O157:H7 can be transmitted through water (USDA/APHIS, 1997) and its dissemination could occur from farm to farm. Because of the increasing number of outbreaks and recalls, it is possible that the prevalence in cattle is also rising, which can potentially increase the risk of transmission to other animal species.

Vehicles of Transmission

The vehicle of *E. coli* O157:H7 transmission in the U. S. outbreaks between 1982 and 1996 was food (67%), person-to-person contact, mostly among children in day-care centers (22%), swimming (8%) and drinking water (2%) (Griffin, 1998). Most foodborne outbreaks have originated at home or at restaurants, but an increasing number of school-related cases have been reported. Ground beef has been the single most frequently implicated food in foodborne outbreaks (60%) and all bovine food products comprise as many as 75% of outbreaks (Buzby et al., 1996). Deer meat has also caused 3 outbreaks and among vegetable products, lettuce, alfalfa sprouts and unpasteurized apple cider and juices have been implicated in at least 5 outbreaks.

Methods to Reduce Contamination

Due to the epidemiology of this organism, *E. coli* O157 eradication does not appear to be possible using test and cull methods. From studies to date, risk factors associated with fecal shedding of *E. coli* O157 in dairy cows are unclear. Factors that may be involved include feed and water management. Dietary factors appear to be involved; one clinical trial showed that fasted calves shed the organism longer than non-fasted controls (Cray et al., 1995). Similarly, pens of feedlot cattle that were on feed less than 20 days were more likely to have positive cultures than those pens on feed longer (Dargatz et al., 1997). Another study suggested drinking water of cattle as a source of *E. coli* O157 (Faith et al., 1996); water troughs have been identified as sources of *E. coli* O157 (Hancock et al, 1998). Increased host resistance through competitive exclusion may prove useful in the future.

It is unlikely that the elimination of *E. coli* O157:H7 from the food supply will be achieved by a single method, but it will have to arise from the combination of a variety of actions. Improvements in sanitation, HACCP programs and organic acid washes can decrease the risk of *E. coli* O157:H7 at slaughter, but it is virtually impossible to prevent all fecal contamination (USDA/APHIS, 1997). Cooking and pasteurization are highly effective, but these processes can greatly affect the cost and sensory characteristics of food. Irradiation is another avenue of prevention (Thayer, 1995) and a vaccine has shown promising results in trial tests, but to date there is no effective vaccine against enteropathogens. The use of probiotics can also significantly contribute to reduce the colonization of *E. coli* O157:H7 in the digestive system (Zhao et al., 1998). A recent paper suggested that changes in the diet of cattle can affect fecal *E. coli* populations, but the effect of feeding hay or grain on *E. coli* O157:H7 incidence remains to be determined (Diez-Gonzalez et al., 1998)

Listeria monocytogenes

Listeria monocytogenes, another emerging pathogen, is a gram-positive organism (Rocourt and Cossart, 1997). Before 1980, *L. monocytogenes* had not been detected as causing major foodborne outbreak; only sporadic cases had been reported (Bell and Kiriakides, 1998). The symptoms of infection by *L. monocytogenes* are typically fever and headache, but a series of serious conditions can develop. In pregnant women, spontaneous abortion, still-birth, septicemia and meningitis may occur (Bula et al., 1995); in other susceptible populations like the elderly, encephalitis and bacteremia are more common. Listeriosis is particularly dangerous because the case-fatality rate can be as high as 30% (Rocourt and Cossart, 1998).

Human Incidence

The overall rate of infection in human populations is relatively low with approximately 5 cases per million population in the U.S. (FoodNet, 1998). Epidemiological studies have calculated that *L. monocytogenes* infections only account for 0.02% of total foodborne infections, but cause approximately 7% of the total food-related deaths (Buzby et al., 1996). A wide variety of foods have been implicated in outbreaks since 1981, but most have been related to dairy products like unpasteurized milk and cheese (Bell and Kiriakides, 1998). In recent years, however an increased number of outbreaks and food recalls have been triggered by contaminated ready-to-eat meats (Kuhn, 1999).

Incidence in Foods of Animal Origin

Listeria has a widespread distribution in nature and it can be associated with decaying plant material, freshwater, feces and sewage. This pathogen is now considered a frequent inhabitant of the gastrointestinal tract of mammals, and even approximately 5% of humans are asymptomatic carriers (Bell and Kiriakides, 1998). It is particularly well adapted to thrive in the wet environment of food processing plants (Rocourt and Cossart, 1998). *L. monocytogenes* can be detected in many different foods including processed products. In a large survey, McLauchlin and Gilbert (1990) analyzed 18,000 samples of foods and found *L. monocytogenes* in 6% of the samples with more than 1,000 cfu/g found in most of them. This pathogen is also frequently detected in raw milk (5%), meat products (1 to 70%), poultry (as high as 50% in some studies), and eggs (5%) (Johnson et al., 1990; Leasor and Foegeding, 1989; Lovett et al., 1987; Uyttendaele et al., 1997).

Very little is known about the ecology of *Listeria monocytogenes* on dairy operations, though it is considered to be ubiquitous in many environments. Weber found 33% of 138 German cattle shedding in feces (1995). Risk factors among French farms included poor quality of silage (pH > 4.0), inadequate frequency of cleaning the exercise area, poor cow cleanliness, insufficient lighting of milking barns and parlors, and incorrect disinfection of towels between milkings (Sanaa, 1993).

Listeria can survive and grow at refrigeration temperatures; milk, cheese and ready-to-eat meats have been implicated in many outbreaks. This is a characteristic that distinguish this bacterium from other foodborne pathogens, even a few contaminant cells can be enough inoculum to reach

infectious dose levels (Bell and Kiriakides, 1998).

Vehicles of Transmission

Because of the pervasive distribution of *L. monocytogenes*, the source of food contamination could come from any material in contact with foodstuff. Lack of sanitary conditions and good manufacturing practices at processing plants are frequently implicated in outbreaks (Kuhn, 1999). Airborne transmission of Listeria, however, has not been demonstrated (Autio et al., 1999). In the case of *Listeria* there is little evidence of a link between the prevalence in livestock with the increase in human infections.

Methods to Reduce Contamination

Improvement in sanitary conditions, use of HACCP systems, and use of irradiation can potentially prevent *Listeria* infections (Bell and Kiriakides, 1998; Thayer, 1995). Improvements in processing conditions can markedly reduce the incidence in meat [33] and poultry (Uyttendaele, 1997). Nisin as proven to be an effective antimicrobial against *Listeria* and it is currently under active investigation to apply this bacteriocin on ready-to-eat meats (Murray and Richard, 1997). The use of bacteriocin-producing bacteria, sodium lactate and a variety of chemicals in meat products has shown limited but promising results (De Martinis and Franco, 1998; Dorsa et al., 1998; Greer and Dilts, 1995; Hume et al. 1998). Fenlon and coworkers (1996) indicated that the incidence of *Listeria* in cattle feces was directly linked to their diet. When animals were fed corn silage this pathogen was almost always detected on their feces, but if cattle was fed only hay no animal was positive.

Yersinia enterocolitica

The genus Yersinia are part of the family *Enterobacteriaceae* and include three pathogenic species: *Y. pestis*, the causative agent of plague; *Y. pseudotuberculosis*, a rodent pathogen, and *Y. enterocolitica*, a foodborne pathogen of humans (Robins-Browne, 1997). Children are particularly susceptible to *Yersinia* and the symptoms of infection are diarrhea, low-grade fever and abdominal pain (Hoogkamp-Korstanje and Stolk-Engelaar, 1995). The illness can last from a few days to 3 weeks and in some cases chronic enterocolitis is observed.

Human Incidence

The incidence of yersiniosis in the U.S. is relatively low (0.9 cases/100,000 people) compared to other foodborne pathogens and outbreaks are very unusual (FoodNet, 1998; Robins-Browne, 1998). A relatively significant number of humans carry *Yersinia* asymptomatically in their intestines (Varnam and Evans, 1991).

Incidence in Foods of Animal Origin

Y. enterocolitica is widely distributed in the gastrointestinal tract of mammals, birds, fish and insects (Cover and Aber, 1989). *Yersinia* has been detected in pork, beef, lamb, poultry and dairy products, but the majority of outbreaks are caused by milk (Kapperud, 1991). However, cattle do not appear to be a natural reservoir of *Yersinia* and cases related to milk were probably due to contamination of pasteurized milk and the ability of this pathogen to grow at low

temperature (Schiemann, 1987). Based on the fact that most isolates from food or livestock are not virulent serovars the transmission from animals to humans might not be significant (Robins-Browne, 1998). The only livestock that can frequently carry human pathogenic serovars (e.g. O:3) are pigs (Kapperud, 1991) and as many as 3% of pork meat can be contaminated (Fukushima et al., 1997).

Vehicles of Transmission

The evidence for the transmission between pork and humans is supported by a variety of epidemiological observations. In countries with the highest incidence, like Denmark, *Y. enterocolitica* is frequently isolated from pork carcasses (Christensen, 1987) and the consumption of raw pork meat is directly linked to infections (Tauxe et al., 1987). *Yersinia* can survive in water streams for long periods of time and this can potentially be a source of infection (Chao et al., 1988). This pathogen can also be transmitted by direct contact with chitterlings (Stoddard et al., 1994), but there is no evidence for airborne dissemination.

Methods to Reduce Contamination

Application of HACCP programs and improvement in manufacturing practices and sanitation could prevent and decrease *Yersinia* contamination. Irradiation is a very effective method to eliminate *Y. enterocolitica* from pork meat (Shenoy, 1998). Treatment of pork meat with lactic acid greatly reduced the counts of *Y. enterocolitica* (Greer and Dilts, 1995).

Mycobacterium paratuberculosis

While the zoonotic nature of *Mycobacterium paratuberculosis* remains unclear, domestic and international consumer demands raise the importance of on-farm control. The NAHMS 1996 national dairy study has estimated at least 22% of dairy herds have at least one test-positive cow with a milk cow prevalence of 3.4% (NAHMS, 1997). This prevalence in dairy herds is greater than that found in U.S. beef cow-calf operations. Control of infection is possible, though requires long-term commitment using currently available tests. Control is focused on fecal hygiene, especially towards susceptible young calves, identifying and removing infected animals and their manure, and reducing the risks of introducing infected cattle to the operation. A herd status program is developing in many states to identify low-risk herds to serve as replacements.

Protozooa

While the foodborne significance of *Cryptosporidium parvum* remains in question, its importance as a water-borne pathogen adds it to this discussion. Many different species of animals shed *C. parvum* oocysts, including cattle. Oocyst shedding appears to be clustered in young calves (primarily less than 30 days of age) and efforts to detect shedding of oocysts from cows around the time of calving have failed to date (Atwill et al., 1998). The NAHMS 1991-92 national dairy heifer study estimated at least 90% of dairy operations were positive for *C. parvum*, with 22% of preweaned dairy heifers shedding oocysts at any one point of time and nearly 50% of calves shedding the pathogen 1-3 weeks of age (NAHMS, 1993). Because of the clustering of fecal shedding in very young calves, environmental control may be feasible, with focus on preventing calf feces from contaminating surface water.

Very little is known about *Giardia lamblia* on dairy operations in terms of prevalence or control measures but the organism has been isolated in 50% of beef calves (NAHMS, 1993).

Variation by Segment of the Population: Food-borne Disease

In general, the segments of the population most susceptible to disease and sickness through consumption of animal products are children, pregnant women, the elderly, and other immuno-compromised groups. For example:

E. coli can cause serious complications in children (hemolytic uremic syndrome (HUS)) and in the elderly (Thrombocytopenic Thrombotic Purpura (TTP)).

Listeria monocytogenes can cause serious conditions in pregnant women, such as spontaneous abortion, still-birth, septicemia and meningitis (Bula et al., 1995); in other susceptible populations like the elderly, it can cause encephalitis and bacteremia.

Children are particularly susceptible to *Yersinia.*

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Food-borne Disease

Species

The prevalence of pathogens varies by species. For information on the presence of pathogens by species, see "Foods of Animal Origin as a Source" under each individual pathogen above.

System Type and Management

Factors that may be involved in the presence of *E. coli* include feed and water management. Dietary factors appear to be involved; one clinical trial showed that fasted calves shed the organism longer than non-fasted controls (Cray et al., 1995). Similarly, pens of feedlot cattle that were on feed less than 20 days were more likely to have positive cultures than those pens on feed longer (Dargatz et al., 1997). A recent paper suggested that changes in the diet of cattle can affect fecal *E. coli* populations, but the effect of feeding hay or grain on *E. coli* O157:H7 incidence remains to be determined (Diez-Gonzalez et al., 1998)

Risk factors for *Listeria* among French farms included poor quality of silage (pH > 4.0), inadequate frequency of cleaning the exercise area, poor cow cleanliness, insufficient lighting of milking barns and parlors, and incorrect disinfection of towels between milkings (Sanaa, 1993). Fenlon and coworkers (1996) indicated that the incidence of *Listeria* in cattle feces was directly linked to their diet. When animals were fed corn silage this pathogen was almost always detected on their feces, but if cattle was fed only hay no animal was positive.

Scale

Some of these concerns of foodborne disease are associated with the size of livestock operations, to some extent, since scale contributes to disease transmission, transportation choices, and other factors. However, size alone is not definitive, and appears to be much less important than

production management practices, as well as practices downstream from production (slaughterhouses, etc.).

Monitoring Techniques, Modeling Approaches, and Standards: Food-borne Disease

FoodNet and PulseNet systems are available to monitor foodborne disease in human populations (Centers for Disease Control and Prevention). Minnesota Department of Health and Minnesota Department of Agriculture have monitoring and food inspection programs. National Animal Health Monitoring System (NAHMS) conducts national studies to monitor foodborne pathogens in livestock and poultry species on-farm. An example of NAHMS studies includes the upcoming 1999 NAHMS Cattle-on-Feed Study, with the objective of documenting patterns of pathogen shedding and evaluating those factors that contribute to shedding of pathogens such as *Escherichia coli* (i.e., *E. coli* O157), *Salmonella* (e.g., *Salmonella typhimurium* DT104), and *Campylobacter*. Another objective of this study is to identify types of antimicrobials in use in the U.S. and the extent to which they are used.

What food safety hazards should be considered for food products from livestock and poultry? How can one evaluate the risks due to safety hazards on a specific operation? These questions may be addressed formally using a risk analysis framework (Bridges, 1998), with steps of identifying hazards and estimating risks associated with those hazards (risk assessment), making decisions regarding risk reduction (risk management), and communicating decisions to others to effect the changes needed (risk communication). Briefly, one way to identify and prioritize potential hazards is to use recent human foodborne disease information, summarized in Table 3. These human foodborne illnesses originate from a variety of sources, and it is not currently possible to estimate the proportion due to foods from a specific class of animal.

It should be noted that these numbers represent a relatively conservative estimate of the number of cases of foodborne disease because most cases go undiagnosed and many that are diagnosed go unreported. Respectable estimates go several orders of magnitude higher (e.g., former Minnesota State Epidemiologist, Michael Osterholm, has estimated over 200 million cases per year in the U.S.). Given these ranges of estimates, all specific numbers for incidence must be considered rough and probably quite low.

Prevention and Mitigation Measures: Food-borne Disease

For detailed information prevention and mitigation measures for each pathogen, see "Methods to Reduce Contamination" under each pathogen above.

In general, education and specialization of the producers and compliance with existing rules and regulations throughout the entire food production chain are of major importance. The majority of the real and perceived reasons for the increased concerns with the safety and quality of food of animal origin apply to the pre-harvest area of the food production chain. Thus, the traditional mandatory meat inspection and the classical post-harvest food safety measures have a limited potential for major improvements of the safety and quality of meat (Blaha, 1996; Buntain, 1997).

Table 3. Major foodborne pathogens by incidence (Shallow et al., 1999) and cost of human illness (Buzby et al., 1996) in U.S.

Pathogen	Incidence of human illness (per 100,000 population)	Annual cost of illness
Campylobacter	21.7	$0.6-1.0 bil
Salmonella	12.4	$0.6-3.5 bil
Shigella	8.5	?
E coli O157	2.8	$0.2-0.6 bil
Cryptosporidia	2.5	?
Yersinia	1.0	?
Listeria	0.5	$0.2-0.3 bil
Vibrio	0.3	?

Clearly the potential impact of pre-harvest food safety measures based on the HACCP concept is different depending on the nature of the addressed defect or pathogen. There are different areas in which the defect or pathogen enters the food production chain and the possibility to reduce the risk in question by proper handling and/or cooking prior to consumption are different. In the case of residues, on- and off-farm residue avoidance programs are the only opportunity of prevention, since there is no pre-consumption procedure that reduces the residue-associated risks to human health. In contrast, proper handling and freezing and/or cooking of the final product reduces the risks due to pathogens, but pre-harvest risk-reduction programs can either prevent the contamination of the carcass (*Trichinella* and *Toxoplasma*) or remarkably contribute to minimizing the pathogen-associated risks (*Salmonella, Campylobacter, Yersinia*, and *Listeria).* Therefore, the targets for intervention measures in the animal product should be prioritized as follows:

1) On- and off-farm programs to develop trichinella-and toxoplasma-free herds, regions, areas and countries (Berends, 1991; EU, 1995; Gamble, 1996; Gamble and Patrascu, 1996; USDA, 1997) with a well-coordinated cooperation between packers, producers, veterinary officers and practitioners, and epidemiologists.

2) On-farm *Salmonella* reduction programs with a statistically justified monitoring, either bacteriologically or serologically, of the *Salmonella* load of the animals supplied for slaughter. Research is still needed to evaluate the risk factors for the introduction of *Salmonella* into herds, to evaluate the feasibility and effectiveness of *Salmonella*-reducing measures. It is also still necessary to evaluate to which extend the recommended pre-harvest *Salmonella*-reducing measures contribute to a measurable *Salmonella* reduction in the final product.
3) On-farm programs to reduce the introduction of Yersinia enterocolitica (Nesbakken et al., 1994; USDA, 1997), Campylobacter jejuni (Moore et al., 1996) and Listeria monocytogenes (Nesbakken et al., 1994). However, more research on the prevalence of these pathogens in swine herds and on the feasibility of control measures is needed.

To reliably decrease foodborne health risks and to improve the consumer's confidence in food of animal origin, pre-harvest food safety programs should consist of three elements:

1) Implementation of GMPs and HACCP programs aiming at reducing food-borne risks to human health at farm level.

2) Implementation of monitoring and surveillance programs at slaughter to determine the frequency of the introduction of foodborne health risks into the food chain identifying the farms of origin and mechanisms to develop incentives for the farming community to reduce these risks. This element is, as a rule, the "trigger" and "modulator" of any pre-harvest food safety program.

3) Implementation of a certification procedure involving independent agencies and persons such as accredited veterinarians and quality consultants.

Conclusions

- **A wide variety of foodborne disease organisms exist in animal products.**
- **Many of these newly emerging diseases have a significant impact on human health (including "external" impacts on people who are not eating the food that was responsible for the pathogens in the environment) and economic impact on the livestock industry.**
- **Children, pregnant women, the elderly, and the immunocompromised are most susceptible to pathogens in animal products.**
- **An extremely large literature exists but the development of "emerging pathogens," newer microorganisms that account for a rapidly escalating number of cases of human illnesses, indicates that knowledge gaps are likely to be constantly appearing as organisms alter characteristics.**
- **More information is needed on management practices, pre-cooking, probiotics, and impact of antimicrobial agents.**
- **Consumer education regarding the proper cooking, storage and handling of animal products and all foods is still necessary.**

QUESTION 2.E. - ANTIBIOTICS (ANTIMICROBIALS), HEAVY METALS AND OTHER CHEMICALS

Toxicology Primer

Chemicals are a contentious subject in our society; therefore, the subject of toxicology of chemicals can sometimes create controversy, generating more heat than light. In doing so, such controversies often cause citizens to overlook the fact that everything in the world is comprised of chemicals, including every cell in the human and animal body. One of many common misconceptions is that man-made or "synthetic" chemicals are inherently more toxic than those produced in nature. However, natural bio-systems synthesize chemicals and no difference exists between, for example, vitamin C in orange juice and vitamin C synthesized in a chemical manufacturing plant. Furthermore, a natural product, botulism toxin, is one of the most poisonous substances known to man: one milligram (1/28,000 of an ounce) will kill 20 million mice. Two excellent references on man-made and natural toxicants are Shibamoto and Bjeldanes (1993) and National Academy of Sciences (1973).

It is also crucial to understand that the property of toxicity is not the same as the ability to cause harm under normal circumstances. Toxicity is a measurement quantifying the degree of development of adverse effects of chemicals on living tissue. By this definition, everything is toxic, including water and oxygen, two very important chemicals upon which life depends. Oxygen exhibits substantial toxicity as evidenced by adverse reactions to atmospheres containing more than 20 % oxygen, including blindness in premature babies given pure oxygen. These facts were recognized by Paracelsus, the Swiss physician who wrote in the year 1567 : "What is it that is not poison? All things are poison and nothing is without poison. It is the dose only that makes a thing not a poison." This is nowadays paraphrased into "only the dose makes the poison," which served as the basis for a well-written monograph on the subject, written for the non-scientist, by Alice Ottoboni (1984).

Chemicals that can harm or kill are commonly referred to as "poisons." However, according to Ottoboni (1984), poisons are, in fact, only those chemicals so highly toxic that illness or death will result if small quantities are administered. All other chemicals are simply able to produce adverse effects, including sensitization, at fairly high levels but one must distinguish between acute or chronic exposure. Acute exposure refers to exposure of subjects to the toxin over a very short period of time and usually only once. Levels are usually very high. Exposure of a child to household chemicals would be one example. Chronic toxicity involves long-term exposure to chemicals at fairly low levels, similar to what might occur in the workplace. It is chronic toxicity that would be the target of most of the studies dealing with the impact of animal agriculture on human health, although there are cases of acute toxicity documented.

Level is only one of many factors that influence the toxicity of substances. Others include route of exposure (dietary, inhalation, skin), host organism (species, age, sex) and nutritional status, especially protein, vitamin and phytochemical intake. (Phytochemicals are plant-derived chemicals, frequently antioxidants that augment the ability of animals to resist carcinogens and

toxins.) Fortunately, the skin is a fairly good barrier to entry of many toxins. Inhalation can be a more serious situation than absorption through the skin but even here there are numerous mechanisms at work to keep clear the alveolus, bronchi and other structures (Ottoboni, 1984).

Oral exposure would occur with most chemicals found in foodstuffs. Toxins could be absorbed in the mouth, stomach, small intestine, large intestine and rectum, depending on the chemical properties of the toxin. There are few toxins that are active by all three routes but one that is, parathion, the pesticide, can block nerve transmission by disrupting a key enzyme. Acute exposure to parathion can be fatal but there are no known adverse effects of chronic exposure to small quantities of parathion (Ottoboni, 1984).

One form of adverse reaction from exposure to chemicals is that of mutation, indicating genetic alteration. The subject is divided into three areas, mutagenesis, carcinogenesis and teratogenesis, which are defined as the causation of genetic change, cancer, and birth defects, respectively. Many types of cancer and birth defects are the result of mutations.

Antibiotics (Antimicrobials)

Issues of Concern: There are two main concerns related to the use of antibiotics (antimicrobials) in animal agriculture. The first is the direct effect of antibiotic residues in animal products. The second is the indirect effect of increasing antimicrobial resistance.

Antibiotic Residues: Consumers are concerned with the likelihood of residues from antibiotics and chemotherapeutics and/or their metabolites in edible tissue which potentially leads to the intake of unwanted substances that can result in resistance or allergies (Debeuckelaere and Remy, 1997).

Antimicrobial Resistance: The public and especially the medical society (World Health Organization [WHO], public health authorities, physicians, and bio-medical scientists) are concerned with increasing resistance in bacteria that are relevant in human diseases. There is a strong belief (especially in Europe) that the use of antimicrobials in food animals might contribute to the problem or aggravate its magnitude (WHO, 1997).

These concerns have triggered a growing discussion of the issue by the public and by scientists. The usage of antimicrobials in the United States is large; 36% of the total use is for animals (Hays et al., 1986; Institute of Medicine, 1989). In 1991, 76 million pounds of antibiotics were used for the treatment of disease in humans and animals and 25% of this total was used in therapeutic, disease prevention and growth promotion in animals (NRC, 1999). Between 60 and 80% of all livestock and poultry receive antibiotics during their productive lifespan. For a more in-depth discussion of the use of antibiotics in animal production, see the Animal Health Report, GEIS topic IV.L.

Antimicrobial Residues

Human Health Effects: Antimicrobial Residues

Over the last decade, the prevalence of serious problems of antimicrobial residues has significantly decreased. This is due to the mandatory residue testing of meat and milk prior to further processing conducted by USDA/FSIS and intensive educational efforts by USDA and the livestock industries (mostly as result of quality assurance programs for e.g. pork, dairy, poultry, etc. on a national or state basis). Since 1996 raw milk antibiotic contamination claims have steadily declined. Claims in herds that have been through the educational process of the Quality Assurance program are significantly less than those dairies that have not enrolled in the program (Wright, 1999). Minnesota has the second highest enrollment in the Dairy Quality Assurance program in the United States (10% of the dairy herds) but still has a long way to go.

Variation by Segment of the Population: Antimicrobial Residues

Nothing in the literature was found on this topic.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Antimicrobial Residues

Nothing in the literature was found on this issue.

Monitoring Techniques, Modeling Approaches, and Standards: Antimicrobial Residues

USDA/FSIS conducts mandatory residue testing of meat and milk prior to further processing.

Prevention and Mitigation Measures: Antimicrobial Residues

Further improvement in reducing the presence of antimicrobial residues is possible. Some observers conclude that it should be achieved by voluntary on-farm residue avoidance programs rather than by increasing the sample size of residue testing in the framework of mandatory monitoring systems (Blaha, 1997; Blaha, 1999). The on-farm residue avoidance programs should include consistent record keeping, proper drug use, storage and extended withdrawal times. A successful example of applying voluntary incentives to encourage farm enrollment in the Quality Assurance Programs can be found in Wisconsin. Reductions in insurance premiums for those dairies participating in the Milk and Dairy Beef Quality Assurance programs stimulated 7478 dairies (34% of Wisconsin dairies) to finish the program. As a result Wisconsin enjoys the highest level of enrollment in the Dairy Quality Assurance Program.

In general, an overall reduction of antimicrobial substances used in agriculture both for medical and production purposes is necessary (USDA, 1996a; USDA, 1996b; WHO, 1996).

Another priority is off-farm residue programs via GMP and HACCP programs in the supplying feed mills aiming at the prevention of cross-contamination and promotion of proper labeling.

Antimicrobial Resistance

Human Health Effects: Antimicrobial Resistance

Development of antimicrobial resistance to human pathogens is the result of the use of antimicrobials in both humans and animals (including pets and agricultural animals), and is usually attributed largely to inappropriate use. Physicians acknowledge 20-50% overuse of antibiotics. They cite unrealistic parental and patient expectations as a major factor as well as physician diagnostic uncertainly (Bell, 1998). In much of the world, antibiotics are used without physician supervision. They are also used at subtherapeutic doses for growth enhancement in the animal agriculture industry.

It has been clearly established that zoonotic enteric pathogens, which are antimicrobial resistant, are transmitted from animals to humans. There are five references used by the Centers of Disease Control and Prevention (CDC) that demonstrate the link between antimicrobial use in food animals and the transfer of resistant *Salmonella* to human patients (Morb and Mortsl 1977, Lyons 1980, Holmberg 1984, Tacket 1985, Spika 1987). A recent Minnesota study (Smith 1999) adds to the accumulating evidence that quinolone-resistent Camplylobactor jejuni infections (diarrhea) are on the increase. Many other papers in the literature link resistant pathogens to the production of animal foods (e.g., Corre et al., 1999; Cody et al., 1999; Villar RG et al., 1999; Glynn et al., 1998; Witte, 1998; Aarestrup, 1998; Bates et al., 1994; Klare et al., 1995; Bager et al., 1997).

Among the meetings, conferences and workshops on this issue, a WHO meeting in 1997 in Berlin, Germany set the stage for the ongoing discussion about the "Medical Impact of the Use of Antimicrobials in Food Animals." Quotations from the report of this meeting are (WHO, 1997):

- "Antimicrobials are vital medicines for the treatment of bacterial infections in both humans and animals."
- "The magnitude of the medical and public health impact of antimicrobial use in food animal production is not known."
- "Timely public action is needed to control medical problems related to the widespread application of antimicrobials outside the medical sphere."
- "National policies on the use of antimicrobials in animals must balance the possible benefits to livestock production against the medical risk and public health consequences deriving from their use."
- "Bacteria and genes, including resistance genes, can pass between human, animal and other ecosystems."
- "Following the introduction of fluoroquinolones in food-producing animals, the emergence of *Salmonella* serotypes with reduced susceptibility in humans has become a cause for particular concern."
- "Reducing the need for antimicrobials is an important means of managing resistance risk."

The following microorganisms are either known to have developed some degree of antibiotic resistance or are potentially developing resistance but have not been studied sufficiently. This area has many knowledge gaps that need to be addressed. For information on each of these

microorganisms and their associated human incidence of infection, incidence in foods of animal origin, and vehicles of transmission, see Question 2.d. in this report on Transmission of Disease and Sickness through Consumption of Animal Products.

Salmonella: There is a worldwide increase of the so-called phage type DT104 of *S. typhimurium*, which is resistant to a broad variety of antimicrobials (Threllfall et al., 1996; Akkina et al., 1999).

Campylobacter: There is a growing concern that the use of fluoroquinolones (a class of antibiotics) in poultry may contribute to the recent increase of drug-resistant *Campylobacter* strains. The discussion about the use of fluoroquinolones in food-producing animals has been fueled only recently by a study of researchers from the Minnesota Department of Health (Smith et al., 1999). The study concludes that "The use of fluoroquinolones in poultry, which began in the United States in 1995, has created a reservoir of resistant *Campylobacter (C.) jejuni*." The authors found that the proportion of quinolone-resistant *C. jejuni* isolates from humans increased from 1.3% in 1992 to 10.2% in 1998. Quinolone-resistant *C. jejuni* was isolated from 14% of 91 domestic chicken products obtained from retail markets in 1997. Molecular sub-typing showed an association between resistant *C. jejuni* strains from chicken products and domestically acquired infections in Minnesota residents. Conclusion: Apart from more infections with resistant *C. jejuni* strains acquired via foreign travel, the number of quinolone-resistant infections acquired domestically has also increased, largely because of the acquisition of resistant strains from poultry.

Escherichia (E.) coli O157:H7: There is nothing in the literature yet that discusses antimicrobial resistance of E. coli. But because E. coli poses a severe health threat, potential resistance is a concern.

Two other organisms need much further research to fill in gaps in our knowledge of development of antibiotic resistance.

Yersinia enterocolitica: Because of the fact that *Yersinia* grows at refrigeration temperatures, there is potential for populations to grow to a health-threatening level even when food is stored in the refrigerator and thought to be safe. This also means it has greater potential to develop resistance.

Listeria monocytogenes: The prevalence of the diseases caused by Listeria monocytogenes, Listeriosis, appears to be increasing. The cause of the rise of this "emerging pathogen" could be natural mutation, antibiotic-induced resistance, or some other, unknown, factor.

All in all, it is generally recognized that there is an increase in cases where bacterial resistance complicates the treatment of human disease. There are several reasons for the phenomenon, with the (over)use of antimicrobials by physicians and the non-compliance of the rules for the use of antimicrobials by ambulant patients being major reasons (Levy, 1997), and the use in animal

agriculture being increasing acknowledged – as long suspected – as a major contributor. The possibility of subtherapeutic use of antimicrobials becoming a serious human health problem requires further research and regulatory vigilance.

Variation by Segment of the Population: Antimicrobial Resistance
As discussed in Question 2.d. in this report, Transmission of Disease and Sickness through Consumption of Animal Products, children, pregnant women, the elderly, and the immunocompromised are most likely to develop severe symptoms and serious consequences of pathogens. This susceptibility would be complicated by antimicrobial resistance.

Variation by Species, Operation, System Type, Management, Geography, and Concentration: Antimicrobial Resistance
Nothing in the literature was found on this topic.

Monitoring Techniques, Modeling Approaches, and Standards: Antimicrobial Resistance
Nothin in the literature was found on this topic.

Prevention and Mitigation Measures: Antimicrobial Resistance
Since "...any use of antibiotics leads to a selective pressure in favor of resistant strains..." (Levy, 1997), the use of antibiotics in animals needs to be guided toward the "prudent use of antibiotics" (WHO definition: "the use must guarantee the highest possible effect and the lowest possible risk of resistance").

Heavy Metals

Human Health Effects: Heavy Metals
Not much is known about heavy metals or other chemicals from animal production influencing human health. Heavy metals in the form of mineral nutrient supplements could lead to excessive amounts (unabsorbed) excreted in manure. However, given the low toxicity of these trace minerals, acute effects are not likely. Metals in antimicrobial agents are potentially a greater problem.

One problem mineral may be phosphorus, which affects water and soil if high concentrations of unabsorbed phosphorus are found in manure. Part of this phosphorus comes from supplements and part comes from a naturally occurring chemical called phytate, found in plants, which is largely unabsorbable by animals.

For more information on heavy metals in manure, see the Manure and Crop Nutrients Report, GEIS topic III. J.

Other Chemicals

Human Health Effects: Other Chemicals

Endocrine Disruptors

The problem of endocrine disruption has received very high level attention. These compounds are important because they are capable of altering hormone pathways that regulate reproductive processes. At least two papers have reported estrogens in runoff on lands that were intensively grazed (Shore et al., 1995; and Nichols et al., 1997). However, attributing impacts to "endocrine disruption" or the presence of a hormone is more symptomatic than causal. Endocrine disruption is poorly understood science at this time.

Steroid Implants

An April 30, 1999 report (http/europa.eu.int.dg24/health/sc/scv/index_en.html) from the European Union Scientific Committee for Veterinary Measures Relating to Public Health recently raised concerns about the use of naturally occurring sex steroid hormones (estradiol, progesterone, testosterone) and their synthetic mimics (zeranol, melengestrol acetate, trenbolone acetate) in growing beef cattle and their potential effects in humans. The report concludes the issues of concern include potential neurobiological, developmental, reproductive and immunological effects, as well as immunotoxicity, genotoxicity, and carcinogenicity. These conclusions have been sharply criticized (Science, 1999.284:1453) as another component in the on-going trade war between the U.S. and E.U. concerning imported beef.

The World Health Organization (WHO) and the United Nations Food and Agriculture Organization (FAO) Joint Expert Committee on Food Additives (JECFA) is composed of scientists from Europe, Australia and the U.S. They also reviewed hormone use in cattle and issued their report in February 1999. These scientists concluded the use of steroid hormones did not decrease the safety of food products from treated beef cattle.

Bovine Somatotropin

The Vermont Public Interest Research Group and Rural Vermont recently questioned the validity of FDA's ruling that milk and milk products from cows treated with bST are safe for human consumption. Their concerns were raised in part by an analysis of the data that was conducted by Health Canada. After completing a comprehensive audit of the human food safety data used to support the approval of bST use in dairy cows, FDA responded (**http://www.fda.gov.infores/other/RBRPTFNL.html**) to the questions. FDA indicated they believed the Canadian reviewers did not interpret the study results correctly and that there were no new scientific concerns regarding the safety of milk from cows treated with bST.

The Canadian report expressed concern that increased amounts of insulin-like growth factor-1 (IGF-1) in milk from cows treated with bST would pose a health risk to humans and the Vermont Groups were especially concerned about this relative to milk consumption by children. FDA's initial evaluation did suggest a modest increase in IGF-1 content of milk but this was not deemed a health risk because the increases were within the normal range of concentrations in untreated cows. Subsequent information has been reviewed by FDA which demonstrates the use of bST

does not increase milk IGF-1 concentrations above those of untreated cows.

The WHO/FAO JECFA (1998) also reaffirmed earlier assessments that use of bST did not pose a risk to human food safety. The Department of Health and Human Services' Office of Inspector General (OIG, 1992) and the General Accounting Office (GAO) audited FDA's approval of bST and found no reason to question the food safety issue. The White House Office of Management and Budget (1994) reached similar conclusions.

Other Contaminants

There are risks of contamination in production due to unintentional introduction of contaminants into livestock. This includes the relatively common (e.g, the slight accumulation of heavy metals from ambient pollution in food and water), the sporadic (e.g., the current dioxin problem in Belgium due to feed contamination), to the rare and very specific (e.g. contamination of pasture and feed crops from nuclear tests or accidents). Risks from such completely unintentional exposures are very difficult to quantify and predict. Though the rare dramatic case of contamination is more likely to make the newspapers (due to its novelty), these exposures appear to be relatively minor compared to the regular exposures discussed in this report.

Conclusions

- **Antibiotic residues in food are a problem of much less significance than the development of resistant strains of pathogens in living animals.**
- **The development of foodborne disease pathogens with increasing resistance to antimicrobials is a growing problem.**
- **There is some concern about the human health risks associated with steroid implants and Bovine Somatotropin used in animal production, but they have not been substantiated.**

QUESTION 2.F. - NUTRITIONAL WHOLESOMENESS OF ANIMAL PRODUCTS

Issues of Concern: This section attempted to summarize the effects of the animal industry in its broad context on human health as related to human nutrition. The literature in this area easily exceeds100,000 scientific publications. The key issues:

- What is the net effect of consumption of animal products on human health?
- Does consumption of animal products *per se* accelerate the normal aging process and therefore the diseases of aging-namely, coronary heart disease and some types of cancer?
- Do diets that are improperly balanced with respect to a wide variety of foods, especially fruits, vegetables and whole-grains, cause health problems?

Introduction

The GEIS is a study of production and spillover effects, and so an extensive discussion of nutritional issues associated with non-contaminated animal products is not appropriate and, indeed, was not attempted. However, some mention of nutritional aspects of animal products must be made, here under the question of wholesomeness, because the impact of animal agriculture on human health comes primarily from eating its outputs. We also attempted to place the role of animal products in human nutrition in a broad context by addressing some aspects of the diet/heart disease controversy that are not related to animal products. Only with this included can the reader become adequately and intelligently informed on such a contentious and fluid area of research.

The sciences of human nutrition, coronary heart disease and cancer are each extensive; yet, all are in some ways related to, or at least suspected of being related to, consumption of animal products. Furthermore, scientists and clinicians have serious disagreements over the potential positive and negative roles of animal products in human health and nutrition. Animal products are excellent sources of most nutrients for the human body. Many public health researchers agree that reducing consumption of animals products will make people healthier. This is particularly true of epidemiologists, who study the effects of certain real-world behaviors such as diet, on people by statistical procedures, relating lifestyle factors to disease incidence. Attempts to associate certain health outcomes with certain ingredients of animal foods, have not been able to explain much of the effect that is observed in the population, which leaves some room for controversy. The relation of dietary animal fat, animal protein, and cholesterol (as well as other more subtle components) to coronary heart disease and certain cancers mean that consuming animal foods probably has a net negative effect on health at the margin, especially if the diet is imbalanced in terms of fruits, vegetables and whole grains. Such dietary imbalance is common among Americans, perhaps as high as 90% (Wardlaw, 1999).

Primers on Human Mortality and Nutrition

It is well established that Americans are living longer. However, the prominence of diseases of the heart and cancer in the overall mortality statistics may suggest that further gains are possible (Table 4). Many scientists and medical authorities believe that heart disease is preventable in

terms of a cause of premature death. It is also thought by many that environment is a very large factor in development of cancer and, therefore, improvements in the environment could reduce cancer prevalence. Indeed, in most diseases listed in Table 4, a substantial reduction was seen between the most recent two years reported by the Centers for Disease Control and Prevention (CDC), 1995 to 1996. However, while the age adjusted trends are encouraging, there appears to be much improvement possible. Moreover, emphasis is also being placed on reducing morbidity (illness), improving quality of life, and reducing health care costs as well as extending life expectancy (Wardlaw, 1999).

In Table 4, an asterisk was placed by all categories that are potentially impacted by the environment. The use of the term environment is broad and includes nutrition, food, water, air, and all factors included in this report on human health. It should be noted that only the top 15 causes of mortality are included, omitting other environment-related causes of death, which would be a significant number of the 346,574 deaths not in the top 15.

Diseases which rank 1,2,3, and 7 are closely linked to diet (Wardlaw, 1999). The importance of nutritional status to overall heath, vitality and resistance to the diseases of aging has received a tremendous amount of research in recent years. It is interesting that over the past century the United States has seen death rates due to nutrient deficiencies drop to virtually zero, as the quality, variety and availability of food has increased, but the death rates due to heart disease and cancer increase to high levels. It is often stated that we are suffering from diseases of affluence. Some basic facts concerning the science of nutrition are relevant.

Nutrition is defined as "The science of food, the nutrients, and the substances therein, their action, interaction, and balance in relation to health and disease, and the process by which the organism ingests, digests, absorbs, transports, utilizes and excretes food substances."

There are 33 known essential nutrients. Three nutrients, carbohydrates, protein and fat, yield energy. Nine water-soluble vitamins and four fat-soluble vitamins are essential for growth and maintenance of healthy tissues and permit the energy to be removed from fat, protein and carbohydrates. Water is an essential nutrient and is used for many important functions in the human body. Essential minerals are divided into three groups; major minerals, including sodium, potassium, calcium, phosphorus, chloride, magnesium, and sulfur; trace minerals, including chromium, copper, fluoride, iodide, iron, manganese, molybdenum, selenium and zinc; and trace minerals that are possibly nutrients but not yet proven, arsenic, boron, cadmium, cobalt, lithium, nickel, silicon, and tin (Wardlaw, 1999). It is interesting and perhaps significant that many trace minerals are highly toxic if consumed at levels exceeding the quantity required for life and are also considered as "heavy metal contaminants" if found at inappropriately high levels in the environment.

Table 4. Fifteen leading causes of death in the U.S., 1996

				Age-adjusted death rate		
Rank	Causes of death	Number	Death rate	1996	1995	Percent change
	All causes	2,322,421	875.4	494.1	503.9	-1.9%
1 *	Heart disease	733,834	276.6	134.6	138.3	-2.7
2 *	Cancer	544,278	205.2	129.1	129.9	-0.6
3 *	Stroke	160,431	60.5	26.5	26.7	-0.7
4 *	Lung disease	106,146	40.0	21.0	20.8	1.0
5	Accidents and adverse effects	93,874	35.4	30.1	30.5	-1.3
	Motor vehicle accidents	43,449	16.4	16.2	16.3	-0.6
	All other accidents and adverse effects	50,425	19.0	13.9	14.2	-2.1
6 *	Pneumonia and influenza	82,579	31.1	12.6	12.9	-2.3
7 *	Diabetes mellitus	61,559	23.2	13.6	13.3	2.3
8	Immuno-deficiency virus	32,655	12.3	11.6	15.6	-25.6
9	Suicide	30,862	11.6	10.8	11.2	-3.6
10 *	Chronic liver disease and cirrhosis	25,135	9.5	7.5	7.6	-1.3
11	Nephritis, nephrotic syndrome, and nephrosis	24,392	9.2	4.3	4.3	--
12	Septicemia	21,395	8.1	4.1	4.1	--
13	Alzheimer's disease	21,166	8.0	2.7	2.7	--
14	Homicide and legal intervention	20,738	7.8	8.4	9.4	-10.6
15 *	Atherosclerosis	16,803	6.3	2.2	2.3	-4.3
	All other causes	346,574	130.6	n.a.	n.a.	n.a.

There are hundreds of other components, mostly derived from plants, which are not considered nutrients but are essential for optimal health. Fiber is a key factor in a healthy diet but for the most part is not digested and absorbed and therefore is not considered a nutrient. Phytochemicals are mostly absorbed but are not required for life and therefore are not classified as nutrients. Nevertheless, phytochemicals are believed to be important in prevention of diseases of aging (Wardlaw, 1999). This is a complex group of chemicals and a very active area of research in human nutrition and medicine. These include the carotenoids, of which there are in excess of four hundred known. One of these, _-carotene, is a major source of vitamin A. Yet, many of the other carotenoids have been shown to be more effective in terms of cancer and heart disease prevention than vitamin A. Other phytochemical groups include polyphenols, indoles, isothiocyanates, isoflavones, lignans, phytic acid, phenolic acids and saponins (Wardlaw, 1999).

Nutritional Toxicology

As discussed earlier, the nutrient status of an individual is key with respect to his or her ability to withstand chemical toxicants and carcinogens. The study of the results of good or poor nutrition on the susceptibility of organisms to chemical toxicants is the science of nutritional toxicology. Some examples of how diverse the mechanisms are can be extremely revealing and perhaps temper some of the enthusiasm for simplistic solutions to complex issues.

Adequate intake of protein and trace minerals is crucial in helping to fortify the levels of a key enzyme that protects tissues from a toxic form of oxygen. Selenium, a trace mineral required for life, becomes part of the structure of glutathione peroxidase, an enzyme that protects the body from one of the harmful forms of oxygen that occurs during metabolism or exposure to some environmental toxins. This type of protection, antioxidant protection, is being increasingly recognized as important in prevention of coronary heart disease, some cancers, and other age-related diseases. Glutathione peroxidase is representative of an important group of chemicals known as antimutagens/anticarcinogens because of the protection they impart to tissues. Phytochemicals, antimutagens/anticarcinogens derived from plants, are a vast array of widely varying chemicals that for the most part are antioxidants and are under intense study. A balanced diet containing meat, to provide selenium and high quality protein, and whole grain cereals, fruits and vegetables, to provide phytochemicals, including dietary fiber, may well provide the optimum resistance to carcinogens and mutagens.

The area of nutritional toxicology is an extremely active one and important discoveries are continually being made. A promising and relatively new anticarcinogen has been found in beef and dairy products. Conjugated linoleic acid, a derivative of the essential fatty acid, linoleic acid, is being studied intensively by several laboratories including Dr. Pariza's at the University of Wisconsin (Ha and coworkers, 1987).

Human Health Effects: Nutritional Wholesomeness

Positive Role of Consuming Animal Products in Human Health

The three issues of importance regarding nutrients consumed by humans are concentration of the nutrient in a food, bioavailability (percentage absorbed into the blood), and safety (lack of harmful materials accompanying the nutrient). For example, dairy products are an excellent source of calcium, exceeded in bioavailable calcium (among foods that are common and easy to consume) only by fortified orange juice and certain other fortified products.

Red meat is also a good source of most micronutrients. It is a good source of dietary iron source, with a fairly high concentration and the highest bioavailability. Meat contains a form of iron that is far more absorbable, heme iron, than inorganic forms of iron found in vegetables. Moreover, meat contains an unknown factor that aids in the absorption of iron from plant sources (Wardlaw, 1999).

An additional indirect effect of the animal industry on human health is that the industry produces a large number of useful by-products with medicinal value, such as blood factors, chymotrypsin,

collagen, cortisol, glucogen, heparin, and others. By-products from animal feed are also being included in medical treatment.

Negative Impacts of Consuming Animal Products in Human Health

It is generally agreed in the health community that people with access to modern agriculture (i.e., anyone not engaged in subsistence agriculture that depends on animals) do not need to eat meat or any animal product to consume a healthful diet (e.g., Messina and Burke, 1997; Messina and Messina, 1996). Evidence in public health and clinical nutrition shows that reducing consumption of animals foods reduces age-specific mortality and various diseases (including cardiovascular diseases, various cancers, and diabetes). There is a substantial controversy in the literature about the magnitude, ranges, and importance of these effects (Pinckney and Pinckney, 1973; Smith and Pinckney, 1991).

Many of the negative health impacts of consuming animal products have been linked specifically to saturated fat, cholesterol, and proteins, though these do not explain the entire effect. Thus, it is not completely clear why eating animal foods has a negative health impact. A partial explanation may be the replacement of phytochemical-rich plant foods by more than adequate intake of animal foods. However, these observations are largely moot for the purpose of the GEIS, other than to observe that animal agriculture is not a "necessity" in our society, an observation which may or may not make any difference from a policy perspective.

For more than a century, cholesterol, which is found only in animal products, and saturated fat, which appears in many foods in addition to animal products, have been the main targets of research attempting to link their consumption to coronary heart disease. Recently, iron as a factor in coronary disease has been studied. However, a direct scientific assessment of the published literature on all three components must conclude that a linkage of any or all of the three to coronary heart disease has not been scientifically proven. Furthermore, a growing body of evidence has implicated polyunsaturated fatty acids, specifically heated polyunsaturates, as an important causative agent in coronary heart disease. It is a gross understatement to say that the relationship between animal product consumption and coronary heart disease is complex and controversial. To better understand the scientific basis for the competing hypotheses regarding this important question, more in-depth information is necessary. This can be found in Appendix 1 of this Human Health Report.

Variation by Segment of the Population: Nutritional Wholesomeness

The health effects described above in general can affect all consumers of animal products. A more detailed analysis of the different risks among segments of the population is an enormous undertaking and was not attempted for this Report.

Variation by Species, Operation, System Type, Management: Nutritional Wholesomeness

For the area of nutritional wholesomeness, limited work has been completed. Gil and Addis (1997) showed that in Uruguayan cattle, grass fed cattle displayed lower fat than corn fed cattle. Cholesterol did not vary, likely due to the essential nature of cholesterol in the cells of animals.

Monitoring Techniques, Modeling Approaches, and Standards: Nutritional Wholesomeness

This question is not applicable for the issue of nutritional wholesomeness.

Prevention and Mitigation Measures: Nutritional Wholesomeness

Most prevention and mitigation measures have to do with changing diet. As discussed above (and in Appendix 1), this issue is characterized by many complexities and quickly changing research findings. Therefore, to avoid over simplification, prevention and mitigation measures through diet will not be summarized here.

An area of new interest in prevention and mitigation of nutritional health effects is nutraceuticals, or functional foods. Nutraceuticals (also called functional foods) represent not only the frontiers of medicine and food science but the marriage of the two as well. A functional food or nutraceutical can be defined as a substance that may be considered a food or part of a food and provides medical or health benefits, including prevention and treatment of diseases (Pszczola, 1992). These beneficial effects are considered to be additional benefits, beyond the normal prevention of nutritional deficiency diseases (such as prevention of scurvy by vitamin C); for example, adding vitamin C at levels far above the quantity needed to prevent scurvy so as to prevent cancer.

Another nutraceutical example would be adding fiber to a meat product to accomplish a lowering of energy content, a dilution of cholesterol or, in the human consuming the meat product, a possible additional mechanism for delivery of fiber for purposes of lowering serum cholesterol. Part of the interest in nutraceuticals stems from the fact that only 10% of the population in the U. S. consumes the recommended quantities of fruit, vegetables and whole grains. The nutraceutical approach may be a more expeditious method of increasing the human dietary intake of nutraceuticals from plants. Many of these compounds have beneficial effects in meat products and can be used to improve the acceptability of low fat meat products. For example, Minerich and coworkers (1991) at the University of Minnesota demonstrated that Minnesota grown wild rice, a rich source of phytic acid and other nutraceutical, could be blended with low-fat ground beef to produce a product preferred in taste panel comparisons over full fat (30%) ground beef.

Conclusions

- **Animal products can make positive contributions to human health by providing essential nutrients.**
- **Consumption of animal products has been statistically associated through epidemiological studies with increased mortality and morbidity in Western populations. However, controlled laboratory studies designed to analyze these statistical associations have not been able to identify any causative mechanism and thus have not been able to validate these statistical associations.**

Recommendations for Additional Research

1) The empirical evidence regarding the marginal risks posed by contaminated flies as spreaders of enteric pathogens. Just how many contaminated flies around a picnic table is sufficient to increase the incidence of any food-borne disease? *Campylobacter* and *Salmonella* are most likely to be around caged layers, the source most likely to contribute the most flies into their surroundings. Unfortunately, that subject will be intractable at the epidemiological level. Perhaps this is a topic that could be modeled quantitatively? Such an effort would require a team: entomologist, bacteriologist and modeler at minimum.

2) Recommendations for future research in food-borne pathogens:

- Identify management practices that promote the incidence of pathogens in livestock
- Develop effective methods to reduce dissemination of pathogens in manure
- Assess the feasibility of HACCP programs on-farm
- Study the ecological factors that influence the incidence in livestock
- Develop competitive exclusion systems to reduce fecal carriage

3) Airborne dust, gases, and biogenic particles can negatively impact human health. There are a number of research reports documenting that neighbors of large swine facilities experience higher incidences of health symptoms than comparable rural residences near minimal livestock production. Similar studies around other animal production facilities are limited. Clearly more research is needed to relate emissions from animal facilities to airborne concentrations and the health effects on individuals living near animal production facilities.

4) Dust from animal facilities and feed mills can contribute to the ambient dust levels. Emissions from large beef cattle feedlots in Texas and California are regulated (Sweeten and others, 1998). Dust mitigation methods are used to reduce emissions from these sources. No research was found reporting on the health effects of ambient dust from animal facilities in the Midwest or Minnesota. This might be a topic for future research.

List of Major Relevant Ongoing Work

Transmission by Flies: Roger Moon listed the following three projects:

(1)Ohio: Dr. Richard Berry, Vector Borne Disease Program, Bureau of Infectious Disease Control, Ohio Dept. of Health, 900 Freeway Dr. N, Columbus Ohio, (614) 752-1029.

(2)Minnesota: Dr. Craig Hedberg, Acute Disease Epidemiology, MDH, 717 SE Delaware, Minneapolis. (612) 623-5414. However, Hedberg has left MDH for a post with UMN, and I do not know who (if anyone) will take up the lead on their fly-diarrhea study.

(3)Minnesota: Dr. Roger Moon is leading a study this summer designed to assess the relation between human annoyance and fly abundance. That CURA-funded project involves help from Sarah Kuha and MES staff in Clay, Jackson and Renville Counties. We are attempting to establish a basis for counties to set their own nuisance thresholds, and develop an objective means of assessing fly abundance around residences in their communities.

Transmission of Pathogens: Researchers at the USDA/MARC in Nebraska and at the University of Idaho are currently studying the effect of forage feeding on the fecal shedding of *E. coli* O157:H7 in cattle.

Nutritional Wholesomeness of Animal Products: Dr. Paul Addis interviewed three scientists involved in active laboratory research on diet and health. Research is ongoing in the laboratories of all three scientists and professor Addis is doing cooperative research with one of these groups. All three projects are substantially related to the nutritional wholesomeness of animal products, especially if viewed from the standpoint of relative risks of other types of foods common to the diet of people in Minnesota.

(1) *Dr. Martin Grootveld of London Hospital Medical School is cooperating with Dr. Addis and will be visiting the University of Minnesota in September or October to determine the thermal stressing of cooking oils in the Minnesota. Dr. Grootveld and his colleagues made the following comment:*

"Thermal stressing of polyunsaturated fatty acid-rich culinary oils according to routine frying practices (30-90 min. at 180_C in the presence of atmospheric O_2 generates high levels of cytotoxic aldehydic products (up to 50 m.mol.kg^{-1}) (Haywood *et al.*, 1995) via autocatalytic, self-propagating peroxidation processes. In addition to being implicated in the development of

atherosclerosis (Witzum and Steinberg, 1991), and its associated pathological sequelae such as ischaemic heart disease and peripheral vascular disease, such aldehydic lipid oxidation products have been shown to exert genotoxicological (Esterbauer, 1982) and pro-inflammatory (Benedetti *et al.,* 1980) properties, and can also give rise to gastropathic conditions (Jayaraj *et al.*, 1986) ; phenomena that are undoubtedly ascribable to the high reactivity of these agents with critical biomolecules (e.g., the apolipoprotein B component of low-density-lipoprotein, DNA base adducts and thiols such as glutathione) (Esterbauer, 1982). However, with the exception of direct damage to the gastrointestinal epithelium, the toxicological properties exerted by orally-ingested aldehydes are, of course, critically dependent on the rate and extent of their *in vivo* absorption from the gut into the systemic circulation. Therefore, we recently employed high resolution ^{1}H nuclear magnetic resonance analysis to probe the *in vivo* absorption, metabolism and urinary excretion of typical aldehydic lipid oxidation products (*trans*-2-nonenal and *trans*-2-pentenal) and found that both of these _,_-unsaturated aldehydes are indeed absorbed from the gut into the systemic circulation *in vivo*, metabolised (primarily via the addition of glutathione across their electrophilic carbon-carbon double bonds), and excreted in the urine as C-3 mercapturate conjugates (Grootveld *et al.*, 1998)

The above results indicate that the dietary ingestion of thermally-stressed polyunsaturated fatty acid-rich culinary oils promotes the induction, development and progression of cardiovascular diseases since highly reactive aldehydes therein have the ability to covalently modify lysine residues of the apolipoprotein B moiety of low-density-lipoprotein, rendering it susceptible to uptake by macrophages, a critical stage in the generation of foam cells *in vivo* (Witzum and Steinberg, 1991). Indeed, our data are consistent with recent studies which demonstrated that oxidised lipids in the diet substantially accelerate the development of fatty streaks *in vivo* (Staprans *et al.*, 1996).

Although we do not dispute the perceived notion that ***intact, unperoxidised*** dietary polyunsaturated fatty acids are protective against the development of atherosclerosis, the frequent utilisation of culinary oils containing high levels of these agents (predominantly linoleoylglycerols) for frying/cooking processes, and the consequent ingestion of pro-atherogenic aldehydic peroxidation products therein clearly pose health hazards worthy of increased clinical and public concern. Moreover, the inhalation of vapourised aldehydes by subjects conducting commercial or domestic frying practices involving polyunsaturate-rich culinary oils also affords a potential threat to human health.

The frequent ingestion of such lipid oxidation products (LOPs) may represent a greater hazard to human health than elevated blood plasma cholesterol levels, as indeed may further factors such as smoking and uncontrolled diabetes. Interestingly, cigarette smoke contains significant amounts of cytotoxic aldehydes (e.g., acrolein, crotonaldehyde and acetaldehydes) and its inhalation gives rise to the covalent modification of proteins, generating protein carbonyl adducts via Michael addition ($\alpha.\beta$,-unsaturated aldehydes) and Schiff base (saturated and unsaturated aldehydes) reactions. Hence, cigarette smoke-derived aldehydes could, in principle, derivatize lysine residues of the apolipoprotein B moiety of low-density-lipoprotein (LDL), rendering it

susceptible to uptake by macrophages and hence produce foam cells *in vivo*. Similarly, high blood plasma levels of the reducing sugar glucose, which arise during episodes of hyperglycaemia in poorly-controlled, insulin-dependent diabetics, can also effect the covalent modification of LDL, a phenomenon providing a plausible explanation for the increased risk of cardiovascular diseases in patients with this condition. Although the potential deleterious health effects of *trans*-fatty acids are now well documented, researchers involved do not appear to have considered the presence of LOPs in margarines and shortenings which are very likely to be generated from remaining, unhydrogenated polyunsaturates under the high temperatures required to produce margarines and shortenings from vegetable oils. Hence, in my view the toxicological studies conducted on *trans*-fatty acids present in margarines and shortenings are severely obscured by the presence of LOPs therein, together with any other "foreign" compounds generated during the hydrogenation process."

(2) *Dr. Ilona Staprans is a leading atherosclerosis research at the University of California Medical School and a scientist at the Veterans Hospital, both located in San Francisco. Her discussion:*

"I think it is premature at this time to speculate whether oxidized fats are a risk factor for atherosclerostic disease in humans. Moreover, I do not think it is not possible to compare the atherogenic effects of oxidized dietary fats to such fairly well defined risk factors as smoking, diabetes and high serum cholesterol levels.

The evidence that oxidized fats may contribute to heart disease is limited and it is confined to experiments in animals. Whether these observations can be applied to humans is not known. We have shown that oxidized fatty acids are absorbed by humans and are incorporated into serum chylomicrons and chylomicron remnants. One can speculate that these oxidized postprandial remnants are more atherogenic than nonoxidized remnants.

There is no evidence whether there is any incorporation into other lipoproteins. Similar to oxidized fatty acids, oxidized cholesterol is definitely present in the Western diet, but there is no definitive evidence that it is absorbed in humans in any significant quantities.
Thus, since any human studies are not feasible at the present time, it will be difficult to demonstrate that oxidized lipids in the diet constitute a risk factor for atherosclerotic disease in humans.

There is some epidemiological evidence that people that consume diets containing high antioxidant levels and low levels of oxidizable fatty acids (Mediterranean diet) have less cardiovascular disease, but those observations can lead to speculations only. No controlled studies have been done.

We have completed a study demonstrating that oxidized cholesterol is atherogenic in transgenic mice and I am sending you the manuscript. We have also shown that there is an inflammatory reaction in these mice after consuming oxidized cholesterol from the diet (data not shown)."

(3) *Dr. Dan Gallaher, associate professor of nutrition at the University of Minnesota, is an expert in fiber and the effects of fatty acids in the diet of experimental animals used to model the human digestive system response to fiber, cholesterol and fat.*

Dr. Dan Gallagher updated our document by saying that of all the potential trace elements in question, listed in the Primer on Human Health and Nutrition, it appears that only Boron is a trace nutrient. The others listed with it are simply toxic, heavy metals. However, the fact that such metals were considered possible nutrients at one time, demonstrates the extreme difficulty in doing modern nutritional research. He also stated that his research on stearic acid suggests that:

1) stearic acid is not as efficiently absorbed as other fatty acids and
2) stearic acid retards the absorption of cholesterol.

His conclusion is that stearic acid, one of the principle fatty acids in beef fat, is hypocholesterolemic, not hypercholesterolemic.

Responses of Topic Team to External Reviewers' and EQB's Comments

Prior to Final Draft

CAC/EQB Comments/**Team's Response (bold)**

Need References
References were added

Missing information on current practices and regulations

- More information should be added about existing regulations and about the usage of various routine practices that are intended to protect human health from impacts related to animal production? Focus on production rather than processing.
  This is being updated and information about EU regulation is added but information is difficult to find at best or unavailable at worst.

- Is there any information on the extent of producer compliance with recommended/required practices?
  The committee could find little if any information; this is very difficult to obtain from governmental groups and insurance companies

Antibiotics, Hormones, other chemicals

- Can more information be included about the extent of use of various antibiotics and other chemicals in animal agriculture and how it compares to total use of antibiotics in U.S.?
  This has been added to the antimicrobials section.

- Compare the use and regulation of antibiotics in U.S. to those in other countries, such as New Zealand and European countries.
  This has been done for Europe; no data were found concerning New Zealand.

- Do steroids fed to animals remain as residues in meat or other products; does it end up in the manure; are there health risks due to either type of exposure?
  No. All steroidal compounds are difficult to detect in animal tissue because the steroid is excreted in the urine (not the manure) efficiently, leaving virtually no residue.

- Is there any data to validate or refute the notion that antibiotic residues have contributed to the development of resistant strains of bacteria?
  {Brian's report will be cited}

- Discussion of antimicrobial residues on p 18 could go under question K1 instead.
  This was considered but rejected because it would disrupt the flow of ideas.

- P 19, 4th paragraph, should discuss health-related reasons why Europeans rescinded use of antimicrobials as growth promoters.
  A short discussion was added to clarify this.

General Organization, Tone and Content

- The organization within section 2.b. beginning on p 21 is very confusing (REFER TO WATER)

- Quite a few conclusory sentences that seem to be more opinions or value judgements than strict conclusions drawn from the literature summary
  These parts have been changed.

- The general topic according to the scoping document is: health and well-being of people exposed through various paths to toxins and pathogens from animal agriculture. The focus of the report seems to have shifted away from that toward an emphasis on issues relating to the consumption of meat. To shift back, whole sections should be edited down to a minimum: discussion of cholesterol; chemistry of fats in diets; discussion of causes of death; the primers on nutrition and toxicology. More needs to be added on other exposure routes, especially air emissions-if it weren't for air emissions from feedlots we wouldn't likely be doing this GEIS!
  Apparently the reviewers and the committee members, save one, disagree with the CAC/EQB on the foregoing points. Nutrition was listed on page 9 of the scoping document "Health and Nutrition Effects" and the coverage given is not even a small synopsis of this area. It is important to understand the total picture of the various hypotheses concerning nutrition and human health effect; otherwise, erroneous, unproven assertions about animal products may lead the CAC in the wrong direction. Adequate nutrient intake helps organisms resist effects of toxins. Moreover not one reviewer called for more, not less, discussion of nutrients (PBA)

  Regarding the primers on nutrition and toxicology, first we were told that primers were a good idea; the CAC "really liked them." Now we are being told to drop them. Nutrition is broadly interpreted as part of the human environment. The primer on toxicology was designed to help the CAC read intelligently the rest of the report, not just the nutrition part. Air-borne emissions are, in some cases, toxic and obtaining some background in toxicology should help the reader make informed decisions regarding the material that followed.

  It is difficult to understand why more information is requested on the subject of air emissions. This area was thoroughly covered in this report. (PBA)

- Does the report include all available information about health impacts from animal production (as opposed to impacts from consumption of animal products)?
  As was discussed in the Executive Summary, it was impossible in the time available to

assure the CAC that every paper was reviewed. In addition, much information is unpublished, is unavailable to the public, or is not available for web-based literature searches.

Treatment of "odors"

- The report often refers to "odors" in relation to health effects when it is not clear that the effects are due to "odor" but rather to certain chemicals in the air emissions. The report should be more precise about this. E.g., pgs 25-27; 34-35
  This is discussed in the air quality document (III. H.). It is a confusing area precisely because the science is incomplete. The primary problem is the fact that mood of individuals can be affected by odors and mood can subsequently influence how an individual reacts to air-borne materials.

Miscellaneous

- Can death rates from food-borne diseases be added to or discussed in reference to the data of Table 3 (death rates from various causes)?
  Information was listed for each disease in the section covering food borne disease.

- Can some basic information be added under scoping document question K6 about protective measures available to producers and neighbors to protect themselves against adverse health effects?
  Almost nothing is published or available but some information about the experience in Europe has been added.

- The issue of estrogenic compounds released into the environment from feedlots and potential effects of endocrine disrupters is an emerging issue that should be addressed.
  Endocrine disrupters are basically an environmental issue rather than direct human health impact.

- The discussion of HACCP fails to explain how this program provides for the safety and wholesomeness of the food supply.
  Dr. Joellen Feirtag, HACCP expert, added several sentences to clarify.

- Pgs 22-23, specify that time-weighted averages (TWA) apply to worker protection, not the general public.
  This was clarified.

- P 28 and following table: CRELs are product of Cal. EPA, not Cal. D of Health
  This was clarified.

- Discussion of Pathogens on p33-34 is mostly about animal health, not human
  Needed as part of HH because animals and humans can pass pathogens back and forth + the fact that antibiotic resistance is closely related to food borne disease.

- P 38, re hydrogen sulfide, clarify that fatal circumstances involve confined space
  This section has been appropriately expanded.

- P 65, question 3: shouldn't info. from worker studies be covered here? The other sections of the report covering the question should be cited here. The data gaps should be specified, also.
  It is virtually impossible to get insurance companies to release data about their clients that could result in stigmatizing the client.

- P 65, question 4: cite other sections addressing question; specify data gaps; Health Dept. staff believe there is some data comparing system types, operations and management; past facilities vs. present facilities and those in Europe.
  We requested this information from the Health Department but it has not materialized. Some information was provided relative to European regulations, specifically Germany.

- P 66, question 5: cite other sections addressing question; specify data gaps; air emissions from feedlots does not seem to have been addressed-what about MPCA air monitoring data?
  MPCA data are covered in III. H. Air Quality quite thoroughly.

- P 66,question 6: cite other sections addressing question; specify data gaps; HACCP and GMPs need more thorough explanation for readers.
  Dr. Joellen Feirtag, HACCP expert, added several sentences to clarify.

- P 66, summary of questions 4 to 6: focus is on food-borne disease risks-what about air emissions and other routes of exposure?
  Other reports in GEIS covered this is greater detail but little is published.

Committee Responses to Comments by External Reviewers

One person thought that the comment dealing with consumer education about how to handle and store animal products so as to reduce the risk of food borne diseases was a good one. However, while he agreed generally with the concept he did not think that this should be used to alleviate the need for vigilance, HACCP, and sanitation, on the part of the animal production and product processing industry and the regulatory agencies. In other words, consumer education is good but we still need to produce safe products.

Appendix 1

Coronary Heart Disease: Three Distinct Disease Processes

The common view by the public, often fostered by advertising in the media, is that the accumulation of cholesterol in or on the artery is sine qua non of coronary heart disease (CHD) and describes the disease process in its entirety. Unfortunately, it is not as simple as this view indicates. To aid in understanding of the pathology of arteries that lead to heart attacks, Addis of the University of Minnesota, developed a paradigm that clarifies the chronological steps in the disease (Addis, 1990).

CHD may be viewed as a three-phase process. Phase 1, *initiation*—blood vessel injury—produces the necessary pathological conditions conducive to phase 2, *progression*, which entails the accumulation of plaque (atherosclerosis). Phase 3, *termination,* resulting from blood clots leading to a heart attack, heart muscle damage and, frequently, death (Addis, 1990).

Arterial Injury Initiates Pathological Reactions

Ross's group at the University of Washington has clearly established atherosclerosis as a *response to injury* (Ross, 1986). The exact nature of the initial arterial injury is unknown but evidence now supports the concept that fatty acids that have been altered by a process called *oxidation* are involved. Interestingly, saturated fatty acids do not undergo oxidation; polyunsaturates are extremely susceptible to oxidative change (Addis et al., 1995). Aging, smoking and hypertension may also be involved.

The complex pathological process involves arterial injury followed by attachment by white blood cells and platelets (blood clotting factors) to the injured area in a "response to injury." White blood cells migrate into the arterial wall and convert into scavenger cells called macrophages. Low-density lipoprotein particles (LDL), which have also passed through into the lining of the blood vessel, are now engulfed by the macrophage.

As this process continues, macrophages and other cells are converted into foam cells (fat filled cells) by absorbing LDL particles. Fatty streaks in the blood vessel are formed by the prolific production of foam cells from macrophages and from smooth muscle cells derived from other layers of arterial cells. These fatty streaks continue to develop into mature plague.

The traditional view of coronary disease has serum lipid levels playing an important role in the rate of plaque build up on the arterial wall. Animal fats have been the targets of this view, the assumption being that animal fats are saturated and saturated fats (plus dietary cholesterol) are important in raising serum cholesterol, especially the low-density lipoprotein (LDL) closely associated with plaque. Statements often made regarding composition of meat are incorrect: not all the fat in meat is saturated. Accurate composition information has been provided by the University of Minnesota (Epley, 1990). The total percentage saturated and unsaturated fatty

acids for lamb, beef, pork, chickens and turkeys are 56/44, 45/55, 38/62, 30/70, and 29/71, respectively. In spite of this, the statements frequently made about red meat in particular are that it contains only saturated fat.

Gallaher and coworkers of the University of Minnesota (Monsma et al., 1996; Hassel et al., 1997) have demonstrated that stearic acid, one of the major saturated fats in beef, actually lowers plasma cholesterol, in part by restricting the absorption of cholesterol from the small intestine (Schmidt and Gallaher, 1999). The finding that stearic acid, a principal component of animal fat, reduces serum cholesterol means that a major portion of the fatty acids in animal fats may actually be considered hypocholesterolemic rather than hypercholesterolemic fatty acids. (Beef fat is 52% saturated, including 20% stearic; 44% monounsaturated; and 4% polyunsaturated). If all three groups of cholesterol lowering fatty acids in beef fat are summed, the total is 68% of the total fatty acids. Perhaps these compositional facts and laboratory findings explain the results of a very recent study that demonstrated that lean red meats (beef, veal and pork) and lean white meat (fish, poultry), as part of the diet of hypercholesterolemic subjects, produced no difference in serum cholesterol. This study, conducted by three respected medical centers (Chicago Center for Clinical Research; Heart Disease Prevention Clinic, University of Minnesota Hospital; and Johns Hopkins University Lipid Clinic), together with previously discussed findings on dietary cholesterol, suggest the need for new and novel research approaches and possible alternative dietary recommendations (Addis et al., 1995; Hassel, 1990).

Nevertheless, total fat in the diet is a risk factor related to increased serum cholesterol and meat has received its share of criticism for contributing to the total fat of the human diet. In response to this criticism, the meat industry has altered genetic selection and feeding practices so that today it is possible to purchase meats in the lower range of marbling (visible intramuscular fat) and, therefore, it is possible to purchase meat with very low total fat content (Epley, 1992). In fact, the proximate composition of beef on a fresh (raw) weight basis is: water (75%), protein (18.5%), lipid, including fat and cholesterol (3.0%), and other components, including minerals (3.0%), according to Epley of the University of Minnesota Extension Service. This is much lower than frequently cited values because of the inclusion of "separable fat" in many figures, in spite of the fact that people generally choose not to eat pure beef fat.

Lowering blood lipids by reducing the consumption of dietary cholesterol has been an important strategy to reduce CHD. Many controversies surround this lipid lowering strategy. The difference in cholesterol intake represented by two eggs per week versus seven eggs per week did not appear to have any significant long-term effects on total serum cholesterol according to researchers in the U. K. Edington et al. (1987) concluded that people do not respond to dietary cholesterol if other guidelines issued by the AHA concerning total fat, saturated fat and fiber intake are followed.

Finally, the issue of *trans* fatty acids must be addressed. Early in the development of polyunsaturated vegetable oils for use as butter substitutes and cooking oils it became apparent to the vegetable oil processors that their product was a liquid, therefore not spreadible, and very

unstable due to oxidation of the fatty acids during heating and storage. To impart the spreadibility of butter and to help stabilize these oils against oxidation, a process called hydrogenation was developed. Hydrogenation converts some of the polyunsaturated fatty acids to monounsaturated fatty acids or even saturated fatty acids. In the process, a new form of fatty acid, the *trans* fatty acid, was introduced into the human diet. (Most naturally occurring unsaturated fatty acids are in the *cis* form. In recent years, a growing body of evidence has linked *trans* fatty acid consumption to coronary heart disease (Addis et al., 1995).

Wood and coworkers (1993) compared butter, mono- and polyunsaturated fatty acid-enriched butter, *trans* fatty acid margarine, and zero *trans* fatty acid margarine on serum lipids and lipoproteins in healthy men. The authors concluded, "the data indicate that *trans* fatty acids are not metabolically equivalent to the natural *cis* isomers and that they affect the serum lipid profile adversely." Researchers in Norway noted that because of concerns about *trans* fatty acids, the vegetable oil industry had greatly curtailed the practice of heavy hydrogenation; most oils are now lightly hydrogenated. The result of these changes has been a dramatic drop in consumption of *trans* fats in Norway from 15 g/day in 1958 to about 4 g/day currently, about 10% of the intake of saturated fat (Pedersen et al., 1998). In general, the vegetable oil industry has altered oils to respond to the problems related to *trans*-fatty acids. This is typical of the dynamic nature of the food and meat industries that continues today, responding quickly to real or perceived problems. Of course, with less hydrogenation, oils are inherently more unstable, leading to more accumulation of lipid oxidation products.

Role of Lipid Oxidation Products in CHD

Do lipid oxidation products have a role in CHD? Several reviews of the subject have been published. Relevant lipid oxidation products involved may include one or more of the following, according to experts at a prominent laboratory at London Hospital Medical School in London, U. K: aldehydes, α,β - unsaturated aldehydes, and hydroperoxides of fatty acids (Claxson et al., 1994; Haywood et al., 1995; Atherton et al., 1997; Sheerin et al., 1997; Grootveld et al., 1998; Silwood et al., 1999; Grootveld et al., 1999a; Grootveld et al., 1999b). These researchers have clearly demonstrated toxic effects of the foregoing polyunsaturated fatty acid degradation products and their generation in heated polyunsaturated oils.

The adverse effects of heated vegetable oils have also been studied extensively by a prominent group of researchers at the University of California Medical School, San Francisco. The finding that heated corn oils produced much higher levels of fatty deposits on arteries of cholesterol-fed rabbits than fresh corn oil is consistent with the concept of heated vegetable oils being involved in coronary heart disease development in humans (Staprans et al., 1996). In both rabbits and humans, it was demonstrated that diabetics were much more active than normal individuals at absorbing lipid oxidation products from the digestive tract, possibly explaining the high risk for heart disease in diabetic patients (Staprans et al., 1996). Much more research is needed in this area.

Polyunsaturated fatty acids are far more susceptible to oxidation than the principal fatty acids found in beef and lamb, and also more so than cholesterol. However, cholesterol also can react with oxygen and over the past few decades this subject has been the subject of a surprising amount of research activity. As discussed earlier, CHD is the result of plaque accumulations in arteries. Cholesterol oxidation products (COPs) have been demonstrated to be cytotoxic and atherogenic by numerous researchers in scores of studies. Several reviews of this area have been published (Smith, 1981; Addis et al., 1983; Addis and Park, 1989; Addis and Warner, 1990; Guardiola et al., 1996; and Addis et al., 1996). Therefore, animal products subjected to abusive temperature and storage conditions, especially those that permit the development of rancidity (a common form of lipid oxidation), are likely to contain at least trace levels of COPs (Park and Addis, 1987).

Polyunsaturates have other problems related to atherosclerosis that need to be briefly addressed. Even in the absence of heating polyunsaturates and development of lipid oxidation products in foods, polyunsaturates, if consumed in excess, can render the LDL particles more susceptible to changes in the blood vessel that increases their atherogenicity (Addis and Warner, 1991). This has been shown to accelerate plaque build up. This alteration involves lipid oxidation, albeit milder that what occurs during cooking. However, the chemical changes are qualitatively similar. Again, polyunsaturates are more susceptible than saturates.

Antioxidants help slow the lipid oxidation occurring in the human body which reiterates the importance of adequate intake of fruits, vegetables and whole-grains. Two common polyunsaturated fatty acids are essential, that is they cannot be made by the human body and are, therefore, required for life. However, it is well-established that consumption of high polyunsaturated fatty acid containing diets needs to be accompanied by an increase in consumption of antioxidants, especially vitamin E, to provide protection against oxidation (Addis, 1990; Wardlaw, 1999). Saturated fatty acids can be made by the body from other dietary components and are therefore not essential in the diet. While it is true that some saturated fatty acids elevate serum cholesterol, these same fatty acids do not undergo oxidation in the body.

There are three major risk factors for CHD: smoking, hypertension (sustained high blood pressure) and elevated serum cholesterol (Wardlaw, 1999). Of the three, the latter is the most contentious (Pinckney and Pinckney, 1973; Smith and Pinckney, 1991). Serum cholesterol also is thought of be relevant to consumption of animal products. The three risk factors for elevated serum cholesterol are diets high in fat and saturated fat and low in fiber, especially soluble fiber (Wardlaw, 1999). Dietary cholesterol is less important than saturated fat, fiber and total fat as a factor affecting serum cholesterol, although people vary markedly in their responses (Hopkins, 1992). However, Stamler and Shekelle (1988) found dietary cholesterol to be an "independent" risk factor for human coronary heart disease and suggested that life expectancy increase of 3.4 years would occur in people who decrease their cholesterol intakes by 200 mg/ 1000 kilocalories energy intake. Others have not found dietary cholesterol to be so closely linked to development of coronary disease.

Smith and Pinckney (1991) raise serious questions about the use of relative risk ratio as opposed to absolute risk in many of the diet, drug and coronary heart disease studies. Paraphrasing the conclusions of Smith and Pinckney (1991): the annual CHD death rate difference between the vegetarian at 170 mg/dl serum cholesterol and the meat eating individual at 220 mg/dl serum cholesterol is a trivial 0.03%. The use of relative risk ratio recalculates and amplifies trivial risks into larger, more alarming risks.

Also relevant is the "U-shaped" total mortality curve, meaning that total death rate increases at low serum cholesterol levels even as death rate from heart disease declines. Part of the increased death rate experienced by those persons exhibiting lower serum cholesterol is due to cancer (Kritchevsky, 1992).

Atherogenic and Anti-Atherogenic Factors in the Human Diet

Based on the literature published to date, it is difficult to conclude that animal products increase arterial plaque formation unless they are replacing fruits, vegetables and whole grains, foods rich in phytochemicals, in the human diet. It is now clear that foods of plant and animal origin contain atherogenic factors and also contain anti-atherogenic factors Addis et al., 1995). The following are atherogenic factors in the human diet: COPS, lipid oxidation products from polyunsaturated fatty acids, *trans*-fatty acids, saturated fats (but not stearic), and possibly dietary cholesterol, in combination with high levels of the cholesterolemic saturated fatty acids. Stored iron (serum ferritin) and therefore dietary iron has been identified by one study as a risk factor for human heart disease but Addis and coworkers (1995) cited many studies that have disputed this finding. Moreover, there are scientific grounds on which to argue that dietary iron may help protect arterial health (Addis et al., 1995).

The studies of anti-atherogenic factors in the human diet are relatively new compared wit the traditional studies on atherogenic factors. Nevertheless, the addition or augmentation of anti-atherogenic factors has potential to reduce CHD to a greater degree than does the restriction of atherogenic factors. It is easier to add than to prohibit dietary components, especially if prohibition involves foods of high culinary value. Such anti-atherogenic factors include antioxidants, fish oils, protected (from oxidation) polyunsaturates, fiber, and the trace minerals iron, copper and selenium. All can be added to the diet without serious sensory problems, assuming the polyunsaturates, including fish oils, are adequately protected against oxidative deterioration. Currently, there is great activity in the food industry in this area, commonly referred to as functional foods or nutraceuticals.

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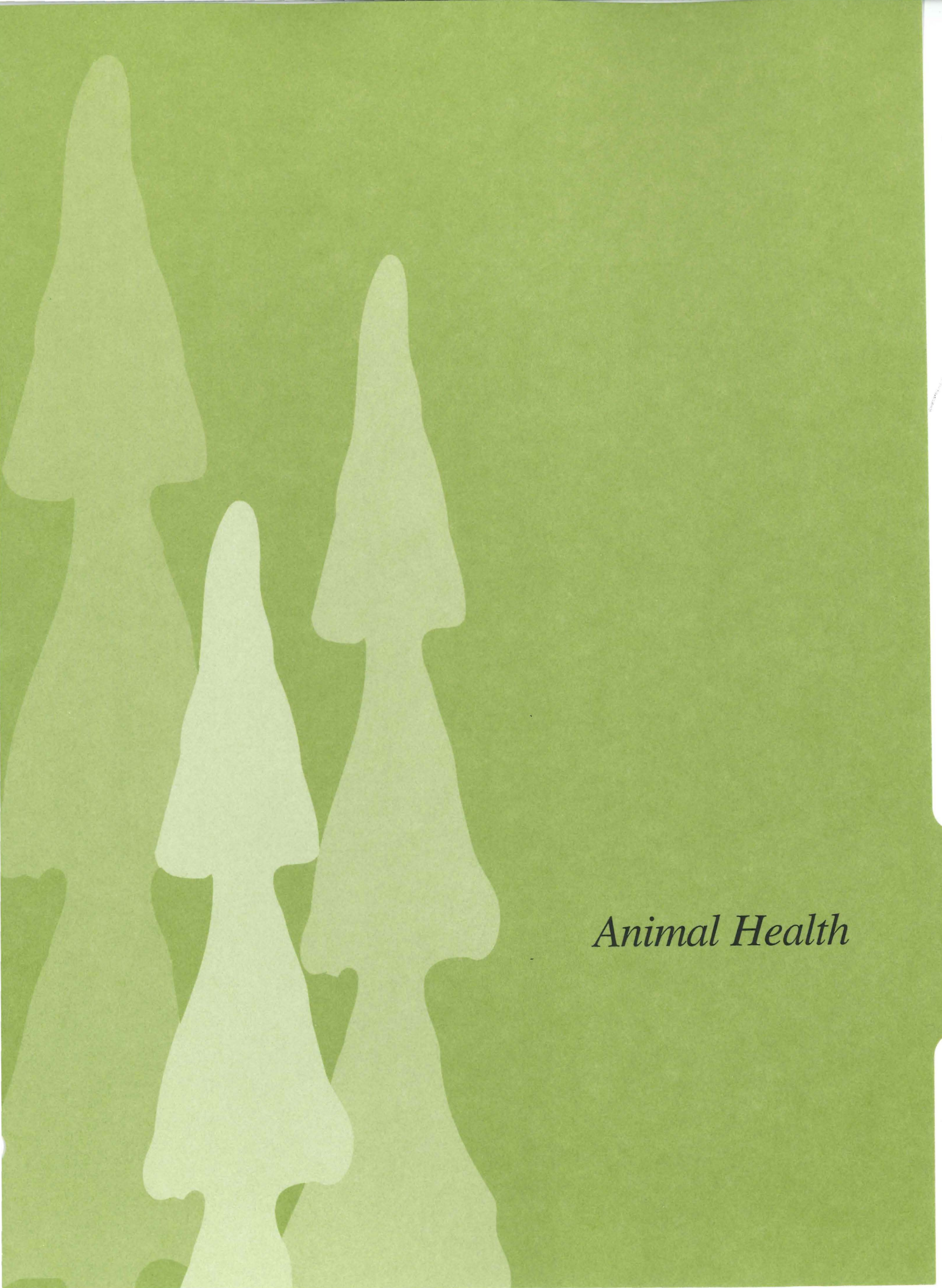

Animal Health

L

Generic Environmental Impact Statement on Animal Agriculture:
A Summary of the Literature Related to Animal Health (L)

Prepared for the Minnesota Environmental Quality Board

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Executive Summary

Animal health and well being are the foundation of any humane, sustainable livestock production system. Producers must therefore insure the management practices they use are appropriate for the species, the type of production system, and the environment. To do otherwise would be detrimental to their animals and their livelihood. Much of what is known has been determined through years of hard work and refinement. Thus, producers are frequently reluctant to impose new management methods on their animals until it has been demonstrated that the new methods work in a setting similar to the one they use. This emphasizes the need for research with appropriate controls so that effects of management practices can be thoroughly evaluated.

Livestock production systems convert feed into valuable products such as meat, milk, eggs, and wool. Sustainable livestock production systems perform this conversion through effective management practices and the use of animals that efficiently convert the feed they consume into useable products. Animal research has increased our understanding of the interactions of production animals with their environment and management practices and has greatly enhanced the efficiency of producing animal products. This increased efficiency means more product can be produced per unit of feed consumed and less waste (manure, methane, etc.) generated per unit of product produced.

In the short-term, disease and stress reduce the ability of animals to efficiently convert feed to product. This has a profound negative impact on farm profitability. Prolonged or uncorrected periods of disease and stress are inhumane, compromise animal health and well being, greatly decrease efficiency and result in an unsustainable system. These factors are clearly undesirable for the animal, the producer, and society. Thus, sustainable systems strive to prevent disease and stress, quickly treat detected cases, and correct the conditions that contributed to the occurrence.

Traditional, contemporary, and alternative livestock production systems of various sizes operate in Minnesota. Within each system, management practices exist that can allow the producer to meet a variety of income and quality of life goals. Large units provide perceived advantages (including labor efficiency, volume of production, and the ability to provide uniform management for groups of similar animals) but the concentration of animals imposes challenges associated with disease control and manure management. Small units and certain alternative systems are frequently perceived as being more environmentally friendly, more family oriented, and more supportive of animal well being. However, these systems also impose challenges associated with animal health and well being and may not have sufficient resources to institute protection practices needed to properly manage animals and the waste they generate.

All sustainable livestock production systems strive to minimize any potential negative impacts of the system on the animal, the producer, the environment, and society. However, there is no one perfect set of methods that is applicable to all livestock production systems. Management practices that are effective in small units may or may not be effective in larger units. Regardless of the size or type of system used, public awareness and expression of concerns (perceived and/or real) for animal health and well being have increased.

This emphasizes the need to clearly understand the varied and multiple interactions of livestock species with their environment, the production system used, and societal concerns. Improving this understanding will explain how changes in animal management can have significant effects on animal health and well being, productive efficiency of the system, the environment, and society. To be beneficial to the animals, environment, producer and society, regulations on livestock production systems should reflect a comprehensive understanding of these interactions.

Critique of Questions

Question 1.

The question was straightforward and clear. Federal, State, and Local **regulations** comprise vast volumes – even when restricted to the health and well-being of agricultural animals. Sections that were considered to be most pertinent were reviewed and described. **Routine practices** in animal agriculture also comprise a vast volume of information. Several textbooks have been written that describes these practices. Topics that were identified as being of interest to EQB/CAC were discussed. It was more difficult to obtain **compliance** data. Records appear to be limited. The question could have been improved by the identification of specific areas of interest. This would have provided more focus. However, EQB/CAC provided helpful feedback as the process evolved.

Questions 2, 3, and 4 were highly inter-related.

Question 2 asked for information of how animal agricultural **systems** affected animal health and well-being and how these effects were measured and address. Five specific factors were identified and information requested as to how they were affected by the system. Although the basic question is straightforward, a response based on a systematic analyses was not possible because such data generally do not exist. The first four of the specifically identified factors do play important roles in animal health and well-being. The fifth factor (use of processed manure as feed) can play an important role, especially if processing is inadequate. However, little processed manure is fed to animals in Minnesota or in the U.S. Although not specifically requested, the team chose to include information on other factors that are known to have important affects on animal health and well-being. For these questions and the report in general, more information was available for effects of these factors on animal health than animal well-being.

Question 3 asked how the effects of animal agricultural system varied by species, operation, system type, and management practice. EQB/CAC provided the needed (and requested) clarification of their working definitions of these terms. The resulting coalescence of operation, system type and system into the single term **system** (consistent with Question 2) was beneficial. On a gross comparative level, relative effects of extensive and intensive systems could be made across species. However, specific systems generally differ sufficiently among species to make such comparison invalid, or at least difficult to interpret.

Question 4 asked what techniques and standards were available to determine and address the effects of the system on animals in Minnesota and other places. This question was straightforward but difficult to answer in a direct, specific manner because such data are generally not available. Relatively recent efforts through the National Animal Health Monitoring System provide a growing database. As the name implies, the focus of this system is animal health.

Question 5.

This question was also straightforward. It was relatively easy to summarize available preventive and mitigative measures for addressing negative effects on animal health and general aspects of animal well-being (animal comfort, physical stress, etc.). This occurred in part because the industry responds quickly to address aspects that are detrimental to animal health performance. Considerable less is known relative to the cognitive aspects of animal well-being.

SECTION A. INTRODUCTION

1. Animal Health and Well-Being

Caretakers of animals used to produce food and non-food products for human consumption have long recognized the need and value of ensuring the health of their animals. Most animal caretakers are sensitive to the health and safety of their animals and they have many reasons to do so (Ewing; Lay, and von Borell 1999). There are many obvious negative impacts of unhealthy animals on an animal unit including less efficient production, greater inputs of time, money and treatments required to return animals to a healthy condition, and reduced economic returns to the producer. The multiple detrimental consequences of unhealthy animals quickly become apparent to the producer and this encourages producers to manage their animals to prevent many health problems from occurring. Other factors that affect aspects of overall animal well-being are more difficult to assess and receive varying degrees of attention. Society (both producers and consumers) is paying more attention to these aspects of animal care and is exerting pressure to influence current production practices.

Various animal health measures can be used to assess the overall or specific health of animals. These include measures of animal productivity (e.g., lbs. of milk produced per day, average daily gain), frequency of detecting clinical signs of sickness (e.g., diarrhea and weight loss, coughing and respiratory discharge), and results from specific tests (e.g., parasite burden, specific antibody to disease-causing agents). Although these measures are frequently used to assess overall health quality and usually provide adequate information, the incidence of animal health problems on any animal unit can be difficult to estimate due to inconsistent reporting, use of imperfect tests, variation in the diagnostic abilities of individuals, and presence of subclinical disorders. An ability to accurately assess animal health is required before effects of a production system or management style on animal health can be determined. Herd level animal productivity and health databases (PigCHAMP, DairyCHAMP, DairyCOMP 305, Dairy Herd Improvement Association (DHIA), Standardized Performance Analysis (SPA))are management tools that provide useful information to assist the assessment of individual herd health. National and regional assessment of disease incidence are available through the National Animal Health Monitoring System (NAHMS).

Healthy animals will not prosper if they are managed in an improper manner. Thus, management skills must do more than simply promote animal health. These additional management skills generally fall under the realm of animal well-being and are part of what has been called the "ancient contract between humans and animals". However, although there is good scientific and social consensus on the definition of physical health, the definition of well-being is more nebulous for both humans and other animals. Thus, as summarized by the Council for Agricultural Science and Technology (CAST 1997) several definitions have been proposed but no consensus has yet emerged for the definition of well-being of agricultural animals. This lack of a consensus definition reflects the fact that there is inadequate information available to assess animal well-being (CAST 1997).

Despite this lack of a specific consensus definition of animal well-being, most agricultural animal scientists believe an acceptable level of well-being is achieved in most of the production systems on American farms (CAST 1997). The overall care provided to agricultural animals occurs in no small part because animal caretakers have a strong working knowledge of animal husbandry and recognize factors that affect animal comfort and normal behavioral patterns (Albright 1993a). However, as in any population, variation certainly exists among animal caretakers in their knowledge, understanding, and ability to practice proper animal care techniques and principles. New employees require proper training before they can effectively master the techniques of proper animal management. New knowledge results in modifications of old techniques and/or generates new techniques. Continued adoption of new, improved methodologies require continued upgrades in training of animal caretakers. Variation in facilities, operating methods, and animal species can make techniques more applicable to some livestock production units and less applicable to others. Throughout the livestock production sectors, there are training programs (see below) designed to improve the understanding and effectiveness of animal caretakers so they may provide proper animal care and enhance overall health and well-being of agricultural animals.

Although results of opinion polls are greatly influenced by the tone, structure and implied message of the questions asked, surveys indicate most Americans support the agricultural use of animals (Becker 1992), believe most producers generally provide humane treatment of their animals (Becker 1992). A more recent survey indicates consumers are concerned about and would like to prevent inhumane treatment of agricultural animals (HSUS, 1999). Many individuals also support governmental regulations to ensure the humane treatment of agricultural animals (Becker 1992). This new social ethic for animals, one that recognizes concern about all animals that suffer and not just those treated with blatant cruelty, has been discussed (Rollin 1995;Rollin 1996;Rollin 1996). Most in the livestock production industries recognize the need for continued improvments in the care of agricultural animals.

Many public and private organizations involved in livestock production have developed training manuals and programs designed to increase the proficiency of animal caretakers. Recently, swine extension specialists at major land-grant universities developed a training curriculum entitled "Farrowing House Management". This curriculum is designed to train animal caretakers in the proper management of sows and piglets housed in farrowing facilities. The curriculum is available in hardcopy and on the worldwide web through the National Pork Producers Council (www.nppc.org). Curricula for other phases of production are under development. Several private companies involved in large scale livestock production use training manuals that include Standard Operating Procedures (SOP's) for proper care of livestock in their operations.

2. Assessment of Animal Well-Being

Animal well-being has been described as a situation in which an animal exists within a range of acceptable environmental specifications and has been identified as the ultimate goal of farm animal use strategies (Ewing and others 1999). In a relatively simplistic manner, farm animal well-being has been described as implying a reasonable quality of life and a gentle death (Webster 1989). Additional criteria are clearly required to achieve a comprehensive definition of well-being. A special committee report to the British Parliament (Brambell 1965) provided the framework for subsequent efforts to assess farm animal well-being.
A considerable lack of consensus remains among individuals attempting to assess the well-being of agricultural animals. This may not be too surprising when one considers that the well-being of agricultural animals only began to have a significant public impact after Harrison (1964) wrote "Animal Machines" and Singer (Singer 1975a;Singer 1990;Singer 1990) wrote "Animal Liberation: A New Ethics for Our Treatment of Animals". Other summaries of the associated issues are found in Singer (1975), Mason and Singer (1980), Midgley (Midgley 1984), Regan (Regan 1983b), and Rowan (Rowan 1993). The fact that much of the concerted effort to specifically assess animal well-being has only been initiated since 1990 contributes to the lack of consensus in this area (CAST 1997).

The difficulty in defining animal well-being is due in part to the different approaches taken to assess it and to the use, and implied meaning, of the various terms used to describe it. For example, animal biologists tend to use the term well-being and frequently speak about it in context with the biological, physiological, biochemical and physical interactions of an animal with its environment. Socio-behavioral scientists appear to favor use of the term welfare and include psychological considerations. Scientists from similar disciplines also use a variety of definitions. Some choose to describe this component of animal husbandry as the animal ability to cope with it's environment (Broom 1986) while others indicate well-being goes beyond the mere absence of disease and include the absence of discomfort and stress (Albright 1997). Cultural differences also contribute to the confusion as Europe tends to favor welfare while the term of choice in North America is well-being (Ewing and others 1999).

Scientists attempting to assess animal well-being tend to be applied ecologists or applied ethologists (Gonyou 1994;CAST 1997). Ethologists (Lorenz 1981) have developed ethograms for a number of livestock species in different conditions to use as standards for animal behavior. Ethograms are catalogs of behavioral patterns that occur during the life cycle of an animal species. Thus, an ethogram should (ideally) provide a benchmark against which one can measure deviations from normal behavior (Banks 1982). Interpretation of these deviations are based on the assumption that an animal's behavior in a specific situation somehow reflects what the animal feels about that situation. Thus, ethograms depend on a sound knowledge of an animal's behavior in a variety of conditions (Duncan, 1993; Fraser, 1993; (Gonyou 1986;Moberg 1985).

It was recognized early in the development of ethology that, to be really competent, the ethologist required a strong understanding of a variety of scientific fields (Klopfer 1974). This becomes increasing difficult and future advances will likely occur through extensive collaboration. In addition, the extensive and detailed nature of ethograms make them difficult to develop for all

species in all possible situations. Consequently, they are of limited value in current production settings and will remain limited until a larger catalog of ethograms is available (Ladewig and Von Borell 1988). The difficulty of assessing animal behavioral characteristics was recently highlighted when the behavior of well-characterized mice housed under defined laboratory conditions failed to match expectations and failed to agree among laboratory sites despite extensive efforts to ensure laboratory environments and stimuli were similar (Crabbe and others 1999). Nonetheless, these efforts have increased our understanding of interactions between animal behavior and the animals environment and continued efforts are warranted.

CAST (CAST 1997) provides a summary of scientific approaches used to assess animal well-being. These approaches differ in emphasis with some being purely hedonic [relating to an animal's pleasure] (Bennett 1995), others purely cognitive [based on thinking, feeling, remembering, abstract presentation] and others based on only physical or physiological assessments (CAST 1997). However, most attempts to assess animal well-being reflect a more moderate and inclusive approach. Approaches that are based on multiple indicators (Smidt 1983) appear to be gaining popularity and are frequently based on some combination of agricultural, ethological, pathological, and physiological criteria. Interpretations from these approaches also must be tempered because comprehensive multifactorial indexes have not yet been developed and because animal responses can vary considerably across genotype, age, gender, experiences and motivational impetus (CAST 1997).

A summary of this issue (CAST 1997) indicates that animal scientists and other agricultural stakeholders generally agree on six priority areas for research required to develop an improved assessment of animal well-being:

1. Bioethics and conflict resolution
2. Individual animal response to production environments
3. Stress
4. Social behavior and space requirements
5. Cognition
6. Alternative production practices and systems

Producers of livestock and their advisors often use easily measured traits as indicators of overall animal health and well-being. For instance, the quantity of feed and water consumed by animals is often used as an indicator of the animals' condition. These traits are routinely measured on farms and compared against some expected intake for that size and class of livestock. If intake of feed and/or water are below the expectation, the animals' condition probably is compromised to some degree. Many factors such as clinical disease, subclinical disease, high environmental temperatures, poor quality feed, and many others can reduce feed intake below the expected amount. The factor responsible for the low feed intake may represent a serious threat to the animal's health or merely a temporary uncomfortable, less-than-ideal environment. It could also be the result of a normal physiological process such as when a lactating cow experiences estrus and temporarily decreases the amount of feed she consumes. Clearly a sound animal husbandry background is beneficial, if not required, to accurately assess the factors responsible in any particular situation. A more complete understanding of animal health and well-being requires

a coupling of this husbandry background with advances in ethological knowledge.

Social interactions among penmates and herdmates are used by some producers as indicators of animal well-being. Certainly, these observations provide important information about animal well-being in extreme cases (see behavioral vices below). However, in less extreme situations it is difficult for humans to interpret the significance of social interactions to the animal's well-being due to an incomplete knowledge of animal behavior. Active research programs are underway in some universities (including Purdue University and Texas Tech University) and the USDA Agricultural Research Service to fill this void of knowledge. Nonetheless, certain minimal aspects of animal health and well-being are generally accepted by society. Ewing and colleagues (Ewing and others 1999) summarize work in the UK that describe these minimal aspects as basic needs required for health and well-being. These include the need to be free from hunger and malnutrition, free from thermal or physical distress, free from disease and injury, free from fear, and the need to be able to express most normal behaviors (Webster 1989). Although society has chosen to restrict certain animal behaviors in the interest of management, population control, and liability, these needs can provide the conceptual basis for the design and management of animal units (Ewing and others 1999) and, if necessary, the modification of current management practices.

3. Animal Well-Being - Beyond Health

There are definite limits to what a literature review about animal well-being can tell us. The philosophy of science tells us that something that is, even in theory, impossible to measure is outside the realm of science. However, something that is difficult to measure is no less scientific than that which is easy to measure. Two possible implications of this are that animal well-being is a scientific issue (beyond simple measures of health) and that *standards* of animal welfare are not a matter of science. For example, Broom states: "The scientist and the non-scientist can have an opinion of where to draw the line between the morally tolerable and the morally intolerable." (Broom 1993). Determining the sufficient level of animal well-being is a socio-political (or moral-philosophy) question. Science, by its nature, can tell us "how much," but not "how much is enough."

The public opinion of the treatment of animals has evolved with time and is fundamentally a social construction (McInerney 1996). That is, it cannot be grounded in any fixed measure of acceptable treatment because the acceptability of any treatment changes with the existence of alternatives and changing human sensibilities. The External Benefits and Costs Report (section F of the overall GEIS) provides further discussion about these results and the potential economic significance of people being unhappy about animals' situations.

An extensive discussion of animal well-being philosophy, let alone an examination of current socio-political motivations, was not requested in the GEIS Scoping Document. However, just as a basic overview of the underlying principles of economics or water quality is needed for other reports in the GEIS, it is valuable to set the stage in this area too. It is especially worthwhile to examine the origins of animal well-being (or welfare) because the area frequently generates controversy. This controversy is largely attributable to the fact that animal well-being involves

both science and social preferences.

Several books are particularly important for establishing the case for animals as interested parties, rather than simple objects, in the production process. Singer's (Singer 1975b) *Animal Liberation* presents the utilitarian case for consideration of animal well-being. Regan's (Regan 1983a) *The Case for Animal Rights* presents the case from a rightists perspective. Midgley's (Midgley 1983) *Animals and Why They Matter* and Mason and Singer's *Animal Factories* [1980] are less well-known but provide critical arguments in the field. Other works present extensive discussions of animal consciousness and pain underpinning those characteristics of well-being (Langley 1989;Rollin 1998). Others chronicle the development of modern concern about animals (Finsen and Finsen 1994;Regan 1987;Walters and Portness 1999). Rollin's (Rollin 1995) *Farm Animal Welfare: Social, Bioethical, and Research Issues* is particularly comprehensive, offering a definitive summary of the issues surrounding the welfare of farm animals in terms of breadth and depth. It addresses the importance of the well-being of animals, especially farm animals, in the minds of the public. It covers each of the major farm species, including cows (beef, dairy, and veal), chickens (layers and broilers), and pigs. It explores the various perspectives of animal well-being issues that get particular press and popular attention, such as "downer" cows, veal production, and transportation practices, as well as less visible issues such as forced molting in layer hens and farrowing crates in pigs. When possible, alternatives to these practices are identified, as are areas where further investigation for alternative protocols is needed

The bulk of the Animal Health report is based on the premise that high levels of productivity from farm animals (and the closely related absence of diagnosable morbidity) are sufficient evidence that animals are well cared for and have an acceptable level of well-being. In many – but not all – ways, animal productivity and well-being go hand-in-hand. Most productivity measures are very likely to be positively related to animal welfare (Ekstrand, 1997). There is a lot to be said for basic non-morbidity and protection from gross adversity (as well as for measurability). Furthermore, one possible interpretation of the animal health questions in the GEIS is that health as it is measured by productivity is exactly what this report is about. Nothing in the Scoping Document clearly contradicts this interpretation.

However, many observers point out that productivity is not a sufficient measure of animal well-being. Measures of productivity may only indicators of lowered welfare, rather than indicators of good welfare, and thus should be combined with other measures (Baxter, 1989). Duncan (1993) points out that welfare has to do with what sentient animals feel, and offers what he calls the "pine tree" test of supposed measures of animal welfare – if the measure can be applied sensibly to pine trees (as can health, absence of stress, and biological fitness) then it is not actually measuring welfare. Attempting to measure well-being through proxies that are easily measured has clear advantages, but it does not mean that what is being measured is actually welfare. Much of the literature in the field that measures things that are legitimate *proxies* for or *contributors* to welfare implicitly makes the ungrounded claim that the factors being measured *are* welfare. But there is no reason to accept the validity of this equation when it is not based on socially defined notions of what we really want to measure when we consider well-being [Rutter, 1995].

The literature frequently suggests that the proxy measures are more scientific than (and thus superior to) intuitive notions of well-being. Indeed, uncritical appeals to intuition can go

astray and are no substitute for the best possible research of things measurable. But this does not mean that intuition should be dismissed out of hand, nor that empirical science does not often lead us astray or contain embedded socio-political agendas. It is most people's intuition that other animals are bothered by many of the same things humans would be bothered by. Studying something by drawing analogies to the most similar system that we do understand is a typical and well-respected method in the natural sciences, including life sciences. Indeed, it is the bedrock of a huge portion of scientific research. In the animal well-being literature this approach is even given a label, "the analogy postulate" (Alban and Agger, 1997). As a jargon-free description, we can simply say that good science is generally aided, not degraded, by common sense. In the social sciences, the issue is even clearer. If people are concerned about something, then it is real -- emotion *is* reality when it comes to valuing something economically (Frank, 1991).

It is obvious that sometimes productivity and well-being are inversely related. An example is the stress associated with persistent, prolonged overcrowding that prevents the animal from engaging in virtually all of its natural behavior, as is the case in some confinement facilities. Other activities that cause acute temporary pain, such as administering vaccines, have obvious positive effects on long-term well-being (and are similar to what we do for human children). Other situations fall in the middle of these extremes. This is where the interpretation of potential effects on animal well-being become more controversial. Examples include the immediate separation of a newborn dairy calf and its mother (the dam) or the removal of body parts (chickens' beaks, pigs' tails) without anesthesia in order to reduce the negative effects of subsequent behavior. Appealing to the closest model that we do understand – human well-being – suggests that a valid starting assumption is that many such activities lower animal well-being (until and unless proven otherwise, of course).

As described in a subsequent section of this report (Routine Practices), the literature reports that practice of separating the dairy calf and dam soon after birth facilitates the transition of the cow and the calf to the production environment, and contends that both appear to adjust rapidly, and neither suffers any apparent long-term effects. However, this practice raises the question of the relative magnitude of distress and whether this represents a significant compromise of animal well-being. The philosophy of current management practices is that restriction of this aspect of animal behavior represents a temporary, justifiable, minimal distress that is imposed to facilitate long-term management goals. Can we quantify the magnitude and consequences of this practice to animal well-being? Will society consider this practice too detrimental and choose to pay a potentially increased price for dairy products to eliminate this practice? Answers to these questions for this practice and for other currently routine management practices are generally lacking.

A wide variety of indicators of animal well-being and suffering have been proposed and examined. Some, but not all of these are discussed in specific applications elsewhere in this report. These include vocalization [Braithwaite et al., 1995; Leppelt and Marx, 1995; Marx, 1995; Weary et al., 1998; Weary and Fraser, 1995], habitual biting and chewing [McGreevy and Nicol, 1995], various forms of violence toward their fellows [Kjaer, 1995], heart rate [Uetake, et al., 1995], multiple manifestations of stress and diversion of resources [Dantzer, 1993; Moberg, 1993], coping behavior [Broom, 1998], pain perception mechanisms [Rose and Adams, 1989], cognition and related manipulation of their surroundings [Dawkins, 1988; Nicol, 1995; Kiley-Worthington, 1993; Duncan and Petherick, 1991], play behavior [Jensen et al., 1998], true feelings/emotional expressions/friendships [Duncan, 1996; Wiepkema et al. 1993], integrative

examination of emotional, motivational, and cognitive factors [Mench, 1993], preference as indicated by choice or expenditure of resources to acquire a good or situation [Dawkins, 1980; Faure, 1986; Lagadic and Faure, 1987; Fraser, et al., 1993], and, of course, various measures of production (growth, food consumption, lactation, etc.).

It is indeed telling that this list is similar to how we judge the well-being of human children and even adults under some circumstances. This similarity is frequently described as attributing human characteristics (desires and feelings) to that which is non-human (anthropomorphism). Though often used as an accusation of non-scientific behavior in the literature, "anthropomorphism" is more-or-less a synonym for "using the best available model for animal well-being, namely human well-being." There is not a morphological or physiological determinant of suffering in humans, but most people believe that human suffering is possible [Rose and Adams, 1989].

Most of the articles cited in the previous paragraph are quite conservative in withholding assignment of unproven abilities to animals, and many present standards of well-being that might be considered "weaker" than production-oriented definitions. The only thing remotely unifying all these different approaches is that they imply dissatisfaction with indirect measures of well-being, such as productivity . As with production-oriented measures, most of the literature on well-being focuses on management skill and practice rather than size and type of operation. It is not obvious from the literature whether this is because management is so much more important than other factors in all types of operations or just because the findings are only likely to change management practices and not fundamental decisions about operation size. The research that actually measures indicators of well-being is largely reductionist in that it has looked at experimental settings rather than considering animal "lifestyles" as a whole. Reductionist experiments can be much easier to conduct and may produce cleaner results, but they can result in major gaps in our understanding. Studies that have a broader, more comprehensive design and include a mixture of scientific fields (including ethology, which has inherent similarities to human ethnology) may offer deeper insights.

4. The Importance of Management

The overall care provided to agricultural animals occurs in no small part because animal caretakers have a strong working knowledge of animal husbandry and recognize factors that affect animal comfort and normal behavioral patterns (Albright 1993a). This working knowledge provides an understanding of animals and results in husbandry practices that achieve and maintain health, general well-being and productivity (CAST 1997). This may or may not provide an overall acceptable level of well-being as (or if) society's perspective changes. A variety of guidelines based on this accumulated knowledge for the proper care of agricultural animals have been published (Canadian Agri-Food Research Council 1998;American Veal Association 1994;National Pork Producers Council 1996;National Cattlemen's Beef Association 1997;National Turkey Federation 1997). The Guide for the Care and Use of Animals in Agricultural Research and Teaching (Federation of Animal Science Societies 1999) outlines

standard management practices that are followed by agricultural universities and research institutes throughout the U.S.

Agricultural animals of today are considerably different than their predecessors. Contemporary agricultural animals evolved from those that had traits favorable for domestication. These traits include agreeable temperaments, readily adaptable to new environments, ability to live in groups, weak mate bonds, and delivery of precocious [exhibit mature qualities (locomotion, feeding, etc.) soon after birth] offspring (Craig and Swanson 1994). Domestication and selection for particular traits of economic importance have modified some of these characteristics and have resulted in animals that have specific environmental needs. Management of these animals must be based on their specific needs, not the needs of their predecessors or of humans (Craig and Swanson 1994;Siegel 1995;Siegel 1995). Thus, the continued selection for desirable traits through selective matings and through genetic modification and the use of metabolic modifiers (such as steroid implants and somatotropin) require that the assessment of management techniques relative to animal care be an ongoing process (Gonyou 1994). Producers that fail to improve their management skills to meet the increased needs of contemporary animals may be reducing the well-being of their animals.

Some animal scientists have argued that livestock breeding practices that select primarily for traits of economic importance have compromised the "fitness" of modern, commercial agricultural animals. (Rauw and others 1998). They cite the Resource Allocation Theory of Beilharz et al. (Beilharz and others 1993) as evidence for this lack of fitness. The Resource Allocation Theory suggests that animals continuously selected for traits that increase production of products (meat, milk, eggs, wool, offspring) will be less able to cope with stressors such as disease or adverse environmental conditions when they are encountered. The theory predicts these animals will have difficulty coping with additional stressors because most of their resources (feed nutrients, body stores of nutrients, metabolic processes) are programmed to produce products. The final result according to is presumed to be an increased incidence of disease or pathological conditions that presumably compromise animal well-being (Rauw and others 1998).

However, it is becoming increasingly apparent that the biological processes within the body, the metabolic function of the various body organs, do not compete with one another for available resources but instead function in a coordinated manner to benefit the animal. The concept of homeorhesis (Bauman and Currie 1980) has been described as the ability of the animal to adjust its biological processes in a manner that supports a dominant physiological function and preserves animal health and well-being. Several good examples exist (Bauman 1999) but perhaps the best example is the high producing dairy cow.

The contemporary cow produces considerably more milk than her distant ancestors and nearly twice as much milk as cows did 40 years ago. For example, Minnesota cows produced an average of 10,022 pounds/lactation in 1956 and 18,920 pounds/lactation in 1998 (MN-DHIA 1999). Despite this tremendous increase in productivity and the increased metabolic activity associated with milk production, the contemporary cow compensates (just as her ancestors did) by reducing the quantity of milk she produces when she is confronted with adverse

environmental conditions, poor health, or poor management. She also decreases her milk production when she becomes pregnant. The physiological adaptations of pregnancy result in the diversion of nutrients away from milk production and toward those processes that support fetal growth and development.

These alterations clearly indicate the biological mechanisms within the contemporary high-producing cow continue to function in a coordinated manner to support the dominant physiological function. The fact that the cow decreases the quantity of milk she produces when confronted with less than ideal conditions clearly indicates that selection for milk yield has not made the cow an appendage to her mammary gland and does not force the cow to produce milk at the expense of her health, well-being and survival. Instead, the homeorhetic mechanisms continue to coordinate her overall metabolic processes and physiological functions.

Thus, as described by Bauman (Bauman 1999), the suggestions by some (Rauw and others 1998;Broom 1999) that genetic selection results in stressed animals that have "their normal biological functioning controls are overtaxed" (Broom 1999) fail to recognize that genetic selection is successful because it results in improvements in the biological control and coordination of mechanisms in the entire animal. To do otherwise would result in a non-sustainable biological system and would indeed be detrimental to animal health and well-being. These observations magnify the importance of developing management systems that match the genetic potential of livestock to the environment within which they are housed. This is discussed in more detail in subsequent sections of this literature review.

As in any effort, a range of abilities exist among individuals involved in animal agriculture. This contributes to easily recognizable instances where animals have not received adequate care. This variation in care is not limited to any particular type of production system. Poor to excellent care can occur in small to large units, in extensive to intensive units, and in grazing to confinement units for any animal species. As in other endeavors, continued acquisition of knowledge and experience plays an important role in improving performance. For animal agriculture, this continued acquisition of knowledge includes a wide variety of topics including health, physiology, nutrition, behavior, environment, and facility design.

The production system plays a very important role in determining the health and well-being of the animals. The design of the production system provides a physical layout or structure which dictates what management practices are required to meet the basic needs of the animal. Production systems provide for those needs in different ways. For example, protection from predators is essentially guaranteed in confinement systems by placing animals inside a building that excludes predators. This form of predator protection is very effective. In outdoor systems, predator protection is accomplished with extensive fencing, companion animals that act as guards (dogs, donkeys, llamas), and mechanical devices (pop guns). These predator protection measures may or may not be effective. Other aspects of aniaml care are more difficult to provide in confinement systems (see below).

Similar to predator protection, the production system determines the methods required to influence or control the environmental conditions (temperature, humidity, wind, precipitation)

to which livestock are exposed. Windbreaks (natural or manmade), offering more feed, providing bedding material to act as insulation, and group housing are all methods of combating cold weather for animals housed outdoors in extensive production systems. In confinement systems, supplemental heat from furnaces and air flow (ventilation rates) from fans (usually) are used to obtain a temperature previously determined to be ideal for a given size and class of livestock (Jacobson and others 1985).

Regardless of the production system, management is the key to ensuring good animal health and well-being. A properly designed system operated with poor management will likely compromise animal health and well-being. For example, if animals are provided bedding material to combat effects of cold weather in an outdoor system but the bedding becomes wet and is not replaced, the animals will become chilled, uncomfortable, and likely will be more susceptible to disease. Although the system was designed properly, a management error (not replacing the wet bedding) compromised animal well-being. Another example of a properly designed system operated incorrectly can occur in confinement barns when ventilation rates are reduced in winter to conserve heat and keep animals warm. If the reduction is too severe, air quality in the barn can be compromised. Poor air quality could foster respiratory diseases in the confined animals.

Management decisions have a large influence on the ability of the system to provide for animal health and well-being. A production system is only as good as the management used to operate the system. Excellent systems can be managed improperly and be detrimental to animal health and well-being. In poor systems, animal health and well-being can be improved through appropriate modifications in how the system is managed. Management strategies need to be directed towards the specific operation, regardless of whether the system is intensively or extensively managed, or the facility is large or small. Given the important interactive roles of facilities and management in determining health and well-being of production animals, considerable research efforts will continue to be focused towards development of new strategies that improve animal health, well-being and productivity.

Most agricultural animals eventually leave the animal unit for slaughter and harvesting of food and non-food products. Caretakers are becoming increasingly aware of the need to ensure animal well-being after the animal has left the production unit. Many of the factors that contributed to reduced animal well-being during handling, transporting, and slaughtering can be and have been corrected through appropriate training of individuals involved in these tasks (Grandin 1994a;Grandin 1994b;Grandin 1994c;Grandin 1994c;CAST 1997). Areas that require additional research include long-distance transport and the handling of excitable animals (Grandin 1993;Grandin 1996). Improvements in equipment design and animal handling facilities (Grandin 1993) will make quiet humane slaughter of farm animals easier to achieve. Difficulties with situations such as the downer cow have been improved but identify that continued improvements in the handling, transportation, and slaughter of farm animals would improve animal well-being.

The well-being of animals that must be destroyed prior to slaughter due to injury or chronic disease that is unresponsive to treatment must also be maintained. The National Pork Producers Council (NPPC) has developed a pamphlet that describes humane methods available to euthanize swine on farms (National Pork Producers Council 1997). These guidelines are based on

standards for euthanasia developed by the American Veterinary Medical Association (AVMA 1993). The Canadian Council on Animal Care (CCAC) has developed similar guidelines for humane euthanasia of animals (CCAC 1993).

5. Confinement Systems

Animal health and well-being are influenced by a broad array of factors. Some factors are controllable by the caretaker (stockperson, livestock producer) while others are not. Production system and management abilities of the livestock producer are two very important factors that have a large influence on animal health and well-being. Systems for livestock production in Minnesota range from fairly extensive systems in which the animals spend most if not all of their life outside to intensive, environmentally-controlled, confinement systems that house animals indoors throughout their life. To more clearly appreciate the potential impacts of confinement systems on health and well-being of animals, an understanding of what indoor confinement is and why it evolved is beneficial.

Prior to the 1960's, practically all livestock were raised in some type of outdoor system. Typically, some type of shelter was provided to protect animals from the harshest environmental conditions. Livestock producers planned production schedules based on seasonal changes in weather and feed availability. This in turn created seasonality in the quantity of retail animal products that were available to the end consumer. The daily work of caring for livestock was physically demanding due to a lack of mechanization in feed processing and handling, removal and distribution of animal manure, animal handling and restraint, and fencing. The hard work and high labor requirements limited the number of animals one person could properly maintain. Cold and snow during winter and rain with associated mud during spring made caring for livestock outside difficult. Environmental conditions during parts of the year were very uncomfortable for the animals and their caretakers.

Livestock producers started to exert greater control over environmental conditions for housing livestock in the late 1950's and early 1960's by moving livestock indoors. Indoor confinement systems were developed to provide producers greater control of the environment that housed their livestock. Indoor confinement systems usually

1. house animals at a greater density than is typical of outdoor systems;
2. maintain a targeted room temperature by capturing heat radiating from the animals, and/or providing supplemental heat with furnaces in winter and providing mechanical cooling systems in summer; and
3. control quality of air in the building with a ventilation system that relies on exhaust fans and/or strategic control of openings to allow outdoor air to enter the barn.

Targeted conditions inside the barn vary depending on the species and age/size of the animal. By-products, such as manure, urine, wasted water, and wasted feed, can be handled as a liquid slurry collected under perforated floors or as a solid that includes bedding material collected from solid floors. Confinement systems concentrate these by-products in one location and generally provide more control in collecting and managing these waste products than is possible

with less intensive operations. This concentration of waste products requires a greater management effort but also provides the economies of scale to properly address the issue of waste management, something that is more difficult to achieve with smaller units.

Producers of the nonruminant species of livestock (swine and poultry) rapidly adopted intensive, indoor confinement systems such that the vast majority of current production of these two species is in confinement facilities. Producers of the ruminant species (dairy cattle, beef cattle, and sheep) with the exception of dairy cattle have been slower to adopt the confinement model of production. Presumably, swine and poultry were moved into confinement production barns because their rapid and efficient growth does not require that grass, hay or other forages be provided in the diet. Hence, there is no strict nutritional requirement for pigs or poultry to graze forages and no need for the large land base required for forage production. Effects of housing and intensive and extensive production conditions on animal well-being and economics have been evaluated (Barnett and others 1984;Curtis 1993;Lyons and others 1995;Waterhouse 1996).

Indoor confinement systems address many of the challenges associated with outdoor production systems. Increased animal density allows one person to care for more animals than was previously possible. More uniform production of livestock can occur year round with a reduced seasonal influence. Production flow can be scheduled and tightly controlled to increase biological efficiency. The increased biological and labor efficiency compared with outdoor systems allow indoor confinement systems to be profitable despite the high capital costs of constructing environmentally controlled barns. In addition, stockpersons are indoors and not exposed to challenging environmental conditions in winter and spring. They are also indoors during the nice weather of summer and fall and are exposed to the same environment as their animals (see the Air Quality section of this report and the Air Quality Report - Topic H).

The typical minimum standards of acceptable health and well-being criteria include adequate nutrition, freedom from environmental stress, and lack of disease, injury, and pain (Smith 1989). Other identified criteria include general behavior, cognition, and satisfaction of non-nutritional desires (Klopfer 1974;Broom 1999). One of the main criticisms of confinement systems is that they deny normal animal behavior. This is true in some cases. This evaluation must be placed in context with other animal health and well-being criteria when comparing alternative husbandry systems. The interaction of these criteria was exemplified by research conducted in the UK that evaluated free-range and confinement laying hens. Although allowed access to go outside, half of the 'liberated' hens choose to remain inside. This behavior was presumed to be caused by the natural behavioral instinct of the birds to seek somewhere to hide and take cover from potential predators. Free-range birds also exhibited increased aggression which led to cannibalism and mass hysteria to perceived outside threats such as crows and passing helicopters (Webster 1989).

The confinement system in this study was also viewed as less than ideal. Concerns of the confinement system focused on poor physical comfort, the prevalence of osteoporosis, bone fractures, and deformed feet caused by the restricted space (70 sq inches/bird) provided by multi-occupancy cages (battery cage). In addition, the absence of a nesting site and nesting materials caused apparent bird frustration and abnormal anti-social habits such as feather-pecking. These

concerns prompted proposed changes in the late 1980's to increase the space allowance by 45%, and provide a suitable nest and perch (Webster 1989). Some European countries have increased the minimum space allowance for laying hens and others have banned battery cages altogether. Several alternative systems for laying hens are being investigated in Europe. These vary from an intensive system which includes a modified battery cage with perches, dustbaths and nestboxes (the Edinburgh cage) to extensive systems such as aviaries, straw yards, and free range (Mench and Siegel 1997;Appleby and others 1992;Appleby and Hughes 1995). It is still being debated if the more extensive alternative systems will prove to be economically viable and to result in improvements in animal well-being. A major difficulty with extensive systems is the enhanced aggressive behavior patterns exhibited under free range conditions. In Britain, free-range eggs cost 50% more to produce than cage eggs and this is primarily due to increased labor costs per egg produced. Use of a careful balance of intensive and extensive systems has been suggested (Mench and Siegel 1997).

In some instances, a compromise of indoor and outdoor husbandry is beneficial to meet the seasonal needs of animals. An example would be the provision of winter housing for breeding ewes. This housing provides shelter for newborn lambs and provides improved access to proper nutrition and health programs. The sheep flock is subsequently pastured throughout the summer months. Breeding ewes housed outside during the winter frequently are exposed to muddy paddocks, inconsistent nutrition and potential threat from dogs or other predators (Webster 1989). The use of winter housing reduces lamb mortality and can increase the net economic return to the farm.

Increased animal density associated with confinement requires improved management skills to meet the needs (nutrition, health, well-being, etc.) of the contemporary animal. Because contemporary animals produce more than their ancestors, their specific needs, and the management required to meet these needs, also differ. Genetic potential, housing, production system, and other factors interact and impinge on the health and well-being of the contemporary animal and the profitability of the farm. Thus, it is difficult to compare specific items such as animal health and well-being across a variety of farms. For example, there is a perception that the average veterinary and medicine costs for dairy cows in confinement exceed those of cows that are grazed and that this must reflect a negative impact of confinement on animal health and well-being. However, a specific comparison of the medical expenses for these diverse management systems appears to be lacking. This is especially true when one seeks information on individual health expenses across a variety of production systems. Use of total health costs per animal within a system can provide a certain indication of the relative health and well-being status of animals in a particular unit, especially over time within a unit. Although also useful to compare health and well-being across units, total health costs can frequently provide misleading information. For example, special biosecurity health measures and the practice of preventative medicine to minimize health problems are an increasing priority for livestock systems. Producers using confinement systems may spend more on disease prevention which would increase their total medical expenses but would likely (should) result in an overall greater health status of their animals.

Animal health and well-being considerations are size neutral for both indoor and outdoor systems. Since their inception, the size and scale of indoor confinement systems has continued to increase. Increased size allows these production units to capture economies of scale and spread their large fixed costs of facilities over more production units. Rising input costs with static commodity prices have squeezed profit margins for livestock producers over the last 30 or so years. One response to these shrinking margins is to increase biological efficiency and output. Large-scale production units compensate for slim margins with increased output to generate the desired income. While a large unit may be more likely to capture benefits associated with economies of scale compared with a smaller unit, being large does not guarantee profitability. Large units are less able than smaller, less capitalized units to respond to changes in market conditions. Similarly, size of the production facility does not automatically infer a particular state of animal health and well-being. The perception that extensification of livestock systems is synomynous with animal well-being and that intensification is synomynous with animal abuse is a myth (Webster 1989). The decision by society and/or by individuals to use animals (labor, recreation, etc.) and to consume the products they produce (meat, milk, eggs, etc. requires steps to ensure that the health and well-being of these animals is adequate and consistent with societal norms and expectations. In order to achieve and maintain these norms, society needs to have an understanding of where and how their food sources are produced, have an active invovement in the process, and intervene if and when necessary.

SECTION B: RULES AND REGULATIONS

1. Introduction

One of the first Federal laws protecting animals against cruelty or abusive treatments was the Twenty-Eight Hour Law of 1873. This law was intended to insure that livestock being transported to market would be rested and watered at least once every 28 hours during their journey. As in Europe, it was not until much later that other specific Federal regulations and standards were put into law. In 1958, the Humane Methods of Livestock Slaughter Act (7 U.S.C. 1901) was enacted. The Act stated that "The Congress finds that the use of humane methods in the slaughter of livestock prevents needless suffering". In 1966, the Laboratory Animal Welfare Act (7 U.S.C. 2131) was passed that set standards for use of animals in biomedical research. The Animal Welfare Act was amended in 1970, 1976, 1985, and 1990. The Act requires that "minimum standards of care and treatment be provided for most warm-blooded animals bred for commercial sale, used in research, transported commercially, or exhibited in public".

Minnesota animal agriculture is regulated by an extensive group of laws developed by the federal and state government. Animal caretakers and farm businesses are subject to laws and regulations that cover many aspects of animal agriculture, including those that deal with animal health and well-being. Our review of the statutes, rules and regulations has included extensive research on both federal and state legislation for all sections that relate to livestock. We have specifically focused on the main agricultural animals of Minnesota: dairy and beef cattle, swine, poultry, sheep and horses.

As with all law in the United States, the highest level of legal authority governing animal agriculture rests with Federal Statutes. There are more than ten (10) Federal Statues that directly relate to animals raised for food or fiber in agricultural settings. At the next lower level of regulation, the Code of Federal Regulations (CFR) takes effect, with many volumes related to animal agriculture. After that, Minnesota State Statutes add to the scheme, followed by the Minnesota Code of Agency Regulations or, as they are commonly referred to, the "Minnesota Rules".

The "Animal Welfare Act" (Animal Welfare Act.) (7 U.S.C. et. seq. 1970 as ammended) is the federal government's principal law protecting the welfare and well-being of animals. It provides that animals covered under the act be provided with "humane care and treatment", that "animal pain and distress are minimized", and that animals be given the services of doctors of veterinary medicine whenever necessary. The Act was first passed in 1970 and has been amended since its initial passage.

However, animals raised for food or fiber, the animals of animal agriculture, are specifically excluded from the Animal Welfare Act and the regulations promulgated thereunder. The farm animal exclusion states:

"...but such term excludes horses not used for research purposes and other farm animals, such

as, but not limited to livestock or poultry, used or intended for use as food or fiber, or livestock or poultry used or intended for improving animal nutrition, breeding, management or production efficiency, or for improving the quality of food or fiber (7 U.S.C. 2132)."

Thus, farm animals are excluded from the primary federal law protecting the welfare of animals. This exception plays an important role in legislation applicable to farm animals. Therefore, while the Scoping Document does not specifically define the terms "animal", "animal agriculture", "livestock", "poultry", or their related terms, it is clear that, for purposes of this literature review, the Animal Welfare Act does not apply. However, it should be noted that Minnesota animal welfare laws do not necessarily make the same distinction as the federal act (covered in following sections).

2. Federal Statutes

The United States federal statutes are contained in the United States Code (U.S.C.), a Fifty (50) volume set of titles. Title Seven (7) of the U.S.C. entitled "Agriculture" and Title Twenty-One (21) entitled "Food and Drugs" contain most laws related to animal agriculture. Federal statutory law covering animal agriculture is centered on, but not limited to three specific areas: (1) drugs/controlled substances, (2) transportation/slaughter, and (3) marketing.

For animals raised for food or fiber, federal law has a fairly large number of statutes and regulations relating to the use of drugs on the animals. Principal examples of these federal statutes referenced by popular name are the following:

Animal Drug Availability Act of 1996 (Pub.L. 104-250, 110 Stat. 3151) (Animal Drug Availability Act. (1996))
Animal Medicinal Drug Use Clarification Act of 1994 (Pub.L. 103-396, 108 Stat. 4153) (Animal Medicinal Drug Use Clarification Act (1994))
Food, Drug, and Cosmetic Act of 1938 (21 U.S.C. 301) (Food 1938)
Generic Animal Drug and Patent Term Restoration Act of 1988 (Pub.L. 100-670, 102 stat. 3971) (Generic Animal Drug and Patent Term Restoration Act)
Virus-Serum-Toxin Act of 1988, (7 U.S.C. 851) (Virus-Serum-Toxin Act) and,
Swine Health Protection Act of 1980, (7 U.S.C. 3801) (Swine Health Protection Act)

These federal statues cover activities on three areas of drug use in animal agriculture: (1) testing and approval for use of new drugs, (2) appropriate use of drugs on the farm, and (3) use of drugs/controlled substances in animal feed.

Federal statutory law covering the means of transport of farm animals are based on the federal preemption granted under the "Commerce Clause" (Article 1, Section 8) of the United States Constitution. The principal statutes are "Livestock Transportation Act of 1995" (49 U.S.C. 13501) (Livestock Transportation Act) and the "Packers and Stockyards Act of 1921" (7 U.S.C. 182) (Packers & Stockyards Act).
Related to transport, marketing, and sale of food and fiber animals are the "Humane Methods of Livestock Slaughter Act of 1958" (7 U.S.C. 1901), the "Agricultural Marketing Act of 1929"

(12 U.S.C. 1141) , the "Livestock Bankruptcy Act of 1935" (49 U.S.C. 246) (Livestock Bankruptcy Act), the "Anti-Hog-Cholera serum and Hog-Cholera virus Act of 1935" (7 U.S.C. 851), and the "Horse Protection Act of 1970" (15 U.S.C. 1821) (Horse Protection Act). As to slaughter, Congress stated: "It is therefore declared to be the policy of the United States that the slaughtering of livestock and the handling of livestock in connection with slaughter shall be carried out only by humane methods". Congress has not, however, extended the requirement of humane treatment to these same animals while they are being raised on the farm.

Federal tax law also affects animal agriculture. The federal statutes on taxation, the Internal Revenue Code (I.R.C.), is contained in Title 26 of the U.S. Code. An important section of the Code for producers is Section 1231 (26 U.S.C. 1231). Section 1231 of the I.R.C. defines "property used in the trade or business and involuntary conversions." Under subsection 1231 (b) (3) "Livestock" including "cattle and horses" are "property" used in the trade of business of farming. The live animals on the farm are considered no differently than crops. The animals can be depreciated, and capital gains and losses are applied to them. The animals on the farm are another business commodity, much like cars, paper, steel or any other business product.

The Federal Acts cited above, under the auspices of the United States Department of Agriculture, have commenced activities designed to promote agriculture, including animal agriculture. These Statutes, and the regulations promulgated thereunder, are examples of government policies that directly affect animal agriculture. In fact, some of the sections promote different species of agricultural animals. An example is the National Poultry Improvement Plan, which is discussed later in this report.

Another example of marketing is pork promotion. Congress has stated: "Congress finds that pork and pork products are basic foods that are a valuable and healthy part of the humane diet...pork and pork products must be available readily and marketed efficiently to ensure that the people of the United States receive adequate nourishment" (7 U.S.C. 4801). Sheep are also included in the regulatory marketing scheme. About sheep Congress has stated: "Congress finds that sheep and sheep products are important goods" (7 U.S.C. 7101).

The Federal Statutes cited above comprise hundreds of pages in the United States Code, and are often enabling statutes. The Rules and Regulations promulgated under the authority of these enabling acts comprise many thousands of pages in the Code of Federal Regulations (CFR). The United States Department of Agriculture (USDA) and the Food Drug Administration (McChesney and others 1995) have primarily promulgated these Federal Rules and Regulations. The CFR consists of volumes containing section 1.1 through 4287.200. For purposes of a literature search relating to animal agriculture, CFR volumes Seven (7), Nine (9), and Twenty-one (21) are most applicable (CFR ;CFR ;CFR). Sections of these volumes are used to make applicable the requirements and purposes of the Federal Statutes to everyday life on the farm. Caretakers of animals are required to comply with the regulations.

The sections of CFR relating to animal agriculture are lengthy. CFR Title 7, entitled "Agriculture" contains most of the regulations used by the USDA regarding animals on the farm. These include regulations for the marketing of animal products. The USDA performs most of

its regulatory duties through its division of Animal and Plant Health Inspection Services (APHIS) which is set out in CFR Title 9 "Animals and Animal Products". Examples of APHIS activities include:

a. Animal Welfare:

As discussed above, the Federal Animal Welfare Act itself does not regulate animal agriculture. Code section 9 CFR 3, implements much of the requirements and purposes of the Animal Welfare Act. This CFR section contains Subpart F and Subpart F covers warm-blooded animals other than dogs, cats, rabbits, etc. Thus, Subpart F does regulate farm animals and places requirements on the animal caretakers in some circumstances. Subpart F contains sections that relate to transportation and requires a number of criteria (safe ambient temperatures, ventilation, lighting, etc.) for animal well-being. A thorough discussion of the common management systems and practices used to comply with these federal regulations are discussed later in this report.

b. Livestock:

This includes horses, mules, zebras, cattle, bison, sheep, swine, and poultry. As described in Code section 9 CFR 71, APHIS has extensive regulations concerning these animals. The regulations in this section cover diseases such as scabies, pseudo-rabies, anthrax, and many other communicable diseases. In addition, the regulations also cover many other areas related to these animals, including testing by veterinarians; sanitation conditions in yards, pens, trucks, trains, boats, and other facilities; disinfection requirements; and recordkeeping.

c. Cattle:

Section 9 CFR 72 describes extensive regulation over cattle infested with ticks and tick fever.

d. Swine and Poultry:

Title Nine (9) of CFR also contains the National Poultry Improvement Plan regulations (discussed below), the Swine Health Protection regulations, the Rules under the Virus-Serum-Toxin Act, and other applicable sections.

e. Horses:

Code section, 9 CFR 11, contains horse protection regulations. These are applicable to horses at an auction, sale, exhibition, show, or otherwise on public display. The regulations are very extensive, requiring unlimited access to inspectors of the horses and records relating to each horse. While they do not directly cover horses on a farm, they are applicable to animal agriculture in that the regulations do cover sales and auctions of horses.

f. Animal Food Products:

CFR Title 7 contains the Rules and Regulations relating to the Secretary of Agriculture and the USDA. Regulations relating to the Agriculture Marketing Service of the USDA, which relate to milk marketing in the "upper Midwest marketing area", and regulations under the Agricultural Marketing Act of 1946 are also contained in these sections. The latter include livestock grading and certification, inspection and grading of eggs, and other similar animal food products.

3. Minnesota Statutes

Proceeding through levels of authority from federal statutes to federal regulations leads to state statutes. In Minnesota, three statutes are central to animal welfare, health, and animal agriculture:

Minnesota Statute 35.01 et. seq., Animal Health (Minn Stat 35.01 et. seq.),
Minnesota Statute 343.01 et. seq., Prevention of Cruelty (Minn. Stat. 343.01 et. seq.), and
Minnesota Statute 116.01 et. seq., Pollution Control Agency (Minn. Stat. §116.07).

a. Animal Health:

Minn. Stat. 35.01 through 35.96 creates the Minnesota Board of Animal Health. The principal duty of the 5-member Board of Animal Health as described in the statute is to "protect the health of Minnesota domestic animals". This statute provides considerable detail to define the activities of the board and what it should do to protect the health of Minnesota domestic animals. The statute includes sections on diseased animals, quarantine and killing of diseased animals, transportation of livestock and poultry, testing and vaccinations of cattle offered for sale, and rendering plants. The statute also gives the Board rulemaking authority to promulgate Rules in the Minnesota Code of Agency Rules.

Some sections of the statute get quite specific. For example, Minn.Stat. 35.76 states that "No person may feed garbage to livestock or poultry until it has been thoroughly heated" Garbage is defined under Minn.Stat. 35.73 Subd. 4.

The Board of Animal Health in Minn. Stat. 35.92 Subds. 1-5 is given authority to enforce the statute and the Board's promulgated Rules. The Board's state budget is $2.3 million dollars. The Board employs three (3) inspectors to enforce the statute and its Rules. These three inspectors are assigned to cover 36,000 cattle farms, 11,000 hog farms, 3,000 sheep farms, 650 turkey farms, and 350 chicken farms. On those farms are a total of approximately 1.2 million to 2 million Minnesota animals. In the most recent annual data available, the Board inspectors did approximately 2,000 inspections for non-compliance. Of these inspections, 98% were for non-compliance with swine pseudo-rabies testing. In the most recent reported year, only one (1) fine was levied against a Minnesota farmer and that was related to allowing dead animals to remain unburied.

b. Prevention of Cruelty:

Minn. Stat. 343.01 et. seq. (Minn. Stat. 343.01 et. seq.), is Minnesota's animal cruelty statute. Major amendments to the statute took place in 1987 when the legislature created the Minnesota Federated Humane Societies (Federation). The Federation is a private, non-profit, Minnesota corporation whose principal duty is to assist in the enforcement of animal cruelty laws. The Federation receives no state funds. The Federation trains and appoints State Humane Agents under the statute. These agents work with local law enforcement to enforce the cruelty laws. The Federation is often involved as an investigating agency when significant cases of animal abuse, cruelty and neglect occur with pets or agricultural animals.

The Minnesota Statute (Minn. Stat. 343.20 Subd. 2.) defines animal as "Animal means every living creature except members of the human race". Thus, the Minnesota cruelty statute covers all animals in Minnesota, including those in animal agriculture. This differs from the Federal Animal Welfare Act as discussed above. The statute uses a common definition, one used in many other states, to define animal cruelty. Simply stated, it is any act or omission that causes unnecessary or unjustifiable pain, suffering or death to an animal (Minn. Stat. 343.20 Subd. 3).

While Minn.Stat. 343.01 et. seq. covers all animals in Minnesota, the statute provides weak penalties for violations, no matter how severe. For example, a farmer who neglects to feed his animals to the point that they starve to death is subject to a possible misdemeanor penalty only of $700.00 and a possible 90 days (See Minn.Stat. 343.21 Subd. 9 and MinnStat. 609. 02 Subd. 3). Several bills have been introduced in the Minnesota legislature over the past ten years to increase penalties to a felony level (See Minn.Stat. 609.02 Subd. 2 and 609.0341 Subd. 2), but none have been passed into law.

All animals in Minnesota that are not living in the wild, or are in the ownership or possession of a human, are the personal or "chattel" property of the human owner (See Wilson v. City of Eagan, 1980, 297 N.W. 2nd 146). This is consistent with federal law as discussed above (See Francione, G., "Animal, Property and the Law", 1995 Temple Univ. Press).

In Minnesota, there are unanswered legal questions on this point. Because the animals are the sole, individual property of the owner, to what extent can the state interfere with the right of ownership? Could the state, for example, enact a statute or rule requiring dairy farmers to release their dairy cows to pasture once a day? Could the state require poultry producers to stop artificially inseminating their birds and only allow natural reproductive processes to occur? Could the state mandate what drugs are to be given a farmer's animals?

Minnesota law, with the exception of disease control section cited below, does not currently regulate what have often been called "husbandry" practices, or are referred to generally in this report as management systems.
Minn. Stat. 343.21 also makes it a crime to "...overdrive, overload, ...or cruelly work any animal when it is unfit for labor...". Minn. Stat. 343.21 Subd. 2 states that no one may deprive an animal of necessary food, water or shelter. Subd. 3 states "No person shall keep

any cow or other animal in any enclosure without providing wholesome exercise and change of air."

Minn. Stat. 343.21 Subd. 4 states "No person shall feed any cow on food which produces impure or unwholesome milk". The statute defines impure and unwholesome milk "...all milk obtained from diseased or unhealthy animals, or from animals fed on any substance which is putrefied or fermented." This statute may be in conflict with the use of animal wastes (manure) as feed, which is discussed more fully later in this report. This statute also highlights the need for healthy animals, as milk from an unhealthy cow is legally deficient.

Minn. Stat. 343.24, defines animal cruelty in transportation. This section places various requirements on those shipping animals and livestock. The sections are designed to promote the humane treatment and well-being of the animals while in transport.

Minnesota law follows the federal lead and excludes farm animals from some of the humane requirements of Minnesota law. For example, the Minnesota statute on seizures of animals for animal cruelty, (Minn. Stat. 343.235) does not allow the seizure of animals raised for food or fiber without a warrant, no matter what the circumstance. In contrast, seizure of pets (dogs, cats, etc.) can occur without a warrant if circumstances threaten the life of the animal. An additional Minnesota Statute (Minn. Stat. 346.43 – Animal Humane Treatment Standards) defines humane conditions for animals in Minnesota. This statute excludes farm animals from its requirements.

c. Pollution Control:

Minnesota Statute Minn.Stat. 116.01 et. seq. (Minn. Stat. §116.07) and more specifically Minn.Stat. 116.07 ("Powers") and Subd. 7 which covers animal lot permits regulates pollution control. Under this statute, the Minnesota Pollution Control Agency (MPCA) is directed "to improve air quality" by a variety of means, with the overall goal of reducing all forms of pollution. In Minn. Stat. 115.01 et seq., the MPCA is also granted the authority to regulate water quality. Under these statutes, the MPCA regulates animal feedlots, pollution runoff from farms, and other forms of pollution from animal units.

The MPCA employs Nine(9) feedlot inspectors in Minnesota. There are approximately 16,000 licensed feedlots in Minnesota and an estimated 40,000 to 45,000 total feedlots. The Nine inspectors issue about 15 enforcement actions per year. In the 1995-1998 period, no feedlots were closed by the MPCA.

Under Subd. 7, the MPCA may delegate to Minnesota counties the responsibility for processing applications for livestock feedlots, poultry lots, or other animal lots. The statute (Subd. 7 (3) (k)) also allows counties to adopt ordinance standards for animal feedlots that are more stringent than the standards issued by the MPCA. Just recently (May 1999), the Minnesota Court Appeals decided a case that interpreted these sections (See Stearns County Alliance v. MPCA, C7-98-2203).

4. Minnesota Regulations

Similar to the federal government, the state of Minnesota and its agencies have issued Rules and Regulations governing the production of livestock in Minnesota. The Minnesota Department of Agriculture promulgates in section 1500 through 1572, the Minnesota State Board of Animal Health in sections 1700 through 1720, and the MPCA in sections 7000 through 7150. In a clear distinction from the Statutory Requirements, for its purposes the Minnesota Department of Agriculture defines "animal" as "cattle, sheep, swine, or goat" (Minn. R. 1540.0010 Subp. 2).

Like the federal regulations, the Minnesota regulations are also numerous and lengthy. A detailed description of these regulations is beyond the scope of this document, but they can be summarized. In general, the regulations cover aspects of meat inspection, poultry and eggs, transportation, exhibitions, and disease control.

Minnesota Department of Agriculture
Livestock (MN.R.1515 et. seq.)
Poultry and Eggs (MN.R. 1520 et.seq.)
Dairy Industry (MN.R. 1525 et. seq.) - contains a 350-word definition of "dairy product"
Milk, Milk Products, and Standards (MN.R. 1530 et. seq.)
Cheese and Cheese Products (MN.R. 1535 et. seq.)
Meat Inspection (MN.R. 1540 et.seq.)
Meat, Fish and Poultry Industry (MN.R. 1545 et.seq.)
Genetically Engineered Organisms (MN.R. 1558 et. seq.).

Minnesota State Board of Animal Health
Importation of Livestock and Poultry (MN.R. 1700 et. seq.)
Diseases of Domestic Animals (MN.R. 1705 et. seq.)
Diseases of Poultry (MN.R. 1710 et. seq.)
Livestock Exhibitions and Markets (MN.R. 1715 et. seq.)
Animal Carcasses (MN.R. 1719 et. seq.).

Minnesota Pollution Control Agency
Ambient Air Quality Standards (MN.R. 7009 et. seq.)
Animal Feedlots (MN.R. 7020 et. seq.)
Solid Waste (MN.R. 7035 et. seq.).

The extent of compliance to all these regulations by Minnesota animal agriculture is greatly unknown. With only a very few inspectors employed by the combined state agencies, to oversee the thousands of farms and the over one-million farm animals, it is difficult to imagine that even statistics on compliance could be generated.

5. The United Kingdom

The first relevant legislation in the UK, with the sole purpose of preventing ill treatment of horses and cattle, was passed by Parliament in 1822 (Smith 1989). Much later, the 1958 Slaughter of Animals Act (Minn. Stat. 343.01 et. seq.) and the 1974 Slaughter of Animals Act governed the proper handling of animals for the red meat industry. These Acts have been replaced by more specific codes (Smith 1989). A Protection of Animals in Markets Order is now also in place. The UK Brambell report in the 1960's addressed the proper treatment of farm animals. This report led to a new section under the 1968 Agricultural Provisions Act and to the appointment of the Farm Animal Welfare Council (Macpherson 1998).

The FAWC was charged with development of welfare codes for the care and treatment of farm animals. These codes were initially only enforced on a voluntary basis. The work of FAWC resulted in the definitive code of recommendations for the welfare of livestock beginning with cattle in 1983 (Farm Animal Welfare Council 1983). From 1983 to 1989 a further series of individual bulletins were developed for codes to address pigs, domestic fowl, turkeys, sheep, farmed deer and goats. These codes are equivalent to the animal care guidelines now used in the US.

Work by the FAWC and UK Ministry of Agriculture resulted in key legislation in the late 1980's and early 1990's. The UK was the first European nation to establish formalized legislation in Animal Welfare and Health. The Welfare of Calves Regulations was passed in 1987. The Welfare of Livestock Regulations established in 1990 were enforced between 1991 and 1992. During the same period The Veterinary Surgeons Act and the Prohibited Operations Act for farm animals had a profound affect on UK animal agriculture. These Acts detailed operations that should be carried out by veterinarians and prohibit on-farm practices such as short-tail docking of sheep and tooth grinding in animals.

Livestock practices that have been of public concern initially included intensive farming practices such as battery cages for hens, veal calves, tethered sows, and the use of sow stalls. All of these practices are now prohibited. Public concerns about "unnatural practices" such as castration, use of hormones and genetic engineering have been addressed by legislation (Webster 1989) as have concerns related to animal transport and slaughter. The FAWC codes have contributed to many improvements in animal husbandry that have addressed animal needs for adequate nutrition, comfort and shelter, freedom from injury, disease and fear, and the opportunity to express normal patterns of behavior (Smith 1989).

6. The European Economic Community

The European Economic Community (Tarrant 1984) has also made great strides in promoting animal welfare and health standards, especially through the Standing Committee of the European Convention for the Protection of Animals kept for Farming Purposes. In 1976, the Council of Europe adopted common provisions for animal protection that focused on intensive livestock agriculture. In 1978, battery cages for laying hens were banned.

Pigs were also an early legislation focus. In 1987, practices of multi-tier pens, sow stalls, tethered sows, weaning at less than 3 weeks of age, tail docking, and castration were all prohibited for swine production.

The European Council adopted laws related to cattle in 1988 and individual countries were requested to decide how they should be best implemented. Many of these laws were similar to those already established in the UK.

European Council Directives for transport of animals between EEC countries were in place by 1977 (revised in 1992) and Animal Welfare Directives related to Humane Slaughter were established in 1985 (Smith 1989). By January 1, 1999, all intensive livestock systems in the EEC had to comply with the provisions set for pigs.

Other individual European countries, in addition to the UK, have implemented Animal Welfare and Health Laws. For example, Germany (1971), the Netherlands (1981), and Switzerland (1981) have established such laws. Germand and Canadian animal welfare rules, laws and regulations have been discussed and sumarized (Meyer 1996). One of the most exacting animal welfare laws in Europe was the Swedish Animal Welfare Act developed in 1988. The fundamental principle of this law is that technology must be adapted to the animal and not the reverse (Smith 1989). An example is the requirement that all cattle are entitled to be able to graze. The Act was fully implemented by 1998. Although controversy continues in the EEC regarding use of hormones and genetic engineering in animal agriculture, the codes for animal welfare and health have been successfully adopted.

SECTION C: ROUTINE PRACTICES

1. Introduction

Use of various management practices and environmental conditions by livestock production species has been estimated by the National Animal Health Monitoring System (NAHMS), through national studies conducted by the U.S. Department of Agriculture Animal and Plant Health Inspection Service. These estimates are available at the NAHMS website (http://www.aphis.usda.gov/vs/ceah\cahm) or hard copies can be ordered without cost to requester.

From this source, estimates are available for swine operations (NAHMS, 1990, 1995), dairy operations (NAHMS, 1991, 1992, (NAHMS 1996) and beef feedlot operations (NAHMS, 1994 and one being planned for 1999), among others. Results from these NAHMS studies show a variety of livestock production management practices in use across the U.S. Herd size and regional differences are notable, an indication of the broad differences in management strategies being employed. In addition to the availability of summary estimates, the data sets can be obtained from USDA-APHIS under a memorandum of understanding agreement that clearly defines the use of data and outlines steps to be taken to ensure confidentiality of individual records. Therefore, further analysis could be conducted, if needed to provide additional information about particular management practices of interest.

2. Management

Descriptions of many of the common practices used in animal agriculture can be found in the multiple textbooks that address farm animal management. Example include textbooks that cover many species (Gillespie 1998) and those for individual animal species (Bath and others 1985;Van Horn and Wilcox 1992). Ongoing research with agricultural animals continues to generate new knowledge that can be incorporated into management practices in the effort to enhance animal performance, productive efficiency, health and well-being. As a result of this effort, management practices undergo constant evaluation and re-evaluation. These research efforts are prompted by a variety of factors including response of the scientific community to suggestions from and concerns of producers, consumers, and government agencies.

Public interest in animal agriculture reflects their interest in the source and quality of their food and an underlying concern for animal well-being. As a greater proportion of our society becomes more and more removed from direct contact with the farm, it becomes increasingly necessary to be able to explain the reason(s) for the common practices of aniaml agriculture. This is especially true when certain practices are viewed as unnatural (Webster 1989). Other management practices conducted for the long-term health and well-being benefit of the animal and/or caretaker may result in temporary pain or discomfort.

These procedures are generally only accepted as standard if they are warranted within the context of agricultural production; are performed by, or under the supervision of, capable, trained, and

experienced personnel; and are peformed with precautions taken to reduce stress, pain, and infection (Albright 1997). Current management practices in U.S. animal agriculture are discussed in relationship to animal well-being issues of discomfort, pain and stress in an Animal Welfare Compendium (Reynells and Eastwood 1997). Guidelines for these procedures and methods should be and are revised when new information suggests improvements are needed.

a. Beef Cattle

Beef calves are usually dehorned at a young age when the horns are small to prevent significant injuries to the cattle and their caretakers. Establishment and maintenace of a social order within a group of cattle can lead to "fights" between animals during normal daily interactions such as competition for water and feed (Goodrich and Sticklin 1997). Fights between horned animals can lead to injury of one or both animals as a result of these interactions. Dehorned or polled animals are much less likely to fight and when they do, the potential for injuries is greatly reduced.

Male calves are castrated to prevent physically or genetically inferior males from reproducing, to reduce the aggressive nature of intact males, and to improve meat quality. Beef calves are castrated when they are less than 3 month of age to minimize stress.

Cattle are frequently branded, especially in western states to provide permanent identification and ownership. This becomes especially important when cattle from more than one ranch are co-mingled on rangeland. Hot and cold braning methods are utilized. Hot branding inflicts pain for a short period of time and tends to be a more permanent identification than the alternative freeze branding method of identification. Freeze branding causes hair to change color and does not cause as much pain to the animal. Ear tag identification is more commonly used in Eastern States. Branding is prefered in Western States because ear tags can become caught in trees and brush on the range. The animal experiences pain and has an increased potential for infection when its ear tag is ripped out (Goodrich and Sticklin 1997).

Beef calves will normally remain with their dam until about 7 months of age. After reaching this age, calves may be 'backgrounded' on pasture, fed a diet containing a large proportion of forage until they are moved to feedlots as yearlings (100 to 140 days in the feedlot), or may move directly to a feedlot where they will remain for 200 to 250 days. Sometimes calves remain on pasture and are supplemented with concentrates until they attain a suitable market weight.

Feedlots are designed to provide adequate space for resting areas and to minimize animal to animal conflicts. Cattle are fed balanced diets, are protected from the elements and have intensive health care. Typical feedlot pens hold between 75 and 200 cattle. Even in large feedlots, each animal interacts with a limited number of other cattle. This allows for rapid adjustment to the feedlot environment and minimizes the stress of animal to animal interactions. Beef cows remain on pasture or range throughout the year. Much of this pasture and rangeland cannot be used for food crop production. In the winter, beef cows are fed harvested forages when standing forage is not available. The beef cow/calf segment of the

industry represents the ultimate in renewable resource utilization as the animals are free to roam on pastures and ranges (Goodrich and Sticklin 1997).

b. Dairy Cattle

Assessment of Animal Welfare Issues in the dairy industry has been succintly addressed (Arave and Albright 1997). Issues and concerns include the potential for reduced quality and quantity of individual attention in large dairy herds; dehorning of calves; prolonged stanchion-tying of cows; tail docking; separation of cow and calf; and raising calves in hutches rather than in groups. Improved management practices have been adopted in both confinement and grazing dairy herds, regardless of size, to enhance the quality of cow care. These practices include managed rotational grazing to maintain consistent availablity of high quality pasture for grazing herds, close attention to cow comfort and facility design for confinement herds, and improved milking practices and dairy herd health management for all dairy herds.

Dehorning, castration and identification are common pratices in the dairy cattle for similar reasons described for beef cattle. The most popular method for dehorning dairy calves is use of an electric dehorning iron under 30 days of age. This method presents no long-term stress (Laden and others 1985). Male dairy calves are usually castrated when they are dehorned (usually before 45 days ofage). Surgical castration and use of an elastrator are two common methods. The former causes less pain to the calf (Roy 1980). Dairy animals must be permanently identified for production, health and registration records (Arave and Albright 1997). Metal ear tags, tattoos, hide brands, and more recently transponders implanted under the skin are methods used for identification. In other countries, such as the UK, freeze branding is acceptable but hot branding is prohibited (MAFF 1983).

The increased popularity of freestall barns (invented in 1960) thoughout the US dairy sector has contributed to the decline in the use of stanchion tie-stalls. Freestalls typically have been designed to be wider and longer than the stanchion tie-stall. Research in the early days of freestall use demonstrated that cows spent more time lying in comfort freestalls (10.2 hours) than they did in stanchion tie-stalls (8.8 hours). This has been interpreted as indicating some discomfort in the latter system (Reeves and Henderson 1963). Cows require 10 to 12 hours of resting time daily that includes time for rumination (Hodgson 1990;Albright 1993b;Arave and Albright 1997). Freestall design continues to be improved and includes efforts to find appropriate bedding material (mattresses, sand, etc.) to provide cows with a most comfortable place to lie. This can have a positive effect on health and reduce the propensity for udder infections. Farms that have moved from confinement to grazing systems have often modified their stanchion tie-stall barns to develop a flat-barn milking parlor or to simply use them for winter shelter.

Tail docking is an emerging issue is the US. The pratcice is primarily limited to cows milked in rotary and parallel milking parlors to prevent disease, improve hygiene, and enhance ease of milking from the rear. The practice originated in New Zealand to keep dirty tails from impeding the milking of pastured animals in rotary parlors. The general effects of tail

docking on cow well-being and behavior requires additional study (Albright 1992;Arave and Albright 1997).

A critical aspect for newborn calves is to consume sufficient colostral antibodies as soon as possbile after birth. This provides sufficient passive disease immunity in their new environment. On typical dairy farms, calves are separated from their dam within 24-48 hours after birth. The ability of the calf to absorb colostral antibodies quickly diminishes to almost zero by 24 hours of-age. Consequently on many dairy farms, calves are hand-fed sufficient colostrum antibodies as soon as possible after birth and the calf separated from its dam immediately. Research has demonstrated that there is no direct relationship between calf mortality and the time the cow and calf remained together (Arave and Albright 1997). These authors discussed the example of the Camargue breed in Southern France where the pregnant cow leaves the herd to deliver the calf, hides the calf for 3-4 days, and returns only to nurse for short periods of time. Calves then join a small group of other calves that play and rest together and nursing becomes a community activity. It is not unusual for cows to accept several calves for nursing although there is a bond between the cow and her calf shortly after birth. Friesian calves that suckled for 7 months and then taken to a new environment required longer to adjust than artificially reared Friesian calves (4 vs 2 days) but previous rearing had no long-term effects on behavior (Veisser and others 1989). In modern dairy cattle, maternal instincts have not been the focus of genetic selection. Consequently the bonding between the dairy calf and its dam is not considered to be as strong as in beef cattle or other species. Emotional upset may be lessened by early separation before bonding has occurred. Intimate human contact during the critical period improves behavior of the cattle during sebsquent handling and milking (Craig 1981;Arave and Albright 1997).

Concerns have been expressed about the potential stress of rearing calves in individual hutches or pens vs group housing in pens. Diseases are easier to control and intersucking can be avoided when calves are raised individually (Arave and Albright 1997). In a study with six pairs of monzygous twin heifers, feed intake and daily gain did not differ when one twin was reared in a group and the other in a hutch (Purcell, 1988). On some dairy farms, after calves have received sufficient colsotrum, they are raised in small groups with common nursette liquid feeding systems.

c. Poultry

The poultry industry is the largest and most highly automated, vertically integrated and intensified of the animal produciton industries. There has been a great deal of public concern about the welfare of poultry and this has stimulated much research, especially in Europe. The practice of battery cages for laying hens has been modified or banned all together in the European Community (Webster 1989). Mortality of hens has increased as they moved from cages (4%) to a group litter pen (9%) or allowed to free range (16%). Much of this mortality is due to more opportuities to express aggressive behavior and cannabilism. As a result, a balance of well-being assessment to minimize aggression and allow for optimal animal well-being should be a goal for management systems (Mench and Siegel 1997).

The procedure for reducing cannabilism is beak trimming which involves the removal of ½ of the beak. It is used for laying hens and less commonly in broiler chickens. It can be used for male turkeys to reduce injuries associated with aggressive behavior (Mench and Siegel 1997). Research has demonstrated that traditional hot-blade beak trimming after 5 weeks of age can result in acute and chronic pain (Cunningham and Maudlin 1996;Gentle 1986;Craig and Lee 1990). Precision trimmers that cut a small hole in the beak causing the tip to fall off are now available but this method has not been thoroughly examined from the effect of pain on the bird. Viable alterntatives to beak trimming have been related to reduced light intensity. Some evidence indicates that genetic selection could be used to decrease cannibalism in flocks (Mench and Siegel 1997;Craig and Lee 1990).

Toe trimming is sometimes used in commercial poultry production where the middle toe of laying hens may be removed to reduce eggshell damage and toes of chickens and turkeys trimmed to prevent injuries to other birds. Trimming one toe of breeder chickens does not appear to cause chronic pain when performed properly (Gentle and Hunter 1988;Mench and Siegel 1997).

d. Swine

Common practices in the swine industry include ear notching and tagging, teeth clipping, tail docking, and castration. Most procedures are performed shortly after birth when pain is considered to be minimal. Stressed pigs show signs of immunosuppression, behavioral changes, and greater disease incidence. Stress factors can differ between intensive and extensive swine systems. In both systems, good management and understanding of animal well-being concerns are critical. A positive relationship with sows that are at ease with their human handler and the number of pigs raised/sow annualy has been detected (Holden and McGlone 1997).

3. Animal Handling

During the decade of the 1990's livestock handling practices have been much improved, although the handling of "downer" and crippled non-ambulatory animals still needs some attention (Grandin 1997;Grandin 1990a;Grandin 1990b). The leadership of Temple Grandin has had a profound impact on the ways animals are handled and how facilities are designed to improve animal well-being throughout the US livestock industry.

a. Handling-Induced Animal Stress

Livestock that are handled gently will be calmer and less stressed. Yelling and screaming stress animals. An overall understanding animal psychology will reduce stress and potential injury to animals. It was noted that cattle, sheep and hogs have wide-angle, panoramic vision that enables them to see behind them without turning heads, an important consideration when approaching or moving animals. Things that spook animals or make them balk when moving, should be recognized and corrected. Examples and some corrective measures have been summarized and described (Grandin 1992).

b. Handling and Moving a Single Animal or a Group of Animals

Cattle and sheep have a natural tendency to circle around handlers and keep them in view at all times. For single animals it is suggested that the handler remain at the boundary edge of the flight zone and not get too close to the animal. The most effective position for a group of animals is to stand at an angle behind the animals rather than directly behind. For cattle, use of plastic ribbons tied to the end of a stick is as effective as electric prods more moving cattle. Cattle with horns can cause significant injury and bruising when handled as a group. In the case of hogs, electric prods are discouraged in favor of a soft canvas slapper or plastic paddle

c. Handling Facility - Design Examples

Solid fences in single-file chutes, crowding pens, and loading chutes should be installed to block outside distractions;

- Crowd pen gates should be solid but sliding and one-way gates in single-file chutes should be constructed so animals can see through them;
- A curved chute works better than a straight chute;
- Escape gates should be installed in solid fence areas of cattle facilities for handler safety;
- All facilities should be designed to eliminate potential bruises and injuries of animals by using rounded corners and avoiding sharp edges in the facilities;
- Facilities should provide good footing for animals;
- Hog gates should be hung no more than 4 inches from the floor and the gates latched at the top. Bruise hazard zone for hogs is 12 to 30 inches from the floor;
- The most common cause of bruising in sheep is grabbing them by the wool or hind leg;
- Loading ramps should have no more than a 20 degree slope if permanently installed and no more than 25 degree slope for a portable of adjustable ramp. All permanently installed ramps should have a flat landing at the top (5ft minimum for cattle and 3 ft minimum for hog ramps);
- Bruise hazard zone for cattle is 28 to 52 inches from the floor.

d. Handling Crippled and Non-Ambulatory Livestock

Aggressive handling in pen facilities or loading and unloading from trucks can also cause injury and bruising (Grandin 1997). A large percentage (more than half) of crippled downed cattle (downer cow) are old dairy cows which often are emaciated and weak. The number of these 'downer cows' could be reduced if they had been transported to market in stronger physical condition (Grandin 1997). A National Cattlemen's Non-fed Beef Quality Audit conducted in 21 cow and bull slaughter plants indicated that 0.9% of cull beef cows and 1.3% of cull dairy cows were disabled and unable to walk. Severely lame cattle represented 3.4% of cull beef cows and 5.8% of cull dairy cows. These animals were in poor condition

when they left the farm (Smith 1994;Grandin 1997).

It was determined that 5% of the dairy farms were responsible for 95% of the 'downer' cull dairy cow problem (Grandin 1997). Surveys reported by Grandin (Grandin 1985;Grandin 1997) indicated that 8% of 51 auction markets in the Southeast had 'downer' cows. In addition, five of 27 (18.5%) major hog and cattle packing plants mishandled non-ambulatory livestock. Good management practices can prevent 8 of 10 dairy cow 'downers' and education of dairy and beef producers in proper handling of animals will contribute much towards prevention or reduction 'downer' problems (Grandin 1997).

e. Young Calves

There is still concern about the marketing and handling of newborn dairy calves destined for market, especially male calves and female free-martins. In England and Canada, Animal Welfare Codes prohibit sale of calves under 1 week of-age (MAFF 1983;Grandin 1997). This is not the case in the U.S. as many calves are sold at less than 3 days of age. There has been much improvement recently throughout the U.S. by many dairy producers who ensure that calves receive adequate colostrum, have dry hair coats and navels, have sound legs, can walk without assistance, and are in overall good health before being moved from the farm (Grandin 1990b). Often these calves are marketed directly to neighbors or specialized calf raisers who understand the need for optimum animal care and well-being. There is still room for improvement in marketing management of these young calves as they are loaded, transported, and loaded from trucks or trailers (Grandin 1997).

f. Hogs

The incidence of 'downer' hogs, many of which are young finished market hogs, are much greater than with cattle. Old sows allowed to deteriorate on the farm to a weak and emaciated condition also become 'downers'. Producers who feed hogs under contract have been known to bring sick, decrepit hogs to the auction market to get credit for them from the contracting company. This practice should not continue (Grandin 1997). As with cattle, improved management practices should be implemented on the farm to reduce the incidence of 'downer' hogs. Breeding and selection for soundness and reduction of inherited stress genes such as Porcine Stress Syndrome (PSS) are suggested as a priority. Prompt marketing or euthanization of hogs with hernias and prolapses is recommended before they become potential 'downers' (Grandin 1997). Careful attention to facility design and proper flooring suitable for type and age of pigs will prevent some of the 'downer' problems.

g. Markets and Stockyards

Grandin (Grandin 1997) strongly suggested that downed non-ambulatory livestock at markets should be immediately euthanized, or transported to a local, convenient slaughter facility. It was noted that many markets now have a 'no downer' policy. Some markets and slaughter plants do not allow 'downers' to be unloaded. In order to prevent crippled or weak 'downer' livestock from being shipped for many miles, it was proposed they be sent to a local

slaughter plant near to the farm or euthanized on the farm. A number of livestock groups such as the National Pork Producers have adopted 'no downer' policies. Continued improvements should include proactive team efforts between the farm, livestock organizations, livestock markets and slaughter plants.

4. Alternative Livestock Production Systems

a. Poultry:

The U.S. Commercial poultry industry is based on the production of eggs and meat under intensive management. About 98% of the 245 million laying hens are kept in cages. Turkey production (over 300 million) has changed from range rearing to confinement rearing on litter floors. About 7 billion broilers and roaster chickens are produced annually mostly reared in confinement on litter floors. Breeder poultry are typically confined in 1/3 litter and 2/3 slatted floor houses. The poultry industry is the most intensive and vertically integrated of all animal production industries and as such has been the subject of much public concern related to welfare especially in Europe (Mench and Siegel 1997). This scrutiny has led to system modifications based on animal well-being and behavioral criteria. The initial focus has been on the battery cages for laying hens which have been extensively researched by ethologists, behaviorial scientists and poultry commodity organizations over the past decade (Gentle 1986;Gentle and Hunter 1988;Webster 1989;Craig and Lee 1990;Mench 1992;Appleby and others 1992;Appleby and Hughes 1995;Cunningham and Maudlin 1996). Some European countries have mandated an increased space allowance for laying hens in cages or banned cages altogether. Extensive systems such as avaries, straw yards and free range have been evaluated (Appleby and others 1992). A modified cage known as the Edinburgh cage that contains perches, dust baths and nest boxes does address the natural behavioral instincts of laying hens and provides liberal space (Webster 1989;Appleby and Hughes 1995;Mench and Siegel 1997). Hen mortality has been shown to be 4% in conventional cages, 9% in litter pens, and 16% on free range systems (Mench and Siegel 1997). Most mortality is due to increased aggressive behavior and canabilism. A balance between an extensive and intensive system seems appropriate for laying hens which allows for improvements in animal well-being and maintains some economic viability for the producers.

In poultry meat production the main focus has been to develop birds genetically selected for efficient growth characteristics. This approach has led to some animal well-being concerns which is now being extensively researched. At present, strategic approaches are being used to modify bird growth rate during certain periods of its life. More work is needed on improvements in animal husbandry and modifications of systems that allow for optimal animal well-being and provide an economical return to the producer (Mench and Siegel 1997).

b. Swine:

Today, pork production in the U.S. is, for the most part, a vertically integrated industry predominated by indoor confinement systems rather than extensive pastoral settings which were more common three decades ago. Extensive swine production can be an economical low capital input component for the pig industry although land and labor requirements are greater than for confinement systems. On a per head basis, extensive systems are as profitable as indoor production, but net profit will be less because of the smaller volume and less consistent production (Holden and McGlone 1997). A survey in 1991 indicated that sows farrowing on pasture in portable houses weaned 0.8 pigs fewer pigs per litter than confined sows. Pig death losses were higher outside in wet cold weather. In mild weather, pigs raised outdoors have grown as well, if not better than, those raised inside. In hot and cold seasons, inside pigs grow faster. Farrowing sows in pens then turned out to feed and water, weaned as many or more pigs than sows confined to a stall for the entire lactation. Labor requirements to manage the sows turned out daily were greater than those kept in stalls but the former had access to more exercise and consumed more feed (Stevermer 1992;Holden and McGlone 1997).

An increasing number of today's producers are re-evaluating the viability of alternative swine production systems that may include pasture farrowing and finishing, hoop houses, utilizing straw for farrowing and finishing and Swedish deep straw-bedded systems (Bergh 1998). Evaluation criteria include economics, labor, animal well-being, productivity, environment, and marketability. Based on these criteria the alternative systems can be financially competitive for beginning, small and medium size producers and can mitigate many of the environmental concerns caused by confinement buildings utilizing liquid manure (Bergh 1998). Examples of alternative systems are discussed below.

A long-time Minnesota hog producer recently established a small intensive rotational grazing system for sows and gilts with concepts similar to that of grazing management for cattle and sheep (Bartz 1995). Sows were divided into 3 groups and grazing initiated the middle of June. Fifteen gilts and 1 boar were placed on two acres of alfalfa with orchard grass; seven 4th litter sows on 1 ½ acres of oats, rape, and field peas; and 7 sows kept in confinement and fed a coventional corn and soybean meal diet. Each grazing system was divided into paddocks and sows rotated between paddocks every 4 days. Sows on pasture were fed 1 ½ lbs corn daily. The systems were grazed through two cycles and sows were taken off pasture between September 15 (91 days on alfalfa pastures only) and October 15 (112 days on other pastures). An additional system was used from September 20 to November 10 when 7 sows and 1 boar were put on corn and non-winter hardy alfalfa pastures with a portable shade that had straw bedding. The average labor was ½ hour/day for each outside system. Overall annual feed costs/sow were reduced by $60/sow when pasture was integrated into the system compared to total confinement. Total variable costs/acre were $119.41, $292.96, and $294.96 for the alfalfa pastures, oats/rape/field pea pastures, and corn/alfalfa pastures, respectively. Observations were that sowsa nd gilts kept outside during gestation had better appetites when they came into the farrowing barn than the confined gestating sows. The birth weight of pigs from outside sows were similar for those kept indoors. The average 21-

day weight for the outdoor pigs was 2 lbs heavier/pig and pigs from sows kept outdoors reached a 230 lbs market weight 4 days faster than pigs form indoor sows. The project demonstrated the potential for using grazing in a pig enterprise.

In Sweden by 1985, the deep-bedded housing systems with individual feeding stalls and spacious area in uninsulated barns had become the conventional method of dry sow housing (Halverson 1998). These systems worked integrated well into the 1988 Swedish Farm Animal Protection Act which required phasing out of gestation crate systems. Adoption of deep-bedded systems for farrowing sows soon followed in the late 1980's (Halverson 1998). This technology has recently been evaluated in the U.S. Midwestern states.

A 70 ft x 37 ft Swedish style deep-bedded gestating and farrowing loose housing hoop structure for the Iowa State Univesity breeding herd has been recently evaluated (Kent 1998). The structure consisted of 22 ft x 16.3 ft pens for 12 breeding sows, a 14.3 ft x 16.3 ft pens for 6 gilts, and a 25.2 ft x 16.3 ft pens for 12 gestating sows. All pens included 7 ft individual feeding stalls plus a single waterer. Across a 4 ft alley from these pens were a weigh scale, 2 individual pens for boars, two spare pens and area for bedding storage etc. Drippers were installed over the feeding stalls to cool sows down in hot days. All floors were concreted. Large round bale cornstalks were used for bedding. The structure had an adjustable fabric curtain on the north end. Access for bedding was from the south end. The herd was based on Yorkshire x Landrace F1 gilts crossed with Hampshire boars. The hoop building is cleaned-out 4-5 times a year. Manure is either spread directly on the land or composted. The systems worked well in both summer and winter months. An average of 2.5 litters have been born/sow by the end of the first year with a 5-week weaning period. Heat, conception, and farrowing rates have been between 96 and 97%. Pre-weaning mortality was 20% which was considered the weakest part of the system. It was observed that the system has potential for midwest producers with close attention in adjusting management to sows' natural behavioral needs under a loose housing system (Kent 1998). Learning how to manage a commercial breeding and farrowing Swedish style deep-bedded unit is critical as shown by the change an average of 2.5 pigs lost/litter from crushing down to less than 1 pig crushed /litter in just over a year in a recently built 35 ft x 85 ft unit (deep-bedded straw on a dirt floor) on an Iowa farm (Wilson and Wilson 1998).

Post weaned growing-finishing pigs have been adapted to three 30 ft x 72 ft deep-bedded hoop structures housing 160-170 pigs/group on a Minnesota hog operation that also has a conventional 120-sow farrow to finish confinement system (Moulton and Moulton 1998). Straw, marsh grass or corn stalks are used for bedding on top of clay-based pens. An average of 3 x 170 market-pig groups are moved through the structure each year. Between 60 and 80 large 1200 lb round bales of bedding/year are needed for the system. The building costs averaged $58.80/pig space compared to $180-$200/pig space for a conventional confinement building. Pigs are placed in the the hoop buildings at 40 to 50 lbs weight and marketed at 240 lbs. Feed costs at $0.07/lb average $3/pig greater for the hoop buildings compared to confinement. Overall costs (including capital investment, variable and fixed costs) of raising 3,060 pigs/year in 6 hoop buildings averaged $102.60/pig compared $140.50/pig for raising 3,000 pigs/year in a 1,000 head confinement building.

c. Beef:

The beef cow/calf segment of the beef industry is traditionally based on pastures and range systems, much of the land being used for grazing cannot be used for food crop production (Goodrich and Sticklin 1997). The focus of alternative systems for beef animals are based on efficient management intensive rotational grazing optimizing a forage based diet for growing finishing cattle all the way from weaning to market weight with some nutrient supplementation when pasture availability is limiting. Improvement in technology of grazing systems, understanding of plant growth and grazing behavior of animals have contributed to effective use of livestock production from grasslands (Gerrish 1993;DiCostanzo 1994). Traditionally, pasture has been used under intensive management or range conditions for 'backgrounding '7 month-old weaned calves until they are yearlings or older prior to being moved into a commercial feedlots for a minimum of 140 days until they reach a finished market weight.

Continuation of these lower input systems have been applied to finishing cattle on pasture in a number of states for many years. A successful pasture finishing system in North Carolina in the late 1970's utilized steer calves wintered on accumulated or harvested forage and concentrates to gain 1 to 1.3 lbs/day. The calves then were self-fed grain (limit to 1% body weight) during the spring and summer finishing period on good pasture (Barrick and Dobson 1978). Cattle that are finished on pasture are typically much older because of slower gain than those that finish in feedlot on high grain diets (20-24 months or > vs. 12 to 18 months). However, the quality of the meat from finished beef from pasture appears to be very acceptable to the consumer in countries were it is more regularly practiced than in the U.S., such as in Europe and South America.

d. Dairy:

The Minnesota dairy industry over the past 3 decades has been predominantly a confinement system emphasizing production per cow, growing and feed increased amounts of grain, reducing pasture use, and a tendency to specialize. Cost of producing milk has continued to increase (Johnson 1994). Confinement housing in Minnesota is rapidly changing from the stanchion tie-stall barns to naturally ventilated free-stall systems where cow comfort is of uppermost priority. Many dairy producers may still continue to pasture dry cows and heifer but focus on a specialized confinement barn for the milking herd (Arave and Albright 1997). However, as input costs and debt loads on many dairy farms continued to rise a renewed interest in grazing systems in the Upper Midwest occurred driven by the recognition that pasture can provide an economical source of forage for dairy cattle and the potential for reduction of overall input costs to the dairy. The improvement in fencing technology since the dairy farm pasture days of the 1950-60's and concerns about the environment have also contributed to the resurgence, especially the small to medium size dairy farms (Muller 1993). As an alternative system for dairying, pasture is thought of as idyllic in terms of animal welfare. As a farming practice, good nutritional management (pasture quality and availability) and animal husbandry are still most prevalent to be successful as with

confinement dairying. Some of the challenges of pasture dairy farming include limited grazing season in the Upper Midwest; pasture quality and quantity; inconsistent supply of nutrients to sustain milk production throughout the grazing season; accessibility to shade and water; heat stress; rain and wind stress; insects and parasites; energy expenditure in grazing and travelling to the milking parlor, toxicity of certain soils affecting pasture and other considerations such as less time for milking cows to lie down than in confinement (Arave and Albright 1997). Despite the challenges, many producer in Minnesota have moved to grazing dairying. It has been a 'grass-roots' network resurgence with farmers continually learning from each other during pasture walks at workshops supported by other resources.

One of the more recent research studies conducted at the University of Minnnesota North Central Research and Outreach Center compared confinement and intensive rotational grazing for lactating dairy cows over two years (Rust and others 1993). They found that cows in confinement produced 5 to 8% more milk than the grazing cows, but total production costs were reduced by 30% for grazing cows. Milk production was very sensitive to pasture quality changes during the season and across the two years. Net return averaged $64.05/cow > in 1991 and $88.66/cow > in 1992 for grazing vs. the confinement system, respectively. The concept of net return/cow or per acre rather than milk production is the key emphasis for grazing dairy farms (Hanson 1995). The use of seasonal grazing has offset some of the limitations of the shorter grazing season and management challenges in Upper Midwest states. Managing seasonal grazing allows designed of calving patterns to take full advantage of available pasture, the number of cows milking during the winter months either reduced to a minimum or completely stopped, winter feed storage needs are much reduced, and provides more quality time for the farm family (Hanson 1995;Stelling 1999). In addition, the refinement of pasture systems for replacement heifers allows for further reduction in overhead costs to the dairy herd and more optimal heifer growth to first calving (Chester-Jones 1996).

In a survey summary of 29 grazing operations throughout Minnesota, emphasized the optimism for the potential of grazing dairy herds especially adopting management intensive grazing (MIG) techniques in Minnesota (Loeffler and others 1996). These 29 farms were considered typical Midwestern family dairy farms averaging 58 cows and 300 acres of land. Improved quality of life because of reduction of time spent doing chores was considered a primary benefit of adopting MIG.

e. Sheep:

As with beef cow/calf operations, the ewe and lamb flock have been based on pasture systems under intensive or extensive grazing management. Modifications are now centered on improving the understanding of grazing behavior and plant growth and their interface (DiCostanzo 1994). Confinement feedlots are common for market lamb production. A balance between inside housing and pasture is often needed for the ewe flock during lambing season and in the winter months. Much research has been conducted to genetically select breeds or crosses that will best utilize the diverse regions of the US. Recent efforts in Minnesota at the University of Minnesota West Central Research and Outreach Center

(WROC) are focusing on matching the ewe and lamb flock to their production environment by optimizing the use of a forage based intensive rotational grazing systems with an emphasis on low input systems and good pasture management (Head 1999).

An example of alternative systems for growing market lambs by grazing fall forages vs. more conventional systems were investigated by Head and Cuomo (Head and Cuomo 1998) at WROC. August weaned lambs were assigned to feedlot or grazing diets. Feedlot lambs were fed alfalfa meal and whole corn (ALM) or alfalfa hay, whole corn and ½ lb soybean meal (AC). Grazing lambs were offered alfalfa pasture (AG – grazed from August to October 31) or turnips (T – grazed from August to November 18). When removed from their respective pastures, grazing lambs were fed a feedlot diet until December 5, when all the study lambs were marketed. There were no differences in lamb performance of ALM. AC or AG lambs. Lambs that grazed turnips had the lowest gains but were on the feedlot diet less than the AG grazed lambs. Grazed lambs had leaner carcasses and thinner body wall measurements than feedlot lambs. The study indicated that grazing can be a viable alternative to finishing lambs in a dry feedlot if environmental conditions allow.

SECTION D: INCIDENCE OF DISEASE AND SICKNESS

1. Introduction

In the U.S., the primary national animal health-monitoring role is provided by the National Animal Health Monitoring System (NAHMS), conducted by the United States Department of Agriculture Animal and Plant Health Inspection Services (USDA-APHIS) (Wineland and Dargatz 1998). Its initial direction was provided by the Animal Industry Act of 1884, which directed the Bureau of Animal Industry (the APHIS predecessor) to "collect such information...as shall be valuable to the agricultural and commercial interests of the country." In the 1970's, the National Academy of Science provided direction for APHIS to re-evaluate its role in providing animal agriculture's information needs in the context of contemporary food animal production (National Academy of Sciences 1974). This report outlined the need for scientifically sound and statistically valid national information, that is also timely, accurate, and user-friendly. Collaboration of the APHIS network of federal veterinarians located throughout the U.S. with animal diagnostic laboratories and ongoing collaborations with State animal health officials were recognized strengths to enhance the development of a monitoring system.

The National Academy of Sciences vision was pursued, starting in the mid-80's and has led to the development of the current NAHMS program. This program operates differently from other APHIS regulatory programs in that producer participation is voluntary and the confidentiality of data from individual operations is assured. Data quality is critical to the validity of NAHMS national estimates and a key part of data quality is the selection of a random sample of food animal populations. Collaboration with the USDA-National Agricultural Statistics Service (NASS) allows statistical sampling of U.S. food animal operations for data collection. NAHMS conducts a needs assessment of critical information gaps involving the industry and related groups, before a study is designed. This allows the selection of the optimal study design to collect the needed data. After data collection and validation, data are analyzed and interpreted, and reports are made available via multiple formats, including the NAHMS webpage (http://www.aphis.usda.gov/vs/ceah/cahm).

2. Herd Size

Because of management practice differences by herd size, herd size has long been used as a proxy for management practice differences between livestock production enterprises and many diseases have been reported in epidemiologic studies in relation to herd size. Examples include Salmonella shedding in swine and cattle. When related to animal health or disease, however, this information should be viewed cautiously. Larger herds are more likely to contain at least one diseased or infected animal even if the prevalence of disease is the same across herd sizes, due only to increased numbers of animals at risk. When reviewing the scientific literature, it is sometimes difficult to separate this diagnostic bias from factors that are truly related to herd size. In addition, herd size is often evaluated in epidemiologic studies as a proxy for management practices and environmental conditions which were not specifically evaluated in the study. It may be important to include herd size in the evaluation, to best estimate effects of other specified

factors, but it may not be possible to directly interpret herd size in relation to the health problem. Therefore interpretation of herd size relationship with health problems from epidemiologic studies evaluating associations between management practices and health problems at the herd level should be viewed cautiously.

Some studies have shown higher prevalence of disease (e.g., footwarts in dairy herds) and disease pathogens (e.g., Johne's disease and Salmonella in dairy herds) in larger herds (NAHMS 1996). Other studies have demonstrated certain health advantages are more common in larger size herds. For example, higher milk quality and reduced incidence of subclinical mastitis has been shown with larger dairy herd sizes (NAHMS and USDA Ag. Marketing Service). Similarly, lower incidences of clinical mastitis and metabolic diseases such as milk fever and displaced abomasum have been evidenced in larger dairy herd sizes (NAHMS 1996). In swine, the adoption of high-health techniques, such as segregated early weaning (SEW) are only possible in large herds. Because of this, modern large SEW herds have a much higher level of health than the conventional small continuous-flow herds (see following section on Prevention and Mitagation Measures).

3. Behavioral Vices – Poultry

Two vices, which appear common across all domestic poultry, are feather pecking and cannibalism. Feather pecking can result in significant loss of feathers most often along the back of the bird. Feather pecking is not associated with aggression and its activity has been hypothesized to be redirected feeding activity. As reviewed by Appleby and co-authors (Appleby and others 1992), there are many different influences on the incidence of the behavior which relate to individual bird characteristics, genetics, and environmental conditions such as housing, density, feed, and lighting. The behavior can spread rapidly as others in the flock copy the activity.

Feather pecking has been associated with cage systems but can be observed regardless of housing condition (free-range, deep litter, or cage). In either case, increasing bird density appears to be associated with more feather loss. However, an exact space requirement to reduce feather pecking may not exist due to the influence of other management and environmental conditions. Density studies conducted under similar conditions vary in the incidence of feather pecking and impact of space allotment.

In contrast to feather pecking, cannibalism is more often observed in non-cage systems. Significant losses due to cannibalism can occur in confinement as well as alternative systems such as free range. There is some speculation that it may arise from feather pecking due to the skin damage or bleeding that may occur when the feather is pulled out. Pecking at the vent of laying hens may also occur just after egg laying. Aggressive pecking (feather pulling) which draws blood can induce cannibalism. As in feather pecking, other individuals in the flock will copy the behavior. Mortality loss can be severe. The incidence, which again can be variable, appears to be related to flock size as increasing group size increases the chance for more birds to imitate the undesirable behavior. This contributed to the use of cages which restrict the access of the birds to the "pecking bird".

Beak trimming is used to reduce feather pecking and cannibalism (Cunningham 1992). At this time there are no other effective alternative methods. There is research being conducted on ways which would allow less dependence on beak trimming as a control method, such as, enhancing the environment of the cage, improving cage design, and low light intensity, (Appleby 1998;Tauson 1998) and genetic selection for strains of chickens to reduce the incidence of feather pecking and cannibalism (Muir and Craig 1998). Some management considerations include feeding of mash instead of pellets (Lindberg and Nicol 1994) and using low light intensities (Kjaer and Vestergaard 1999). However, these have limitations relative to the type of production and controls available. Research is also being conducted on obtaining better understanding of the behaviors itself that may lead to improved housing design. As indicated earlier, the behavior seems to mimic feeding behavior thus research is examining foraging behavior and its relationship to feather pecking (Hubereicher and Wechsler 1997;Hubereicher B. and Wechsler 1998;Blokhuis and Wiepkema 1998;Hubereicher B. and Wechsler 1998;Blokhuis and Wiepkema 1998).

4. Behavioral Vices – Swine

Behavioral problems in swine include stereotypic behaviors, cannabalism, and aggression between contemporary animals. Stereotypic behaviors are activities performed by pigs that seem to serve no useful purpose to the animal. Most often, these behaviors are associated with pregnant sows housed in confinement systems. Some examples of stereotypic behaviors include bar biting, sham chewing, licking, and other mouth-based activities which may be expressed due to the sow's frustration with the limited amount of feed offered her (Appleby and Lawrence 1987). Usually, sows are restricted in their feed intake during pregnancy to avoid excessive weight gains that are detrimental to efficient farrowing performance and milk production in the subsequent lactation. Bar biting is a behavior that is not expressed in outdoor or group housing systems but that does not mean that welfare of sows in such systems is better than similar sows in confinement. Bar biting is not an appropriate behavior for sows housed outdoors because there are no bars to bite. Mench and van Tienhoven (Mench and van Tienhoven 1986) warned that the absence or presence of a particular behavior in relation to animal welfare must be interpreted in the context of the production setting. Den Hartog et al. (Den Hartog and others 1993) reported that sows housed in stalls, confined to stalls with a girth tether or housed in groups demonstrated no significant differences in the incidence of stereotypic behaviors. They suggested that stereotypic behaviors expressed by sows are a result of the feeding system rather than the housing system.

Cannibalism is most often expressed as tail biting and ear biting in growing-finishing pigs and is more prevalent in confinement systems compared with extensive systems. The suspected causes of these behavioral vices are many. Our limited understanding of this problem is derived primarily from anecdotal evidence. There are very few controlled studies that have characterized the causes and solutions to problems of tail biting and ear biting. A basic premise is that cannibalism occurs when environmental stressors compromise the pig's comfort. Poor air quality, overcrowding, insufficient access to feed or water, and dietary mineral deficiencies have all been suggested as causes of tail biting. These suspected causes can all be corrected through

improved management; however, these changes in management are not always 100% effective in correcting the problem. The widespread practice of docking tails in confinement systems seems to be the most effective management practice to control tail biting (Ensminger and Parker 1997;Simonsen and others 1991).

Aggression among pigs housed in groups whether in confinement or extensive systems is a constant issue for pig producers. The social hierarchy among animals creates a dominance and submissive relationship between each member of the group. With sow groups, the "boss sow syndrome" makes it difficult for producers to satisfy the nutritional needs of all females in the group because the dominant sow (the boss sow) controls and consumes more than her share of the feed. When pigs of any age from different contemporary groups are mixed, fights break out as pigs establish their social hierarchy. There is little managers can do to eliminate this aggression. McGlone et al. (McGlone and others 1986) reported that spraying androstenone (an androgenic hormone) on the noses and heads of recently mixed nursery pigs reduced aggression and transiently improved the performance of regrouped finishing pigs. Bjork et al. (Bjork and others 1988) injected pigs with amperozide (a tranquilizer) immediately before mixing strange pigs and found a reduction in fighting and fighting induced injuries. The practical significance of these studies in production settings and their efficacy with sows is yet to be determined.

In extensive systems group farrowing and lactation are common. Under this approach, a group of sows are housed together but are provided individual huts or cubicle in which they can deliver and nurture their piglets. The young litter is confined to its hut or cubicle until they are large enough to jump out the front door which usually occurs at about one week of age. All sows must farrow within one week of each other or cross robbing will occur. Cross robbing is when older, more dominant piglets suckle other sows in addition to their own dam. This behavior steals milk from the younger piglets and compromises their ability to obtain nourishment and grow normally. The pork producer can virtually eliminate this problem by ensuring that all sows in a group farrow as close to the same day as possible.

Vocalization is sometimes viewed as indicating a problem in certain husbandry practices and especially so in confinement systems. Examination of swine vocalization revealed several factors played a role (Xin and others 1988). Vocalization was recorded via a microphone after 10-15 minute for the pigs to adjust to the presence of the recorder. The data were processed using a signal processor for sampling rates of 10 to 20 Hz. Vocalization occurred for several reasons which were categorized as follows:

Prior to feeding of hungry breeding-gestation sows who were anticipating feed – ***Food Anticipation;***
Breeding sows in heat while in their own pen – ***In Heat;***
Greeting response of breeding sow to mate (boar) – ***Mate greeting;***
Farrowing sows – ***Farrowing;***
Sow response to piglets suckling – ***Nursing;***
Processing piglets, i.e., castration, teeth clipping, ear notching, and tail removal – ***Processing;***
Isolation of piglets with human disturbance – ***Isolation;***

Startled response of nursery pigs by sudden appearance of people in the facility – ***Startled.***

As the stress of the animal became more severe, the duration and frequency of the vocalizations increased. The processing of piglets was most severe followed by food anticipation, sows in heat, isolation of piglets, startling of nursery pigs, and farrowing. Nursing and mate greeting responses were considered to be non-stressful indicating calls. This information can be applied to the understanding of animal well-being.

5. Behavioral Vices – Cattle

Behavioral vices in cattle are related to the social structure established within a group and is frequently expressed as a tendency to follow group leaders and their tendency to be inquisitive (Albright 1993b). Depending on the livestock system and particular stimuli, beneficial (following leaders to a feedbunk, milking parlor, to and from pasture etc.) or detrimental (stampede) behavioral patterns may be expressed (Baker 1981). A knowledge of the physiological needs of cattle go hand-in hand with animal well-being, animal health, animal management and system design.

Cattle alternate between eating, ruminating, defecating, urinating, and postural changes (getting up and lying down). Grazing cattle will have 3 to 5 periods of grazing during the day, the longest and most intensive just after dawn or before dusk. They will graze for 6 to 12 hours and use 20,000 to 40,000 bites to consume their feed. This depends in part on the availability of pasture. They ruminate for 6 to 8 hours/day and typically walk over 2 miles daily (Hodgson 1990). Cattle prefer to defecate and urinate in areas where they rest and congregate. This includes areas typically frequented such as under shade or near their source of food and water. Good pasture management and strategic placement of water/feeding areas will improve distribution of manure nutrients across paddocks. Proper management will also prevent excessive wasteage of pasture due to refusal to consume pasture from manure contaminated areas (Gerrish and Patterson, 1994).

In confinement, cattle will eat for 4 to 6 hours per day and ruminate for time periods (6 to 8 hours) similar to those of grazing cattle. Confined cattle expend 10 to 20% less energy than cows on pasture. An example of the breakdown of daily behavior by a high producing dairy cow (Beecher Arlinda Ellen, the world milk production record holder at one time) in confinement has been documented (Albright 1993b). Within a 24 hour period, she spent 6.25 hours consuming feed, almost 14 hours resting (she ruminated for 7 ½ hours while resting) and she defecated 12 times and urinated 7 times.

In both indoor and outdoor systems, young, less-experienced animals need to learn feeding and water locations. Thus, these locations must be placed to encourage their accessibility (Albright 1993b). A number of research studies have been conducted to evaluate cattle behavior (Arave and others 1974;Friend and Polan 1974)(Fraser and Herchen, 1979)(Curtis and Stricklin 1991;Albright 1993b;Reynells and Eastwood 1997). Every group of cattle contains those that are totally dominant, medium dominant, or totally submissive. Dehorned or naturally polled

cattle are much less likely to be involved in fights that result in injury (Goodrich and Sticklin 1997).

Mixing a group of cattle will cause aggressive behavior until a social order is established (Friend and Polan 1974). Once an order is established, the feeding drive becomes dominant and cows in the group will conform to the established social order. In pasture situations, cows will follow their group leaders as these more dominant cows satisfy their own needs in an independent manner. In controlled feeding situations the dominant cows will spend more time eating than cows lower in the established social order. This behavior becomes more apparent in competitive situations when feed availability is limited (Manson and Appleby 1990).

Less physiological stress is placed on dairy cows, for example, if the feeding area in a confined system allows cows to consume feed in the natural head-down grazing position. This head position stimulates saliva production. Poorly designed feeding areas with elevated bunks will cause more feed sorting and feed tossing which results in animal stress, feed waste, and reduced feed intake (Albright 1993b). When one cow eats, her expressed behavior stimulates others to follow. The dominant animal in the group initiates this and serves as a social facilitator (Curtis and Houpt 1983). When cattle are moved to new locations (pens or paddocks), it is best to move them as a group to minimize the stress of social adjustments. Differences among cattle in their expression of behavioral patterns and temperament will be determined in part by their experiences as a young animal. Consistent, gentle handling throughout their productive life (Curtis and others 1988) contributes to the development of cattle that are comfortable with their surroundings.

6. Parasites

a. Introduction

Many different kinds of parasites affect agricultural animals in North America. Some of the parasites are host specific, meaning they are associated with just one kind of host animal; these probably "came along" while their hosts were being domesticated in the Old World. In contrast, others evolved with wild animals in North America, and expanded their host range to include domesticated animals when Europeans immigrated to this continent. From an ecological perspective, free-ranging animals are exposed to the greatest variety of parasites, whereas animals that are confined in drylots or indoors are exposed to progressively fewer kinds.

The effects of parasites on agricultural animals are quite varied, and depend on kind of parasite, on kind of host, on host condition, and on number of parasites per host animal (parasite density) (Campbell and Thomas 1996;Leaning and Guerrero 1987;Stromberg 1997;Stromberg and Averbeck 1999;Leaning and Guerrero 1987;Stromberg 1997;Stromberg and Averbeck 1999). Effects include changes in host behavior and appearance, and reductions in rates of gain, lactation, wool growth, egg laying and feed conversion efficiency. Consequently, parasites are generally regarded as threats to animal health and well-being. A goal of husbandry should be to minimize parasitism by preventing transmission if possible,

or through treatment and control of the parasites on their hosts or in their hosts' environments.

Several types of parasites (Tables 1B5) attack each of Minnesota's principal agricultural animals. There are too many parasites to review each host-parasite combination in detail for this review. To simplify the coverage, it is convenient to consider them in five functional groups:

Skin inhabiting ectoparasites are host specific and spread by animal-to-animal contact.

Free living flies are less host specific and develop as immatures off their host in various substrates in the environment.

Internal parasites are host specific and can be grouped according to route of spread. They can be acquired by

a. ingestion of feed that was contaminated earlier with feces (fecal-oral route),
b. ingestion of intermediate hosts such as earthworms, or
c. sexual contact with other infected animals.

The purpose of this review is to summarize what is known or can be inferred about the factors that affect diseases caused by parasites in these functional groups in Minnesota. It should be stated at the outset that many individual farms have routine parasite monitoring and control programs, but there are no systematic reporting systems for any of Minnesota's animal industries. The following summaries are based mainly on personal observations of the authors, on frequencies of cases submitted to the University's diagnostic labs, and on reports and inquiries from producers, veterinarians and Extension personnel throughout Minnesota and neighboring states.

b. Swine

1) *Skin Inhabiting Parasites:*

Itch mites (*Sarcoptes scabiei*) and hog lice (*Haematopinus suis*) cause mange and pediculosis, respectively, and these two parasites are endemic in Minnesota swine herds. Itch mites can cause pruritus, dermatitis and economically significant reductions in growth rate, feed conversion and piglet survival (Arends and others 1990;Arlian 1989;Davis and Moon 1990;Dobson 1971;Arlian 1989;Davis and Moon 1990;Dobson 1971). Herd prevalence in Minnesota ranged from 5% in summer to 21% in winter (Davies and others 1996), as determined by slaughter check-backs for herds that probably were better managed than average. Prevalence of hog lice has not been quantified, but they are widely prevalent elsewhere (Wooton-Saadi and others 1987;Sabiiti and others 1979;Sabiiti and others 1979). Pediculosis is apparently benign (Bynum Jr. and others 1978;Davis and Williams 1986;Davis and Williams 1986).

Mites and lice are vulnerable to control with a variety of acaricides and insecticides that can be applied by injection, spray, pour-on, or feed additive. Resistance has not been documented. Efficacy depends mainly on whether or not all animals in the unit receive treatment, and on thoroughness (effective dose) of application. Availability of effective controls has made it possible to eradicate these parasites from closed herds. Because these parasites are host specific and spread mainly by contact, it is reasonable to expect that prevalence has more to do with whether a given herd was established from parasite-free stock and has remained closed to contact with other herds, and less to do with housing style, animal density and farm size, *per se*.

Table 1. Important parasites of swine in Minnesota, compiled from various sources.

			Prevalence, by style of housing*			
Type of parasite	Site of attack	Route of spread	Pasture	Open front bedded pens	Concrete or slat-floor (indoors)	Crates (indoors)
Mites and lice (2 spp)	External	Contact	+	+	+	+
House fly	External	Flight	+	+	+	+
Aquatic biting flies (>20)	External	Flight	+	+	-	-
Swine roundworm	Internal	Ingested	+	+	+	-
Lung worms	Internal	Ingested earthworm	+	+	-	-
Kidney worms	Internal	Ingested	+	-	-	-
Gastrointestinal (GI) worms	Internal	Ingested or penetrate	+	-	-	-
Coccidia	Internal	Ingested	+	+	+	-

*Prevalence codes: + = important or common; - = rare or absent

2) *Free Living Flies:*

The house fly (Musca domestica) is a cosmopolitan species that breeds readily in decomposing organic matter around pastured and penned swine (Table 1). One experimental study showed that house fly had no effect on hog growth and feed conversion (Campbell and others 1984). House flies are important, however, as potential vectors of diarrheal pathogens (GEIS Topic IV.K) and as nuisance pests of humans (GEIS Topic III.L). House flies breed wherever spoiled feed and swine manure accumulate and remain moist (30-80% water). As reviewed elsewhere (GEIS Topic III.L), premise sanitation is the key to reduction of house fly and stable fly populations, and many insecticides are available for temporary population suppression. House flies are notoriously resistant to many of the available compounds. Effects of housing type, animal density and farm size on prevalence of house flies has not been studied directly, but the authors' impressions are that prevalence of these two flies depends more on availability of breeding sites than on anything else.

Aquatic biting flies in Minnesota consist of many species of blood sucking mosquitoes, horse flies, deer flies, blackflies and biting gnats that originate as larvae in wetlands and other aquatic sources (Williams and others 1985). Swine housed outdoors are exposed to attack, just like all other kinds of vertebrates, whereas those housed indoors are protected by exclusion (Table 1). None of these biting flies is known to vector pathogens of any importance to swine in Minnesota, and their direct effects on swine health and

well-being have not been studied.

The stable fly, which can aggregate around swine housed outdoors, does not breed readily in hog manure, so this species is much less problematic with swine than with cattle and horses. One experimental study indicated that attack by stable fly did affect piglet behavior, but did not affect growth rate or feed conversion (Moon and others 1987).

3) *Internal Parasites:*

Swine are hosts to a variety of internal parasites, many of which spread from pig to pig via fecally contaminated feed (Table 1). Others spread by more specific routes involving intermediate hosts such as earthworms, or direct penetration of the skin by mobile larvae contacted in the environment. Consequently, prevalence of these parasites depends greatly on how animals are housed; transmission is most likely among pastured swine, whereas transmission is more limited with pigs housed on concrete or in raised crates. These settings minimize contact with soil and contamination of feed with feces.

Perhaps the most prevalent internal parasite in the North Central states is the swine roundworm (Drummond and others 1981b;Kennedy and others 1986). This worm spreads through contaminated feed, so prevalence is greatest with pastured hogs, and as density (stocking rate, animals per unit area) increases, so does prevalence. If animals are housed indoors on concrete or raised crates, where contact with manure is limited, then prevalence is potentially lower, because source of infection is minimized. Similarly, transmission of coccidia that cause scours is minimized when young animals are raised in crates that minimize fecal-oral transmission.

A variety of antiparasitic drugs are available for control of internal parasites of swine, and these are administered as feed additives, oral drenches, pour-ons or injections. As with the skin inhabiting parasites, availability of effective products makes it possible to minimize disease severity and eradicate internal parasites from closed herds.

c. Cattle:

Dairy and beef cattle are housed in similar settings and are hosts for the same kinds of parasites, and they can be reviewed jointly.

1) *Skin Inhabiting Parasites:*

Skin inhabiting mites (2 species) and lice (4 species) can infest cattle and cause mange and pediculosis, respectively. Each disease involves pruritus, dermatitis and economically significant reductions in growth rate, feed conversion and lactation rate (Campbell and Thomas 1996). All are easily controlled with a variety of parasiticides, and resistance has not been detected. As with swine, skin inhabiting parasites can be eradicated from closed herds, and prevalence has more to do with whether a given herd

is closed than with anything else.

2) *Free Living Flies:*

Four kinds of free living flies are associated with cattle (Table 2). The most ubiquitous ones are the stable fly and the house fly, both of which develop as larvae in decomposing organic debris (GEIS Topic III.H). Stable flies and house flies are most abundant around confined cattle, but stable flies will disperse readily from confinement breeding sites to surrounding areas, so they are abundant on pastured cattle, too. Stable flies cause noticeable irritation (leg stamping and bunching) and measurable reductions in growth rate, feed conversion and lactation (Campbell and Thomas 1996;Thomas and Skoda 1992;Thomas and Skoda 1992). House flies, in contrast, are known to be a nuisance, but they have not been shown to affect animal health. Two other kinds of flies (horn fly and face fly) develop in isolated dung pats, so these species predominate on grazing cattle and are rare around confined herds. Horn flies reduce calf weaning weights, whereas face flies are secondary mechanical vectors of *Moraxella bovis*, the causative agent of bovine pinkeye (Campbell and Thomas 1996). Finally, cattle outdoors are exposed to attack by a wide variety of blood feeding, aquatic flies, few of which will enter buildings and attack cattle indoors.

Table 2. Important parasites of cattle in Minnesota, compiled from various sources.

			Prevalence, by style of housing*			
Kind of parasite	Site of attack	Route of spread	Pasture	Drylot (outdoors)	Tie or free stall (indoors)	Slat or scrape floor (indoors)
Mites and lice (6 spp)	External	Contact	+	+	+	+
Stable fly	External	Flight	+	+	+	+
House fly	External	Flight	-	+	+	+
Dung breeding flies (2)	External	Flight	+	-	-	-
Aquatic biting flies (>20)	External	Flight	+	+	-	-
Cattle grubs (2)	Internal	Flight	+	-	-	-
Lung worms	Internal	Ingested	+	-	-	-
Abomasal worms	Internal	Ingested	+	+	+	-
Gastrointestinal (GI) worms	Internal	Ingested	+	-	-	-
Tapeworms	Internal	Ingested mite	+	+	+	+
Flukes	Internal	Ingested	+	-	-	-
Coccidia	Internal	Ingested	+	+	+	+
Trichomonas	Internal	Sexual	+	+	+	+

*Prevalence codes: + = important or common; - = rare or absent

3) *Internal Parasites:*

As with swine, style of housing has a great influence on transmission of internal parasites (Table 2). Cattle grubs were once common among cattle outdoors during summer, and caused substantial losses due to slaughter condemnation and hide injury. However, their prevalence has been greatly reduced through use of systemic insecticides administered

in fall. Grubs were never abundant among dairy cattle housed indoors, because egg laying adults are reluctant to enter buildings. Lungworms and gastrointestinal worms are transmitted by the ingestion of infective larvae on herbage in fecally contaminated pasture. As animal density (stocking rates) increase, the potential for increased contamination and ingestion increase. Cattle housed elsewhere are much less exposed to infection. The abomasal worms are also transmitted by the ingestion of contaminated forage, but potential for carryover from prior grazing and subsequent expression of disease in confined settings is greater than with the other gastrointestinal parasites. Anthelmintics can reduce internal parasite burdens, and in turn reduce rate of pasture contamination. If coupled strategically with pasture rotation, it is possible to minimize disease caused by these pasture borne parasites.

Tapeworms (*Moniezia* sp.) are transmitted when cattle ingest feed that is contaminated with an oribatid mite that is the intermediate host for the immature tapeworms. The oribatid mite occurs in all styles of housing. Cattle are also intermediate hosts for other kinds of tapeworms, which occur in their muscle, and can lead to condemnation at slaughter. Prevalence of tapeworms and effects on cattle health are not well documented.

Cattle flukes can occur in animals that graze in marshy areas. Fluke eggs are shed in feces, larvae infect and develop in snails, and then exit to grass where they encyst before being ingested by grazing cattle. Flukes have a significant impact on cattle growth and productivity. Transmission is prevented if cattle are prevented from grazing on marsh grass.

Coccidia in cattle are distinct from those in other species, but their transmission by fecal-oral route is the same. Animal density is important, but as animals are moved to confinement the chance of infection decreases significantly.

Trichomonas foetus infects the cattle reproductive tract and causes abortion. Infection occurs during intercourse and is totally independent of stocking density, relying on infected anal contact. There is not treatment for this disease.

d. Sheep

1) *Skin Inhabiting Parasites:*

Sheep (Table 3) are known to be infested by mites and lice elsewhere in the world, but mites have been eradicated from North American sheep flocks, and lice are rare for reason(s) that are not clear.

Table 3. Important parasites of sheep in Minnesota, compiled from various sources.

Kind of parasite	Site of attack	Route of spread	Prevalence, by style or housing*	
			Pasture	Drylot (outdoors)
Stable fly	External	Flight	+	+
House fly	External	Flight	-	+
Wool maggots (2 spp)	External	Flight	+	-
Aquatic biting flies (>20)	External	Flight	+	+
Sheep nose bot	Internal	Flight	+	+
Lung worms	Internal	Intermed hosts	+	-
Abomasal worms	Internal	Ingested	+	-
Gastrointestinal (GI) worms	Internal	Ingested	+	-
Tapeworms	Internal	Ingested	+	+
Flukes	Internal	Ingested	+	-
Coccidia	Internal	Ingested	+	+

*Prevalence codes: + = important or common; - = rare or absent

2) *Free Living Flies:*

Both stable fly and house fly are associated with sheep in Minnesota, but effects on health and well-being have not been studied. Wool maggots are larvae that cause grisly infestations on skin of mature sheep. Egg laying females are attracted to soiled wool, so infestations are more common on ewes than on feeder lambs (in drylots), whose fleeces are generally shorter and cleaner. Sheep housed outdoors are attacked by aquatic biting flies, but effects on health and well-being have not been assessed. Biting gnats (*Culicoides* sp.) elsewhere in the US spread blue tongue virus, but the gnats here are refractory to infection by the virus.

3) *Internal Parasites:*

Sheep nose bots reside in the nasal passages of sheep housed outdoors, but infections are benign. This parasite was widely prevalent at slaughterhouse surveys in North Dakota (Meyer 1999). Other internal parasites are similar to those found in cattle, with the exception that sheep have several additional lungworms. These lungworms are acquired by ingesting snails and slugs, which are the intermediate hosts. Thus, pastured animals are at greater risk than those in drylots. In contrast, transmission of sheep tapeworms is equally likely in both settings because the oribatid mites that are the intermediate host are available in both environments.

e. Horses

1) *Skin Inhabiting Parasites:*

Horses have their respective species of mites and lice, which cause dermatitis, hair loss and pruritus. Outbreaks are rare, and usually associated with cases of extreme neglect.

Table 4. Important parasites of horses in Minnesota, compiled from various sources.

			Prevalence, by style of housing*	
Type of parasite	Site of attack	Route of spread	Pasture	Stable (indoors)
Mites and lice (3)	External	Contact	+	+
Stable fly	External	Flight	+	+
House fly	External	Flight	-	+
Face fly	External	Flight	+	-
Aquatic biting flies (>20)	External	Flight	+	-
Horse stomach bots (3 spp)	Internal	Flight	+	+
Gastrointestinal (GI) worms	Internal	Ingested	+	-
Large bowel worms	Internal	Ingested	+	-
Tapeworms	Internal	Ingested mite	+	+
Trichinella	Internal	Ingested muscle	+	-

*Prevalence codes: + = important or common; - = rare or absent

2) *Free Living Flies:*

Stable fly and house fly are common around horses. Their biology and management is the same as with cattle. Face fly adults occur on pastured horses, cause noticeable irritation, and transmit eye worms (*Thelazia* spp.). Because this fly breeds exclusively in fresh cattle dung pats, face fly problems on horses are restricted to situations where cattle are present in neighboring pastures. Aquatic biting flies, especially blackflies and horse flies, can interfere with horse comfort and equestrian pleasure. These insects are reluctant to enter buildings. One mosquito is known to transmit Western Equine Encephalitis virus from birds to horses in Minnesota. Fortunately, effective vaccines are available.

3) *Internal Parasites:*

Horse stomach bots (Knowles and Wilkins 1998) are widely prevalent, as judged from necropsies. Adult females glue their eggs to hairs on the legs and heads of horses, and will enter buildings, so prevalence is independent of housing. Larvae reside in the stomach, attached to the mucosa, but infections are benign. Nonetheless, treatment by oral drench or injection is a routine part of fall horse care.

Other gastrointestinal parasites include the large bowel worms. These are the primary pathogens and consist of large and the small strongyles. The large strongyles (i.e. *Strongylus vulgaris*) may be very pathogenic, potentially causing death. The small strongyles (of which there are over 30 different species) are less virulent, but can cause clinical parasitism (sick horses). All of these worms are acquired from fecally contaminated pasture, so they are more abundant among pastured horses than among stabled ones. Many of these worms have developed resistance to some anthelmintics, so it is now necessary to alternate between classes with different modes of action.

The more specialized parasites can occur in both pastured and stabled horses. With tapeworms, the intermediate host, an oribatid mite, occurs in both environments. Similarly, *Trichinella spiralis* requires a rodent as an intermediate host. A number of foreign countries are unwilling to import horsemeat from the U.S., in part because this parasite is endemic in this country.

f. Poultry

1) *Skin Inhabiting Parasites:*

Broiler chickens and turkeys are generally free of skin inhabiting mites and lice. It may be that these meat birds simply do not live long enough to become noticeably infested. It may also be that source populations of mites and lice have been eradicated from breeder flocks, or that production flocks are prevented from becoming infested by all-in, all-out housing in closed facilities. The lack of exposure to infected, wild birds clearly contributes to this low level of infestation.

In marked contrast, northern fowl mite (Kells and Surgeoner 1997) is a chronic problem in many laying hen flocks in Minnesota and elsewhere in North America that consist of multi-age birds. This mite's host range includes all forms of poultry, pigeons and sparrows, and it has noticeable effects on hen comfort and productivity. Populations in California, Arkansas and Atlantic Seaboard states are known to be resistant to several acaricides.

It is not clear why this mite is peculiarly troublesome in caged layer flocks, but it appears to be more prevalent in units that contain birds of multiple ages. Canadian workers (Kells and Surgeoner 1997) found that mites were imported into study barns on pullets at time of stocking, and spread among barns on egg handling equipment. Once a few birds in a house were infested, the mites reproduced rapidly among adjacent cages, suggesting crowding and cage design predispose caged layers to mite outbreaks. Although, it is known that resistance to mites increases with hen age, and that susceptibility varies among some lines of breeding hens units that contain birds of multiple ages have older birds with these mites. Thus it appears that mite outbreaks could be traced to factors other than housing.

2) *Free Living Flies:*

Poultry housed in open sided barns and on pasture are attacked by several species of aquatic biting flies, but their effects on bird comfort and productivity have not been assessed. One species of mosquito (*Culex tarsalis*) vectors western encephalitis virus among birds, including poultry, but infections in poultry are benign. Mosquitos do serve as a vector for pox virus. Blackflies are known to vector protozoa that cause duck malarias in Minnesota, and a form of turkey malaria in the Gulf Coast states but not in Minnesota.

3) *Internal Parasites:*

Although poultry are hosts for a wide variety of internal parasites, the most important ones are coccidia. Birds raised on pasture or barn litter are more exposed to infection than birds housed in wire cages, and coccidia have a very significant impact on growth and productivity. Similarly, gastrointestinal worms, tapeworms and flukes can affect poultry health and are more prevalent among flocks on pasture or litter, where fecal contamination of feed and intermediate hosts are more accessible. Contemporary birds (broilers) grow more rapidly than their ancestors. Their shorter life cycle is less than that of the fluke worm which makes this less of a problem for the contemporary broiler.

Table 5. Important parasites of poultry in Minnesota, compiled from various sources.

			Prevalence, by type of bird and style of housing*				
			Egg layer	Broiler		Turkey	
Type of parasite	Site of attack	Route of spread	High or low-rise (indoors)	Pasture	Litter barn (open sides)	Pasture	Litter barn (open sides)
Northern fowl mite	External	Contact	+	-	-	-	-
Aquatic biting flies (>20 spp)	External	Flight	-	+	+	+	+
Gastrointestinal (GI) worms	Internal	Ingested	-	+	-	+	-
Tapeworms	Internal	Intermed host	-	+	+	+	+
Flukes**	Internal	Ingested	-	+	+	+	+
Coccidia	Internal	Ingested	-	+	+	+	+

*Prevalence codes: + = important or common; - = rare or absent

**Birds serve as an intermediate host. Contemporary broilers have a life cycle that is less than that of the worm cycle.

7. Bovine Spongiform Encephalopathy (BSE)

Bovine Spongiform Encephalopathy (BSE or mad-cow disease) is a transmissible, slow progressing, fatal, nervous disorder of adult cattle. It is characterized by the formation of holes in the nerve cells and results in a chronic degeneration of the brain (a spongy brain disease). The first known case of BSE was diagnosed by a veterinarian in the UK in April 1985 (Lanchester 1996). The first account of the disorder was published in the British Journal, Veterinary Record in October, 31, 1987 and by the end of 1987 there had been 420 cases of confirmed cases of BSE (Lanchester 1996). The disease became a National Notifiable disease by the Ministry of

Agriculture, Fisheries, and Food (MAFF) in the UK in June 1988. The events surrounding the increased awareness of BSE, the need for clear and timely explanation of risks, and the importance of effective communication of scientific information on potential health problems have been summarized (Powell and Leiss 1997;Ratzan 1998).

Affected cattle may display changes in temperament, such as nervousness or aggression; abnormal posture; in coordination and difficulty in rising; decreased milk production; or loss of body weight despite continued appetite. The incubation period (time from when animal becomes infected until it first shows the disease signs) is from 2 to 8 years. Following onset of clinical signs, deterioration is rapid and the infected animal dies, or is destroyed, anywhere from 2 weeks to 6 months. Most cases in the UK occurred in cattle from 3 to 5 years of age.

The symptoms are similar to other rare, neurological disorders that affect humans and other animals. The most common of these is scrapie, which causes sheep to compulsively scratch themselves. The epidemiology of BSE in the UK suggests that it is linked to feeding cattle rendered protein produced from the carcasses of scrapie-infected sheep. Scrapie has been endemic in the UK for centuries and rendered products from sheep have been used in cattle rations in the UK for decades.

The transmissibility of the disease is linked to infectious proteinaceous particles known as prions or "slow viruses" which are more difficult to destroy than normal viruses. As infectious agents, prions are extremely resistant to heat and normal sterilization processes (Pratt 1996). In the early 1980's, rendering plants in the UK stopped using a steam-heat enhanced solvent extraction process to enhance the yield of tallow and fat from carcasses because of safety concerns for the workforce. This change in processing is considered a causal factor in the outbreak of the disease (IFST 1999;Pratt 1996;Lanchester 1996). The prion has only been found in brain tissue and spinal cords of cattle infected with BSE.

The disease became an epidemic in the UK. From April 1985 to April 1999, some 176,433 cases of BSE were confirmed in the UK (IFST 1999). The number of new UK cases peaked in 1992 at 36,682. In contrast, only 911 non-UK cases of BSE had been detected by May 1999 (IFST 1999). Confirmed cases of the disease have been reported in domestic cattle in Ireland, France, Portugal, and Switzerland and in cattle exported from England to Oman, the Falkland Islands, Germany, Denmark, Canada, and Italy. In March 1996, the European Union banned the export of British beef. This ban was lifted in November 1998 (IFST 1999).

Implementation of a number of measures reduced new cases dramatically. By April 30, 1999, new cases had declined to 599. These measures included a prohibition in 1988 of the use of rendered by-products derived from ruminants as a feed for ruminants in the UK. A nation-wide slaughter and destroy policy for animals clinically diagnosed with BSE and offspring of infected cattle was implemented in 1988. The reduced number of cases indicates the program is on target for the epidemic to come to an end very quickly (IFST 1999).

Related transmissible spongiform encephalopathy (TSE) disorders include scrapie in sheep and goats, transmissible mink encephalopathy, feline spongiform encephalopathy, chronic wasting

disease of mule deer and elk, and three rare diseases in humans (Kuru, Creutzfeldt-Jakob Disease- CJD, and Gertsmann-Straussler Syndrome). Evaluation of more recent CJD cases in the UK identified a new variant of the disease (v-CJD). The prion protein from individuals with this variant of the disease has a similar molecular structure as the BSE prion. This at least raises the concern that BSE could have been transmitted to humans (Collinge and others 1995). However, there remains no direct evidence of a link between BSE and CJD (IFST 1999). In addition, there is no scientific evidence that sheep scrapie can be transmitted to humans either occupationally or by eating sheep meat (IFST 1999). Surveillance of CJD in the UK indicates an average incidence of 50 cases per years during the 90's (IFST 1999). This agrees with the annual rate of CJD cases of 1 in 1 million for other European countries and the US (IFST 1999;Lanchester 1996).

No cases of BSE have been detected in the U.S. The USDA Animal Health and Plant Health Inspection Service (APHIS) has become very proactive to ensure that the disease is not established in the United States (Pratt 1996). The USDA/APHIS restricts importation of live ruminants and ruminant products from countries where BSE is know to exist. Import restrictions have been imposed on other products derived from ruminants such as fetal bovine serum, bone-meal, meat and bone-meal, blood-meal, offal, fats, and glands except for special permits for scientific research only (Pratt 1996). Trained BSE Veterinarians have found no evidence of BSE in 93% of the 499 cattle imported cattle from England between 1981 and 1989. Efforts are continuing to trace the other 7%. A large effort involving APHIS veterinary pathologists, field food safety inspectors, and other trained investigators in numerous state diagnostics labs and animal health services, are conducting surveillance activities. In the US, rendering companies can no longer pick up deceased or destroyed sheep. The National Animal Feed Industry has implemented a ban on use of animal protein byproducts from processed sheep. These are pro-active measures that will ensure continued supply of safe food in the U.S.

SECTION E: AIR QUALITY

1. Introduction

Air quality is part of the environment that affects animals health and well-being. Other environmental characteristics include temperature (i.e., dry-bulb, surrounding surface, dew-point), moisture (i.e, air, surfaces, bedding/litter), light (i.e., intensity, photoperiod length, color characteristics, uniformity), nutrition, and many other factors.

Clean dry air is comprised of many gases including nitrogen (78%), oxygen (21%), argon (0.9%), carbon dioxide (0.03%), and trace amounts of neon, helium, methane, sulfur dioxide, hydrogen, krypton, xenon, and ozone (ASHRAE 1997). Atmospheric air contains these gases plus water vapor and miscellaneous contaminants, some from natural sources and some the result of human activity.

Airborne contaminants can be categorized in numerous ways. The categories used for this report are; gases and odors, particulates or dusts, and biogenic particles. O'Neill and Phillips (O'Neill and Phillips 1992) created a list of 168 compounds identified in livestock wastes or the air around them. The list is in the GEIS Air Quality and Odor report. Dusts in and around animal facilities include bits of feed, dried skin, hair or feathers, dried feces, and soil particles (Koon and others 1963;Anderson and others 1966;Curtis and others 1975;Heber and others 1988;Alegro and others 1972;Sweeten and others 1988;Sweeten and others 1998;Anderson and others 1966;Alegro and others 1972;Sweeten and others 1988;Sweeten and others 1998). Feed was found to be the primary component of the dust (Curtis and others 1975;Heber and others 1988). Biogenic particles include bacteria, viruses, fungi spores, amoebae, algae, pollen, plant parts, insect parts and wastes, endotoxins and mycotoxins. Endotoxins are naturally occurring substances in the cell walls of gram negative bacteria that are released when the microogranisms die. Mycotoxins are toxins produced by fungi.

Air quality within animal facilities depends on many factors including the ventilating system and air exchange rate, temperature, relative humidity, manure system and management, bedding use, feed form and quality, feeding system, and animal activity. Many air quality studies have reported contaminant concentrations measured in livestock facilities. Some of the studies are summarized in the following sections. It should noted that many of these studies are from European research, climates and some specifics that may differ significantly from US or Midwest conditions. It should also be noted that both indoor and outdoor animal units (as well as agronomic fields and other situations) have periods where dust and microbe contents in the air are less than, equal to, or greater than the levels established by regulations such as the EPA clean air act. For example, a recent study demonstrated that methods to reduce particulate matter (dust particles and associated fungi) are needed on certain days to enhance animal and worker health and well-being within indoor and outdoor pig production units (Morrow-Tesch and others 1999).

2. Dust Concentrations in Animal Buildings

There is a large amount of literature reporting dust concentrations in animal buildings. Sampling techniques and building conditions vary widely. The results indicate that animal buildings can be quite dusty. Inhalable and respirable dust concentrations within various cattle, swine, and poultry facilities have been reported (Table 1) in Europe (Takai and others 1998).

Inhalable dust was collected using an IOM (Institute of Occupational Medicine, Edinburgh) dust sampler, which represents the dust inhaled through a human's nose and mouth (Mark and Vincent 1986). Respirable dust was measured using a cyclone in series with a filter. The cyclone removes most of the particles with an aerodynamic diameter of 5 microns or more. The remaining respirable dust captured on the filter represents the dust that can penetrate deeply into the respiratory tract and the lungs. Both samplers are commonly used in personal dust sampling.

Table 1. Mean inhalable and respirable dust concentrations in English, Dutch, Danish, and German livestock buildings (Takai and others 1998).

	Mean inhalable dust concentration (mg/m^3)	Mean respirable dust concentration (mg/m^3)
Cattle Buildings (dairy and beef)		
England	0.22	0.15
The Netherlands	0.30	0.09
Denmark	0.39	0.04
Germany	0.65	0.05
Overall mean	**0.38**	**0.07**
Pig Buildings		
England	1.87	0.24
The Netherlands	2.43	0.25
Denmark	2.76	0.26
Germany	1.95	0.18
Overall mean	**2.19**	**0.23**
Poultry Buildings		
England	3.31	0.51
The Netherlands	4.58	0.58
Denmark	4.52	0.64
Germany	2.22	0.19
Overall mean	**3.60**	**0.45**

Overall, airborne dust levels were higher in pig and poultry buildings than in cattle buildings (Takai and others 1998). Statistical analysis indicated that the interaction between country and housing type was significantly different for both inhalable and respirable dust concentrations. Dust concentrations in cattle buildings were not affected greatly by season. Inhalable dust

concentrations in both pig and poultry buildings were significantly affected by country, housing type, season, and sampling period (day versus night). Respirable dust concentrations in pig barns were not affected by country. Respirable dust concentrations in poultry buildings were not affected by sampling period. Inhalable and respirable dust concentrations were lower in caged layer buildings compared to those in percheries (laying hen facilities with litter flooring and perches). Inhalable and respirable dust concentrations in broiler barns were generally comparable to those in percheries in England and The Netherlands but slightly lower in Denmark. Ventilation and feeding practices, bedding materials, manure handling all affect dust concentrations (Takai and others 1998).

Total dust concentrations in turkey barns in Minnesota ranged from 0.4 to 13.8 mg/m^3 across two studies (Mulhausen and others 1987) (Reynolds 1994). Concentrations were highest in the winter. Respirable dust concentrations ranged from 0.1 to 2.6 mg/m^3 (Reynolds 1994). Total dust concentrations in broiler barns in North Carolina ranged from 0.02 to 11 mg/m^3 (Jones and others 1984). Respirable dust levels ranged from 0.02 to 0.62 mg/m^3. Bird age, litter age, and animal activity were factors (Jones and others 1984). Total and respirable dust concentrations in caged layer barns in Sweden were comparable or less than those in barns without cages (alternative housing) (Martensson 1995). Total dust concentrations in the conventional caged layer barns ranged from 1.3 to 2.7 mg/m^3 while respirable dust concentrations ranged from 0.08 to 1.04 mg/m^3. Corresponding total and respirable dust concentrations in the alternative barns ranged from 2.6 to 4.1 mg/m^3 and 0.08 to 1.13 mg/m^3, respectively.

Total dust concentrations in an Italian horse stable ranged from 0.26 to 10.82 mg/m^3 with a mean concentration of 1.95 mg/m^3. Respirable dust concentrations ranged from 0.03 to 1.46 mg/m^3 with a mean of 0.38 mg/m^3 (Navarotto and others 1994).

Research in swine buildings indicates that total dust concentrations are higher in finishing barns than either nursery or gestation barns. Donham et al. (Donham and others 1986) reported mean total mass dust concentrations to be 3.2 mg/m^3 in farrowing units, 5.2 mg/m^3 in nursery units, and 15.3 mg/m^3 in finishing buildings. The respirable fractions were 20%, 13.4%, and 12.4% of the total dust in the farrowing, nursery, and finishing buildings, respectively. Maghirang et al (Maghirang and others 1997) reported a mean total dust concentration of 0.72 mg/m^3, ranging from 0.12 to 2.14 mg/m^3 in a test swine nursery. The respirable fraction ranged from 2 to 30% of the total dust, with an overall mean of 11%.

3. Gas Concentrations in Animal Buildings

Groot Koerkamp et al (Groot Koerkamp and others 1998) reported on ammonia concentrations in cattle, pig, and poultry houses in England, Denmark, The Netherlands and Germany. Mean ammonia concentrations in the cattle buildings were below 8 parts per million (ppm). Mean values ranged from 0.3 to 7.7 ppm. The maximum concentrations ranged from 1.7 to 20.1 ppm. Mean ammonia concentrations in pig buildings were between 4.3 and 18.2 ppm.. Maximum concentrations in pig buildings ranged from 14.3 to 59.8 ppm. Mean ammonia concentrations in poultry buildings ranged from 1.6 to 29.6 ppm. Maximum ammonia concentrations in poultry buildings ranged from 14.5 to 72.9 ppm. The data suggests that health risks would be greater

due to ammonia in the pig and poultry buildings than in the cattle buildings (Groot Koerkamp and others 1998).

Ammonia concentrations in pig buildings in Minnesota were less than 30 parts per million (ppm) averaging only 10-15 ppm (Jacobson and others 1996).

Ammonia levels in turkey grower barns in Minnesota were higher in the fall and winter season compared to the spring and summer (Mulhausen and others 1987). Seasonal average values ranged from 10 to 35 ppm. Mean ammonia concentrations in turkey buildings ranged from 1.9 ppm in brooder barns in the summer to 46.2 ppm in grower barns with hens in the winter (Reynolds 1994). Concentrations of carbon monoxide, hydrogen sulfide, nitrogen dixoxide, and methane in turkey grower barns were below detectable levels (Mulhausen and others 1987). Mean sulfur dioxide concentrations in turkey barns ranged from 0.13 to 0.36 ppm (Reynolds 1994)

Ammonia concentrations in three broiler barns in North Carolina had average concentrations around 25 ppm ranging from 6 to 75 ppm. Carbon dioxide concentrations ranged from 500 to 1,000 ppm. Carbon monoxide, hydrogen sulfide, nitrogen dioxide, oxides of nitrogen (NOx), methane, mercaptan, formaldehyde, and hydrocarbons concentrations were all below the detection limits of the detector tubes used (Jones and others 1984).

4. Biogenic Concentrations in Animal Buildings

Researchers have reported biogenic concentrations for bacteria, fungi and endotoxins. Concentrations differ depending on animal species, manure system and management, bedding use, feed form and quality, feeding system, animal activity, and management. Microbial emissions can come from the animals, bedding, feed, manure or exterior (outside) sources.

Airborne endotoxin concentrations measured in cattle, pig, and poultry buildings in Europe are summarized in Table 2 (Seedorf and others 1998). In general both inhalable and respirable concentrations were higher in poultry buildings than pig buildings than cattle buildings. Generally daytime concentrations were higher than nighttime concentrations.

Table 2. Mean airborne endotoxin concentrations (ng/m^3) in different animal buildings at day and night.

	Inhalabel endotoxin concentration (ng/m^3)		Respirable endotoxin concentration (ng/m^3)	
Species	Day	Night	Day	Night
Cows	15.1	7.4	0.6	1.6
Beef cattle	11.8	13.6	1.0	1.3
Calves	48.7	63.9	6.3	6.7
Sows	114.6	52.3	8.3	7.4
Weaners	186.5	157.4	17.7	18.9
Fattening pigs	135.1	109.1	13.0	11.4
Layers	860.4	338.9	58.1	29.6
Broilers	785.7	784.2	35.1	71.8

Seedorf et al (Seedorf and others 1998) measured airborne microorganism concentrations in animal buildings, mostly in Germany. The highest mean bacterial concentrations were measured in broiler buildings where the mean concentration was 6.43 logrithim of colony-forming-units per cubic meter of air (log cfu/m^3). Mean bacterial concentrations in layer and pig houses ranged from 4 to slightly over 5 log cfu/m^3. Mean bacterial concentrations in cattle barns were generally slightly over 4 log cfu/m^3. Mean daytime Enterobacteriaceae concentrations ranged from 3.2 to 4.5 log cfu/m^3. Mean daytime fungi concentrations were 3.8 for cattle, 3.7 for pigs, and 4.0 for poultry log cfu/m^3, respectively with similar values for nighttime (Seedorf and others 1998).

Hartung (Hartung 1994) noted some generalities in a review regarding airborne microbes in poultry buildings. Airborne microorganisms found in poultry buildings, as in most livestock facilities include: staphylococci, streptococci, pseudomonas, E. coli/Enterobacter, fungi, molds and yeasts. Of the fungi, several different species were found B some of which considered to be allergenic (Penicillium, Aspergillus, Cladosporium, and Alternaria) (Hartung 1994). Airborne bacteria concentrations in three broiler barns in North Carolina were around 150,000 cfu/m^3 (Jones and others 1994). Fungi concentrations were 10,000 cfu/m^3. Endotoxin concentrations ranged from 0.77 to 61 ng/m^3 in the total dust samples and from 0.71 to 15 ng/m^3 in the respirable dust.

Because methods of microbial determination (i.e., bacteria and/or fungi) and differentiation (i.e., fungi species), sampling times and sites differed between studies, there may be limited value in reported quantities of airborne particulates as absolute values. For instance, three papers reported widely varying airborne microbial concentrations in egg layer houses for layers in cages: range of 360 to 3781 Colony Forming Units (CFU's) per liter of air (Hartung 1994); range of 17 to 5860 CFU's per liter of air (Loeper and others); and, range of total bacteria of 290,000 to 680,000 CFU's per cubic meter (Clark and Rylander 1983).

The effects of independent variables can be assessed when measurements are taken using the same standard procedures for specific comparison purposes. For instance, the type of poultry and housing shows an effect on airborne microorganism concentrations. Hartung (Hartung 1994)

indicated that airborne microorganisms in houses with chicken layers on litter (bedding) had approximately 5 times the concentrations compared to chicken layers in cages, perhaps reflecting the difference in hen activity and contributions of the litter material.

In the Midwest US season has a significant affect on airborne microorganisms in turkey houses. Mulhausen et al. (Mulhausen and others 1987) found that airborne Aspergillus concentrations in a turkey barn in Minnesota never exceeded 73 colony forming units per cubic meter (cfu/m^3), which was less than background levels found in two ambient air studies (Alvo 1980;Jones and Cookson 1983;Jones and Cookson 1983). Reynolds et al. (Reynolds 1994) found that mean bacteria concentrations in turkey barns that ranged from 300,000 to 38,700,000 cfu/m^3. Higher levels of bacteria, approximately 5 fold, (Debey and others 1995) and higher levels of Aspergillus, approximately 3.5 fold (Janni and others 1985) were found in rearing facilities in the winter compared to summer. The large difference is most likely due to ventilation rates targeted toward keeping barns warm in the winter and heat removal in the summer time.

There is limited research information on microbial populations as affected by feed type, animal activity, bedding type and management, manure handling system, stocking density, air temperature, and relative humidity. Bedding provides environmental conditions appropriate for bacterial growth and fungal spores (Beran 1991). Populations change with bedding use. Fungi populations in fresh and used litter in broiler houses had different specie populations. Aspergillus spp. and Scopulariopsis brevicaulis were predominant in the litter after one cycle of birds (Dennis and Gee 1973). Research reported by Jones et al (Jones and others 1984) for broiler farms in North Carolina indicated airborne fungal counts were an order of magnitude higher in a house with fresh litter compared to a flock housed on old litter (same age birds).

5. Animal Response

An animal's response to airborne contaminants will depend on the dose of contaminant absorbed, inhaled, or ingested and the impact that the contaminant has on the animal. Dose through the respiratory tracts is extremely difficult to measure because it depends in part on animal activity, environmental temperature, and respiration rate. Exposure is typically used as a surrogate for dose. Exposure describes the contact between the animal and contaminant in terms of contaminant concentration and duration of contact. Exposure also describes the contact in terms of the surfaces that are exposed to the contact (i.e., eyes, skin, respiratory tract, other).

Animals exhibit their responses to airborne contaminants in many ways and through various biological systems. Changes in production (e.g., average daily gain, feed conversion) or reproduction are common response indicators. Other indices include health, morbidity, mortality, and thermal comfort. Animals can also exhibit physiological and behavioral changes. Responses can be seen in the respiratory, circulatory, immunological, and thermoregulatory systems. Individual responses vary, requiring extensive studies to develop the statistical base to describe the probabilistic response of the animal population. The number, diversity, and interactions of response variables to multiple stressors, including air quality, makes quantification of the effects difficult at best (Janni 1989).

The impact of airborne contaminant on animals raised for food has been very difficult to assess. There are a number of published papers dealing with this issue, but there is no consensus to date as to whether airborne contaminants at levels found commonly in animal facilities has an impact on animal health and performance. The potential direct impact on animal (swine, cattle, and poultry) health can be:

1. physical impairment of mechanical defense mechanisms by dust (e.g. immobilization of the cilia layer that transports mucus and foreign bodies out of the respiratory tract),
2. chemical irritation of the membranous lining of the respiratory tract by gases (e.g. impairment of the cellular defense mechanisms against respiratory bacterial or viral pathogens),
3. infection with bacteria or viruses that have a pathogenic potential for the animal respiratory tract (e.g. Streptococcus, Staphylococcus, Pasteurella and Haemophilus). These may be spread from animal to animal or from animal unit to animals in other units by transference.

a. Particulates:

Airborne particulate or dust is considered to be a health risk for workers exposed over a prolonged period of time. Although there are no data available to demonstrate specific effects of dust on the health of pigs, cattle, or poultry (Heber and others 1988), it is known that dusty environments are associated with decreased health. For example, dust accumulates in the airsacs of turkeys whether they are housed indoors or outdoors (D.A. Halvorson, personal communication). Assignment of the associated reduction in health to the dust, to the attached fungi, or to other factors is problematic and not yet resolved. Pigs exposed to ammonia, hydrogen sulfide, and airborne dust at concentrations at or higher than those typically found in pig finishing houses had little effect on body weight, rate of gain, or respiratory tract structure (Curtis and others 1975).

Animals have the ability to clear particles from the lungs after inhaling but the pattern of clearance will vary with distribution of the particles as reflected by a rapid clearance of 30-60 minutes and a slower clearance lasting a number of hours. Particles remaining after 24 hours have been shown to be trapped in the lung alveoli and terminal non-ciliated bronchioles (Webster 1990). Effects of particle size and distribution in lungs of 2 and 8 month-old calves have been investigated and summarized (Table 3).

Table 3. Effect of age and particle size on percentage distribution of particles in the respiratory tract of 2 and 8 month-old calves[a]

Age	Lung Region	Particle Size, Microns		
		2.0	3.3	5.0
2 months	Nose	2	6	12
	Airways	15	34	32
	Alveoli	60	47	26
	Exhaled	13	13	30
8 months	Nose	9	17	34
	Airways	34	43	55
	Alveoli	32	24	6
	Exhaled	21	16	5

[a]Adapted from Webster (Webster 1990).

These data (Table 3) illustrate that the smaller particles penetrate more deeply into the lungs. The nose was not a very good filter of inhaled particles. The younger calf had a higher percentage of particles in the alveoli. Inert particles, such as might be found in dust, may remain in the alveoli for months. Other research studies have indicated that the majority of inhaled particles enter parts of the lung that are least sensitive to enzootic pneumonia in calves. However, it has been suggested that these particles move through the lungs along lines of least resistance and will cause the regional distribution of enzootic pneumonia (Davies and Webster 1989).

A hypothesis was tested in mice to find out how inhaled dust particles may compromise the resistance defenses of the respiratory tract and cause build up of bacteria that may cause pneumonia problems in farm animals such as enzootic pneumomia in calves and atrophic rhinitis in pigs (Gilmour and others 1989a;Gilmour and others 1989b). Mice were exposed to controlled doses of inert dust (titanium dioxide) over a 4 weeks period (2 and 20 milligrams/cubic meter) vs clean air, and then challenged with an aerosol of Pasteurella haemolytica (PH; causes primary and secondary pneumonia in young farm animals). The number of PH bacteria were similar initially and over the next 7 days were effectively cleared in mice exposed to clean air and the lower dust dose. The PH bacteria multiplied 4-fold by 24 hours in mice exposed to the higher dust dose. After 7 days the PH bacteria had been cleared to lower concentrations that the initial PH challenge but higher than the clean air and lower dust dose levels. It was suggested that the level of PH bacteria found after 24 hours with the higher dust dose is not outside the limits found in animal housing and emphasized that the 'natural' animal house dust would be potentially more damaging to the lungs than the inert titanium dioxide (Webster 1990).

b. Gases:

Animals housed in intensive production systems (essentially housed indoors) such as those commonly found in Minnesota, are exposed to a number of different atmospheric gases at levels that are higher than those found outdoors. Although many gases were identified in and near animal housing systems only two, ammonia and hydrogen sulfide, have been studied extensively for their effect on animal health. Many of the other gases are at trace levels and are not normally considered to limit farm animal productivity (Scott and others 1983). Concentrations of carbon monoxide, hydrogen sulfide, nitrogen sulfide, and methane were below detectable levels in Minnesota turkey barns (Mulhausen and others 1987).

Studies on the effect of ammonia on swine have yielded mostly negative results, when studied with levels found in commercial farms (Jacobson and others 1985). Pigs exposed to ammonia and hydrogen sulfide concentrations at typically found in pig finishing houses had little effect on body weight, rate of gain, or respiratory tract structure (Curtis and others 1975). A couple of studies have shown that pigs exposed to high ammonia concentrations, greater than 50 ppm, develop more lung lesions due to Ascaris larvae migration and more Atrophic Rhinitis lesions when challenged with the causative organism for this disease (Hamilton and others 1999). Studies performed at farm ammonia levels have also found negative effects on growth, up to a 1-6% difference in feed efficiency in gilts. However, these studies compared two different production systems. The differences observed could have therefore been the result of less microbial exposure and not only the effect of the presence of ammonia (Dierkman and others 1993;Dierkman and others 1997;Dierkman and others 1997).

Studies on turkeys have shown that ammonia can affect turkeys. Nagaraja et al. (Nagaraja and others 1983) found that prolonged exposure to ammonia at concentrations as low as 10 and 40 ppm damaged tracheal tissues in turkeys.

Hydrogen sulfide (H_2S) is a very toxic gas, as mentioned previously, which is also derived from the decomposition of manure. Unlike ammonia, which is water soluble and lighter than air, H_2S is heavier than air and tends to stay in the lowest points in a barn such as the pit area. As with the human safety concern when manure in pits or tanks are agitated and pumped onto cropland, the sudden death of housed animals in these confined barn has been reported (Curtis 1981). A few (estimated to be 5 to 10 per year) of these occur each year in Minnesota, even though numerous organization, including the University of Minnesota Extension Service, recommends that buildings be empty of animals when deep pits are agitated and pumped.

c. Biogenics:

Airborne endotoxins, microbes, and pathogens are other airborne contaminants that may pose a health risk to animals housed inside buildings. Although colony forming units (CFU) have been measured in animal facilities, especially poultry units, the significance of this microbial exposure on the impact of health and performance of poultry is not well established. As noted by Hartung (Hartung 1994) this could be due to several possibilities. A different mechanism is in affect for response to the airborne microorganisms. One would be the effect where specific microbes (pathogens) cause respiratory disease if present in the environment in sufficient number to cause infection. The other may be a non-specific effect where the immune system is stimulated by exposure and over time it is compromised (Hartung 1994).

Another reason why it is difficult to separate the impact of microbial insult from that of other air contaminants, such as dust and ammonia, is that pathogens may attach themselves to dust particles thus making it difficult to distinguish or isolate the impact they have on an animal. For example, on-farm air quality monitoring of turkey flocks and their performance has indicated higher rates of carcass condemnation for turkeys marketed in the winter as compared to the summer (Debey and others 1995;Janni and Redig 1986;Janni and Redig 1986). This carcass condemnation is most often attributed to air sacculitis indicative of respiratory disease. However, overall air quality in the winter season is poorer with higher observed levels of ammonia, dust, bacteria, and fungi.

Many poultry veterinarians are of the opinion that the microbes are opportunistic and that other conditions need to be present in order to allow infection to occur which is supported by research. Barnes (Barnes 1982) cites evidence that reproduction of respiratory disease is difficult in a research laboratory using the infectious agent alone. Poss (Poss 1994) has indicated that respiratory disease in turkeys is often preceded by exposure to ammonia and dust, which reduces defense capabilities of the respiratory system. In fact Janni and Redig (Janni and Redig 1986;Janni and Redig 1986) found that direct exposure of turkeys to aspergillus spores did not cause the expected development of aspergillosis in turkeys. Rearing of turkeys in the presence of varying levels of ammonia without dust exposure also resulted in no negative effects. However, exposure of poultry to ammonia followed by challenge to respiratory diseases often worsens infection rate (Anderson and others 1966;Nagaraja and others 1984;Nagaraja and others 1984). Dust is of concern due to the association of some bacteria and virus with dust particles of respirable sizes (Carpenter 1986). Once the disease organisms are introduced to the flock, dust may play a role in the transmission among the birds.

Thus the interaction of the air contaminants and other environmental conditions may be as important as defining the airborne microbial environment. As indicated in a review (Halvorson and Noll 1989), there are many factors in the environment and management of poultry houses that could affect respiratory disease. Litter moisture, ventilation rate, environmental temperature, heat stress, vaccination programs, and water sanitation.

6. Indoor Confinement

a. General:

Animal housing must provide an acceptable environment that meets the needs of the animals occupying the structure. The environment in livestock facilities is often incompletely defined and difficult to characterize definitively (Hahn and others 1983). Hahn et al. (Hahn and others 1983) defined environment in a broad sense to include all non-genetic factors influencing an animal. The environment includes all conditions except those imposed by heredity and includes external factors (e.g., temperature, light, moisture, social factors) as well as internal factors (e.g., nutrition, disease organisms, parasites) (CAST 1981b). With such an inclusive definition for the term environment it is practically impossible to completely and quantitatively measure an animal's environment. For this discussion on animal housing, the environment will be limited to the following characteristics:

Temperature (dry-bulb air and surface)
Moisture (air and surfaces)
Air velocity (drafts)
Light (intensity, color characteristics, photoperiod length, uniformity)
Space
Airborne contaminants (dust, gases, and biogenic particles).

These characteristics do not completely define an environment. For example, dry-bulb air temperature, the temperature commonly measured with either liquid-in-glass or digital thermometers, is commonly used to represent the entire thermal environment. However, air temperature does not describe the radiant environment, heat gain or loss by radiant heat exchange to surrounding hot and cold surfaces. Also, air temperature alone does not describe the thermal effect of both evaporative cooling from animals with wet coats and convective heat exchange from animals in drafts. In some cases these other environmental characteristics can have a significant effect on an animal's effort to maintain homeothermy (i.e, constant core body temperature).

The desired environmental conditions are a management decision based on animal well-being, economics, and management preferences. Desired conditions usually depend on species, animal age, and season. As environmental conditions approach the boundaries of the desired conditions, animal care givers need to decide whether to implement corrective actions (i.e., change ventilation rates, open or close curtains, add bedding, adjust thermostats) to maintain desired environmental conditions. In many instances short-term excursions beyond the desired environmental limits are not a cause for significant concern.

Hahn et al. (Hahn and others 1983) defined a stressor as an environmental factor that imposes stress on an animal as evidenced by altered physiological, behavioral, immunological, or other parameters, and which may or may not alter overall performance. Stott (Stott 1981) reviewed various concepts of stress and quoted Lee's (Lee 1965) definition of stress often used by physiologists: "(1) Stress denotes the magnitude of forces external to

the bodily system which tend to displace that system from its resting or ground state; (2) strain is the internal displacement from the resting or ground state brought about by the application of the stress." This definition is consistent with the use of the terms stress and strain in engineering (CAST 1981b).

Research on the effects of multiple stressors has been conducted on swine, turkeys and chicks. Many studies produce results that conflict with "common" field experience. This indicates the adaptability of animals. It also indicates that simplified controlled experiments do not incorporate enough stressors that exist in the field. Most experiments have been exploratory to identify the important factors and how they interact.

In confinement housing, efficient ventilation systems and sufficient air changes/hour are key factors to removal of air-borne challenges. Air changes that fall below 4 changes/hour will exacerbate the challenges from fungal spores, allergens or dusts (Webster and others 1987). Most of the organisms that can be recovered from the air are non-pathogenic, although if present in large numbers may contain a high level of endotoxins which can be deleterious to the animal. Survival time of aerosolized primary pathogens is very short, even when there are a number of infected animals in the building. However, efficient ventilation will not counteract respiratory infections if animal stocking density exceeds that recommended for the size of the facility (Webster 1990).

b. Swine:

Curtis et al. (Curtis and others 1975) conducted a study to determine the effects of exposure to ammonia, hydrogen sulfide, and dust at various levels and in combinations on the rate of body weight gain and gross and microscopic integrity of the respiratory tract of the pig. Ammonia levels were 0, 50, and 75 ppm. Dust levels were 10 and 300 mg/m^3. Hydrogen sulfide levels were 2 and 8.5 ppm. Only one trial (NH_3 - 50 ppm and 300 mg/m^3 of dust) produced statistically significant differences in rate of gain. With the exception of one pig with minor conjunctivitis and blepharitis (swollen eyelids) out of 100 pigs, there was no evidence of structural alteration in any organ or tissue.

Another study with ammonia (0, 50, 100, and 150 ppm) was conducted after carefully selecting the animals to reduce non-uniformity in initial pig body weights and eliminating possible crowding effects. Statistically significant effects of week and ammonia on body weight were observed. Differences in pig activity levels, coughing, nasal and lacrimal secretions, and upper respiratory tract (trachea and turbinates) tissues were also observed (Drummond and others 1980).

Further studies were conducted to determine the effects of ammonia and infections (e.g., *Bordetella bronchiseptica, Ascaris suum*) on production performance and the respiratory tract health of young (four to eight week) pigs (Drummond and others 1981a;Drummond and others 1981b;Drummond and others 1981b). Body weights of *Bordetella*-infected pigs correlated with infection and age but not ammonia concentration. This unexpected result was explained as possibly having been due to the increased mucus production due to the

infection, which may have also protected the upper respiratory tract from the ammonia. Gross evidence of pulmonary lesions were found in 13 of 17 infected pigs (Drummond and others 1981a). Body weights of the *A suum*-infected pigs were affected by infection, ammonia, and age. One pig had gross evidence of pulmonary abnormality. Liver scaring due to larval migration was varied in the ascarid infected pigs but did not appear to be affected by ammonia exposure (Drummond and others 1981b;Drummond and others 1981b). These results indicate the ability of young pigs to adapt to and compensate for various stressors. They also indicate the range of animal responses and number of animal response systems (respiratory, immune) that need to be evaluated.

Research to measure the effects of ventilation rate, temperature, and drafts on young pigs has generally found no statistical effect on pig performance (Boedicker and others 1984;Jacobson and others 1985;Jacobson and others 1986;Noyes 1986;Riskowski 1986;Jacobson and others 1985;Jacobson and others 1986;Noyes 1986;Riskowski 1986). Boedicker et al. (Boedicker and others 1984) conducted studies in new swine nursery facilities using two ventilation rates (0.7 and 1.4 L/s). The lower ventilation rate rooms used approximately 37% less supplementary heat, but there was no statistical difference in average daily feed intake, average daily gain, and feed/gain ratio. Early weaned piglets raised in chambers with ventilation rates of 0.2 or 0.9 L/s and intranasally inoculated with *Pasteurella multocida* and *Bordetella bronchiseptica* did not have a statistically significant difference in performance (Jacobson and others 1985). No piglet health performance advantage was found for either ventilation rate based on pneumonic lung lesions and only one pig had lesions (Jacobson and others 1985). Low ventilation rates (0.2 L/s) produced very high humidities and condensation on walls but had no effect on performance (Jacobson and others 1986). Nursery pigs exposed to drafts (0.5 m/s) from the inlet air did not have a statistically significant difference in performance and there were no clinical pig health differences compared to piglets not exposed to a draft (Noyes 1986). Humoral antibody titer suppression, however, was found in the piglets stressed by the draft (Noyes 1986).

Riskowski (Riskowski 1986) studied the effects of air temperature (24 - 35° C) and velocity (0.11 - 0.40 m/s) on the performance, behavior, and time of digesta passage of weanling pigs. He found that average daily gain and average feed intake generally decreased with increased air velocity and increased with decreased air temperature. Huddling and pig lying area were affected by the thermal environmental conditions (stress) (Riskowski 1986). Hoff (Hoff 1987) modeled the sensible heat loss (Hoff 1987) from new-born pigs exposed to a draft and the effects of a hover. He found that hovers reducing the draft velocity and the piglets' exposure to cold surfaces could significantly reduce piglet heat loss (Hoff 1987). These studies using various types of environmental stressors and different methods further indicate the adaptability of pigs to stressful environments. Complex interactions are indicated as the pigs adapt to limited numbers of stressors.

Problems with outbreaks of pneumonia such as enzootic pneumonia in pigs, are often associated with a secondary bacterial infection triggered by a combination of stress in the pigs, inadequate environmental control, presence of airborne dust particles, mixing of pigs, overcrowding of pigs, and poor pen dis-infection between batches of pigs (Whittemore

1993). Use of 5% soybean oil added to the feed has been shown to reduce airborne dust particles (Gore and others 1985). Similar results have occurred from use of a wet feeding system or strategically placing nipple waterers that wet the feed when pigs are drinking (Whittemore 1993).

c. Turkey:

Respiratory health of tom turkeys raised in the winter is a concern to producers because of the economic losses in terms of morbidity, mortality, weight, feed conversion, and processing plant condemnations due to air-sacculitis. Jacobson and Jordan (Jacobson and Jordan 1978), Janni et al. (Janni and others 1984;Janni and others 1985;Janni and Redig 1986;Janni and others 1985;Janni and Redig 1986) and Mulhausen et al. (Mulhausen and others 1987) reported results of environmental and air quality measurements in turkey production facilities. The purpose of these studies was to determine background levels, factors affecting concentrations, and correlations between respiratory disease agents and processing plant condemnations. Similar background level studies have been conducted for layers (McQuitty and others 1985) and broilers (Jones and others 1984).

Results from the field monitoring indicate that large numbers of bacteria and particulate are found in confinement turkey barns. Aerosol concentrations depended on relative humidity, bird activity, litter management, and litter moisture content (Jacobson and Jordan 1978;Janni and others 1984;Janni and others 1985;Janni and Redig 1986;Mulhausen and others 1987;Janni and others 1984;Janni and others 1985;Janni and Redig 1986;Mulhausen and others 1987). Ammonia concentrations depended on litter management, litter moisture content, and ventilation rates (Janni and others 1985;Janni and Redig 1986;Mulhausen and others 1987;Janni and Redig 1986;Mulhausen and others 1987). Ammonia has been shown to adversely affect the normal mucociliary apparatus, resulting in excessive mucous production, matted cilia, and areas of deciliation in tracheal tissues of turkeys exposed to ammonia (Nagaraja and others 1983).

Unpublished research on the effect of ammonia and dust on turkey production and their ability to clear *Aspergullus fumigatus* spores from their respiratory tract produced unexpected results. Ammonia levels as high as 100 ppm alone and combined dust (over 8 mg/m^3) and ammonia (100 ppm) did not show statistical differences in production or lung clearance compared to low dust (5 mg/m^3) and ammonia (10 and 25 ppm) treatments. Current interpretation of these results is that these stressors were not sufficient in themselves to cause reduced performance. The turkeys were able to compensate for these stressors. Turkeys in commercial facilities exposed to additional stressors would be expected to have significant reductions in production if exposed to the ammonia and dust levels used in these experiments.

d. Cattle

Attention should be made beyond stocking density and ventilation when designing and managing facilities for farm animals. For example, calves that appear to be housed in a spacious, well-ventilated barn may be predisposed to more pneumonia in cool and damp winter conditions. Research suggests that when calves lie for long periods with slow shallow breathing, these conditions will cause inadequate pulmonary ventilation of inhaled pathogens (Webster 1990). If the housing system encourages greater animal activity and more exposure to clean air, as may be found in some open-naturally-ventilated barns, the lungs seem to be more protected from prolonged pathogen challenge (Webster 1984).

e. Multiple Stressor Interaction:

A study on how multiple concurrent stressors interact was conducted using chicks (McFarlane 1987). The stressors selected differed in their mode of impingment on the chicks and their ability to produce a repeatable significant growth depression. The stressors were ammonia (0 or 125 ppm), beak-trimming (sham handling vs. trimmed), exposure to coccidiosis, random electrical shock, temperature (30.4 or 36.5° C), and white nose. White nose was produced by a generator designed to broadcast all frequencies within the human auditory range (approximately 20 to 20,000 Hz). The performance results indicated that the stressors added together in their negative effects on performance rather than interacting synergistically. The histopathological results indicated that, in general, the histological integrity of the chicks was similar whether the stressors were imposed singly or concurrently with any other stressor. Behavioral results indicated very few effects on behavior as a result of the stressors singly or in combination. This study presents a clearer understanding of how multiple concurrent stressors interact and their effect on performance, histology, and behavior. However, for building system designers, this information only provides guidelines for an acceptable environment. Further work is needed to relate how an environmental control system creates or affects some of the environmental stressors studied.

7. Summary

Although a large number of studies on the effect of air contaminants on animal health have been published, the results are inconclusive. Some effects have been shown with some gases such as ammonia, but generally at levels that were higher than those found in farm conditions. Airborne pathogens may show the most potential for impacting animal health but even there it seems to take a combination of dust, gases, and pathogens to obtain a measurable health effect. Some studies have been able to show adverse effects of these air contaminants, but others have not.

Air-borne respiratory diseases in farm animals involve the disturbance to the equilibrium between the host animal, the pathogen and the environment (Webster 1990). These challenges relate to air quality and the potential for animals to inhale infectious agents which may multiply within the respiratory tract (viruses, bacteria); allergens which may induce inflammation (fungal spores etc.) or 'nuisance' dusts and gases (e.g. ammonia) which do not directly damage the lungs but may compromise their resistance to pathogens (Webster 1990).

SECTION F: USE OF ANTIBIOTICS, METABOLIC MODIFIERS, PESTICIDES AND IONOPHORES

1. Introduction

Remarkable scientific advances (especially during the last 50 years) in plant and animal agriculture have enabled humans to expand their capacity to produce food to meet the growing demands imposed by the expanding world population. For example, global food supply increased 55% from 1970 to 1995 (Bertini 1998). These advances occurred through increased total production and through increased productive efficiency.

Increases in productive efficiency have provided more food and produced less waste per unit of input which reduces the impact of agriculture on the environment (Bauman 1992;Crooker 1999;CAST. 1998;NRC. 1999). These remarkable advances have been achieved through an increased knowledge and understanding of nearly all aspects of agriculture. Improvements in animal nutrition, health, management, and genetic selection have had major impacts on the advances achieved in animal agriculture. A greater understanding of animal physiology has resulted in the development of a number of chemical compounds that are available to the producer to improve animal health and to increase the productive efficiency of animal agriculture.

Society and the scientific community can not rest on these tremendous accomplishments. Population growth and economic growth will continue and this will continue to increase the demand for safe, nutritious sources of food. It is expected that the combined effects of population and income growth will increase the demand for food by 30 to 50% by 2020 (Bertini 1998) and to double the demand for food over the next 30 to 40 years (Thompson 1998;Etherton and Bauman 1998).

This required doubling of global food production can occur by increasing the quantity of land used to produce food, increasing the yield of food per unit of land, by reducing post-harvest loss (Thompson 1998) or through a combination of these factors. It is clear that a large increase in the quantity of land used to produce food would have a major impact (including reduced forest cover, reduced wildlife habitat, reduced biodiversity) on the environment (Thompson 1998). Continued increases in the efficiency of producing food are required to sustain our ability to provide safe, nutritious food sources in an environmentally friendly manner. Consumers will certainly continue to expect their food supply to be safe and nutritious. In addition, concerns have been raised regarding the effects of these previous achievements on the health and well-being of agricultural animals (Broom 1995;Broom 1999;Rauw and others 1998) and these issues require additional attention.

2. Common Chemical Compounds Used in Animal Agriculture

Science has provided a variety of chemical compounds that have contributed to the health and well-being of agricultural animals and to their productive efficiency. Some types of compounds (antibiotics for example) can serve more than a single function and this sometimes leads to confusion about the reasons for using specific compounds. Antibiotics can be used to treat bacterial infections and thus enhance the health of an animal (therapeutic use) and can be used as growth promotants to enhance the productive efficiency of an animal (sub-therapeutic use). Some antibiotics are classified as ionophores. Certain terminology can be used to describe a variety of compounds and this can also cause confusion. The term growth promotant can refer to antibiotics (subtherapeutic use), hormones (both steroid and protein hormones which differ in many ways), and (although less frequently) ionophores.

The most commonly used chemical compounds in animal agriculture have been classified by the National Research Council (NRC. 1999) as:

1. topical antiseptics, bactericides, and fungicides used to treat skin or hoof infections, cuts, and abrasions and to disinfect barns and barn equipment
2. ionophores, which alter stomach microorganisms to provide more favorable and efficient energy substrates from bacterial conversions of feeds and to impart some degree of protection against parasites
3. hormone and hormone-like production enhancers (steroid implants for meat production and bovine somatotropin for milk production)
4. antiparasite drugs (pesticides) and
5. antibiotics to control overt and occult disease and to promote growth.

The use of chemical compounds (antimicrobials, hormones, etc) in livestock production has generally been accepted and unquestioned until recently. Today's consumers are more sophisticated about the food they eat and are becoming more aware, more concerned, and more critical about food production practices. This has occurred in part due to identified problems within their food supply (BSE, the emergence of E. coli outbreaks, imports of food from countries with distrusted food hygiene, etc.) and the increased opportunity for isolated problems to affect larger numbers of individuals. As a result, the use of chemical compounds in food animals has received increased scrutiny.

Recognizing the important role that chemical compounds play in animal agriculture and the increasing public concern about these chemicals, the Panel on Animal Health, Food Safety, and Public Health, the National Research Council's Board on Agriculture and the Institute of Medicine's Food and Nutrition Board jointly initiated a project and convened a committee (Committee on Drug Use in Food Animals) to examine the benefits and risks associated with drug use in food animal production. The committee recently issued its report (NRC. 1999).

3. Antibiotics

The history of human and veterinary medicine has proven that there is no way to eradicate infectious disease from the earth. "Viruses and bacteria have, due to their million-times faster multiplication, a much better capability to adapt to changing environmental conditions than humans and animals" (Nobel laureate Dr. Lederberg at the ILSI Meeting 1997 in Washington D.C.) - thus, they will always maintain their potential to cause disease. Therefore, the availability of antibiotics to livestock producers and veterinarians for preventing and treating bacterial diseases in food producing animals must be protected (Sundlof and others 1997;McEwen 1997;Wierup 1997;Blaha 1997b;McEwen 1997;Wierup 1997).

a. Issues of Concern

Three major issues of concern, relative to the use of antibiotics, have recently emerged:

1) the public and especially the medical society (WHO, public health authorities, physicians, and bio-medical scientists) are concerned with increasing resistance in bacteria that are relevant in human diseases. There is a strong belief (especially in Europe) that the use of antimicrobials in food animals might contribute to the problem or aggravate its magnitude (WHO 1997);

2) consumers are concerned about the possibility of residues from antibiotics, chemotherapeutics, and/or their metabolites in edible tissue which potentially leads to the intake of unwanted substances that can result in resistance or allergies (Debeuckelaere and Remy, 1997).

3) livestock producers and veterinarians are concerned with the possibility that the increasing pressure to reduce the use of antimicrobials in food animals might lead to limitations in preventing and curing infectious disease in food animals (Frost 1991;Fernandes 1996;McOrist 1997;Fernandes 1996;McOrist 1997).

These concerns have contributed to a growing discussion by the public and by scientists about food production practices and specifically about the use of antibiotics in animal agriculture. Similar concerns can and have been raised for several of the other chemical compounds used in animal agriculture.

b. Microbial Resistance

Many scientific meetings, conferences and workshops on microbial resistance to antibiotics have occurred during the last few years. One conference, titled the "Medical Impact of the Use of Antimicrobials in Food Animals", was held by the World Health Organization (WHO 1997) in Berlin, Germany and provided a framework for the ongoing discussion about microbial resistance to antibiotics. Quotations from the report of this meeting include:

"Antimicrobials are vital medicines for the treatment of bacterial infections in both humans and animals."
"The magnitude of the medical and public health impact of antimicrobial use in food animal production is not known."
"Timely public action is needed to control medical problems related to the widespread application of antimicrobials outside the medical sphere."
"National policies on the use of antimicrobials in animals must balance the possible benefits to livestock production against the medical risk and public health consequences deriving from their use."
"Bacteria and genes, including resistance genes, can pass between human, animal and other ecosystems."
"Following the introduction of fluoroquinolones in food-producing animals, the emergence of Salmonella serotypes with reduced susceptibility in humans has become a cause for particular concern", and
"Reducing the need for antimicrobials is an important means of managing resistance risk".

The discussion about the use of fluoroquinolones in food-producing animals has been fueled recently by a study conducted by the Minnesota Department of Health (Smith and others 1999) that concluded the use of fluoroquinolones in poultry has created a reservoir of resistant Campylobacter (C.) jejuni. Fluoroquinolones were approved for use in poultry in 1995 and this study (Smith and others 1999) determined that the proportion of quinolone-resistant C. jejuni isolates from humans increased from 1.3% in 1992 to 10.2% in 1998. Quinolone-resistant C. jejuni were isolated from 14% of 91 domestic chicken products obtained from retail markets in 1997. Molecular subtyping showed an association between quinolone-resistant C. jejuni strains from chicken products and domestically acquired C. jejuni infections in Minnesota residents.

Fluoroquinolone-resistant Campylobacter isolates have increased in Europe since the 1980's (Piddock, 1995). The Minnesota study (Smith and others 1999) also determined that a larger proportion of the quinolone-resistant C. jejuni infections were associated with foreign travel. Thus, apart from the infections with resistant C. jejuni strains that were acquired during foreign travel, the number of quinolone-resistant infections acquired domestically has increased and this is believed to be largely because of the acquisition of resistant strains from poultry.

All in all, it is generally recognized that there is an increase in cases where bacterial resistance complicates the treatment of human disease. It is also recognized that there are several reasons for the phenomenon, with the (over) use of antimicrobials by physicians and the non-compliance of the rules for the use of antimicrobials by ambulant patients being major reasons (Levy 1997). However, because any use of antibiotics leads to a selective pressure in favor of resistant strains (Levy 1997), the use of antibiotics in animals needs to be guided toward the *"prudent use of antibiotics"* which has been defined as "prudent use must guarantee the highest possible effect and the lowest possible risk of resistance" (WHO 1997).

c. Antibiotic Residues

Over the last decade, the magnitude of antimicrobial residues has significantly decreased to almost tolerably few cases of positive results. This is due to the mandatory residue testing of meat and milk prior to further processing conducted by USDA/FSIS and intensive educational efforts by USDA and the livestock industries (mostly as result of quality assurance programs for e.g. pork, dairy, poultry etc. on a national or state basis).

Nevertheless, there is still room for improvement, which should be achieved more by voluntary on-farm residue avoidance programs than by increasing the sample size of residue testing in the framework of mandatory monitoring systems (Blaha 1997a;Blaha 1999).

d. Use of Antibiotics in Animal Agriculture

The animal industry uses antibiotics at subtherapeutic (to promote animal growth) and therapeutic (Fernandes 1996) levels.

1) *Subtherapeutic Use:*

Antimicrobials are fed at subtherapeutic or low dosages (typically less than 50 grams/ton of feed) to animals to promote growth in a cost-effective manner. The first report of antimicrobial enhanced growth occurred in 1946. However, it wasn't until 1953 that supplementation of antimicrobials to the diets of livestock became a standard practice. During the next 20-30 years, a tremendous amount of research was conducted to evaluate the efficacy of antimicrobial supplementation as a growth promotant for poultry, swine, and cattle (Stockstad 1954;Robinson 1962;Visek 1978;Hays 1991;CAST 1981a;Hays 1981). Considerable effort was devoted to defining the parameters that influence the efficacy of antimicrobial supplementation as growth promotants. A compilation of the information generated during these decades of research has shown that feeding antimicrobials to various species of livestock under a wide variety of conditions results in:

1) an increase in the rate of average daily body weight gain,
2) an improvement in the efficiency with which feed intake is converted to body weight gain (gain:feed ratio),
3) an increase in voluntary feed intake,
4) a reduction in morbidity or the incidence of illness,
5) a reduction in mortality or death, and
6) lack of any consistent effect on the composition of the animal carcass.

If antimicrobials are removed from the diet before market weight is achieved, much of the advantage in average daily gain is lost (Robinson 1962). Therefore, it is most cost-effective to continue the supplementation of antimicrobials throughout the growth phase. Additional studies have shown that when antimicrobials were fed to animals at the same production facility for extended periods of time (i.e. 10 years), the growth rate of the

animals was still greater than that of the animals that did not receive the antimicrobials (Hays 1991). However, the magnitude of the effect was somewhat reduced, apparently because the animals that were not fed the antimicrobials had an improved growth rate. This was attributed to the overall improved health of the animals at the farm (Hays 1991).

In some countries (i.e., Europe), approval for the use of antimicrobials as growth promotants has been rescinded. In those circumstances, the efficiency of animal production practices has declined. There is a reduction in average daily gain, a decrease in the efficiency of weight gain and an increase in morbidity and mortality, especially in the very young animals.

It is estimated that 60-80% of all cattle, sheep, swine and poultry in the United States receives antimicrobials at some point in time (CAST 1981a). It has also been estimated that removal of antimicrobials from production systems would cost the consumer in excess of 3.5 billion dollars annually in the United States (Hays 1991). As a consequence, current research devoted to studying the use of antimicrobials in animal agriculture has concentrated on two concurrent objectives: 1) determining how antimicrobials exert their growth promoting effects and 2) searching for a viable alternative so that antimicrobial supplementation can be halted and replaced with an effective substitute. Little effect is directed towards assessing the efficacy of antimicrobials as growth promotants. However, efforts continue to focus on the mechanism(s) by which antimicrobials exert their growth promoting effects (Hathaway and others 1996). Determination of these mechanisms would assist efforts to develop viatle alternatives to the subtherapeutic use of antimicrobials. Prophylactic or intermediate levels of antimicrobials are given to animals which have been exposed to disease or subjected to stress to prevent the animals from becoming sick.

2) *Therapeutic Use:*

The productivity and profitability of every livestock enterprise is dependent on maintenance of healthy livestock. The concern for animal welfare and health is a high priority for food animal producers. The veterinarian working with food animal producers plays a key role in providing professional guidance in the prevention and treatment of disease. The multiple responsibilities of the veterinarian are best summarized by the veterinarian's oath. *"Being admitted to the profession of veterinary medicine, I solemnly swear to use my scientific knowledge and skills for the benefit of society through the protection of animal health, the relief of animal suffering, the conservation of livestock resources, the promotion of public health, and the advancement of medical knowledge."*

It is well recognized by both the veterinarian and food animal producer that prevention of disease is more desirable than treatment. As herd/flock sizes have increased, modern livestock husbandry has placed increasing emphasis on preventing disease rather than treating disease. Development of more effective vaccines, improved nutrition, housing, and more vigilant monitoring techniques have, in general, given rise to improved herd

health, greater productivity and greater productive efficiency. However, in spite of the consistent application of best management practices, some animals will become clinically infected and will require treatment. When clinical disease does occur and where it is deemed appropriate, antibiotics are used. Clearly defined treatment guidelines have been provided for veterinarians and their livestock-producing clients regarding the prudent use of antibiotics in the treatment of clinical diseases in food producing animals (AVMA. 1999;Pork Quality Assurance Program ;Beef Quality Assurance Program ;Pork Quality Assurance Program ;Beef Quality Assurance Program). The American Academy of Veterinary Pharmacology and Therapeutics (AAVPT) recently held a symposium (AAVPT 1998a) and identified a course for prudent use of antibiotics (AAVPT 1998b).

Prudent use of antibiotics.

Goal: To minimize the general use of antibiotics without compromising animal health.

Sub-therapeutic use
Use alternatives to antibiotics for growth promotion effects where those exist.
Use prophylactic use of antibiotics only when used strategically and not as a general routine and when known herd health benefits can be expected.

Therapeutic use
Use for proven clinical indications.
Use at high enough (Warriss 1998) doses.
Use for as long as necessary.
Use as short as possible.
Preference is given to single animal treatment rather than treating a whole group in order to treat just a few animals.
Follow proper withholding times.
Record all drug use (growth promotant, prophylactic, therapeutic).

There is a paucity of data regarding the issue of antibiotic use in livestock relative to herd size. Observation indicates that antibiotic use as it relates to animal health is more a matter of management quality than it is of farm size. Thus, arguments favoring either "small" or "large" farm size will always fall short. A California study (Bennett 1987) demonstrated that milk somatic cell count (SCC) was a positive predictor of herd management quality. A more recent study in the Netherlands (Rougoor 1999) determined that both herd milk SCC and herd reproductive performance correlated strongly with the quality of herd management. A U.S. NAHMS survey (Wells 1998) determined that, in general, large herds had lower milk SCC than smaller herds. These results support the argument that farm size is not a key issue in management quality. Financial and knowledge-based resources and overall management skills have a much larger role than farm size and greatly affect the health and well-being of animals on any farm regardless of its size.

1. Metabolic Modifiers

Genetic selection has provided animal agriculture with animals that are more efficient than their undomesticated predecessors (CAST 1997). The development of metabolic modifiers has provided producers with options for further enhancing the efficiency of their animals. These advances have contributed to the reduced fat content of animal products and enhanced the ability of consumers to obtain low-fat meat products (Gonyou 1994;Gonyou 1994). Recent advances in molecular biotechnology, genetics and an increased understanding of the specific roles of metabolic modifiers (hormones, growth factors and their modulators) and their interactions with management techniques and the animals environment will provide much of the biological foundation for these continued increases in efficiency of producing food (Crooker 1999). The primary metabolic modifiers currently available for animal agriculture are steroid implants for growing beef cattle and bovine somatotropin (NRC. 1994) for lactating dairy cattle. Hormones and metabolic modifiers are not used in poultry.

a. Steroid Implants:

Steroid implants contain naturally occurring and/or synthetic estrogens and androgens (NRC. 1994;Hafs and Zimbelman 1994;NRC. 1996) and are used to improve efficiency of growth and carcass composition of meat animals. They have been used for more than 40 years and are extensively used in the production of U.S. beef with an estimated 90% of the beef cattle receiving an implant at some point in their life (NRC. 1994). This wide use reflects the significant improved performance (increased growth rate and efficiency of converting feed into tissue, increased protein to lipid content of the carcass) and economic advantage they provide (NRC. 1994;Hafs and Zimbelman 1994;NRC. 1996;NRC. 1996).

An April 30, 1999 report (http/europa.eu.int.dg24/health/sc/scv/index_en.html) from the European Union Scientific Committee for Veterinary Measures Relating to Public Health recently raised concerns about the use of naturally occurring sex steroid hormones (estradiol, progesterone, testosterone) and their synthetic mimics (zeranol, melengestrol acetate, trenbolone acetate) in growing beef cattle and their potential effects in humans. The report concludes the issues of concern include potential neurobiological, developmental, reproductive and immunological effects, as well as immunotoxicity, genotoxicity, and carcinogenicity. These conclusions have been sharply criticized (Science, 1999.284:1453) as another component in the on-going trade war between the U.S. and E.U. concerning imported beef.

The World Health Organization (WHO) and the United Nations Food and Agriculture Organization (FAO) Joint Expert Committee on Food Additives (JECFA) is composed of scientists from Europe, Australia and the U.S. They also reviewed hormone use in cattle and issued their report in February 1999. These scientists concluded the use of steroid hormones did not decrease the safety of food products from treated beef cattle.

b. Bovine Somatotropin:

In the early 1980's, recombinant DNA techniques provided a source of bovine somatotropin (Bauman 1998) in quantities that made commercial application feasible and bST became the most investigated animal production drug ever approved by the Food and Drug Administration, Center for Veterinary Medicine (FDA/CVM) for use in the U.S. The Monsanto bST (Posilac7) data set summarized more than 800 cows and was the largest production drug data set ever reviewed by FDA/CVM. Administration of bST (Monsanto 1998) to lactating dairy cows was approved by the USA Food and Drug Administration, Center for Veterinary Medicine on November 5, 1993 as a safe, efficacious method of increasing milk yield. An economic analysis of the potential impact of Posilac7 was issued in January, 1994 and sale to commercial dairies began on February 4, 1994. There have been a number of reports and reviews confirming the safety of use of bST to humans and to the cow (Bauman 1992;Etherton and Bauman 1998;Juskevich and Guyer 1990).

An estimated 30,000 to 40,000 dairy cows in the US and throughout the world had been used in bST research trials prior to FDA/CVM approval. The data from these studies indicate the important role of management, especially nutritional management, in determining the milk yield response to bST (Bauman 1992;Crooker and and Otterby 1991). The results are consistent with our understanding of biology and lactational physiology. The dairy cow must be healthy, consume sufficient nutrients, inhabit a comfortable environment, and be managed properly to consistently produce large quantities of milk. Stressed and improperly managed cows do not produce large quantities of milk and contribute to an inefficient dairy operation.

When the productive efficiency of an animal is increased, a greater proportion of the consumed nutrients are captured as a product. This is true whether the improvements occur through selective matings or through the use of metabolic modifiers (the growing beef animal that receives a steroid implant or the lactating dairy cow treated with bST). Because a smaller proportion of the consumed nutrients are excreted, the impact of animal waste products on the environment is reduced per unit of product produced. This occurs whether the industry chooses to produce more product or to produce the same amount of product with fewer animals. This allows the industry greater flexibility to respond to consumer demand.

It is instructive to use bST as an example of the potential environmental benefits that can be realized through continued efforts to enhance productive efficiency of agricultural animals. Although recognizing that 100% adoption of bST use was unlikely, Bauman (Bauman 1992) demonstrated the potential environmental benefit that could have been achieved in the U.S. in 1988 if 100% of the industry used bST and if the increased milk response was 12%. He demonstrated the same quantity of milk could have been produced with 1.1 million fewer cows and a substantial reduction in feed required (2.5 billion kg of corn grain and 560 million

kg soybean) and waste produced (6 billion kg manure, 8 billion liters of urine, 80 million kg urinary nitrogen, and 80 billion liters of methane). Similar calculations using the average U.S. cow in 1996 (7600 kg/cow) and the extent of bST use in 1996 (Hartnell 1996) suggest the actual savings were about 20% of these predicted values. A simulation based on DHIA records indicate bST use would increase whole herd nitrogen efficiency by 5% and decrease whole herd manure excretion by 8% (Dunlap and others 1998).

These estimates of reduced environmental impact are based on animal biology and do not account for reductions associated with reductions in growing, harvesting, processing, and storing dairy feedstuffs and handling and processing dairy waste. Johnson and colleagues (Johnson and Johnson 1995) estimated 100% adoption of bST by the dairy industry in 1989 would have allowed the same quantity of milk to be produced with 6% less land, 6% less fossil fuel, and 5% less soil loss.

Concern has been raised regarding the animal health and well-being aspects of bST use. The Canadian Veterinary Medical Association (CVMA. 1998) established a panel to review the efficacy and safety of bST. Their report (CVMA. 1998) indicated there were concerns about increased risk of clinical mastitis, lameness and a reduction in the life-span of treated cows. They were also concerned about the possibility of injection site reactions but felt there were insufficient data to determine if this was a significant health or well-being issue. The Scientific Committee on Animal Health and Animal Welfare in the E.U. reported (SCAHAW 1999) that use of bST decreased the health and well-being of dairy cows by increasing foot disorders, reproductive problems and production-related diseases and recommended that bST not be used. These results are inconsistent with the numerous other reports of bST use and animal health. They are also inconsistent with the continued use of bST by producers, the sustained increases in milk yield achieved by use of bST (Bauman et al., 1999) and the lack of change in culling of U.S. dairy cows (NASS, 1998; NAHMS, 1996).

The Vermont Public Interest Research Group and Rural Vermont recently questioned the validity of FDA's ruling that milk and milk products from cows treated with bST are safe for human consumption. Their concerns were raised in part by an analysis of the data that was conducted by Health Canada. After completing a comprehensive audit of the human food safety data used to support the approval of bST use in dairy cows, FDA responded (http://www.fda.gov.infores/other/RBRPTFNL.html) to the questions. FDA indicated they believed the Canadian reviewers did not interpret the study results correctly and that there were no new scientific concerns regarding the safety of milk from cows treated with bST.

The Canadian report expressed concern that increased amounts of insulin-like growth factor-1 (IGF-1) in milk from cows treated with bST would pose a health risk to humans and the Vermont Groups were especially concerned about this

relative to milk consumption by children. FDA's initial evaluation did suggest a modest increase in IGF-1 content of milk but this was not deemed a health risk because the increases were within the normal range of concentrations in untreated cows. Subsequent information has been reviewed by FDA which demonstrates the use of bST does not increase milk IGF-1 concentrations above those of untreated cows.

The WHO/FAO JECFA (1998) also reaffirmed earlier assessments that use of bST did not pose a risk to human food safety. The Department of Health and Human Services' Office of Inspector General (OIG, 1992) and the General Accounting Office (GAO) audited FDA's approval of bST and found no reason to question the food safety issue. The White House Office of Management and Budget (1994) reached similar conclusions.

5. Pesticides, Anthelmitics and Disinfectants

A variety of pesticides and drugs are used to protect the health of food and fiber animals in the US and throughout the world. The distinctions between pesticides and drugs originate in US law. Pesticides are commercial substances and are defined in the Federal Insecticide, Fungicide, Rodenticide Act as substances intended "...for preventing, destroying, repelling, or mitigating any pest...". Pests that can affect the health of animals in Minnesota include insects, ticks and mites (arthropods); worms (helminths); and microbial pathogens (coccidia, fungi, bacteria and viruses). Pesticides are products that are used in an animal's environment. Pesticides are regulated nationally by the US Environmental Protection Agency (EPA) and within each state by the state's Department of Agriculture.

In contrast to pesticides, other drugs are used to control the same kinds of pests but are applied directly onto or into animals and, therefore, are regulated by the Food and Drug Administration (McChesney and others 1995). The FDA also has authority to establish legal tolerances for pesticides, drugs and their degradation products in human and animal foods. Tolerances are established to ensure food safety. Tolerances identify the quantity (the permissible residue) of pesticide, drug, or degradation product residue determined to be well below the quantity that may have an effect in humans or animals that consume the food.

To be sold for use around or on animals, a pesticide or drug must have a label that is issued by the appropriate regulatory agency. Before a label is issued, candidate products are required to undergo extensive research at the expense of the developing company to assess efficacy against target pests and safety to animals, applicators, and the food supply. Once labeled, packaged products can then be sold for use by the appropriate category of applicator. A product's label states the kind of pest that the product will control, how the product is to be applied (dose and application method), the kind(s) of substrate that can be treated, and situations in which use would be contraindicated (not recommended). Product labels also provide additional information.

The EPA or FDA can either label a product for over-the-counter sale to the general public or they can restrict use to certified pesticide applicators or veterinarians. The designation depends on the risks posed by the specific compound and formulation to animals and humans. Restricted use pesticides can only be purchased and applied by certified pesticide applicators. To become certified, individuals must complete training courses and pass certification tests. In Minnesota, the Minnesota Extension Service conducts the training courses and the Minnesota Department of Agriculture administers the certification and recertification tests. Drugs intended for veterinary use only are marketed through practicing veterinarians who are certified and accredited by the Minnesota's Board of Veterinary Medicine.

The safety of registered products for target animals is monitored formally by the FDA's Center for Veterinary Medicine (CVMA. 1998). The CVM maintains a reporting system designed to capture mandatory reports from veterinarians of any adverse reactions to any products registered by FDA. This process occurs to insure that actual use of the registered products in production

systems continues to be safe for humans and animals. If problems arise, continued use of the product can be eliminated or subject to additional regulation. Marketers probably learn quickly of adverse reactions and withdraw the associated products to prevent litigation and limit liability. Cases of animal poisoning associated with anti-parasitic pesticides and drugs are thought to be rare.

Neither the Minnesota Department of Agriculture, the Minnesota Board of Animal Health nor any other regulatory agency monitors the use (neither frequency nor volume) of pesticides or drugs. The US-FDA conducts market surveys to assess residue levels for selected pesticides and drugs in foods but results of that monitoring are not readily available. Thus, no objective information exists concerning how patterns of use (and possible misuse) of anti-parasitic pesticides and drugs vary among animal species, housing styles or farm sizes in Minnesota or anywhere else in the US. Extent of use could be estimated through surveys of selected animal industries.

6. Ionophores

a. Introduction and Mode of Action

The Random House dictionary definition of an ionophore is "a lipid soluble substance capable of transporting specific ions through cellular membranes". This feature provides ionophores with therapeutic properties useful for both human and animal health (Pressman and Fahim 1982). The use of FDA approved ionophores in livestock agriculture incorporated at appropriate concentrations have realized many positive impacts. Animal well-being and health have been one of the primary beneficiaries of this technology.
Ionophores are compounds of moderate molecular weight (MW 200 to 2,000) that form lipid soluble complexes with polar cations of potassium (K), sodium (Na), calcium (Ca), magnesium (Mg) and biogenic amines (Pressman 1976). Differences exist among the ionophores in their affinity for various ions. Ionophores are often described as antibiotics because they can alter metabolism (cell homeostasis) of microorganisms such that the microorganism either dies or becomes much less active. This accounts for their anti-coccidial effects in poultry and ruminants.

The unique ion transporting properties of ionophores were discovered in the early 1960's at the University of Miami laboratory of Dr B.C. Pressman. The first recognized ionophores were metabolites of microorganisms but synthetic compounds with equivalent properties are now available. Ionophores commonly used in livestock production belong to the carboxylic class of ionophores. These compounds form a ring structure which surrounds ions and facilitates their transport through cell membranes (Smedley 1984). Ionophores mediate cation transport by forming a channel within cell membranes which allow the ion to more easily move (diffuse) through the cell membrane (Smedley 1984). In the animal body, the ionophore ion transport effects may change the bioavailability, gut uptake and tissue deposition of minerals (Elasser 1984).

Use of ionophores in ruminant diets have increased apparent absorption of minerals (Zinn and others 1975;Greene and others 1986;Kirk and others 1985a;Kirk and others 1985b;Spears and others 1989;Reffet-Stabel and others 1989) and result in a sparing-effect on dietary protein (Goodrich and others 1984;Russell and others 1992). The protein sparing effect of ionophores is achieved by decreasing the rate of peptide uptake by rumen microbes (Russell and others 1992).

Effects of ionophores on rumen fermentation have been the focus of much research over the past twenty-five years. Rumen bacterial ecology is altered by addition of ionophores to the rumen. These alterations change the metabolic end-products (volatile fatty acids, methane, etc.) produced during the rumen fermentation process.

Changes in the production of end-products include an increase in the ratio of propionate to acetate, reduction in butryrate, ammonia, and methane production, and decreased protein degradation. (Nan Nevel and Bemayer 1977;Chen and Wolin 1979;Henderson and others 1981;Rumsey 1984;Sticker and others 1991;Johnson and Johnson 1995;Fellner and others 1997). These changes contribute to an improved efficiency of use of dietary energy and protein, a reduced potential of acidosis and bloat in cattle fed large amounts of grain (concentrates), a decreased life-cycle of face and horn flies in feces of ionophore-fed cattle, a reduced amount of methane released to the environment, and an improvement in animal performance (Wallace and others 1980;Goodrich and others 1984;Johnson and Johnson 1995).

Although current regulations prohibit the use of ionophores in lactating dairy cattle, studies have suggested ruminal changes that result from feeding ionophores (especially those changes related to ruminal lipids) could enhance nutritional qualities of milk (Fellner and others 1997). Further refinement of rumen fermentation manipulation to integrate ionophores and advances of genetically modified organisms for the benefit of the animal, are imminent (Wallace 1994).

b. Measurements and Standards for Animal Health and Well-Being

1) *Criteria for Animal Health and Well-Being:*

- Only the ionophores approved by FDA can be incorporated in animal feeds.
- When ionophores are used, the amounts used must be within the limits established by FDA guidelines for proper prophylactic (coccidiosis control – poultry and ruminants) and sub-therapeutic function (increased dietary energy efficiency and nutrient availability in ruminants, and enhanced animal performance).
- Ionophores approved for non-lactating cattle include laidlomycin propionate (Cattlyst®; 30 to 150mg/head daily); monensin sodium (Rumensin®; 50 to 360 mg/head daily); lasalocid sodium (Bovatec®; 100 to 360 mg/head daily), and bambermycin (Gain Pro®; 10 to 20 mg/head daily). Monensin sodium can be fed in combination with tylosin (60 to 90 mg/head daily) and lasalocid sodium can be fed in combination with oxytetracylcine.

- Ionophores approved for sheep include monensin sodium and lasalocid sodium (15 to 70 mg/head daily).
- Amounts of ionophores that can be added to the feed as anticoccidiostats for prophylactic use in poultry include monensin sodium (0.01 to 0.0121% for chickens; 0.006 to 0.01% for turkeys up to 10 wk of-age); maduramicin ammonium (0.0005 to 0.0006% for chickens); narasin (0.006 to 0.008% for chickens) and salinomycin sodium (0.0044 to 0.0066% for chickens).

c. Effects on Animal Health and Well-Being

2) *Effects of Feeding Ionophores on Animal Health and Performance:*

a) Cattle:

Ionophores are well-accepted management tools for cattle production systems. Ionophores can be offered free choice in mineral mixtures and mineral blocks or incorporated in a complete ration at the appropriate concentrations. Controlled daily feeding of an ionophore provides better results than free choice access. (R.James, as reported by Chester-Jones, 1996). Successful administration and use of ionophores, such as monensin, can be accomplished through use of intra-ruminal devices (Cochran and others 1990).

A Minnesota performance summary of 16,000 head of cattle indicated that those fed monensin gained 1.6% faster, consumed 6.4% less feed and required 7.5% less feed per unit gain than cattle fed diets without the ionophore (Goodrich and others 1984). The greatest response occurred when the energy content of the diet was 1.32 Mcals/lb. Responses to a combination of monensin and growth promoting implants were additive.

A recent review of the effects of feeding ionophores to feedlot cattle found that ionophores approved for enhancing feed efficiency (laidlomycin propionate, monensin sodium, lasalocid sodium) increased both gain (9 to 12%) and feed efficiency (7 to 16%) when diets contained less than 70% grain (DiCostanzo and others 1997). The most effective responses were obtained when the diet provided more than 200 mg lasalocid/head or more than 100 mg monensin/head each day. The improved efficiencies had positive economic impacts on feed and non-feed costs of the beef operations. In diets containing more 70% grain, ionophores improved feed efficiency by 4 to 7%. A 5% increase in daily body weight gain without an alteration in daily feed intake occurred when laidlomycin propionate was fed. Daily feed intakes were reduced 5 and 6% when lasalocid and monensin were included in the diet.

Feeding tylosin with or without monensin reduced liver abscesses in slaughtered cattle (DiCostanzo and others 1997). Feeding 2 lbs of a ground corn supplement containing 200 mg lasalocid, 150 mg monensin, or 20 mg of bambermycin to 600 lb

steers on pasture resulted in an average 17.8% increase in average daily gain compared to steers fed the supplement without an ionophore (Rush and others 1996). The three ionophores were equally effective in improving rate of gain.

Feeding monensin with or without tylosin and lasalocid in finishing diets resulted in enhanced propionate production and energetic efficiency of feedlot cattle. Adding 4% fat to the dietary dry matter depressed ruminal propionate production and resulted in negative associative effects which decreased cattle performance (Clary and others 1993). The severity of ruminal acidosis was reduced and feed efficiency improved when cattle were fed laidlomycin propionate during adaptation to a 100% concentrate diet (Bauer and others 1995). In general, use of ionophores is recommended to help control feedlot bloat (Cheng and others 1998).

The differences among ionophores in their affinity for ions, the fact that no adaptation period to the ionophores is needed, and the potential for rumen bacteria to develop resistance to individual ionophores over time suggest that a daily rotation of various ionophores may be beneficial (Duff et al., 1998). A review of available data indicated no overall beneficial affect on feed efficiency occurred when ionophore use was rotated (DiCostanzo and others 1997). However, results suggested that sequencing ionophores may enhance the effectiveness of ionophores through different effects on feed intake (DiCostanzo and others 1997). Research has demonstrated that bacteria that become more resistant to one ionophore will also be resistant to the other and cross-resistance also occurs (Newbold and others 1993).

Incorporating ionophores into grain supplements for grazing growing beef heifers increases average daily gain which decreases the age at which puberty occurs. This earlier attainment of puberty can mean a younger age at first calving which will reduce the cost of raising the heifer (Bagley 1993). Ionophores can also help reduce the age of first calving of dairy heifers with similar economic benefits (Losinger and Heinrichs 1996;Hinders 1997).

Mineral metabolism is also altered when ionophores are fed. Monensin increased apparent absorption of Na, Mg, and P, and increased Mg and P retention in steers (Starnes et al., 1984).

Influence of dietary Mg (.18 vs .32% DM basis) on metabolic and growth responses of feedlot cattle to laidlomycin propionate (0 vs 11 mg/kg or 10 g/ton feed) were examined (Zinn and others 1975). The ionophore decreased ruminal degradation of feed N and microbial efficiency and increased total tract N digestibility. When dietary Mg content was increased, the proportions of propionate to acetate production in the rumen increased when laidlomycin propionate was included in the diet. When Mg content was reduced, laidlomycin propionate increased feed intake but it decreased feed intake when dietary Mg content increased. Both Mg and laidlomycin propionate increased diet energetic efficiencies. This study demonstrates the importance of understanding the interrelationships between mineral metabolism and

ionophore feeding.

Methane production was reduced by laidlomycin propionate, especially when dietary Mg content was increased (Zinn and others 1975). Positive environmental effects have been implicated by reduction of methane production from cattle fed ionophores. Cattle can produce 250 to 500 liters of methane daily. Ionophore feeding can reduce daily methane production to between 50 and 100 liters (Johnson and Johnson 1995). It is worth noting that gas emissions from cattle worldwide contribute less than 2% to the total gases responsible for global warming concerns. Nonetheless, the importance of optimal nutrient management to reduce environmental impacts of beef production systems suggest that the role of ionophores in feeding programs will become even more critical in the next millennium (Kornegay 1996).

b) Sheep:

Ionophores, such as monensin, have been shown to increase feed efficiency in sheep fed high concentrate diets. This occurs through a shift in the rumen microbial population which results in an increased ratio of propionate to acetate in the rumen which enhances energetic efficiencies (Kirk and others 1985a). Other nutritional changes occur that may also contribute to increased performance efficiencies. Monensin has a strong affinity for Na and K ions and increases Na concentration within the cell and K concentration outside of the cell (Pressman 1976). Apparent absorption of P and K increased, but retention of sodium decreased in lambs fed diets containing large amounts of grain and 20 mg monensin/kg body weight (Kirk and others 1985a;Kirk and others 1985b). In a follow-up study, lambs fed 20 mg/kg monensin retained more Mg than those fed no monensin (Kirk and others 1985b). Monensin increased apparent absorption and retention of P and Zn. Feeding monensin also decreased urinary, liver and bone Ca. Ruminal Zn concentrations were decreased. Lambs fed monensin showed alterations in divalent cation and P metabolism as well as changes in tissue and ruminal mineral levels.

Flow of digesta contents through the digestive tract and absorption of minerals in lambs fed a 70% concentrate diet containing monensin or lasalocid (23 g/ ton) were examined (Kirk and others 1994). Calcium and P metabolism were not altered by the ionophores. Urinary excretion of Na was decreased with lasalocid but tended to increase with monensin. Apparent absorption of Cu and Zn were not altered by the ionophores. Digesta flow and extent of mineral absorption in different segments of the digestive tract, particularly for pre-intestinal absorption of Mg, were affected by both ionophores. Results also suggest that hypomagnesium may be prevented by feeding Mg and ionophores. These results support earlier research that suggested monensin could neutralize the K-related depression of Mg absorption in ruminants that consume forage-based diets that contain large amounts of K (Greene and others 1986).

c) Poultry:

In poultry production, ionophores are a well-accepted tool used for their anti-coccidial properties. Belgian work in broiler houses indicated that five Eimeria species were more sensitive to the anticoccidial lasalocid (90 mg/kg), than meduramicin (5 mg/kg), salinomycin (60 mg/kg), narasin (70 mg/kg), and monensin (110 mg/kg), respectively. Lasalocid also had the most effective anti-coccidial control in a study of broiler chickens by Chapman and Haecker, 1994. Field isolates of Eimeria species were more sensitive to ionophore feeding (monensin) after broiler chicks were vaccinated than before vaccination (Chapman 1994).

Use of antioxidants such as dihydroquinolines (Duokvin®) at 120 mg/kg diet in combination with ionophores have shown enhanced anti-coccidial efficiency against Eimeria coccidia species. This allowed for reduced level of ionophore incorporation. The efficiency of this response was greater for meduramicin than monensin, salinomycin, or narasin (Varga and others 1994). The anti-coccidial activity of a test ionophore, semiduramcin (concentration of 25 mk/kg), with broiler cockerels indicate that it had a broad spectrum on Eimeria species control (Logan and others 1993). Another test ionophore (Ricketts and others 1992) has shown anti-coccidial efficacy and chicken tolerance (Ricketts and others 1992).

Some nutritional effects of feeding ionophores to chickens have also been investigated. Monensin has been shown to increase the K requirements of broiler chickens but had no apparent affect on their Na requirements (Hurst and others 1974;Charles and Duke 1981;Damron and Harms 1981;Cervantes and others 1982).

SECTION G: USE OF PROCESSED MANURE AS FEED

1. Introduction

In the US over 1.6 billion tons (over 100 million tons of waste dry matter) of animal wastes are produced annually in livestock agriculture. It has been estimated that 50% to almost all (poultry operations) of these wastes are collectable (Webb Jr. and Fontenot 1975;Fontenot and others 1996;Fontenot and others 1996). Animal wastes are traditionally viewed as a recyclable resource of fertilizer nutrients for soil and plants. Use of animal wastes as feed ingredients can realize a five to ten fold relative economic advantage over using this resource as a fertilizer (Fontenot and others 1996).

Over the past three decades a great deal of work has been conducted to evaluate the proper approach to processing animal wastes prior to use as a feed to ensure animal health and well-being are not compromised (Anthony 1966;Bhattacharya and Fontenot 1975;Webb Jr. and Fontenot 1975;McCaskey and Anthony 1979;Fontenot and Jurubescu 1980;Sutton and others 1990;Fontenot and others 1996;NRC 1983;Bhattacharya and Fontenot 1975;Webb Jr. and Fontenot 1975;NRC 1983;McCaskey and Anthony 1979;Fontenot and Jurubescu 1980;Sutton and others 1990;Fontenot and others 1996). Criteria for evaluating animal health and well-being profiles discussed for previous sections are prevalent for use of animal manure as feed.

Animal wastes have been recycled as feed for cattle, swine, and poultry. Solid or liquid animal wastes to be recycled as feed will include a varying amount and type of bedding material. Wastes from animals housed on dirt lots may also contain soil in addition to bedding. Poultry wastes can occur with or without litter. Waste from laying birds, usually does not contain litter but can contain shed feathers, spilled feed, broken eggs. It is illegal to decompose poultry carcasses in manure. If carcasses are decomposed in a compositing facility, the compost should not be recycled for feed. Wastes from broiler and turkey houses will also include some spilled feed and shed feathers plus bedding material. Spilled or unused feed frequently contributes to swine and cattle wastes, the amount varying by housing system.

Only a small amount of waste (<10%) can be collected and recycled from grazing animals. Most of the waste used for animal feed is from confined systems. Because of the high fiber and non-protein nitrogen content of animal wastes, only ruminants are suited for the efficient utilization of recycled animal wastes. Recycling animal wastes as feed can be used as a tool for whole-farm nutrient management to maintain proper soil fertility profiles Fontenot et al., (Fontenot and others 1996).

2. Measurement and Standards for Animal Health and Well-Being

a. Criteria for Animal Health and Well-Being

1) Proper processing to eliminate potential pathogens, improve storage/handling characteristics and maintain or enhance nutritive value and palatability,
2) Defined limits of feeding that do not compromise animal performance and health, and that do not result in residues in food products from animals,
3) Precise knowledge of nutritive value prior to feeding to minimize potential detrimental effects of variability caused by type of waste and processing method.

b. Processing Management Prior to Feeding Animal Wastes

Dehydration, pelleting, ensiling alone or with other ingredients, deep stacking, composting, preparation for liquid feeding, oxidation-ditch aerobic processing, and use of wastes as substrates for single cell protein production are methods that have been used for processing animal wastes for animal feed (Orr 1973;Fontenot 1981;Fontenot and others 1996;NRC 1983;NRC 1983;Fontenot 1981;Fontenot and others 1996). Dehydrating wastes in commercial dehydrators at temperatures ranging from 370 to 700°C will eliminate pathogens and reduce or remove odor. The process does result in loss of nutrients, especially N, and the final product can be dusty. Dehydrated wastes appear to be stable for long term storage and offer a quality product for livestock feed. The process may not be economically feasible due to high energy input costs. This also applies to pelleting as the waste will have to be dried or dehydrated prior to pelleting. Pelleting wastes does provide a consistent product and prevents sorting when fed.

Liquid waste feeding systems have been evaluated for ruminants (NRC 1983). The main disadvantage is that the system has large potential for transmitting disease. Potential health problems have also been described for use of waste liquor from aerobic digestion of swine waste in an oxidation ditch. In this system, liquid waste is continuously stirred and oxygen is incorporated to promote microbial digestion (Orr 1973). After digestion, the slurry mixture is drawn-off as recycled feed for swine. Health concerns have been caused by increased concentration of intestinal worm eggs, increased nitrate concentration in the ditch liquor, and survival of potential pathogens such as Salmonella typhimurium.

Wastes have been used as substrates for protein production. Substrates include algae, yeast, fungi, bacteria, house-fly larva, and earthworms. Protein quality can be high but yield is variable. A research study conducted as part of Southern Regional Project S-202 utilized large scale cultures of algae and bacteria were on dilute swine manure suspensions to produce a protein feed and to remove the wastewater discharge (Sutton and others 1990). The harvested material contained more than >63% crude protein. These systems are more technologically complex and more difficult to integrate into typical farm operations than other processing methods.

Ensiling, deep stacking or composting offer the most practical and, usually, the most economical methods for on-farm processing and are successful in diminishing health hazards when fed. Ensiling animal waste alone or with other ingredients has been successful. This anaerobic fermentation process converts carbohydrates to lactic and other acids which reduces pH and stabilizes the product after bacterial activity ceases. The process generates heat which aids in eliminating pathogenic organisms. Moisture level is critical for proper packing and promoting the ensiling process. Poultry litter at 40% moisture gave satisfactory ensiling (Caswell and others 1978). Water would have to be added to dry broiler litter (< 20% moisture) to attain sufficient fermentation.

Mixing 70% corn silage:30% broiler or turkey litter (as is basis) has resulted in a good ensiling process (Crickenberger and Goode 1996;Fontenot and others 1996;Fontenot and others 1996). Swine waste mixed 60:40 or 40:60 with orchardgrass hay ensiled well (Berger and others 1981). Cage layer waste was successfully ensiled with wheat straw and dry molasses in a 55:35:10 ratio, wet basis, respectively (Ayangbile and Fontenot 1986a). Corn (1:1) or beet pulp (1.5:1), wet basis, were ensiled successfully with cage layer waste (Cooper and others 1978). Cattle waste mixed 70:30 to 30:70 with rye straw (wet basis) resulted in pH < 5 after 1 week indicating a good ensiling process (Cornman and others 1981). Dairy waste (fresh and stored slurry) were ensiled with wheat straw to 70 and 60% moisture levels with 5% dry molasses resulted in good ensilage with pH of 5 or less (Abazinge and Fontenot 1984).

Deep stacking is more prevalent for dry wastes such as turkey and broiler litter. Litter is deep stacked to depths of 4 to 6.5 ft to allow for heat generation which raises the temperature to approximately 60°C and eliminates pathogens. Litter, deep stacked at 15%, 25%, and 35% moisture reached a maximum temperature of 57.5, 61.2, and 60.2°C, respectively at a distance of 18 inches from the top of a 4 ft stack (Fontenot and others 1996). Excessive heating can decrease DM digestibility and cause N loss and insolubilization. Covering deep stacked litter with 6 mil polyethylene sheeting prevented excessive heating, prevented N loss and eliminated pathogenic organisms (McCaskey and others 1991). Composting animal wastes by aerobic decomposition until stable provides a product that can be fed. The process results in a large loss of N. Composting broiler litter (35% moisture) by stacking and mixing (initially after 2 days then at weekly intervals for 6 weeks) resulted in a 15% decrease in crude protein level, but the composted litter was utilized as well deep stacked litter by sheep (Abdelmawla and others 1988).

3. Effects on Animal Health and Well-Being

a. Comparative Nutritive Value of Animal Wastes

The composition of processed wastes in comparison to commonly fed feeds are summarized in Tables 1 to 3. Animal wastes are a good source of protein (high level of non-protein N), minerals (high ash content) and fiber. Animal wastes tend to be lower in energy (TDN) than the selected compared feed. Relative nutritive value of wastes for ruminants in descending order are excreta of young poultry, deep litter of young poultry, swine feces, excreta of laying

hens, manure solids of swine and laying hens, and cattle waste (Fontenot and others 1996). The degree of variability in nutrient content and digestibility of animal wastes depends on animal species, animal age, feeding regimen, bedding material, animal environment, and manure handling and storage system.

Table 1. Mineral composition of animal wastes, DM basis, to be recycled as animal feed[a].

Waste	Ash	Ca	P	Na	Cl	Mg	K	S	Fe	Cu	Co	Mn	Zn
	----------%----------								----------ppm----------				
Beef Waste	18.9	2.34	1.03	.88	1.32	.4	.5	-	1341	31	-	148	242
Swine Waste	18.0	3.04	2.59	2.75	-	1.1	1.9	.3	3724	114	6	342	709
CLW[b]	30.4	8.13	2.22	.46	1.01	.65	1.63	-	1774	70	2	374	477
Broiler Litter	15.0	2.29	1.81	.38	-	.46	2.16	-	-	23	-	-	343

[a]Adapted from NRC, 1983 and Fontenot, 1981
[b]CLW = Cage Layer Waste

Table 2. Comparative mineral composition of selected feeds, DM basis[a]

Feeds[b]	Ash	Ca	P	Na	Cl	Mg	K	S	Fe	Cu	Co	Mn	Zn
	----------%----------								----------ppm----------				
Grass Hay	8.5	.27	.34	.01	.41	.11	2.91	.26	93	19	.4	157	40
Alfalfa Hay	9.2	1.41	.22	.12	.34	.34	2.51	.30	240	13	.3	36	30
Corn, ground	1.6	.03	.31	.01	.06	.11	.33	.14	30	5	.4	6	-
Corn silage	4.2	.31	.27	.03	.18	.22	1.22	.12	180	9	.1	41	21
SBM	6.3	.40	.71	.04	-	.31	2.22	.16	185	22	.1	35	57

[a]Adapted from NRC, 1996
[b]Grass and alfalfa hay, early bloom analysis; SBM = soybean meal

Table 3. Comparative protein, energy and fiber composition of selected feeds and animal wastes, DM basis[a]

Feeds[b]	CP[c]	Fat	ADF	TDN[d]	Wastes	CP[c]	Fat	ADF	TDN[d]
	----------%----------					----------%----------			
Grass Hay	12.8	2.9	41	65	Cattle	16.9	3.1	40.3	48
Alfalfa Hay	20.1	2.9	31	60	Swine	27.9	7.0	26.5	57
Corn, ground	9.8	4.3	3	88	CLWe	30.0	2.2	17.1	48
Corn Silage	8.0	3.5	28	75	Broiler Litter	30.8	3.3	24.1	60
SBM	52.0	2.3	10	84					

[a]Adapted from (NRC 1983;NRC. 1996;Fontenot 1981)
[b]Grass and alfalfa hay, early bloom analysis; SMB = soybean meal
[c]CP = Crude Protein
[d]TDN = Total Digestible Nutrients
[e]CLW = Cage Layer Waste

b. Effects of Feeding Animal Wastes on Animal Performance:

1) *Poultry:*

Dried or dehydrated poultry waste (DPW) was incorporated up to 20% of diets fed to laying chickens without affecting egg production. Incorporation of DPW up to 30% of the diets fed to meat birds supported adequate growth. In both cases, feed efficiency decreased with DPW addition (El Boushy and Van der Poel 1994). The flavor of eggs and meat were not affected. This study supported the premise that cost:benefit ratio of drying cage layer waste precluded its common use in diets for non-ruminants. Using 10% dried broiler litter in broiler diets showed similar gains and feed conversions to a standard diet. A limited amount of processed poultry waste can be recycled back to growing birds and laying hens but is associated with a reduction in economic efficiencies of the operation. Laying hens fed 10% dehydrated cattle waste as the only source of animal protein experienced a 13.5% decrease in egg production and 11. 4% decrease in feed efficiency (NRC 1983).

2) *Swine:*

Economic criteria and performance must be considered when recycling swine waste as feed. Dried swine feces (DSF) was fed up to a maximum of 22% of a ration without depressing intake of finishing swine (Orr 1973). Further work showed that DSF reduced digestibility of protein and energy when included as replacement for SBM. However, DSF was a good source of minerals (Orr 1975). The use of oxidation ditch slurry for pigs was not beneficial (Orr 1975;Hugh and others 1978;Hugh and others 1978). Recycled swine waste may have a place in supplementing gestating sow diets (Johnston 1981). The digestibility of swine waste fractions fed to growing gilts were 46.7% for energy, 48% for DM; 60.1% for crude protein; and 40.9% for crude fiber (Kornegay and others 1977). Feeding 25 or 50% ensiled cattle waste, or 9, 17,or 23% DPW to growing pigs decreased gain and feed efficiency compared to a control diet (NRC 1983).

3) *Sheep:*

Growing lambs and ewes can utilize animal wastes when incorporated into conventional diets. Phosphorus repleted ewes utilized phosphorus more efficiently from ensiled swine waste and broiler litter supplements than those containing dicalcium phosphate and SBM. However, calcium was less well utilized from the wastes. Magnesium was well utilized by all diets (Cook and Fontenot 1985). Wether lambs fed 0, 33.3 or 66.7% deep stacked broiler litter in a diet of corn, SBM, and wheat straw digested less of DM and excreted more minerals as amounts of litter increased (Fontenot and others 1996). Excretion of all minerals was more than 79% of intake. Implications were that more minerals were excreted on the pasture and the soil as a result of feeding increased amounts of litter.

Growing lambs fed 17% DPW grew as well as lambs fed conventional diets. Lambs fed DPW, which supplied 40% of the dietary N, utilized the N as well as that supplied by

SBM or urea (NRC 1983). Lambs fed ensiled swine waste with orchardgrass hay (60:40 or 40:60 ratio) digested the silage better than lambs fed orchardgrass hay (Berger and others 1981).

Limitations of feeding animal wastes to sheep include the potential for high copper intake and copper toxicity. Use of dietary molybdenum has reduced the potential for copper toxicity (Olson and Fontenot 1984). Diets containing up to 68% broiler litter have been successfully fed to growing and breeding sheep for periods of up to 60 days. Use of 50% DPW in sheep diets was considered excessive (NRC 1983). Wether lambs used the N from 70:30 corn silage:cage;layer waste as effectively as lambs fed a corn silage diet supplemented with SBM (Magar and Fontenot 1988).

4) *Cattle:*

Animal wastes can be well utilized by cattle. Recycled steer waste in a mixture of 40 parts waste and 60 parts dry concentrate was as effective as a diet containing corn silage, ear corn and supplement for yearling steers (Anthony 1970). Feeding up to 40-50% ensiled cattle waste in a total diet provide good steer and heifer performance. Pelleted diets containing 25-30% swine waste provided adequate cattle performance (NRC 1983). Growing heifers and steers fed 30 or 45% deep stacked broiler litter with corn silage and corn (1% body weight/day) supported very acceptable animal performance by response to 60% was decreased (Table 4).

Table 4. Performance of heifers and steers fed high corn silage diets supplemented with deepstacked broiler litter[a]

	Level of supplement, dry basis					
	30%		45%		60%	
Item	Steers	Heifers	Steers	Heifers	Steers	Heifers
Initial wt, lb	693.2	605.2	664.9	570.7	660.2	563.6
Final wt, 118 days, lb	989.2	873.0	973.0	829.8	895.4	785.8
Daily gain, lb/day	2.51	2.27	2.61	2.20	1.99	1.88
Average daily intake, lb/day						
Corn silage	38.9	38.7	32.9	27.8	18.4	19.6
Deep stacked litter	7.8	7.6	12.1	10.0	11.9	12.6
Corn grain[d]	7.8	6.8	7.7	6.5	6.9	6.2
Dry matter intake, lb/day	25.3	24.6	26.5	22.3	20.2	20.8
Feed efficiency[c], lb/lb gain						
Corn silage	15.5	17.1	12.6	12.6	9.3	10.4
Deep stacked litter	3.1	3.4	4.6	4.6	6.0	6.7
Corn grain[d]	3.1	3.0	3.0	3.0	3.5	3.3
Dry matter/lb gain, lb	10.0	10.8	10.2	10.1	10.2	11.1

[a]Adapted from Chester-Jones et al, (Chester-Jones and others 1984)
[b]As fed basis.

[c]Fed during last 56 days

A 3-year summary of feeding 70:30 corn silage:poultry litter with a SBM supplement to fattening beef heifers demonstrated a slightly greater daily gain but lower feed efficiency was attained when compared with heifers fed corn silage and SBM supplement. Carcass quality favored the litter-fed heifers (McClure and others 1979). Lactating cows fed up to 23% cage layer waste (CLW) had similar milk yields as cows fed no CLW (Sutton and others 1990). Stocker cattle fed 50:50 corn:poultry litter diets had similar gains but lower feed efficiency than those fed conventional diets (McCaskey and others 1994). Turkey litter should not provide more than 33.3% of supplemental protein for growing cattle (Harvey and others). A mixture of 30% broiler litter with 70% corn silage was well used by dry cows, lactating cows, and by growing and finishing cattle fed with hay and/or corn (Crickenberger and Goode 1996).

c. Environmental Forces Influencing Animal Health and Well-Being

1) *Potential Hazards of Feeding Animal Wastes:*

Recycled animal wastes for animal feed has the potential of exposing animals to pathogenic organisms, toxigenic molds, parasites, harmful level of pesticides, medicinal drugs, and high concentrations of trace minerals and heavy metals. Human and animal health aspects of feeding animal wastes have been reviewed (Webb Jr. and Fontenot 1975;McCaskey and Anthony 1979;Fontenot 1981;Fontenot and others 1996;NRC 1983;NRC 1983;McCaskey and Anthony 1979;Fontenot 1981;Fontenot and others 1996). Clostridium, Corynebacterium, Salmonella, Enterobacterium, Mycobacterium, Bacillus, Coliforms, Staphylococcus, and Streptococcus species have been isolated in unprocessed poultry litter. Proper processing of animal wastes alone or in mixtures at the correct moisture will dramatically reduce or eliminate organisms. In the commercial dehydration process of poultry waste, for example, there is an inverse relationship between temperature of the dehydrator and the number of organisms, and between the moisture content of the dehydrated waste and number of organisms (Chang and others 1975) (Table 5). Dehydration of broiler litter and layer waste eliminates Salmonella.

Long standing California standards for effectiveness of pasteurization of waste products require less than 20,000 bacteria and 10 coliform organisms/g dried product and no salmonella (NRC 1983). McCaskey and Anthony (McCaskey and Anthony 1979) clearly showed the elimination of Salmonella in an ensiled waste-feed mixture (Table 6). The pH dropped to less than 4.5 in this example and the ensiled temperature exceeded 25°C. Ensiling broiler litter alone has been shown to destroy fecal coliforms at a pH of 5.5.

A minimum of 60 days is required for processing animal waste as silage to ensure it is safe to feed. Decomposed poultry carcasses found in ensiled litter caused an outbreak of botulism and it is recommended waste to be recycled should be free of carcasses (Fontenot and others 1996). A microbiological survey of poultry litter in Georgia found

that it is not a source of harmful bacteria such as E.Coli 0157/H7, Staphylococcus aureus, or Salmonella typhimurium (Martin and others).

Mycotoxins have been isolated from animal wastes, as they have in many common animal feeds, and present no greater concern. Fresh feedlot manure had greater amounts of aflatoxins (Aspergillus flavus) than partially decayed or stockpiled manure. Composted feedlot waste did not contain aflatoxin residue (Fontenot 1981). Concentrations of drugs in broiler litter taken from Virginia farms have been summarized (Table 7). If the drugs were in the poultry diets they were identified in the litter at somewhat variable levels. There have been no accumulation of medicinal drug residues in cattle fed poultry litter. A modest withdrawal period of 5 days is recommended (Webb Jr. and Fontenot 1975). It is recommended that litter not be fed to cows producing milk or hens producing eggs for human consumption. Pesticide residues have not been problem.

Table 5. Effect of temperature and moisture on microbial counts of dehydrated poultry waste

Microbes	Dehydration Temperature	Sample Moisture (Duff and others 1995)	Average Microbial Count/g
Aerobic	260° C	>10	20,281,666
		<10	710,000
	Over 260° C	>10	6,719,520
		<10	183,396
Anaerobic	260° C	>10	6,958,333
		<10	730,000
	Over 260° C	>10	1,360,530
		<10	46,241

[a]Adapted from Chang et al. (Chang and others 1975).

Table 6. Effect of temperature on survival of *Salmonellae* in an ensiled waste-feed mixture.[a]

	Temperature (°C)			
Survival After 4 Days Ensiling	5	15	25	35
Number of cultures[b]	21	25	1	0
Percent of cultures	78	93	4	0
pH, initial	4.8	4.8	4.8	4.8
pH, 4 days	4.6	4.4	4.0	4.1

[a]Adapted from McCaskey and Anthony (McCaskey and Anthony 1975)
[b]27 salmonella cultures were used.

Table 7. Drug residues in broiler litter.[a]

Drug	Concentration[b] Average	Range	Number of Samples
Oxytetracycline (ppm)	10.9	5.5-29.1	12
Chlorotetracycline (ppm)[c]	12.5	0.8-26.3	26
Chlorotetracycline (ppm)[d]	0.75	0.1-2.8	19
Penicillin (units/g)	2.5	0-25.0	2
Neomycin (mg/kg)	0	0	12
Zinc bacitracin (units/g)[e]	7.2	0.8-36.0	6
Zinc bacitracin (units/g)[f]	12.3	0.16-36.0	5
Amprolium (ppm)	27.3	0-77.0	29
Nicarbazin (ppm)	81.2	35.1-152.1	25
Arsenic (ppm)	40.4	1.1-59.7	41
Copper (ppm)[g]	254.7	132.1-329.3	46
Copper (ppm)[h]	50.8	37.3-99.4	35

[a]Webb and Fontenot (Webb Jr. and Fontenot 1975).
[b]Dry matter basis.
[c]Chlortetracycline used continuously in broiler diets.
[d]Chlortetracycline used intermittently in broiler diets.
[e]Zinc bacitracin used in broiler diets.
[f]Zinc bacitracin not used in broiler diets.
[g]Copper sulfate used continuously in broiler diets
[h]No copper sulfate added to broiler diets

The greater concentration of trace minerals found in animal wastes has been a source of animal health concern. Potential problems include mineral toxicity and accumulation of minerals in tissues or in the environment (NRC 1983). Copper and selenium are added to livestock and poultry feeds. Arsenic is added in the form of arsenicals. Heavy metals such as cadmium, lead , and mercury occur naturally in feeds. Animal wastes contain a greater concentration of these minerals than feeds because of low absorption (Fontenot 1981;Olson and Fontenot 1984). Copper content of wastes will vary with the amount added in the diet (Table 7). Sheep are particularly sensitive to dietary copper concentrations greater than 15 ppm of the diet DM. Withdrawing dietary copper for up to 140 days did not substantially reduce liver copper concentrations in ewes Olson and Fontenot (Olson and Fontenot 1984). Cattle are less sensitive to copper than sheep. Profiles of bromine, arsenic, cadmium, copper, mercury, molybdenum, vanadium, and zinc were evaluated in cattle fed 70:30 corn silage:poultry litter diets(Westing and others 1977). Only copper increased in the liver. None of the minerals were increased in the muscle tissue. Feeding molybdenum and sulfate appears to help in reducing the potential for liver copper accumulation and appears to be especially beneficial to prevent copper toxicity problems in sheep. Overall quality of edible animal products have not been compromised from feeding animal wastes (Fontenot and others 1996).

2) *Regulation of Feeding Animal Wastes:*

In 1980 the FDA left the regulation of feeding animal wastes to individual states (revoked 1967 article 21 CFR 500.4 to 45 FR 86272 in 1980). Today, regulation is through AAFCO (1990) for processed animal wastes. This regulation states (Fontenot and others 1996)that:

1. Waste must be processed so it will be free of pathogenic organisms,
2. If it can be documented that animals producing the wastes were not fed drugs, no withdrawal period is required, and the waste can be fed to any class of animals;
3. If it cannot be documented that the animals producing the waste were not fed drugs, a 15-day withdrawal is required prior to slaughtering animals or prior to using milk or eggs for human consumption.

SECTION H: CURRENT AND POTENTIALLY AVAILABLE PREVENTION AND MITIGATION MEASURES

1. Introduction

No other factor can affect the health and well-being of animals as severely as exposure to an infectious disease(s). Exposure to bacterial and viral pathogens occurs frequently in the life of an animal, and can spread laterally throughout animal populations at a rapid rate. Depending on the level of immunity within the population and the degree of management under which they are raised, the effect can be quite severe, especially if concurrent infection of multiple pathogens should occur. The need to mitigate the effects of such pathogens and to improve the health and productivity of animals has resulted in the evolution of disease-control strategies. Many of these strategies are applicable to all animal species and either are or would be implemented depending on the limitations imposed by the particular animal unit. The following sections summarize the published data on health technologies commonly employed to reduce the deleterious effects of pathogens on the various species in animal agriculture.

2. Animal Management

a. Swine:

1) *All In - All Out Animal Flow:*

All in - all out (AIAO) animal flow has been documented to improve the performance of pigs (Scheidt and others 1990). The ability to completely empty a room, building, or site prevents the continuous spread of pathogens from older to younger animals. All in - all out has long been a practice of the poultry industry. Barns of birds are routinely emptied following delivery to the slaughter house, washed, disinfected, fumigated and allowed to remain empty for a period of time to reduce microbial survival outside the host. This technology was initially adapted by the swine industry in order to control diarrhea problems prior to weaning. However, in the last five to ten years, the effect of AIAO on the post weaning pig performance has been extensively studied. Studies demonstrate that such practices improve average daily gain by 7-10% ,and feed efficiency by 3 to 5 %, as well as reduce the level of mortality and the severity of respiratory disease in the grow-finish phase (Clark and others 1991). Furthermore, improvements up to 20% in growth rate and 25% in feed efficiency have been documented in nursery pigs as well.

All in - all out can be practiced by room, building, or site. Data indicate that AIAO by site or airspace results in better performance, than if a single room is emptied (McManus 1991). While pigs ideally should be housed within a week of age of each other, two weeks of production can be grouped together. While AIAO does not result in elimination of disease, it does however, result in a reduction in the prevalence of pneumonic lesions, as well as a reduced severity of intestinal diseases. Conversion of large, continuous flow

facilities to AIAO usually entails construction of walls to establish rooms of pigs within buildings. Each room must be individually ventilated. Another means of converting to AIAO pig flow may require the reorganization of farrowing schedules, resulting in larger "batches" of weaned pigs, completely filling a facility at one time. While it does take prior planning, the effect of AIAO on post weaning performance appears to be well worthwhile.

2) *The F-10 System:*

F-10 stands for "farrowing to 10 weeks of age" and is a new technology recently described for the improvement of weaned pig performance (Schuiteman 1993). In this system, sows are weaned in the normal fashion, however the pigs remain in the farrowing crate until they are 10 weeks old. The farrowing crate is then modified and converted to a nursery pen. The advantage of such a system is that early removal of the sow prevents further spread of infectious agents from sows to weaners, a reduction of labor, and improved performance. While little data is available, it appears that piglets raised under the F-10 system out perform those raised under conventional measures. Improvements in growth rate of 44%, a 30% reduction in feed efficiency, and a 50% reduction in mortality have been documented. The disadvantages of such a system may include a reduction in the utilization of farrowing crate space. Therefore, the system may only be applicable to producers using batch or group farrowing schedules. Despite this limitation, pigs raised under the F-10 system appear to be capable of better performance than those in conventional nurseries.

3) *Multi-Site Systems:*

Prior to beginning the review of segregated early weaning, a brief review of the current production systems in the US is in order. The US swine industry currently uses either 1-site, 2 - site, or 3 - site production systems. In a 3-site production system, one-site consists of breeding, gestation and farrowing on one site, with the nursery and finishing on separate sites. Recommended distances between sites range from 1 to 3 km depending on the health status of the operation and the suspected airborne potential of various microorganisms. Two-site systems consist of breeding, gestation and farrowing on one site, with nursery/finishing on another. The main premise of both systems is that the nursery must be located on a separate site away from the breeding herd. This is important to prevent the transmission of microorganisms from the sow to her offspring. This theory has been the basis of segregated early weaning (SEW) technology and will be summarized in a later section.

Multi-site production systems have many advantages for swine producers, besides the improvement of health status. If nursery and finishing facilities are relocated on other sites, existing facilities can be remodeled to expand the size of the breeding herd, usually with reduced investment. Nurseries can be remodeled into farrowing rooms, while finishing pens can house gestating sows. Frequently, swine producers will network together, and establish off-site weaning facilities to commingle pigs from several farms.

The health status between the sow farm must be similar in order to prevent the exposure of susceptible pigs to new diseases. Three-site production can be costly, and difficult for the majority of smaller commercial swine producers in the USA to use. It is usually reserved for breeding stock companies or large herds with 1,200 or more sows. The two-site system is much easier to operate economically and appears to be just as effective. This technology, in combination with the SEW program, is beneficial to all types of procedures and results in improved efficiency of the swine enterprise. This technology will now be discussed.

4) *Segregated Early Weaning (SEW):*

Segregated early weaning (SEW) is a variation of medicated early weaning (Alexander and others 1980). Further reports have indicated the ability to eliminate certain pathogens and improve weaned pig performance (Harris 1990). A critical component of the program consists of hyperimmunization of the sow prior to farrowing to provide high levels of colostral antibodies against specific pathogens. This is important to reduce transmission of microorganisms between sows and pigs during lactation. The pig is then injected with a series of antibiotics to eliminate specific bacteria prior to weaning. Finally, the pig is weaned at an early age to a separate site to prevent further transmission from the sow. Recent studies have investigated the necessity of antibiotics. Under controlled conditions, it appears that age specific separation from the sow may be more important than medication (Clark and others 1994). As far as proper weaning ages, much work has been done to determine the relationship between weaning age and pathogen elimination. It currently appears impossible to eliminate certain microorganisms with early weaning. Pathogens such as *E. coli*, and Streptococcus suis may be present in the pig shortly after birth (day 1), due to colonization via contact with the mucosal surfaces, secretions or excretions of the sow (Amass and others 1996).

Transplacental transmission of PRRS virus, *Leptospira sp.*, or parvovirus may result in the presence of these specific organisms immediately following parturition. However, published data has indicated an ability to eliminate pathogens if certain weaning ages are met (Wiseman and others 1991). Weaning pigs at 10 days of age or less appears to eliminate *Haemophilus parasuis, Bordetella bronchiseptica, Pasteurella multocida* and *Mycoplasma hyopneumoniae*. The initial presence of these organisms is not detected unless weaning ages reach 15 days or more. Similarly, *Actinobacillus pleuropneumoniae* may be eliminated at 16 to 18 days of age. Finally, pseudorabies virus and transmissible gastroenteritis virus appear to be eliminated at 21-day weaning.

Upon arriving to the nursery, weaners are fed diets high in milk product and plasma protein. It is critical to limit feed five to seven times/day for the first week after weaning. Pigs are placed on a water-soluble antibiotic, chosen based on in vitro susceptibility data. Four different diets are usually fed over the eight-week nursery period. Animals are housed in single stage nurseries with plastic coated flooring at 30 to 31°C and are sorted by size and sex.

The decision of which vaccines and medications to use depends on the individual farm diagnostic data. It is recommended that nasal swabs are collected from sows and two to three sick pigs from the nursery and finishing areas be submitted to the diagnostic laboratory for culture. Based on the sensitivity patterns of bacterial isolates, the medication can be chosen. Serology is also an important tool to determine the exposure level of the breeding herd to specific pathogens that are targeted for eradication and assists with the development of vaccination programs for the breeding herd.

Performance following completion of SEW has been excellent, however, little information is available concerning the effect of SEW on the subsequent performance of the sow. Recently, data from four production units in which SEW has been employed for three years has been published. Despite a weaning age of 12 to 14 days, problems with the breeding herd have been minimal. Little reduction in subsequent live born litter size or weaning to estrus interval was detected in four commercial swine herds when three years of early weaning data were analyzed (Dee 1995).

5) *On-Site Segregated Rearing:*

Despite the success of multi-site production, the ability to use such technology may be limited. Frequently, separate farm sites are difficult to obtain due to lack of capital, overall inconvenience from the existing labor force, or a high density of swine in the surrounding area. Although there is little published data at this time, the concept of raising pigs away from the sow, but on the same site looks promising. If the nursery facility is located a short distance (200 to 500 m) from the breeding and finishing buildings and there are no connecting airspace (hallways) between the nursery and the other facilities, performance may be improved. Also, strict segregation of labor is essential with only one person allowed to work in the nursery. Shower facilities are important; however, the routine practice of changing clothes, (coveralls and footwear) prior to entry into rooms appears to be critical. A regular program of rodent control is practiced on a monthly basis by a professional exterminator as well. Preliminary data from an 800 sow farm raising 22kg pigs indicate a reduction in nursery mortality (2.5 to 1.5%), an increase in average daily gain (.34 kg to 4.5 kg) and an improvement in feed efficiency (1.9 to 1.5).

6) *Whole Herd Depopulation-Repopulation:*

Whole herd depopulation-repopulation has gained increased acceptance as a strategy to improve both health and genetic performance. While the process can be very costly and extremely difficult psychologically, it is very effective at eliminating chronic, endemic diseases, as well as improving genetics at the same time. Reasons to repopulate the entire farm include poor growth rate, excessive numbers of non-marketable or cull pigs, poor feed efficiency and low heterosis. While diseases of the nursery pig are typically not severe enough to warrant whole herd depopulation, the technology will be briefly reviewed at this time.

Prior to initiation of a depopulation program, prior planning is required. A careful evaluation of the present herd performance is necessary, including the identification of all significant disease entities currently in existence. Commonly encountered disease problems, which lead to depopulation including pseudorabies, swine dysentery, *Actinobacillus pleuropneumoniae* and atrophic rhinitis. Such chronic disease usually results in excessive antibiotic usage. It is important to establish the amount of antibiotics and/or vaccine, which are being used to treat disease, in order to assess the potential economic benefits of a whole herd repopulation.

In addition to the assessment of current health problems, an evaluation should be made of the genetic status of the herd. Problems, which indicate poor genetic performance, include low live born litter size, low weaning weights, and excessive backfat at slaughter. Finally, due to the fact that whole herd depopulation results in severe short-term capital losses, arrangements frequently must be made with a lending institution to provide an adequate level of working capital.

The timing of the depopulation is critical. Procedures should take into account the length of downtime required, season of the year and predicted market prices. Ideally to decrease downtime, facilities are rented to insure a constant flow of pigs to market. At least 30 days of downtime are usually required on the home farm to allow for thorough cleaning, repairs and to reduce the survival of pathogens outside the host. Ideally, this should take place during periods of hot weather to take advantage of the bactericidal or virucidal effects of drying, heat and ultraviolet radiation. The clean-up procedure is very involved, and encompasses the washing of the entire swine complex including a thorough cleaning of the pit. All equipment, including feeders, crates, pens and ventilation equipment needs to be thoroughly washed with hot (90 to 94°C), high pressure water and disinfected. Pits should be emptied, and slats lifted to obtain access to fecal material that has built up on the underside of the concrete. Finally, a rodent control program should be implemented, and maintained, ideally by a professional exterminator.

Following repopulation, improved performance is usually seen. Improvements of 10% or more in growth rate, and a five to 10% improvement in feed efficiency have been reported. Other benefits include a 10 to 20% increase in pounds marketed and a reduction in vaccination and medication costs. Problems frequently encountered during or following a repopulation consist of mismanagement of the off-site breeding project, reintroduction of a significant disease via the purchased stock, as well as the enhanced level of specific diseases such as greasy pig disease or parvovirus. Such diseases are thought to arise from a low level of immunity within the immature breeding population. Overall, whole herd depopulation and repopulation can produce both health and genetic benefits; however, due to its high level of economic and psychologic stress it is a technology that should be employed only when other options have been exhausted.

7) *Partial Depopulation:*

Partial depopulation consists of an adjustment in pig flow to interrupt horizontal transmission of pathogens from older, previously infected pigs, to those recently weaned. Partial depopulation (PD) was first utilized for the control of post-weaning PRRS (Dee and Joo 1994;Dee. S.A. and others 1997a;Dee and others 1997b). While PD has been primarily used in PRRS positive nurseries, it can be applied to infected finishers, as well.

The use of PD for PRRS control is bound on the principle that virus circulation exists in a specific stage of production i.e. the nursery or finisher, but is absent in the breeding herd. This specific pattern of spread is critical for success, since infection of piglets prior to weaning results in the introduction of viremic animals to the nursery or finishing population.

Productivity and profitability in 34 nurseries before and after PD is given in Tables 1 and 2. The advantages of PD are a minimal disruption of PD is that the technique depends on an absence of pathogen spread from the sow to the pig, prior to weaning. In addition, it may be logistically difficult to implement in large ($\geq$ 1000 sow) herds and it requires a temporary off-site facility to house depopulated pigs. Finally, the strategy may need to be repeated every 1 to 2 years.

8) *Conclusions*

All of the aforementioned strategies are effective at improving animal health, well-being, and performance. Selection of the strategy depends on the input of the veterinarian, the financial status of the farming operation and the ability of the producer to properly manage the system once changes have been made. Proper planning prior to execution of the plan will enhance its success, and the veterinary practitioner is in an excellent position to provide knowledge and direction to producers in need.

Table 1: Mean differences in the performance of four study groups 12 months before and 12 months after nursery depopulation.

Group	Number of Farms	ADG (kg)		% Mortality		FE		Treatment Cost/Pig**	
		Before	After	Before	After	Before	After	Before	After
1	15	.25	.38*	9.7	2.3*	1.83	1.78	2.88	1.48
2	6	.25	.34*	14.4	2.0*	2.01	1.85	4.17	2.05
3	7	.29	.37*	7.0	1.7*	2.06	1.85	3.63	2.36
4	6	.26	.41*	10.9	1.2*	1.95	1.70	2.15	0.55
Total	34	.26	.38	10.2	1.9	1.91	1.77	2.90	1.63

* = ($p<.0001$)

** = injectable medication and vaccination costs/pig (US dollars)

Table 2: Difference in mean margin over variable cost per sow in four study groups 12 months before and after nursery depopulation.

Group	Number of Farms	Before	After	Difference
1	15	-68	+180	+248
2	6	-150	+23	+173
3	7	-21	+115	+136
4	6	-50	+393	+443
Total	34	-50	+178	+228

b. Cattle:

As suggested earlier in this section, although specific diseases and disorders may differ among species, many of the practices (the biosecurity efforts) used to prevent or mitigate against negative impacts on animal health are similar across species. Thus, the cattle industry faces many of the same biosecurity issues as described for swine and poultry. Beef, swine, and poultry are frequently raised in groups and leave the farm for slaughter as a group. This provides the opportunity to conduct practices such as the all-in-all-out animal flow described for swine. Animal movement in a dairy facility is more frequently based on individual animal flow that generally prevents this type of management practice from being utilized.

A recent dairy health conference at the University of Minnesota provided several presentations that summarized ongoing efforts to prevent and mitigate negative impacts on the health of dairy cattle (Rapnicki 1999;Collins 1999;Godden and others 1999;Buelow 1999;Seguin 1999). The importance role of accurate records in making decisions was stressed as was the importance of developing and following standard treatment protocols - specific procedures to administer medications (Rapnicki 1999). This presentation highlighted the fact that both individual cow and whole herd decisions affect the health of each cow in a unit. Well-designed whole herd policies consider the impact of specific situations on all cows in the herd and thus impact the health of each cow.

1) *Mitigation Strategies*

For cattle, some mitigation strategies include:

1. Vaccination programs, some of which have been documented as effective in field situations.
2. Use of calf hutches for heifer rearing, to reduce exposure to microorganisms causing various contagious diseases such as Johne's disease and Salmonellosis.
3. Feeding of colostrum to newborn calves within the first 12 hours of life (Gay 1983;Wells and others 1996) to provide calves with necessary energy sources, vitamins and minerals, and antibodies to disease-causing pathogens.
4. Early separation of calf from dam, to reduce exposure to pathogens (Jenny and

others 1981;Wells and others 1996).

5. Use of offsite heifer rearing systems, again to reduce exposure to pathogens causing disease, though not well documented effectiveness in improving animal health.
6. Screening cattle before introducing to operation to avoid introducing diseases such as Johne's disease, bovine viral diarrhea, and contagious mastitis.

2) *Biosecurity*

Biosecurity issues were addressed (Collins 1999;Godden and others 1999;Buelow 1999) and several biosecurity programs were described. Biosecurity programs are designed to control infectious diseases, both by preventing their occurrence and by eliminating those that exist. Specific steps of developing a biosecurity program and the importance of such a program were addressed (Godden and others 1999). These programs include management practices that:

-reduce the likelihood of introducing new disease from an external source
-reduce the spread of existing disease
-reduce the impact of the existing disease on the dairy.

Testing animals for the presence of disease and management steps taken to introduce new animals into a unit are major components of a biosecurity program.

3) *Major diseases of cattle*

Major infectious diseases of cattle in the upper Midwest (including Bovine viral diarrhea [BVD], Johne's disease, contagious mastitis, Salmonellosis, Mycoplasma bovis, hairy heel warts, Neospora caninum, and Bovine leukosis [BLV]) were discussed and a brief review of the epidemiology of these diseases, methods of testing for the diseases and some potential measures for prevention and control were presented (Godden and others 1999). Other presentations in this conference described biosecurity programs and potential impact of infectious reproductive diseases such as Neospora caninum induced abortions (Seguin 1999) and of infectious mastitis such as Staph. aureus (Buelow 1999).

Johnes disease is caused by an infectious organism Mycobacterium paratuberculosis (Collins 1999;Buelow 1999). Young calves acquire the disease by ingesting the organism. However, development of the disease is usually slow and most infected animals do not develop clinical signs until the second or third lactation. Evidence suggests the prevalence of the disease is increasing but the greater incidence is also due to increased testing. In 1996, a USDA survey inidcate that 41% of the U.S. daity herds had at least one Johne's positive cow (Collins 1999). Poor farm hygiene increases the rate of transmission among animals. Current efforts to develop a vaccine have not been effective (Collins 1999). Johne's is a disseminated infection and has the potential to contaminate beef products both pre and post-harvest. Crohn's disease and Johne's disease have similar clinical signs and pathologies. Although there is no medical

consensus exists as to whether M. paratuberculosis causes Crohn's disease in humans, there is at least evidence that suggests the disease may have some similar linkages (Collins 1999)

c. Poultry

Because disease is a result of interaction of the host, environment and pathogen, health promotion methods must take all three into account. The following methods are available:

- provide a comfortable environment
- reduce or eliminate vertical transmission
- biosecurity
- immunization
- medication

1) *Provide a Comfortable Environment:*

Poultry are usually kept in confinement facilities to protect them from the elements, from predators and from disease. Such confinement buildings are designed and built for the specific poultry type (broiler, layer or turkey) housed in them. Poultry in confinement suffer from less disease (Shane and others 1995;Zander and others 1997), have better livability and experience fewer environmental extremes than poultry kept outdoors. Problems can arise in confinement facilities that are associated with deficiencies in management (Shane and others 1995;Zander and others 1997) and associated with the Minnesota climate.

2) *Reduce or Eliminate Vertical Transmission:*

The National Poultry Improvement Plan is a voluntary program for the elimination and reduction of vertically transmitted diseases. Nearly all breeder owners and hatcheries (commercial, game bird, waterfowl, and exhibition) are participants. The voluntary plan provides purchasers with information about the health status of breeders from which they buy hatching eggs or baby poultry. This program has resulted in the near eradication of Pullorum disease, Fowl Typhoid, *Mycoplasma gallisepticum, Mycoplasma meliagridis and Mycoplasma synoviae.*

Another method to reduce vertical transmission of disease is proper hatch egg handling. Eggs must be laid in properly designed and constructed nests, the nests must be managed correctly, the eggs must be collected frequently, and the eggs must be kept clean. These practices reduce baby poultry mortality due to *E. coli*, staph, paratyphoid and aspergillosis.

3) *Biosecurity:*

Biosecurity is preventing the introduction of disease. The level of biosecurity practiced in a poultry operation will vary depending on the type of operation, size of the operation and the disease risk. These factors affect the potential financial loss associated with a disease introduction.

Diseases are introduced by other poultry, other birds, domestic and wild animals, insects, people and equipment.

Attempts to keep disease out include all in B all out management used particularly in broiler production, turkey brooding, and commercial pullet production. Cleaning and disinfecting of poultry houses, equipment and vehicles associated with moving poultry is a standard practice. Control of the movement of people and equipment is considered essential to preventing the introduction of diseases. Control of wild and domestic birds and mammals is considered essential to biosecurity.

Conceptual biosecurity is the vision that diseases that do not exist on the farm or in the flock can be kept out. It is the basis for location of farms and buildings, the types of housing utilized and the geographic separation of farms.

Structural biosecurity is applying the concept to the farm layout, location of roads, drainage, fences etc. and provision of controlled access ways to the farm and buildings.

Operational biosecurity is what managers actually do to keep diseases out. It includes the policies, practices and procedures employed to control:
Bird movement policies and procedures
Chick delivery - records from breeders and hatchery
Pullet moving
Hen moving
Slaughter movement
Vehicle and equipment policies and procedures
Poultry moving vehicles and equipment, feed trucks, egg trucks
Clean out procedure and manure disposal
Check list

4) *Immunization:*

Some diseases are sufficiently common or serious to justify routine vaccination. These include Marek's disease, infectious bursal disease, hemorrhagic enteritis, fowl pox, avian encephalomyelitis and infectious bronchitis. There are other diseases for which vaccines are available but their use should depend on a professional assessment of their need. Some attenuated vaccines have the potential for reversion to virulence if allowed sufficient passages through birds, so it is well to remember that vaccines can be harmful if misused.

5) *Medication:*

Medication can be used in poultry for prevention or treatment of disease. Preventive medication includes the use of coccidiostats, antibacterials and anthelminthics. Treatment medication includes treatment for coccidiosis, helminths, external parasites and bacterial diseases.

Preventive medication is usually provided in the feed and use of feed medication is strictly controlled by the U.S. Food and Drug Association (McChesney and others 1995). Treatment medication may be administered in the feed and is then under the control of the FDA. Medication administered by any other route may include over the counter drugs or prescription drugs. Over the counter drugs are approved for specific use by the FDA. Any other use of over the counter drugs and use of prescription drugs requires a veterinary prescription.

3. Facility Design and Management

a. Introduction:

Animal facilities range from environmentally controlled buildings to pasture systems with numerous options in between. Facilities are designed to facilitate animal management, care, and handling; provide environmental conditions to promote animal health and well-being; minimize labor requirements; handle manure properly; be economical; and provide for worker safety and health. Most designs are a compromise between these competing design goals.

Two cooperative regional organizations associated with Land-Grant Universities (e.g. Midwest Plan Service (MWPS) and Natural Resource, Agriculture, and Engineering (NRAES) produce and publish handbooks and other materials that provide design recommendations for animal facilities. These handbooks are commonly used by engineers and allied professionals involved in the design of animal facilities. Proper design, construction, and management are needed to create acceptable animal facilities.

Engineered control strategies for controlling airborne contaminants can be put into three categories source control, ventilation control, and removal control or air cleaning. Two other strategies include administrative control and personal protection. These later two strategies are typically used to control human exposure by limiting the time people are exposed to airborne contaminants (i.e., administratively adjusting work schedules) and by having people wear appropriate personal protection (i.e., filter masks to limit respiratory exposure to dust). Industrial hygienists generally prefer engineered strategies.

In general implementing engineered control practices increases production costs. Implementation often depends on the cost/benefit ratio. Costs include capital (i.e., initial purchase price) and operating costs (i.e., energy, labor, supplies, and maintenance).

Effectiveness, dependability, and ease and amount of maintenance are also important considerations when evaluating air quality control options.

b. Source Control:

Sources of the airborne contaminants found in animal buildings include the building occupants (i.e. animals and humans), feed, manure, bedding/litter, insects, and any chemicals used for cleaning or other purposes. Source control can be fully or partially achieved by removing some or all sources. For example, outdoor manure storage is a way of removing the gases generated by microbial transformation of the manure stored in a deep pit below an animal building.

Source control can also be achieved by manipulating the source to minimize contaminant generation. Diet manipulation is an example. More information on diet manipulation for reducing gas emissions in presented in the Mitigation and Emission Control Technologies section of the GEIS Odor and Air Quality report. Fat and oil addition to a feed can be used to reduce dust generation (Chiba and others 1985;Wilson and others 1993;Chiba and others 1987;Gore and others 1986;Mankell and others 1995;Welford and others 1992;Wilson and others 1993;Chiba and others 1987;Gore and others 1986;Mankell and others 1995;Welford and others 1992).

Dust within an animal building can be reduced by using an enclosed feed delivery system, which will reduce the amount of dust discharged into the building (Feddes and Barber 1995). Feeding system alternatives (Bundy and T.E. Hazen 1975), such as using pelleted vs. ground feed, using wet vs. dry feeders, and even the use of liquid feeding have not all been extensively evaluated in regard to how they control dust levels in animal buildings (Pearson and Sharples 1995). Cleaning surfaces with accumulated dust on a weekly basis was suggested as an option, however labor requirements and limited overall benefit limited its adoption (Dawson 1990;Pedersen 1992;Pedersen 1992).

Oil sprinkling is another dust control practice. Vegetable oils and other materials can be sprayed onto floors to prevent settled dust from being re-entrained into the air by animal activity. The method effectively reduces airborne dust levels, with few apparent side effects (Mankell and others 1995;Takai and others 1995;Takai and others 1995). Takai et al. (Takai and others) found that dust levels could be reduced from 60 to 80% when canola oil was sprayed daily with a high pressure dispensing system in a pig nursery building. They also found that little or no health problems existed with the pigs that were exposed to this oil treatment. Zhang et al. (Zhang and others 1996) showed a similar reduction of dust by simply spraying or sprinkling canola oil once a day with a hand-held sprayer in the pens of a pig-finishing barn. Jacobson et al. (Jacobson and others 1998) used this same oil sprinkling technology (Zhang) to determine if lowering the dust generation also reduced odor emissions from a pig nursery barn. Somewhat mixed results were found as were some disadvantages to this practice, including worker safety issues (slippery floors) and more time needed to clean the room between groups.

Another example of source control is the application of chemical and biological additives to stored manure in an attempt to change manure characteristics or transformations to reduce contaminant emissions from sources. More information on these products is presented in the Mitigation and Emission Control Technologies section of the GEIS Odor and Air Quality report.

Moisture control is a commonly used source control strategy. Dry manure will generally produce less gaseous emission but drier manure and bedding/litter may increase dust generation. Moisture control can be achieved by removing wet litter from the building, avoiding water spillage, adding dry bedding, ventilation, and heating. Moisture control is commonly used in animal buildings.

c. Air Cleaning:

Indoor air cleaning can be accomplished a number of different ways including dry filtration, wet scrubbing, and electrostatic precipitation or ion generation. Information on these methods is provided in the Mitigation and Emission Control Technologies section of the GEIS Odor and Air Quality report.

d. Ventilation:

Ventilation brings relatively clean and dry outdoor air into a building, distributes and mixes the air inside the building where it picks up heat, moisture, and airborne contaminants before the air is exhausted. Increasing air exchange theoretically should reduce indoor air contaminant concentrations. Although increased ventilation is valid for some units, there are some situations (Jacobson and others 1996) when dust levels were actually increased by high ventilation rates because it lowered the air humidity levels, resulting in a higher dust generation rate. Thus, ventilation or dilution of the air inside a building may have only a limited effect (Harry 1978) in controlling dust in an environment like an animal building with so many dusty surfaces and sources.

Studies have shown some benefits by manipulating the ventilating system. Robertson, (Robertson 1989) "purged" a pig building with a high volume of air exchange for a 10 minute period to expel dust (60 % dust reduction) which can be a useful management tool for workers. Another study (van't Klooster and others 1993) modified the inlet system, in a standard negative pressure ventilation system, to bring in fresh air in the worker's zone and exhausted air underneath the slatted floor, resulting in a 40% reduction in dust exposure to the workers.

e. Control of Microbial Concentrations and Emissions:

There is little information available on strategies specifically designed to reduce airborne microbial concentrations and emissions. Some strategies exist to reduce microbial loads in the sources (feed and litter) however, the research does not indicate if this would impact overall airborne microbial emissions. Feed processing technologies such as expanders, pelleting, and extrusion reduce feed microbial load by applying heat and steam. Litter treatment with compounds to reduce ammonia emission also may have an indirect effect on lowering litter microbes by lowering the pH of the litter (Terzich 1998).

Other strategies help prevent disease introduction onto a farm include commonly recommended biosecurity practices such as, purchase disease free stock, clean and disinfect facilities and premises, sanitize the water, and isolation practices that prevent disease introduction and spread through a farm from workers, equipment, and other animals and pests. These management techniques are usually directed toward specific poultry pathogens but have the affect of lowering numbers of microorganisms in between flocks.

Due to the association of microorganisms with dust, technologies and management schemes to reduce dust levels may also impact microbial emissions and disease spread. Such techniques might include fat addition to feed, and oiling the litter (Taschuk and others 1991;McGovern and others 1999;McGovern and others 1999). Others would include management of ventilation rates, temperature and humidity. In the winter season, reducing room temperature (adjusted for the comfort of the bird) has the effect of increasing ventilation rate and increasing humidity level which helps to suppress and reduce dust levels (Noll and others 1991). Misting systems are used to cool and suppress dust however they may not decrease airborne microbial emissions. Willis et al (Willis and others 1987) found that the combination of misting and evaporative cooling for dust control improved broiler performance in comparison to control groups. However, the system also significantly increased airborne bacterial concentrations while decreasing dust level.

Some recent literature on negative air ionization in preventing transmission of some poultry diseases may have eventual application. In controlled environmental chambers, use of negative air ionizers decreased transmission of Newcastle disease and salmonella from infected birds to those kept in chambers without ionizers (Mitchell and King 1994;Gast and others 1999;Gast and others 1999).

SECTION I: MAJOR RELEVANT ONGOING RESEARCH

There are major research and teaching programs that emphasize animal health at most of the land-grant veterinary colleges in the U.S. These programs vary in their species of emphasis and the scope of their programs. Veterinary colleges are charged with training the next generation of veterinarians to serve production agriculture and conducting research to determine treatment and management systems that will promote animal health. Typically, these veterinary programs do not compare and contrast animal health across production systems in favor of studying health management options within a production system. It is very difficult and expensive to study interactions of production system and animal health under controlled conditions. Consequently, veterinarians must rely heavily on observational data and professional experience to promote animal health across a variety of production systems and conditions.

Several universities in North America are studying production and management practices that promote animal well-being. Specifically related to well-being of pigs, active research and education programs are currently in place at: University of Illinois, Purdue University, Texas Tech University, and the Prairie Swine Center in Saskatchewan, Canada. Several universities in Europe are also engaged in similar research programs. Specific projects are too numerous and varied to detail in this summary report. A summary of cooperative Regional Research projects (within the CSREES-USDA) that specifically address animal health topics is provided (Table 1).

Additional governmental (Federal and Stae) efforts are also ongoing. A key effort related to this GEIS topic is that by the National Animal Health Monitoring System (NAHMS). NAHMS is conducting a study to assess animal health on feedlots. Staff from NAHMS met with the National Cattlemen's Beef Association (NCBA), the American Veterinary Consultants, university faculty feedlot personnel, and regulatory officials to prioritize information needs that could and should be addressed by the 1999 NAHMS study and to develop study objectives. Quality assurance and preharvest food safety remain among the top information needs. Product quality efforts will focus on injection routes and locations, implant strategies, and management practices that affect hide quality. Preharvest food safety efforts will focus on factors associated with pathogens such as Escherichia coli (E. coli 0157), Salmonella (salmonella typhimurium DT104), and Campylobacter. NAHMS will document patterns of pathogen shedding and evaluate factors that contribute to shedding. Management practices that could help producers decrease pathogen shedding will be assessed. The study will also identify which antimicrobials are in use and the extent of their use. The study will begin in August 1999. Additional information on this project is available at their website www.aphis.usda.gov/vs/ceah/cahm.

The Food and Drug Administration, Center for Veterinary Medicine is conducting a study of the microbiological hazards associated with the food production environment which includes animal feeds. These efforts are part of an overall effort intended to develop the means to identify and characterize foodborne hazards more rapidly and accurately, to provide tools for regulatory enforcement and to develop interventions that can be used as appropriate to prevent hazards at each step from production to consumption. The role of FDA/CVM in this effort relates to microbial hazards associated with preharvest phases of food animal production and includes aquaculture.

Table 1. Regional Research projects (within CSREES-USDA) working on animal health topics.

Kind of Animal	Project Number	Title
All	S-261	Interior environment and energy use in livestock facilities
All	S-274	Integrated management of arthropod pests of livestock and poultry
All	W-102	Integrated methods of parasite control for improved livestock production
Cattle, beef	NCR-87	Beef cow-calf nutrition and management
Cattle, both	NC-107	Bovine respiratory disease: risk factors, pathogens, diagnosis and management
Cattle, dairy	NE-112	Mastitis resistance to enhance dairy food safety
Cattle, dairy	S-284	Genetic enhancement of health and survival for dairy cattle
Poultry	NCR-187	Enteric diseases of poultry
Poultry	NCR-191	Avian respiratory diseases: pathogenesis, surveillance, diagnosis and control
Poultry	NE-127	Biophysical models for poultry production systems
Poultry	NE-138	Epidemiology and control of emerging strains of poultry respiratory disease agents
Poultry	NE-60	Genetic bases for resistance and immunity to avian diseases
Sheep	NCR-190	Increased efficiency in sheep production
Swine, cattle	NC-62	Enteric diseases of swine and cattle: prevention, control and food safety

Animal Industries are actively involved in research to promote the continued assessment of factors affecting animal health and refinement of management practices to promote improved animal health. This includes efforts by organizations such as the Minnesota Turkey Research and Promotion Council, the National Pork Producers Council, and the National Cattlemen's Beef Association.

SECTION J: RECOMMENDATIONS FOR ADDITIONAL RESEARCH AND ANALYSES

Improvements in the methods to assess animal health and well-being are needed. This has been evaluated and debated by many people for many years, and is unlikely to be resolved by short-term projects. Despite our current knowledge, we seem to be unable to define clearly and specifically the criteria associated with "high health" status. There seems to be no laboratory test or battery of tests that is universally agreed upon to accurately delineate the health status of a group of animals. Veterinarians must use a combination of animal performance records, results of postmortem exams, mortality and morbidity rates, levels of antibodies to specific disease circulating in the animal's blood (titers), presence of infective organisms in the animal or its environment, and visual appraisal to assess the health status of a group of animals. Research that can define these standards for producers and veterinarians would be of immense value to the livestock industry and consumers. Unfortunately, this is not a goal that can be achieved in a short period of time and may, in fact, not be possible to achieve. Comprehensive multi-disciplinary efforts will be certainly be required to develop such an indicator. However, the potential value of achieving this goal and the knowledge gained in pursuit of this goal clearly justify the continuation of efforts in this area.

Another research area that deserves some attention relates to the impact of housing/production system on animal health and the general aspects of animal well-being. There are plenty of anecdotal evidence and observations in the field concerning the benefits and problems with this or that housing/production system. Unfortunately, very few of these are documented under controlled conditions. Under field conditions, genetics of the animals, feeding systems, management approach, disease challenges, and other conditions vary from one production site to another making it very difficult if not impossible to accurately attribute differences in animal health specifically to the housing system. This is a very difficult area of research that needs attention. Such a research objective can most effectively be achieved by universities working in partnership with producers and private industry.

As stated throughout this report, even less is known about the more cognitive aspects of farm animal well-being. Research efforts in this area are also ongoing and the information gained will increase our understanding of animal biology and environmental interactions. However, these efforts represent a smaller component of the overall effort to assess animal health and general well-being. Comprehensive efforts involving multiple disciplines are also required to achieve informative descriptions of animal well-being. Defining well-being without a method to measure it is, of course, insufficient [Sandoe, 1996]. By the same token, taking something we can measure and deciding that it equates to well-being is ultimately unacceptable. Saying "we do not really know if animals are well off in this situation," is fine; saying "they are well off" based on our current limited understanding and incomplete social examination is a mistake.

Clearly, more research is needed on the subject of how much agricultural animals suffer from various practices. The non-productivity measures we have available, even if accepted uncritically as useful, all require more research before we have precise measures of animals in different settings. Furthermore, some commentators contend that to truly understand what is good or bad for a given

species, we need to draw upon "full, systematic observation of a zoologist prepared to be interested in a species for its own sake, not casually for purposes of exploitation" [Midgley, 1983 (38-9)].

Following from the discussion that acceptable levels of well-being are socially constructed, social science research is needed before we can draw conclusions about whether well-being is adequate. We need answers to such questions as "are animals being treated in ways that the people of Minnesota find acceptable?" and "how much are people willing to pay in higher food prices to provide certain amounts of well-being?" Such questions can be researched using methods that are discussed in the External Costs and Benefits report.

The approach used by NAHMS to assess animal health and well-being serves as a good model for efforts in these areas. For example, there are few empirical data available regarding prevalence of the different kinds of parasites among the different housing styles and farm sizes. Cattle and swine are at risk of being parasitized by a number of organisms and housing styles range from animals outside on soil to indoors on concrete. This risk of parasitization is true for every domestic species. Closed units have the potential to eradicate and exclude a number of organisms and this exclusion should benefit animal health. However, we do not know if this actually occurs nor do we know how well the different industries are capitalizing on this potential benefit. An interesting comparison would be to do parasite surveys among grazing and confined cattle or swine and at least stratified these comparisons by farm size. Mail or phone surveys of producers or clinicians would not be sufficient. Objective measures of parasite prevalence are needed.

This effort would involve a large amount of physical labor to collect, categorize and analyze samples from individual animals on individual farms and of actually production practices utilized at each farm. However, the cost-benefit ratio could be improved by expanding this effort to include a number of other important factors (such as those described in the first paragraph in this section) to assess overall animal health. During the on-site interview to assess production practices actually utilized, an assessment of the producers actual awareness of federal, state, and local regulations that govern their industry could be determined. A concurrent assessment of the actual or potential impact of these regulations on the industry could also be obtained. Results would provide an extensive knowledge of the prevalence of various diseases, infections and the causative organisms. Results would also greatly improve our understanding of this aspect of the agricultural animal industry and could provide a foundation for informed discussion by policy makers.

One of the most important recommendations we can make is to re-enforce efforts to increase public awareness of how, when, and where, their plant and animal foods are produced. The proportion of society that has any direct connection with agriculture continues to increase. This growing separation between producers and consumers of food results in multiple misconceptions, confusion, and controversies. Support for educational efforts to facilitate a greater general understanding of animal agriculture and how it continues to change is warranted.

SECTION K: SUMMARY OF COMMENTS - REVIEW TEAM, CITIZENS ADVISORY COMMITTEE, EQB

The Animal Health Topic Team extends it's sincere thanks to the individuals that provided an external review on such a short turn-around time. We apologize as a Team for making their task even more difficult by providing these individuals with only the initial draft rather than a complete document that had undergone intensive internal review. Thus, this should be considered when evaluating reviewer comments. Regardless, the efforts of the external reviewers contributed positively to the current version of this document.

We have received four external reviews to date. They responded to three standard questions and a fourth question which encouraged them to provide additional comments. Responses to the questions are summarized.

The first question asked if the information and data in the document were complete, accurate and understandable. Reviewers responded that the version provided had a very complete reference list. It was apparent that not all of the references had been incorporated into the actual document. This was especially true for the animal well-being section. Additional coverage of swine and cattle vices was also requested. One reviewer commented that the choice of terminology underestimated the sophistication of a typical lay audience while another reviewer commented that the subject matter required additional effort to make it more understandable for the lay audience.

The second question asked if the document adequately addressed the original questions in the GEIS Scoping Document. Reviewers that specifically addressed this question indicated that the document did address the original questions adequately.

The third question asked if there were additional information that should be gathered or additional questions that should be asked. One reviewer thought the document was complete as presented, one asked for specific discussions of agricultural practices that were potentially painful, and one provided numerous comments, especially relative to the animal well-being section that was previously acknowledged as being incomplete. We had addressed some of these issues in the ongoing process of completing the document. In the time remaining after receiving the reviewer comments, we were also able to address some, but not all, of the specific issues raised.

The fourth question gave the reviewers with the opportunity to provide any additional comments. Some reviewers used the document to provide specific editorial comments. Others provided a few comments which we attempted to address.

Response to EQB/CAC Comments on The Initial Draft of the Literature Review For the Animal Health Topic

The Initial Draft submitted by the Animal Health Team to EQB/CAC and to the external reviewers was indeed an initial draft. Not all of the subteam reports had been submitted and no team member had the opportunity to review the compiled sections that comprised the initial draft prior to its submission. Thus, the team recognized there were several missing and inadequately addressed components and that this placed an undue burden on the reviewers. As the initial draft was being reviewed, the team continued to develop the report and addressed several of the questions raised by EQB/CAC and by the external reviewers. Although we believe the report has been substantially improved since the initial draft, we do recognize that most any reader (including team members) will be able to identify sections that could continue to be improved. However, the deadline for completion is upon us. Our response or lack of response to the specific questions and comments from EQB/CAC are provided.

1. Animal well-being is overlooked

- Explain the arguments and the literature behind the arguments
- Is there a working definition of "animal well-being"
- Explain some of the routine practices and situations that public is concerned about. Ex: separation of mother from young, de-beaking, "screaming" pigs

This was perhaps the weakest section of the initial draft and the comments received reflected this status. We have incorporated a substantially developed section on animal well-being to the final draft of the report. Literature relative to animal well-being has been expanded. Working definitions of animal well-being have been presented. Routine industry practices identified as being of concern have been described.

2. Missing information on rules / regulations

- Explain current laws that govern treatment of animals raised for food
- What about compliance and enforcement of these laws

Current laws regulating agricultural animal use are covered in the final version of the report. Information on compliance and enforcement is also provided.

3. Missing information on alternative housing / alternative systems

- More information is needed on alternatives to confinement facilities and alternative practices. EX: antibiotic free production; Swedish deep straw bedding
- Review is too pro-confinement
- What is known about differences in practices and health in these different facilities? EX: Does a pig require hormones for aggression in a deep bedding system too? Does a cow who is grazed require as many vet visits?

Additional information on alternatives to confinement is in the final report. Costs and benefits of confinement are described. The difficulty of comparing veterinary costs across production units is described. Information on various production systems is presented. We were not able to find information regarding hormone treatments for aggressive pigs in deep bedding system.

4. Caution about report assumptions

- EX: feeding the world
- EX: productivity is good

Information on future world food requirements was presented to provide context for society's historical and continued need to produce ever-increasing quantities of food. This historical mandate from society explains, in part, the continued push to increase production and the efforts in animal agriculture to increase productive efficiency of it's animals.

5. Missing information on animal agriculture in other countries

- European policy examples in oral but not written form (ex: animals outside in Norway and Sweden; offal as feed; differences in air quality in confinement facilities; difference in regulation on use of antibiotics for growth purposes).
- Cross reference to role of government.

Information on these topics was expanded. Additional time is required for further expansion.

6. Size, number and density impacts

- Is there a limit to size?
- What would be the impact of no animal (especially the ruminants) in Minnesota? (Cross reference land use)

These items were not requested for this topic of the GEIS report.

Within any facility, there is an upper limit to the number of animals that can be provided adequately health and well-being. Continued increases in size (animal number) require continued increases in the physical infrastructure and labor force in order to provide animal care.

7. Manure as feed

- Explain the practice
- Frequency of the practice in MN
- Legality in MN

The practice of feeding processed manure to animals was explained. The frequency of the practice in Minnesota is minimal while it is more frequent in the South-eastern U.S. (information was not received in time to incorporate into the report).

8. Diseases

- Johnes
- Pseudorabies
- "Mad cow"

Johnes and BSE (mad cow) were included in the report. Pseudorabies was not discussed due to time.

9. Chemicals

- BST. Explain status of the debate. Explain changes in use patterns.
- Steroids
- Hay preservative

Steroids and BST were covered. The "hay preservative" question asked at this meeting was covered orally but not in the final report

10. Odor

- IS odor from manure increasing? Cross-reference air / odor and manure topics.

We did not cover this in the report as it was a component of other GEIS topics.

11. Missing information

- Ionofhores
- More on alternative husbandry under prevention and mitigation measures especially dairy

A section on ionophores was incorporated into the final report. Additional information on prevention and mitigation procedures for dairy were also incorporated.

12. Clarifications

Page 48. Is 260 degrees too hot?

We did not see 260 degrees on page 47-49 and thus can not respond.

Page 51. Missing part of sentence on multi site systems. Third sentence talks about 3 site systems

This was corrected.

Page 53. Missing something at the bottom of the page.

This was corrected.

SECTION L: BIBLIOGRAPHY

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