Assessing Forestation Opportunities for Carbon Sequestration in Minnesota

A report from:

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Executive Summary

As directed by the 2009 Minnesota Legislature, this study assesses the feasibility of creating one million acres of new forests to increase CO_2 sequestration. Nearly 7.6 million acres of the state's current croplands and grasslands were dominated by forests prior to European settlement and subsequently deforested, but likely would support productive forests now.

We used hypothetical scenarios to illustrate a variety of ways in which landowners could replace income from current land uses by managing forest on their lands. The amount of land likely to be forested, however, varies with level of total payment (see Figures 2-4). At annual payments of $30 per acre, approximately 34,000 acres could be forested that are currently in private cropland and grassland. With annual payments of $88, approximately 407,000 acres could be forested. A carbon market with a price of $30/ton of CO_2 sequestered would generate approximately 616,711 new acres with a net sequestration of 44 million tons of CO_2 over 100 years. Nearly 132,000 cords of roundwood from newly forested lands would be available annually at this level of payment. To obtain one million acres of new forest would require annual payments totaling approximately $114 per acre.

Current demand for seedlings in Minnesota is already high relative to in-state production capacity. The maximum number of acres that could be planted based solely on current seedling production capacity in Minnesota is approximately 23,000 acres per year. Given current demand for seedlings to reforest public and private forestland that has been harvested for timber, establishing forests for carbon sequestration likely will require higher seedling production by Minnesota producers, greater reliance on out-of-state producers, or both.

We offer these recommendations.

- Combine existing programs and funding to meet multiple environmental goals. For example, establishing riparian buffers adjacent to water bodies that exceed TMDL thresholds could simultaneously improve waters quality and sequester carbon.
- "Stack" policy incentives with new and existing markets to maximize forestation efforts. Adding publicly funded incentives for carbon sequestration to payments from existing markets and emerging markets may significantly increase forestation.
- Direct the DNR to plant northern white cedar, white spruce, balsam fir, and/or black spruce, the native tree species with the highest potential for long-term carbon sequestration, on 5,000 acres of suitable DNR-administered land by 2025.
- Direct the DNR to help private tree nursery businesses become more competitive with out-of-state seedling producers.
- Identify ways to improve the way we manage and use forest resources to increase carbon sequestration. A comprehensive analysis of the carbon sequestration and climate change mitigation benefits associated with existing forest resource management and use should reveal ways to improve sequestration.

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Introduction

The 2009 Minnesota Legislature directed the Minnesota Forest Resources Council (MFRC) to evaluate the feasibility of creating 1 million acres of new forests to increase CO_2 sequestration, a key recommendation of the Minnesota Climate Change Advisory Group (MCCAG) for reducing the state's net greenhouse gas emissions (see Text Box below). Researchers at the University of Minnesota, Departments of Forest Resources and Applied Economics assisted the MFRC in this analysis. Our analysis used existing information on land uses, soils, and pre-settlement vegetation to identify areas where trees are not the dominant vegetation today but where they could grow successfully and were the dominant vegetation prior to European settlement. For these lands, we compared the estimated financial return to landowners from existing land uses to returns possible under different forest management scenarios. In our analysis, we assumed that economic considerations, specifically income derived by the landowner from agricultural crops or timber, would be the primary factor determining whether landowners would be willing to establish forest as opposed to continuing current land use practices. This report summarizes the information we gathered, our methods of analysis, and our conclusions.

Although the study area included the entire state of Minnesota, we focused only on lands with soils formed under forests and on lands that were forested prior to European settlement. By doing so, we excluded from consideration areas where establishing and maintaining trees is ecologically untenable and/or too costly. This excluded from the analysis the majority of productive cropland in the state and all areas that were native prairie prior to European settlement. Many current grasslands and pastures, however, occupy former forestland. Since less than 1 percent of the state's native grasslands still exist, land use decisions and policies encouraging forestation must carefully consider the impacts on grassland-dependent species of replacing grasslands with forests. We also excluded from the analysis publicly managed areas with management objectives that in most cases preclude forestation (e.g., Wildlife Management Areas, Scientific and Natural Areas, state and national parks, and wilderness areas) and urban areas.

HF2312 Sec. 68. **CARBON SEQUESTRATION FORESTRY REPORT.**
The Minnesota Forest Resources Council shall review the Minnesota Climate Change Advisory Group's recommendation to increase carbon sequestration in forests by planting 1,000,000 acres of trees and shall submit a report to the chairs of the house of representatives and senate committees with jurisdiction over energy and energy finance, environment and natural resources, and environment and natural resources finance; the governor; and the commissioner of natural resources by January 15, 2010. The report shall, at a minimum, include recommendations on implementation and analysis of the number and ownership of acres available for tree planting, the types of native species best suited for planting, the availability of planting stock, and potential costs.

Methods

Our approach consisted of three general steps: 1) identifying land suitable for forestation using data on current land use, land cover, and soils in a geographic information system; 2) estimating and comparing economic returns from a variety of agricultural crops and forest management using a model of the economics of crop production based on current commodity prices and a variety of hypothetical payments; and 3) estimating the amount of CO_2 that could be sequestered over the next 100 years on newly forested lands using the Forest Age Class Change Simulator (FACCS, Domke and Ek 2009). The models allowed us to examine the effects of variations in crop and timber prices, public subsidies, and carbon sequestration payments on a landowner's choice of crop (including trees) to plant. Model outputs illustrate the conditions under which planting trees would be financially attractive to landowners, the tons of CO_2 sequestered, and the volume of harvestable roundwood and biomass that could result from newly forested acres. To keep the analysis tractable while allowing forest type to vary with location and soil quality, we modeled three types of forests—aspen, other hardwoods, and conifers—plus hybrid poplar (a short-rotation woody crop). We discuss the carbon sequestration potential of other tree species and forest types below. We did not conduct lifecycle analyses of the total carbon impact resulting from forestation, production, and transportation. Such an analysis was beyond the scope of this study. Estimates of the carbon sequestered from a more complete analysis would be lower than those presented here.

Identifying Land Suitable for Forestation

We used readily available, spatially explicit data on soils and vegetative cover to identify parcels 20-acres or larger that were not currently forested but are likely to sustain forest vegetation (Figure 1). We assumed that areas with soils formed under forests (Cummins and Grigal 1981) and areas that were forested prior to European settlement would have sufficient soil moisture and nutrients to support forest vegetation. We excluded areas where management objectives likely preclude a change in land use (see examples above). Land use was determined using 2008 data provided by the National Agricultural Statistics Service (http://www.nass.usda.gov/research/Cropland/SARS1a.htm). Each site was classified as high, medium, or low productivity based on crop production index (CPI) data provided by the Minnesota Board of Water and Soil Resources (BWSR). Precipitation and temperature regimes were assumed to remain constant.

CPIs combine information on soils with yield data to quantify the productivity for more than 8,000 soils in Minnesota (Grigal 2009, Valentas et al. 2009). We combined CPI values with comparable tree growth data for the three dominant forest types from the USDA Forest Service Inventory and Analysis (FIA) program to estimate yields of forest products (Forest Inventory and Analysis Program 2009).

Estimating and Comparing Economic Return

Step 1: Estimating the costs of site preparation and tree planting

We used average costs for site preparation, herbicide treatment, planting, and seedlings provided by the Minnesota Department of Natural Resources (see Table 1). Planting density was assumed constant across all forested sites (907 trees per acre or 6x8 foot spacing). Mortality was assumed to be higher on low CPI sites, which resulted in lower yields on those sites. For purposes of the financial analysis, we assumed that the availability of tree nursery stock did not limit the number of acres that could be planted. For carbon sequestration analyses and roundwood and biomass availability via harvesting, however, we assumed that 10% of the acres available for planting were planted each year for the first ten years. In the model, forest stands restocked *naturally* after harvesting and mortality (i.e., no site preparation and planting costs accrued) but hybrid poplar was re-established and incurred establishment costs after each harvest. We did not allow the forest type at a location to change once established.

Step 2: Estimate crop production costs

Crop production budgets identify fixed and variable costs associated with growing and harvesting a crop. In calculating production budgets for crops in the study area, we used agronomic information collected to develop Minnesota Standard Crop Budgets recently published for corn, soybeans, and wheat at a regional level and for corn stover, switchgrass, hybrid poplar, and low- and high-fertilization grasses (Lazarus and Goodkind 2009). Crop production costs coupled with yield estimates allowed us to estimate net returns from growing alternative crops on a specific field (see Table 2).

For trees, we estimated production costs using average costs of silvicultural treatments typical of aspen, northern hardwoods, and conifer stands (Brinker et al. 2002; Sturos et al. 1983), and for hybrid poplar (Berguson 2009). For simplicity, we assumed that all harvested wood is used for biomass or pulpwood using appropriate equipment systems. For other hardwoods, equipment included a feller-buncher, skidder, chipper, and chain flail; for conifers harvest equipment included a feller-buncher, skidder, stroke delimber, and log loader. See Table 2 for details on forest management costs.

Step 3: Calculate net revenue

The objective of our economic analysis was to predict what a profit-maximizing landowner would plant, given crop production characteristics, prevailing commodity prices, and various outside payments that mimic incentives or other forest-based markets. At the core of our economic analysis is a model that mimics landowner crop selections (Valentas et al. 2009) at a single point in time. The essential components of the model are crop choices, crop yields, crop production costs (including shipping and handling), and commodity prices. There is no cost to convert to and from various crops (including forest), other than certain one-time land preparation costs. The delivered cost for each crop is the combined production and harvest costs.

Rather than attempting to predict commodity price fluctuation, we used one set of prices based on published long-term averages adjusted to reflect costs of handling and delivery (Table 3). We calculated all possible net returns (based on the possible crop choices), added any outside payments, and determined the crop with the maximum (positive) net return. The total paid to the landowner thus includes any additional payments by outside parties (e.g., carbon sequestration payments or direct subsidies) that were included in a scenario. Since landowners are assumed to select the crop with the highest annual net return, the most profitable crop is assigned to all acres in the field under consideration. This snapshot of land use provided an estimate of the acres of land that would be planted to trees given the cost of shipping, handling, and storage and economic conditions that were specified in the scenario.

Our decision unit is a "field," defined as all land suitable for forestation in a county in each current land cover: cropland, Conservation Reserve Program (CRP) lands, private grassland and public grassland (Figure 1). Thus we have as many as 4 "fields" in each of 87 counties for which we calculated maximum net income under each scenario. Some counties, however, had no land suitable for forestation in one or more of the current land use categories or lacked soil survey information. These "fields" were dropped from the analysis. See the Appendix for details about "fields."

Estimating CO_2 Sequestration

The forest types we used in the analysis combine several different forest types as defined by the FIA program. In Minnesota, aspen forests occupy more than 30% (4,709,571 acres) of the state's timberland. Aspen forests are dominated by quaking aspen but include substantial amounts of balsam fir, white spruce, big tooth aspen, and paper birch. Our other hardwoods forest type encompasses several FIA forest types – oak/ pine, oak/ hickory, elm/ ash/ cottonwood, and maple/ beech/ birch – that occupy more than 40% (6,320,909 acres) of the state's timberland. Our conifer type includes FIA white/ red/ jack pine, spruce/ fir, and exotic softwood types that occupy about 28% (4,312,467 acres) of the state's timberland.

We used information on pre-settlement vegetation and ecological land classes (http://www.dnr.state.mn.us/ecs/index.html) to identify the ecologically most appropriate forest type for specific locations and site-specific productivity information to estimate biomass production and CO_2 sequestration. Thus, location–specific recommendations on the type of forest to establish combined information on current distributions, soil moisture and nutrient requirements, species-specific CO_2 sequestration potential, and potential market value as forest products.

We estimated forest yield and CO_2 sequestration using FACCS, a spreadsheet-based computational tool designed for estimating roundwood harvest and biomass residues as well as predicting woody biomass availability and amount of CO_2 sequestered. The FACCS version used in this analysis was calibrated using FIA data and published management and CO_2 sequestration information for the region. The primary information needed to produce biomass and CO_2 sequestration estimates included forest area, yield by species, and data on recent harvest intensity.

The model incorporates several simplifications: 1) the area of each forest type area does not change and there are no additions or losses of forestland due to land use change; 2) disturbances (e.g., insects, disease, fire) are not explicitly simulated but their effects are incorporated as reduced average yields; 3) available empirical or estimated yield information for each forest type and age class is assumed to be accurate; 4) harvest residue information is available for the modeled region; and 5) harvest intensity in the model is based on recent harvested volume data from the type of forest and area of interest.

Our estimates of sequestration used published data on the net change in carbon sequestered following changes in land use from non-forest to forest or hybrid poplar (Table 4). Non-forest values are averages from published studies in the Upper Midwest and forest values are a combination of published values from Smith et al. (2006) and live tree carbon estimates derived from the latest FIA inventory for Minnesota.

The model assumes that forest carbon sequestration is a linear function of age from the date of forest establishment (year-1) based on a constant rate of growth and standardized mortality (assumed to be 1 percent/acre/year). Insufficient information exists for modeling any lag in sequestration that might result from competition with grasses and shrubs or damage by deer as trees become established. Thus we assumed that all previous vegetation cover was killed prior to planting and that deer browse damage was minimal. Carbon stock changes and the GHG emissions resulting from site preparation (i.e., biomass burning) and fossil fuel consumption are not included in the analysis.

Scenarios Modeled: What might happen under different public policies or markets

Of primary interest in this analysis are the payments to landowners associated with different land uses. These payments could result from a combination of public policies and commodity markets and could include, for example, public subsidies for tree establishment or management costs, carbon sequestration payments, and wood product prices. Creating realistic alternative scenarios, i.e., combinations of public policy and market conditions, is one way to predict what a profit-maximizing landowner might plant, given different land management options. The following scenarios (A-E) illustrate the effect of differences in payments on 1) the total number of acres forested; 2) net CO_2 sequestered; and 3) the volume of roundwood and biomass available for use.

A) **No Forestation Incentives (Business as Usual) –** Current crop and forest biomass and roundwood prices do not change in this baseline scenario. There is no incentive specifically designed to encourage landowners to plant trees.

B) **Pulpwood Prices Double –** This is a business as usual scenario except that the average price for pulpwood doubles. There is no incentive specifically designed to encourage landowners to plant trees.

C) **CO_2 Market –** In this scenario 2009 prices prevail with the addition of a carbon market that pays, on average, $30/ton of CO_2 sequestered per year. We assume that all carbon sequestered on newly forested lands qualifies for carbon payments.

D) **Cost-Share for Tree Planting –** In this scenario 2009 prices prevail but landowners receive an incentive payment of 50% of the total cost of forestation (site preparation, seedlings, planting, and control). We assume that existing programs (e.g., Reinvest in Minnesota, Agricultural BMP Loan Program, Sustainable Woodlands Program, and Permanent Wetland Preserves) continue to provide payments to landowners.

E) **Targeting Public Lands –** In this scenario all of the 77,494 acres of public grasslands shown in Figure 1 are converted to forest.

In addition, we calculated supply curves to determine the amount of subsidy payment, CO_2 market, or pulpwood price required to achieve the first one-million acres of forestation. We also examined the distribution of newly forested acres, net CO_2 sequestration, and volume of roundwood and residual biomass based on an annual rate of forestation taking into consideration the limited availability of seedling stock.

Results

Here we focus on changes in the amount of forestland and the net change in carbon sequestration that might result under the scenarios described above. Changes among the amounts of cropland and grassland brought about by the different scenarios that do not result in increases in forestland are not reported.

Assuming average crop prices (Table 3) and costs of production (Table 2), Scenario A: **No Forestation Incentives (Business as Usual)**, resulted in no increase in forested acres. No incentives were provided to landowners to encourage forestation. Thus, there was no change in the amount of CO_2 sequestered.

Of the scenarios we examined, Scenario B: Pulpwood Prices Double, Scenario C: **CO_2 Market** and Scenario E: **Targeting Public Lands** resulted in a significant amount of forestation (Table 5). Scenario B: **Pulpwood Prices Double,** resulted in 25,472 acres of forestation, Scenario E: **Targeting Public Lands** in 77,494 acres forested, and Scenario C: **CO_2 Market** in 616,711 acres forested. Subsidizing 50% of the cost of site preparation and planting, Scenario D: **Cost-Share for Tree Planting**, resulted in only 663 acres of forestation.

Payments of $30/ton of CO_2 sequestered could result in 616,711 acres of new conifer forest, with 542,199 acres derived from private grasslands and 37,787 acres from cropland (Table 6). Carbon credit payments favor conifer forests because they sequester more carbon per unit area than do aspen and other hardwood forests. Where forest products revenue is the focus and site characteristics are suitable for aspen, however, aspen is generally the preferred species because of its higher yield. In none of the scenarios was hybrid poplar preferred. Either the costs associated with repeated site preparation and planting were too high or carbon sequestration was too low during the 10-year rotation to make hybrid poplar the best option.

Foresting all 77,494 acres of public grasslands would result in 48,599 acres of other hardwoods, 16,962 acres of aspen, and 11,933 acres of conifers (Table 5). Soil productivity and site characteristics drive the choice of species at individual sites.

The discussion thus far assumes that all trees are planted in the first year. In all likelihood, however, forestation efforts would be severely constrained by the limited availability of seedlings (see **Availability of Planting Stock** below). In the following results, we assume that only 10% of the land available for tree planting is forested each year. Frequency of harvest strongly influences the amount of CO_2 sequestered and the availability of roundwood and residual biomass. In the model, we applied current statewide harvest frequencies (rotation ages) to newly forested acres: aspen harvest at year-50, other hardwoods and conifers at year-75 and hybrid poplar at year-10. As a result, forest age class distributions varied with the region of the state, soil productivity, and tree species. Given this, we estimated cumulative CO_2 sequestered over the 100-year planning period and average annual roundwood and woody biomass availability. Note that the available residual biomass, which includes limbs and tops from harvested trees and small diameter material not suitable for roundwood markets, may be less than our estimates in cases where the Minnesota Biomass Harvest Guidelines (MFRC 2007) suggest higher rates of onsite retention.

Model results suggest that approximately 3.1 million tons of CO_2 would be sequestered over 100 years if pulpwood prices doubled (Scenario B), though only 61,434 tons would sequestered with the cost-share option (Scenario D, Table 7). Forestation of public grasslands (Scenario E) would sequester nearly 6.4 million tons of CO_2. With CO_2 payments (Scenario C), approximately 44 million tons of CO_2 would be sequestered over 100 years. The difference in the amounts of sequestration for these scenarios is mostly a function of large differences in the number of acres forested. Our estimates of the amount of carbon sequestration resulting from forestation are generally lower than those of the MCCAG (Table 8) and would require more time.

Approximately 6,530 dry tons (5,442 cords) of roundwood would be available annually by doubling the price of pulpwood on those 25,472 acres of new forest in Scenario B (Table 7). Approximately 1,044 dry tons of residual biomass would also be available. Under the scenario of foresting public grasslands, approximately 19,866 dry tons (16,554 cords) of roundwood would be available annually along with 3,630 dry tons of residual biomass. The CO_2 market scenario would yield approximately 158,096 dry tons (131,747 cords) of roundwood and 24,754 dry tons of residual biomass annually. As previously suggested, employing the statewide voluntary biomass harvest guidelines (MFRC 2007) may reduce the amount of biomass somewhat under each scenario.

One Million Acres

Our analysis indicates that the amount of land likely to be forested, the cost of converting current lands to forest, and the distribution of newly forested acres vary with level of payment. Supply curves for each scenario illustrate the relationship between acres of potential forestation and magnitude and type of payment (Figures 2-4). The corresponding data indicates which current land uses might be affected by different levels of annual payment (Table 4), pulpwood prices (Table 10), or CO_2 price (Table 11). As total annual payment approaches $88/acre/year, approximately 406,684 acres could be converted to forest (Table 9). At that level of payment, the majority of acres, all aspen, would come from private grasslands (332,252 acres), followed by cropland (37,787 acres) and public grasslands (36,599). Only a small number of acres would be converted from CRP lands (46 acres), largely because of the federal penalty assessed when withdrawing from those contracts. Many more acres of CRP land could be converted if federal rules allowed landowners to establish forests while remaining in the program. Creating one million new acres of forest would require annual payments of approximately $114/acre.

Doubling the price of pulpwood resulted in 25,472 acres of new forest. Higher pulpwood prices could achieve more acres of forestation but those prices would have to be substantially higher than today's market value to result in an appreciable number of new acres (Table 10). Scenario C: CO_2 Market would result in a significant number of acres of new forests (Table 11). A market price of $30/ton of CO_2 sequestered would generate approximately 616,711 acres of forests, whereas $40/ton could generate upwards of 1.3 million acres.

Where direct incentives and market payments can be combined, a significant number of acres could be forested. For example, doubled pulpwood prices added to payments for carbon sequestration could approach one million acres of forestation. Other combinations of public incentives and market payments are conceivable.

Availability of Planting Stock

Minnesota nurseries produce both bare-root and containerized seedlings of native Minnesota trees species from seeds collected in the state. The Minnesota Nursery and Landscape Association (MNLA) reports that private growers in the state are capable of producing 10-12 million seedlings per year, given adequate access to native seed (Robert Fitch, MNLA, personal communication). In addition, growers in neighboring states and Canada already grow stock from Minnesota seed sources, are likely meeting a substantial portion of the current demand for seedlings in the state, and have the capacity to respond to higher demand. Tree nurseries operated by the State of Minnesota have the capacity to produce 20-25 million seedlings per year (Olin Phillips, Minnesota Department of Natural Resources, personal communication) but are prevented by law from producing more than 10 million seedlings per year. Given adequate planning and favorable growing conditions, the maximum number of acres that could be planted based on seedling production capacity in Minnesota is approximately 23,000 acres per year (12 million seedlings per year from private nurseries plus 10 million seedlings per year from DNR nurseries planted at 950 seedlings planted per acre). Seedling survival rates vary widely in response to many factors (e.g., seedling type, soil nutrient and moisture availability, insect and animal herbivory, disease) and replanting to replace seedlings that don't survive is common. Insuring adequate stocking in newly established forests will thus require additional seedlings.

Current demand for seedlings in Minnesota is already high relative to in-state production capacity; a significant portion of that demand is being met by seedling producers outside of Minnesota. In 2008, public and forest industry managers, representing 64 percent of the state's timberland, planted tree seedlings on about 21,000 acres (D'Amato et al. 2009). Nearly all of these acres were planted following harvest and thus are indicative of a relatively steady annual demand for tree seedlings. Demand for seedlings for use on the remaining 36 percent of the state's timberland may be significant. Given current demand for seedlings to reforest public and private forestland that has been harvested for timber, establishing forests for carbon sequestration likely will require higher seedling production by Minnesota producers, greater reliance on out-of-state producers, or both.

Carbon Sequestration Potential of Minnesota Species and Forest Types

The carbon sequestration potential of Minnesota forests varies widely with variation in soils, climate, species composition, management, and other factors, making assessing the effects of species composition alone difficult. The choice of species for specific forestation efforts must consider many factors in addition to the carbon sequestration potential of the tree species to plant or the type of forest to establish. In many cases, site conditions (e.g., soil depth and quality, moisture availability, surrounding land uses) may preclude choosing the tree species with the highest carbon sequestration potential.

Of the seven Minnesota forest types that sequester the most carbon, five are composed primarily of conifers: northern white cedar, white spruce, balsam fir, tamarack, and black spruce (Figure 5). Cottonwood and silver maple forests sequester comparable amounts of carbon, but store less of that carbon in soils than do the forest types dominated by conifers. All Minnesota forests sequester substantial amounts of carbon, giving landowners many options for simultaneously meeting sequestration and other goals through forest management.

The data shown in Figure 5 are a snapshot of the carbon that could be sequestered in Minnesota forests following forestation of currently non-forested lands. They are based on FIA measurements of tree volumes and empirical relationships between tree volumes and carbon content of other forest carbon pools. The estimates thus incorporate the effects of pre-harvest forest management in Minnesota.

Factors Not Included in the Analysis

Many factors influence land use decisions. Key among them for the purposes of this study is landowner preference. This analysis provides a snapshot of the financial feasibility of foresting certain lands. It does not, however, consider many other factors that influence and motivate landowners, many of which are beyond the scope of a financial analysis, or other public benefits that may be obtained simultaneously by forestation. A more thorough evaluation of the effects of forestation would examine:

- changes in the distribution and quality of wildlife habitat, especially for grassland-dependent species;
- changes in the rates of soil degradation and erosion and potential improvements in water quality that might accompany forestation;
- the indirect impacts on commodity prices resulting from reduced food and crop production;
- impacts of fluctuations in commodity and forest product prices.
- economic benefits and jobs that may be created by increase wood supply and forest-based recreation.

This study is not a comprehensive analysis of the carbon sequestration and climate change mitigation benefits of forestation. For example, we did not include the effects of emissions from tillage, harvesting and transporting raw materials, moving heavy equipment, electricity use, and producing energy from wood on the amount of CO_2 sequestered. Our knowledge of carbon accumulation in soils and tree roots is preliminary and subject to change as research into the forest carbon cycle advances. Also not included were data on the "albedo effect." An emerging body of research suggests that some land-use changes decrease the albedo (reflectivity) of the earth surface. Decreases in albedo may result in greater heat capture and diminish or counteract the climate benefits of establishing forests for sequestration (Thompson et al. 2009). In northern climates, for example, planting conifers "darkens" the surface, especially during periods of snow cover, and may increase heat retention. We did not attempt to incorporate projected shifts in tree species distribution resulting from climate change.

Forestation is one of many means to mitigate climate change via carbon sequestration. Other investments in forest management designed to increase the productivity and sequestration of existing forests should also be considered.

Recommendations

Combine existing programs and funding to meet multiple environmental goals. For example, establishing new forests in riparian areas as buffers adjacent to water bodies that exceed TMDL thresholds could simultaneously improve water quality and sequester carbon. Clean Water Legacy funds could be combined with carbon sequestration markets to make this activity attractive to landowners. Similarly, payments from the Outdoor Heritage Fund could be combined with carbon sequestration payments to support forestation projects for fish and wildlife habitat on public lands or on private lands with permanent conservation easements.

"Stack" policy incentives with new and existing markets to maximize forestation efforts. Adding publicly funded incentives for carbon sequestration (e.g., as tax relief or direct payments) to payments from existing markets for pulpwood and other forest outputs and emerging markets for woody biomass for energy and for carbon sequestration may significantly increase the number of landowners who would be willing to undertake forestation projects.

Direct the DNR to plant northern white cedar, white spruce, balsam fir, tamarack, and/or black spruce, the native tree species with the highest potential for long-term carbon sequestration, on 5,000 acres of suitable DNR-administered land by 2025. A conifer restoration initiative, undertaken on an interdisciplinary basis to assure agreement among DNR divisions as to where these plantings should occur, should be in addition to planned planting of these species that is already part of DNR Subsection Forest Resource Management Plans. Planting should be done only on lands that were predominantly conifer prior to European settlement and should consider the effects of decreases in albedo to the extent possible. Funding for the initiative could be obtained from federal, private, or existing state funding sources, including emerging carbon sequestration markets.

Direct the DNR to help private tree nursery businesses be more competitive with out-of-state seedling producers. As demand for seedlings increases in response to climate change mitigation and bioenergy production efforts, existing Minnesota nursery capacity can be used more effectively to help meet that demand. Helping them become more cost effective in producing high quality seedlings will also create and retain private sector jobs in Minnesota.

Conduct lifecycle analyses of the carbon sequestration and climate change mitigation benefits associated with forest resource management and use. This study examined a limited set of factors influencing land use, the amount of forestland, and the consequences for carbon sequestration. A more complete examination of the effects of forest management practices, land use policy, and resource utilization may identify ways in which the carbon sequestered by Minnesota's forests and forest products industry can be increased at minimal cost. Further analysis would also quantify the impacts of forestation and other land use options on wildlife habitat, water quality, and commodity prices and help identify unintended consequences.

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Figures

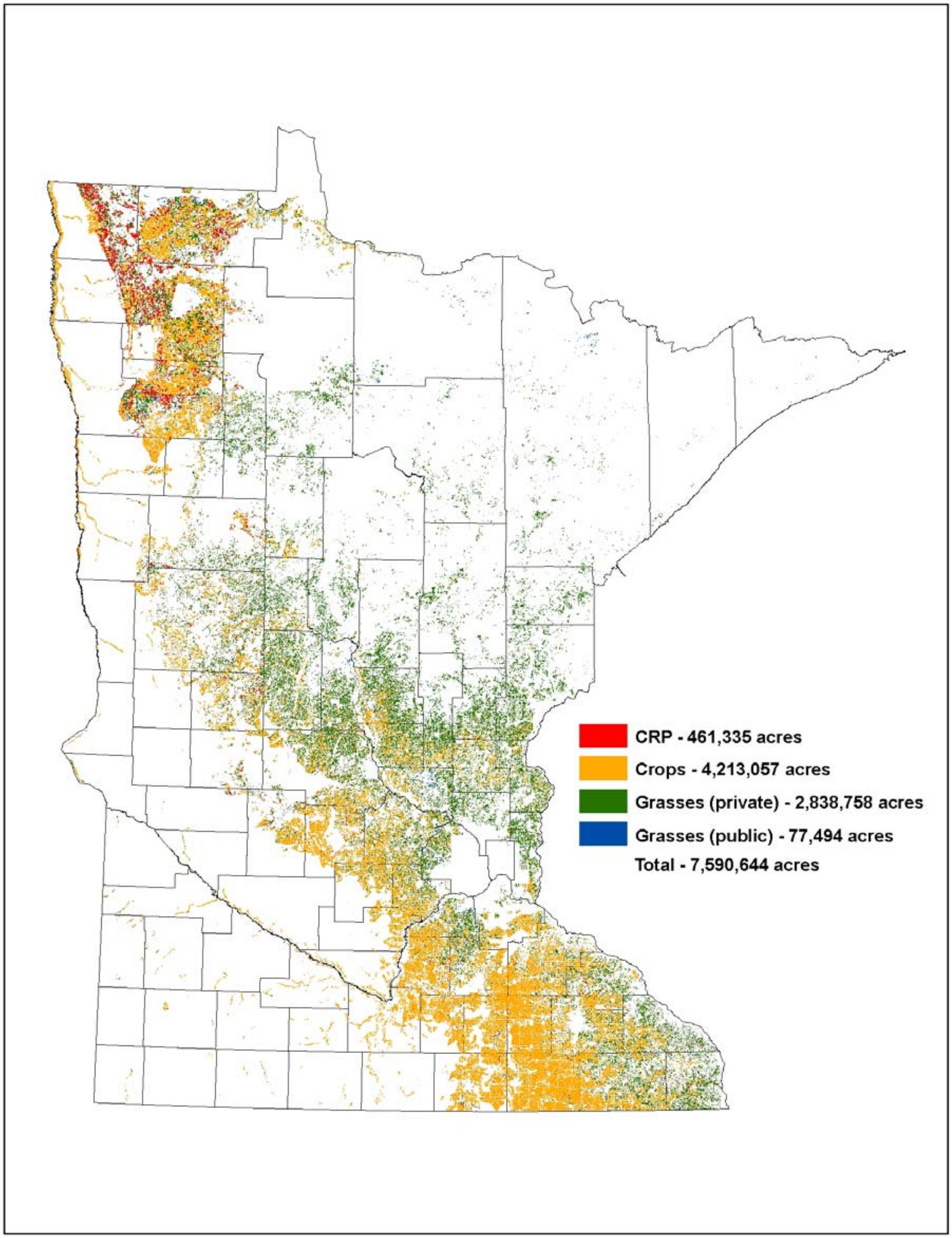

Figure 1. Parcels that are not currently forested but that likely could sustain forest vegetation and their 2008 land uses.

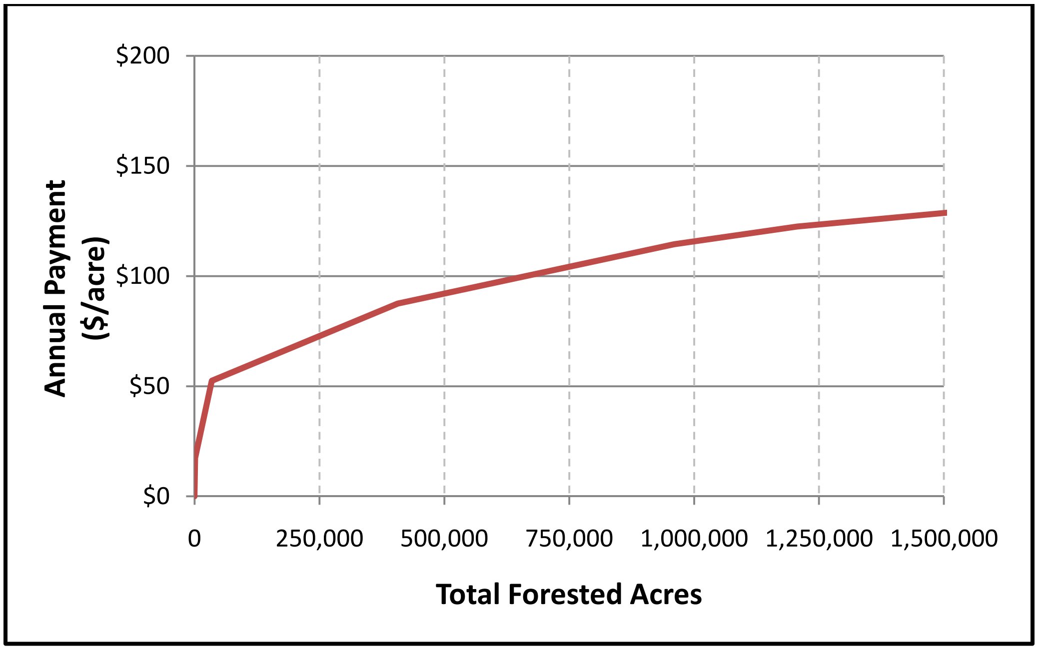

Figure 2. Total acres of forestation by level of annual payment.

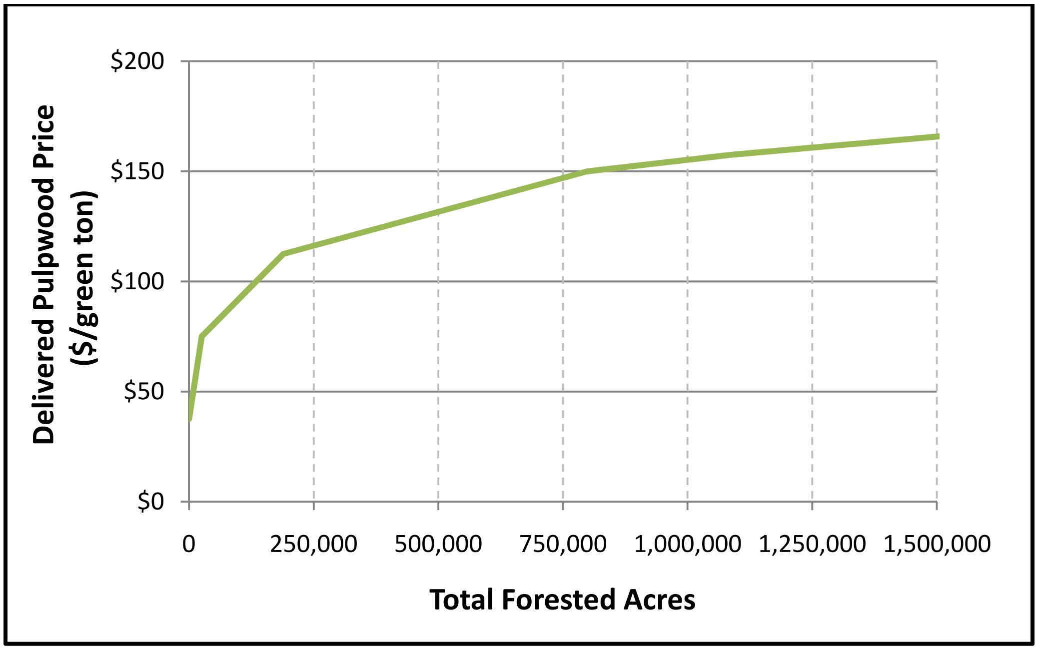

Figure 3. Total acres of forestation by level of delivered pulpwood price.

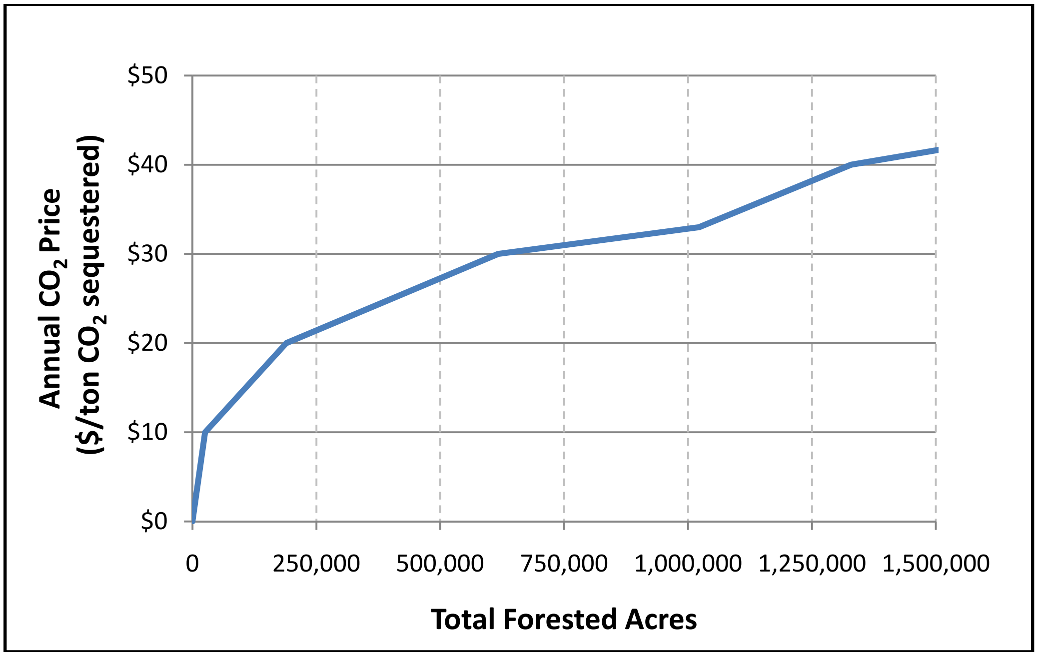

Figure 4. Total acres of forestation by level of CO_2 price.

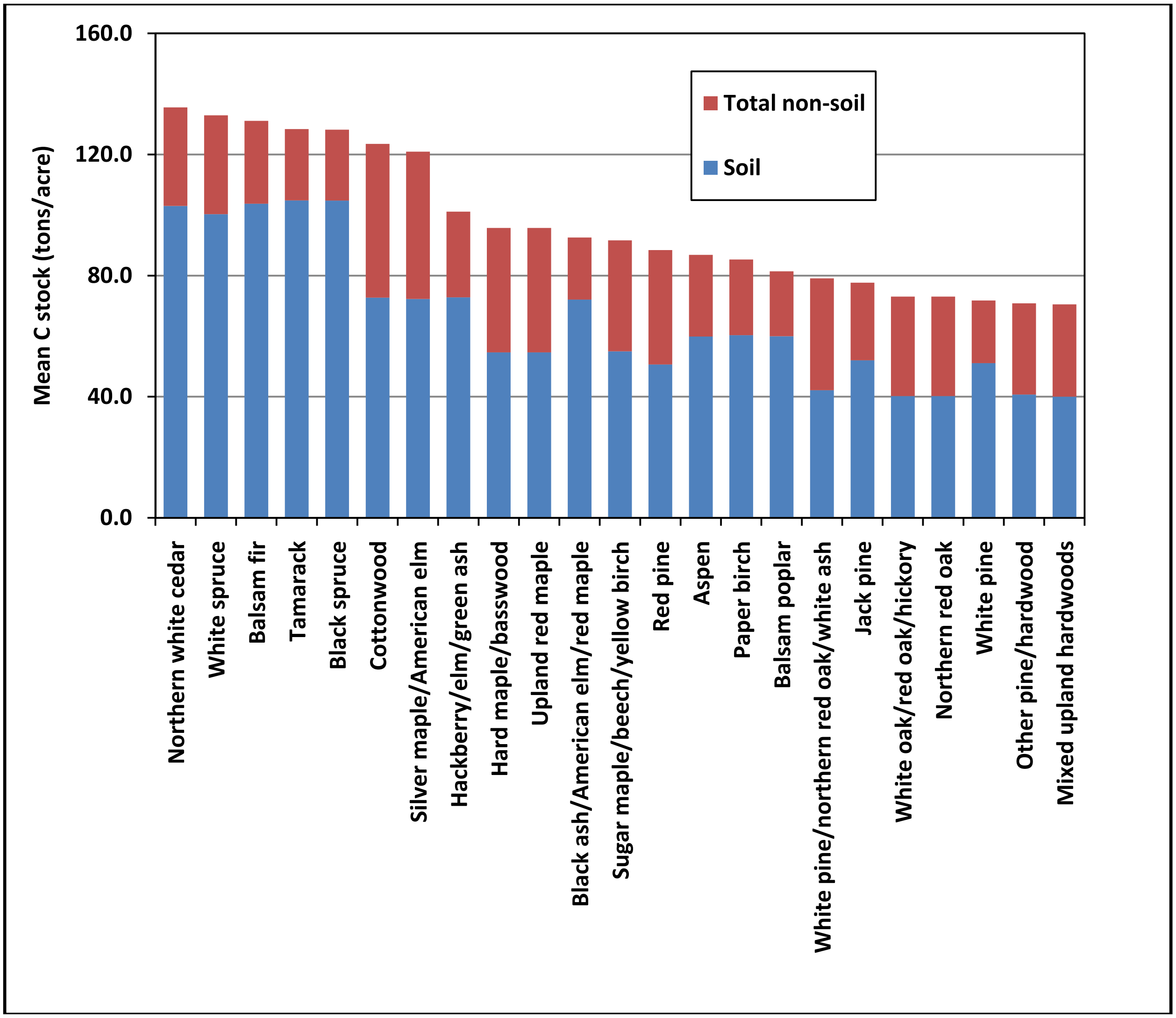

Figure 5. Estimated carbon content of Minnesota forests 55 years after establishment on non-forested lands. Data are from the Carbon OnLine Estimator 1605(b) Report for Minnesota (2010) and based on current FIA data.

Tables

Table 1. Forestation costs by tree species.

Cost activity	Total cost ($/acre)[1] Aspen	Other hardwoods	Conifers	Hybrid poplar
Greenhouse and seedlings	$254	$254	$163	$68
Site preparation	$100	$100	$100	$39
Planting[2]	$210	$210	$210	$38
Fertilizer	$0	$0	$0	$0
Control of competing vegetation	$160	$160	$160	$376
TOTAL COST	**$724**	**$724**	**$633**	**$520**
Annualized[3]	**$7.24**	**$7.24**	**$6.33**	**$52.00**

[1] Assumed cost of greenhouse and seedling expenses: aspen/hardwoods – $0.28/tree; conifers – $0.18/tree (source: Rick Klevorn, pers. comm., Minnesota Department of Natural Resources, October 22, 2009). Hybrid poplar costs derived from Berguson (2009).

[2] Planting density of 908 trees per acre.

[3] One-time site preparation and planting costs are annualized over the 100-year planning period for aspen, other hardwoods and conifers. For hybrid poplar, site preparation and planting reoccur every 10 years. Assumed annual rotations: aspen (50 years), other hardwoods and conifers (75 years), hybrid poplar (10 years).

Table 2. Production costs by activity type and land use ($/acre)

Land use[1,2]	Fertilizer/ herbicide	Site preparation	Seeding/ seedlings	Planting costs	Crop insurance	Harvest	Other machinery interest	Labor and administration	Misc. expenses	Crop drying	TOTAL
Corn stover	$32.00	$0.00	$0.00	$0.00	$0.00	$36.00	$2.00	$0.00	$0.00	$0.00	$70.00
Corn grain	$87.47	$0.00	$116.00	$45.60	$27.89	$65.78	$10.00	$52.11	$20.11	$30.56	$455.51
Wheat	$69.60	$0.00	$20.00	$70.80	$24.00	$43.67	$7.00	$30.00	$12.33	$4.33	$281.73
Soybeans	$2.80	$0.00	$50.00	$56.40	$25.33	$53.00	$5.89	$38.11	$14.89	$0.00	$246.42
Sugar beets	$43.00	$0.00	$90.00	$101.67	$21.67	$153.00	$12.00	$171.67	$94.67	$0.00	$687.67
CRP	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Alfalfa	$29.33	$0.00	$12.00	$23.00	$1.89	$68.00	$4.22	$46.67	$17.89	$0.00	$203.00
Aspen	$1.60	$1.00	$2.54	$2.10	$0.00	$2.40	$0.00	$0.00	$0.00	$0.00	$9.64
Other hardwood	$1.60	$1.00	$2.54	$2.10	$0.00	$2.40	$0.00	$0.00	$0.00	$0.00	$9.64
Conifers	$1.60	$1.00	$1.63	$2.10	$0.00	$5.40	$0.00	$0.00	$0.00	$0.00	$11.73
Short-rotation woody crops	$37.61	$3.83	$6.75	$3.78	$0.00	$68.40	$2.00	$0.00	$0.00	$0.00	$122.37
Low-fertilization grasses	$28.00	$0.00	$5.00	$2.00	$0.00	$23.00	$2.00	$19.00	$0.00	$0.00	$79.00
High-fertilization grasses	$44.00	$0.00	$3.00	$3.00	$0.00	$39.00	$3.00	$19.00	$0.00	$0.00	$111.00

[1] Agriculture production budgets were derived from Lazarus and Goodkind (2009).

[2] Forest production budgets were derived from Berguson (2009), Brinker et al. (2002), and Sturos et al. (1983).

Table 3. Average plant-gate crop and wood prices ($/green ton).[1]

Crop type[1,2]	Price per green ton	Price equivalent	Crop type	Price per green ton	Price equivalent
Corn stover	$60.00	--	**Aspen**	$23.46	$52.79/cord
Corn grain	$128.57	$3.60/bushel	**Other hardwoods**	$19.65	$50.64/cord
Wheat	$166.67	$5.00/bushel	**Conifers**	$26.74	$57.79/cord
Soybeans	$300.00	$9.00/bushel	**Hybrid Poplar**	$30.46	$68.54/cord
Sugar beets	$41.00	--	**Low-fertilization grass**	$60.00	--
CRP	$0.00	--	**High-fertilization grass**	$60.00	--
Alfalfa	$120.00	--			

[1]Plant-gate price covers the cost of stumpage, harvest, transport, and storage. Assumed stumpage price: aspen ($25.80/cord), other hardwoods ($19.71/cord), conifers ($27.53/cord), hybrid poplar ($25.80)
[2]Agriculture commodity prices taken from Lazarus and Goodkind (2009)
[3]Forest product prices provided by the Minnesota Department of Natural Resources (2009)

Table 4. Net change in the amount of CO_2 sequestered (tons of CO_2/ac/yr) following land use change. Positive numbers indicate increases in the amount of carbon sequestered; negative numbers indicate decreases in the amount sequestered. Non-forest values are averages from a large number of studies in the Midwest; forest values incorporate information from current FIA data and Smith et al. (2006).

	---------------------- Converting from ----------------------					
Converting to ---	**Crops**	**Grass**	**Hybrid Poplar**	**Aspen**	**Other hardwoods**	**Conifers**
Crops	0.00	-3.36	-1.75	-9.79	-10.69	-15.39
Grasses	1.79	0.00	0.86	-3.43	-3.91	-6.42
Hybrid Poplar	3.49	-3.23	0.00	-16.09	-17.88	-27.29
Aspen	3.92	2.57	3.22	0.00	-0.36	-2.24
Other hardwoods	2.85	1.95	2.38	0.24	0.00	-1.26
Conifers	4.10	3.21	3.64	1.49	1.26	0.00

Table 5. Newly forested acres statewide by scenario.

Scenario	Aspen	Conifer	Other hardwoods	Short-rotation woody crops	Total acres
A: No Reforestation Incentives (Business as Usual)	-	-	-	**-**	**-**
B: Pulpwood Prices Double	10,716	14,756	-	**-**	**25,472**
C: CO_2 Market	-	616,711	-	**-**	**616,711**
D: Cost-share for Tree Planting	596	67	-	**-**	**663**
E: Targeting public lands	16,962	11,933	48,599	**-**	**77,494**

Table 6. Change in land use by forest type for Scenario C: CO_2 market ($30/ton).

		-------------- Forested acres --------------				
Land use	**Current acres**	**Aspen**	**Conifers**	**Other hardwoods**	**Hybrid Poplar**	**Total acres**
Crops	4,213,057	-	37,787	-	-	37,787
CRP	461,335	-	125	-	-	125
Grasses (private)	2,838,758	-	542,199	-	-	542,199
Grasses (public)	77,494	-	36,599	-	-	36,599
Total	**7,590,643**	**-**	**616,711**	**-**	**-**	**616,711**

Table 7. Tons of CO_2 sequestered and volume of forest roundwood and biomass on lands likely to be forested under different scenarios[1]

Scenario	Total Reforested acres	Tons CO_2 sequestered (100-yrs)	--- oven-try tons (annual) --- Roundwood harvested	Residual remaining
A: No Reforestation Incentives (Business as Usual)	-	-	-	-
B: Pulpwood Prices Double	25,472	3,105,525	6,530	1,044
C: CO_2 Market	616,711	44,033,998	158,096	24,754
D: Cost-share for Tree Planting	662	61,434	170	33
E: Targeting public lands	77,494	6,384,561	19,866	3,630

[1]Assumes an annual 10% phased-in planting schedule for available seedling stock.

Table 8. Estimates of CO_2 emissions, emission reductions, and sequestration from MCCAG (2008) and this study.

Source of Estimate		Emissions, emission reductions (-), or sequestration (-) in millions of tons of CO_2
MCCAG[1]	Statewide Emissions in 2005	157.1
	Low-GHG Fuel Standard	-39.9
	Adopt California Clean Car Standards	-14.4
	Incentives and Resources to Promote Combined Heat and Power	-36.5
	Green Building Guidelines and Standards Based on *Architecture 2030*	-12.2
	Forestry Management Programs to Enhance GHG Benefits: Forestation	-17.0
	Front-End Waste Management Technologies: Composting	-4.9
This Study	Cost-share for Tree Planting[2]	-0.061
	Pulpwood Prices Double[2]	-3.1
	Forestation of Public Grasslands[2]	-6.4
	CO_2 Payment ($30/ton)[2]	-44.0
Estimated Annual Sequestration by Minnesota forests[3]		-11.7
Estimated DNR Fleet Emissions in 2010		0.0135

[1] Selected policy proposals from the Minnesota Climate Change Advisory Group (2008). Emission reductions were projected to be realized during the period 2008-2025.

[2] CO_2 sequestered over 100 years as a result of forestation.

[3] CO2 sequestered in live and dead vegetation and forest floor litter only. The amount of carbon sequestered in soils changes very slowly and is not included here.

Table 9. Total acres and types of land that could be forested as level of annual payment increases.

	------------ Level of annual payment ($/acre) -------------				
Converted from:	**$18**	**$53**	**$88**	**$123**	**$158**
Crops	98	2,880	37,787	273,221	977,726
CRP	-	-	46	23,233	221,893
Grasses (private)	370	6,177	332,252	870,305	1,624,598
Grasses (public)	662	25,244	36,599	40,119	55,853
Total	**1,130**	**34,301**	**406,684**	**1,206,877**	**2,880,069**

Table 10. Total acres and types of land that could be forested as pulpwood price increases.

	---------- Delivered pulpwood price ($/green ton) ----------				
Converted from:	**$38**	**$75**	**$113**	**$150**	**$188**
Crops	-	2,880	34,018	49,790	919,422
CRP	-	-	-	125	63,801
Grasses (private)	-	5,422	121,011	709,054	1,549,248
Grasses (public)	-	17,170	34,300	39,491	52,319
Total	**0**	**25,472**	**189,329**	**798,460**	**2,584,790**

Table 11. Total acres and types of land that could be forested as CO_2 price increases.

	---------- Annual CO_2 price ($/ton CO_2 sequestered) ----------				
Converted from:	**$10**	**$20**	**$30**	**$40**	**$50**
Crops	2,880	34,018	37,787	284,443	490,588
CRP	-	-	125	23,233	221,893
Grasses (private)	5,422	121,011	542,199	979,055	1,624,598
Grasses (public)	17,170	34,222	36,599	42,388	54,665
Total	**25,472**	**189,251**	**616,711**	**1,329,119**	**2,391,743**

Appendix

Acres of land suitable for forestation by county and current land use with the soil productivity and tree yield estimates used in the analysis. The Crop Productivity Index is a relative ranking of soil productivity based on physical and chemical properties of the soils and on such hazards as flooding or ponding. Values range from 0 to 100, with higher values indicating higher productivity. See "Soils Data" at http://landeconomics.umn.edu/ for more information.

				-------Yield(green tons/year)-------			
County	Current land use	Acres	Crop Productivity Index	Aspen	Other hardwoods	Conifers	Hybrid poplar
Aitkin	Crops	2,783	32	1.53	1.18	1.31	3.38
Aitkin	Grass Private	54,405	54	1.56	1.20	1.33	5.77
Aitkin	Grass Public	1,054	38	1.54	1.19	1.32	4.07
Aitkin	CRP	56	57	1.56	1.20	1.33	6.03
Anoka	Crops	3,518	57	1.56	1.20	1.33	6.10
Anoka	Grass Private	46,428	41	1.54	1.19	1.32	4.37
Anoka	Grass Public	1,068	31	1.53	1.18	1.31	3.35
Anoka	CRP	123	63	1.57	1.20	1.34	6.71
Becker	Crops	29,863	67	1.58	1.20	1.34	7.10
Becker	Grass Private	56,670	56	1.56	1.20	1.33	5.95
Becker	Grass Public	411	61	1.57	1.20	1.34	6.51
Becker	CRP	11,527	49	1.55	1.19	1.33	5.24
Beltrami	Crops	12,613	68	1.58	1.20	1.34	7.21
Beltrami	Grass Private	74,805	65	1.58	1.20	1.34	6.98
Beltrami	Grass Public	1,279	60	1.57	1.20	1.33	6.44
Beltrami	CRP	4,091	67	1.58	1.20	1.34	7.18
Benton	Crops	56,918	68	1.58	1.20	1.34	7.27
Benton	Grass Private	73,173	59	1.57	1.20	1.33	6.32
Benton	Grass Public	533	50	1.55	1.19	1.33	5.32
Benton	CRP	385	59	1.57	1.20	1.33	6.27
Big Stone	Crops	2,445	86	1.60	1.21	1.35	9.20
Big Stone	Grass Private	812	52	1.56	1.19	1.33	5.50
Big Stone	Grass Public	67	17	1.51	1.18	1.30	1.77
Big Stone	CRP	36	56	1.56	1.20	1.33	5.95
Blue Earth	Crops	81,236	85	1.60	1.21	1.35	9.05
Blue Earth	Grass Private	1,904	66	1.58	1.20	1.34	7.01
Blue Earth	Grass Public	327	82	1.60	1.21	1.35	8.74

County	Current land use	Acres	Crop Productivity Index	-------Yield(green tons/year)------- Aspen	Other hardwoods	Conifers	Hybrid poplar
Blue Earth	CRP	800	77	1.59	1.21	1.35	8.26
Brown	Crops	13,895	80	1.60	1.21	1.35	8.56
Brown	Grass Private	480	52	1.56	1.19	1.33	5.51
Brown	Grass Public	2	61	1.57	1.20	1.34	6.50
Brown	CRP	488	62	1.57	1.20	1.34	6.65
Carlton	Crops	98	17	1.51	1.18	1.30	1.77
Carlton	Grass Private	47,988	54	1.56	1.20	1.33	5.72
Carlton	Grass Public	505	36	1.53	1.19	1.32	3.84
Carlton	CRP	9	24	1.52	1.18	1.31	2.60
Carver	Crops	70,736	87	1.61	1.21	1.35	9.26
Carver	Grass Private	36,504	80	1.60	1.21	1.35	8.50
Carver	Grass Public	1,597	74	1.59	1.21	1.35	7.93
Carver	CRP	1,515	77	1.59	1.21	1.35	8.26
Cass	Crops	3,769	44	1.55	1.19	1.32	4.71
Cass	Grass Private	74,203	51	1.56	1.19	1.33	5.46
Cass	Grass Public	952	54	1.56	1.20	1.33	5.75
Cass	CRP	80	42	1.54	1.19	1.32	4.47
Chippewa	Crops	1,499	83	1.60	1.21	1.35	8.88
Chippewa	Grass Private	662	64	1.57	1.20	1.34	6.86
Chippewa	Grass Public	84	74	1.59	1.21	1.34	7.85
Chippewa	CRP	150	82	1.60	1.21	1.35	8.73
Chisago	Crops	22,481	66	1.58	1.20	1.34	7.05
Chisago	Grass Private	73,899	55	1.56	1.20	1.33	5.89
Chisago	Grass Public	534	36	1.53	1.19	1.32	3.86
Chisago	CRP	82	57	1.56	1.20	1.33	6.08
Clay	Crops	25,237	84	1.60	1.21	1.35	8.92
Clay	Grass Private	4,199	57	1.56	1.20	1.33	6.04
Clay	Grass Public	135	71	1.58	1.20	1.34	7.57
Clay	CRP	1,839	54	1.56	1.20	1.33	5.80
Clearwater	Crops	10,201	69	1.58	1.20	1.34	7.31
Clearwater	Grass Private	68,451	69	1.58	1.20	1.34	7.31
Clearwater	Grass Public	2,269	56	1.56	1.20	1.33	5.96
Clearwater	CRP	2,362	66	1.58	1.20	1.34	7.01

County	Current land use	Acres	Crop Productivity Index	-------Yield(green tons/year)------- Aspen	Other hardwoods	Conifers	Hybrid poplar
Cook	Crops	Soils information unavailable.					
Cook	Grass Private						
Cook	Grass Public						
Cook	CRP						
Cottonwood	Crops	3,138	88	1.61	1.21	1.36	9.35
Cottonwood	Grass Private	112	64	1.57	1.20	1.34	6.84
Cottonwood	Grass Public	0	88	1.61	1.21	1.36	9.43
Cottonwood	CRP	86	66	1.58	1.20	1.34	7.02
Crow Wing	Crops	Soils information unavailable.					
Crow Wing	Grass Private						
Crow Wing	Grass Public						
Crow Wing	CRP						
Dakota	Crops	60,242	72	1.58	1.21	1.34	7.66
Dakota	Grass Private	19,913	63	1.57	1.20	1.34	6.73
Dakota	Grass Public	506	59	1.57	1.20	1.33	6.34
Dakota	CRP	718	67	1.58	1.20	1.34	7.18
Dodge	Crops	185,979	92	1.61	1.22	1.36	9.80
Dodge	Grass Private	5,118	78	1.59	1.21	1.35	8.37
Dodge	Grass Public	165	79	1.59	1.21	1.35	8.46
Dodge	CRP	1,040	79	1.59	1.21	1.35	8.38
Douglas	Crops	67,720	79	1.60	1.21	1.35	8.48
Douglas	Grass Private	41,363	66	1.58	1.20	1.34	6.99
Douglas	Grass Public	1,188	70	1.58	1.20	1.34	7.47
Douglas	CRP	9,173	61	1.57	1.20	1.34	6.49
Faribault	Crops	7,816	88	1.61	1.21	1.36	9.38
Faribault	Grass Private	119	74	1.59	1.21	1.34	7.84
Faribault	Grass Public	1	72	1.59	1.21	1.34	7.72
Faribault	CRP	48	85	1.60	1.21	1.35	9.03
Fillmore	Crops	176,343	84	1.60	1.21	1.35	8.99
Fillmore	Grass Private	92,137	66	1.58	1.20	1.34	7.01
Fillmore	Grass Public	772	68	1.58	1.20	1.34	7.20
Fillmore	CRP	7,019	73	1.59	1.21	1.34	7.74
Freeborn	Crops	165,177	86	1.60	1.21	1.35	9.21

County	Current land use	Acres	Crop Productivity Index	Aspen	Other hardwoods	Conifers	Hybrid poplar
				-------Yield(green tons/year)-------			
Freeborn	Grass Private	4,343	75	1.59	1.21	1.35	8.05
Freeborn	Grass Public	911	79	1.59	1.21	1.35	8.46
Freeborn	CRP	3,025	82	1.60	1.21	1.35	8.71
Goodhue	Crops	177,082	87	1.61	1.21	1.35	9.29
Goodhue	Grass Private	37,946	69	1.58	1.20	1.34	7.36
Goodhue	Grass Public	243	72	1.58	1.21	1.34	7.64
Goodhue	CRP	2,391	73	1.59	1.21	1.34	7.74
Grant	Crops	4,217	78	1.59	1.21	1.35	8.33
Grant	Grass Private	807	54	1.56	1.20	1.33	5.75
Grant	Grass Public	7	36	1.53	1.19	1.32	3.87
Grant	CRP	593	65	1.57	1.20	1.34	6.91
Hennepin	Crops	14,816	86	1.60	1.21	1.35	9.18
Hennepin	Grass Private	37,713	77	1.59	1.21	1.35	8.19
Hennepin	Grass Public	2,421	70	1.58	1.20	1.34	7.43
Hennepin	CRP	418	84	1.60	1.21	1.35	9.00
Houston	Crops	24,657	83	1.60	1.21	1.35	8.84
Houston	Grass Private	82,591	60	1.57	1.20	1.33	6.43
Houston	Grass Public	843	46	1.55	1.19	1.32	4.94
Houston	CRP	7,141	64	1.57	1.20	1.34	6.80
Hubbard	Crops	14,851	43	1.54	1.19	1.32	4.57
Hubbard	Grass Private	36,789	58	1.56	1.20	1.33	6.14
Hubbard	Grass Public	317	45	1.55	1.19	1.32	4.77
Hubbard	CRP	110	40	1.54	1.19	1.32	4.29
Isanti	Crops	Soils information unavailable.					
Isanti	Grass Private						
Isanti	Grass Public						
Isanti	CRP						
Itasca	Crops	193	80	1.60	1.21	1.35	8.54
Itasca	Grass Private	30,864	65	1.57	1.20	1.34	6.89
Itasca	Grass Public	1,667	53	1.56	1.19	1.33	5.61
Itasca	CRP	0	39	1.54	1.19	1.32	4.16
Jackson	Crops	1,594	86	1.60	1.21	1.35	9.13
Jackson	Grass Private	370	43	1.54	1.19	1.32	4.54

County	Current land use	Acres	Crop Productivity Index	-------Yield(green tons/year)------- Aspen	Other hardwoods	Conifers	Hybrid poplar
Jackson	Grass Public	11	50	1.55	1.19	1.33	5.32
Jackson	CRP	36	80	1.60	1.21	1.35	8.56
Kanabec	Crops	12,003	68	1.58	1.20	1.34	7.25
Kanabec	Grass Private	82,499	65	1.57	1.20	1.34	6.89
Kanabec	Grass Public	260	58	1.57	1.20	1.33	6.21
Kanabec	CRP	36	49	1.55	1.19	1.33	5.21
Kandiyohi	Crops	55,480	84	1.60	1.21	1.35	9.00
Kandiyohi	Grass Private	17,123	69	1.58	1.20	1.34	7.38
Kandiyohi	Grass Public	950	67	1.58	1.20	1.34	7.14
Kandiyohi	CRP	5,926	70	1.58	1.20	1.34	7.49
Kittson	Crops	65,449	75	1.59	1.21	1.35	7.96
Kittson	Grass Private	48,399	49	1.55	1.19	1.33	5.24
Kittson	Grass Public	2,739	35	1.53	1.19	1.32	3.74
Kittson	CRP	75,362	55	1.56	1.20	1.33	5.92
Koochiching	Crops	Soils information unavailable.					
Koochiching	Grass Private						
Koochiching	Grass Public						
Koochiching	CRP						
Lac qui Parle	Crops	476	84	1.60	1.21	1.35	8.94
Lac qui Parle	Grass Private	264	52	1.56	1.19	1.33	5.56
Lac qui Parle	Grass Public	71	80	1.60	1.21	1.35	8.58
Lac qui Parle	CRP	108	82	1.60	1.21	1.35	8.71
Lake	Crops	Soils information unavailable.					
Lake	Grass Private						
Lake	Grass Public						
Lake	CRP						
Lake of the Woods	Crops	22,040	75	1.59	1.21	1.35	7.96
Lake of the Woods	Grass Private	13,690	73	1.59	1.21	1.34	7.84
Lake of the Woods	Grass Public	52	65	1.57	1.20	1.34	6.92
Lake of the Woods	CRP	75	76	1.59	1.21	1.35	8.08
Le Sueur	Crops	140,746	86	1.60	1.21	1.35	9.14
Le Sueur	Grass Private	14,263	80	1.60	1.21	1.35	8.49
Le Sueur	Grass Public	421	78	1.59	1.21	1.35	8.30

				-------Yield(green tons/year)-------			
County	Current land use	Acres	Crop Productivity Index	Aspen	Other hardwoods	Conifers	Hybrid poplar
Le Sueur	CRP	4,479	78	1.59	1.21	1.35	8.35
Lincoln	Crops	2,056	86	1.60	1.21	1.35	9.21
Lincoln	Grass Private	527	50	1.55	1.19	1.33	5.33
Lincoln	Grass Public	32	40	1.54	1.19	1.32	4.23
Lincoln	CRP	165	75	1.59	1.21	1.35	8.01
Lyon	Crops	2,771	88	1.61	1.21	1.36	9.34
Lyon	Grass Private	623	52	1.56	1.19	1.33	5.53
Lyon	Grass Public	78	48	1.55	1.19	1.33	5.09
Lyon	CRP	247	72	1.58	1.21	1.34	7.63
McLeod	Crops	68,571	87	1.61	1.21	1.36	9.31
McLeod	Grass Private	14,415	72	1.58	1.21	1.34	7.69
McLeod	Grass Public	396	73	1.59	1.21	1.34	7.77
McLeod	CRP	899	79	1.59	1.21	1.35	8.43
Mahnomen	Crops	15,179	82	1.60	1.21	1.35	8.76
Mahnomen	Grass Private	9,169	66	1.58	1.20	1.34	7.03
Mahnomen	Grass Public	615	54	1.56	1.20	1.33	5.71
Mahnomen	CRP	1,953	71	1.58	1.20	1.34	7.54
Marshall	Crops	175,937	83	1.60	1.21	1.35	8.89
Marshall	Grass Private	96,574	73	1.59	1.21	1.34	7.80
Marshall	Grass Public	6,248	47	1.55	1.19	1.32	4.99
Marshall	CRP	88,747	69	1.58	1.20	1.34	7.39
Martin	Crops	1,981	90	1.61	1.22	1.36	9.61
Martin	Grass Private	0	-	-	-	-	-
Martin	Grass Public	0	-	-	-	-	-
Martin	CRP	15	84	1.60	1.21	1.35	8.93
Meeker	Crops	125,320	84	1.60	1.21	1.35	8.92
Meeker	Grass Private	21,125	62	1.57	1.20	1.34	6.58
Meeker	Grass Public	720	61	1.57	1.20	1.34	6.52
Meeker	CRP	4,686	71	1.58	1.20	1.34	7.59
Mille Lacs	Crops	20,759	69	1.58	1.20	1.34	7.32
Mille Lacs	Grass Private	78,125	62	1.57	1.20	1.34	6.63
Mille Lacs	Grass Public	965	60	1.57	1.20	1.33	6.43
Mille Lacs	CRP	118	72	1.58	1.21	1.34	7.68

County	Current land use	Acres	Crop Productivity Index	Aspen	Other hardwoods	Conifers	Hybrid poplar
				-------Yield(green tons/year)-------			
Morrison	Crops	56,891	61	1.57	1.20	1.34	6.47
Morrison	Grass Private	193,522	58	1.56	1.20	1.33	6.17
Morrison	Grass Public	5,642	36	1.53	1.19	1.32	3.86
Morrison	CRP	2,155	60	1.57	1.20	1.33	6.36
Mower	Crops	314,737	87	1.61	1.21	1.35	9.27
Mower	Grass Private	6,420	73	1.59	1.21	1.34	7.78
Mower	Grass Public	984	73	1.59	1.21	1.34	7.79
Mower	CRP	1,926	79	1.59	1.21	1.35	8.41
Murray	Crops	2,692	82	1.60	1.21	1.35	8.76
Murray	Grass Private	154	71	1.58	1.20	1.34	7.58
Murray	Grass Public	3	49	1.55	1.19	1.33	5.25
Murray	CRP	78	73	1.59	1.21	1.34	7.77
Nicollet	Crops	23,928	87	1.61	1.21	1.36	9.31
Nicollet	Grass Private	1,229	58	1.56	1.20	1.33	6.19
Nicollet	Grass Public	476	61	1.57	1.20	1.34	6.54
Nicollet	CRP	131	71	1.58	1.21	1.34	7.61
Nobles	Crops	384	92	1.61	1.22	1.36	9.84
Nobles	Grass Private	0	-	-	-	-	-
Nobles	Grass Public	4	94	1.62	1.22	1.36	10.06
Nobles	CRP	0	-	-	-	-	-
Norman	Crops	53,760	84	1.60	1.21	1.35	8.94
Norman	Grass Private	1,134	63	1.57	1.20	1.34	6.71
Norman	Grass Public	387	54	1.56	1.20	1.33	5.75
Norman	CRP	2,129	66	1.58	1.20	1.34	7.09
Olmsted	Crops	137,542	83	1.60	1.21	1.35	8.86
Olmsted	Grass Private	51,890	66	1.58	1.20	1.34	7.06
Olmsted	Grass Public	402	72	1.58	1.21	1.34	7.65
Olmsted	CRP	3,768	68	1.58	1.20	1.34	7.26
Otter Tail	Crops	122,137	67	1.58	1.20	1.34	7.18
Otter Tail	Grass Private	151,342	59	1.57	1.20	1.33	6.27
Otter Tail	Grass Public	1,064	57	1.56	1.20	1.33	6.05
Otter Tail	CRP	19,568	58	1.57	1.20	1.33	6.21
Pennington	Crops	120,028	80	1.60	1.21	1.35	8.56

County	Current land use	Acres	Crop Productivity Index	-------Yield(green tons/year)------- Aspen	Other hardwoods	Conifers	Hybrid poplar
Pennington	Grass Private	40,311	70	1.58	1.20	1.34	7.46
Pennington	Grass Public	596	36	1.53	1.19	1.32	3.87
Pennington	CRP	22,998	69	1.58	1.20	1.34	7.33
Pine	Crops	Soils information unavailable.					
Pine	Grass Private						
Pine	Grass Public						
Pine	CRP						
Pipestone	Crops	0	-	-	-	-	-
Pipestone	Grass Private	0	-	-	-	-	-
Pipestone	Grass Public	0	-	-	-	-	-
Pipestone	CRP	0	-	-	-	-	-
Polk	Crops	168,840	81	1.60	1.21	1.35	8.66
Polk	Grass Private	62,671	59	1.57	1.20	1.33	6.27
Polk	Grass Public	7,980	57	1.56	1.20	1.33	6.06
Polk	CRP	40,568	66	1.58	1.20	1.34	7.04
Pope	Crops	14,044	78	1.59	1.21	1.35	8.28
Pope	Grass Private	8,473	57	1.56	1.20	1.33	6.07
Pope	Grass Public	486	52	1.56	1.19	1.33	5.59
Pope	CRP	3,156	60	1.57	1.20	1.33	6.42
Ramsey	Crops	0	-	-	-	-	-
Ramsey	Grass Private	100	46	1.55	1.19	1.32	4.88
Ramsey	Grass Public	134	48	1.55	1.19	1.33	5.08
Ramsey	CRP	0	-	-	-	-	-
Red Lake	Crops	95,270	79	1.59	1.21	1.35	8.38
Red Lake	Grass Private	22,348	71	1.58	1.20	1.34	7.52
Red Lake	Grass Public	414	57	1.56	1.20	1.33	6.10
Red Lake	CRP	23,889	75	1.59	1.21	1.35	8.05
Redwood	Crops	2,710	86	1.61	1.21	1.35	9.21
Redwood	Grass Private	273	39	1.54	1.19	1.32	4.18
Redwood	Grass Public	176	77	1.59	1.21	1.35	8.23
Redwood	CRP	219	61	1.57	1.20	1.34	6.55
Renville	Crops	8,244	87	1.61	1.21	1.35	9.29
Renville	Grass Private	853	40	1.54	1.19	1.32	4.28

County	Current land use	Acres	Crop Productivity Index	-------Yield(green tons/year)------- Aspen	Other hardwoods	Conifers	Hybrid poplar
Renville	Grass Public	328	74	1.59	1.21	1.34	7.85
Renville	CRP	359	74	1.59	1.21	1.35	7.94
Rice	Crops	104,603	84	1.60	1.21	1.35	8.96
Rice	Grass Private	34,219	68	1.58	1.20	1.34	7.24
Rice	Grass Public	767	57	1.56	1.20	1.33	6.10
Rice	CRP	3,954	75	1.59	1.21	1.35	7.97
Rock	Crops	1,412	76	1.59	1.21	1.35	8.05
Rock	Grass Private	237	45	1.55	1.19	1.32	4.77
Rock	Grass Public	55	54	1.56	1.20	1.33	5.74
Rock	CRP	8	79	1.59	1.21	1.35	8.44
Roseau	Crops	221,419	73	1.59	1.21	1.34	7.82
Roseau	Grass Private	112,712	64	1.57	1.20	1.34	6.81
Roseau	Grass Public	6,966	23	1.52	1.18	1.31	2.50
Roseau	CRP	66,802	72	1.58	1.21	1.34	7.65
St. Louis	Crops	Soils information unavailable.					
St. Louis	Grass Private						
St. Louis	Grass Public						
St. Louis	CRP						
Scott	Crops	49,879	85	1.60	1.21	1.35	9.04
Scott	Grass Private	45,440	73	1.59	1.21	1.34	7.77
Scott	Grass Public	1,662	69	1.58	1.20	1.34	7.34
Scott	CRP	1,464	75	1.59	1.21	1.35	7.95
Sherburne	Crops	25,567	43	1.54	1.19	1.32	4.54
Sherburne	Grass Private	52,080	39	1.54	1.19	1.32	4.18
Sherburne	Grass Public	6,229	40	1.54	1.19	1.32	4.24
Sherburne	CRP	367	45	1.55	1.19	1.32	4.83
Sibley	Crops	52,289	89	1.61	1.21	1.36	9.47
Sibley	Grass Private	5,171	79	1.60	1.21	1.35	8.48
Sibley	Grass Public	145	68	1.58	1.20	1.34	7.26
Sibley	CRP	232	80	1.60	1.21	1.35	8.50
Stearns	Crops	114,065	75	1.59	1.21	1.35	8.04
Stearns	Grass Private	152,193	62	1.57	1.20	1.34	6.66
Stearns	Grass Public	1,788	59	1.57	1.20	1.33	6.27

County	Current land use	Acres	Crop Productivity Index	Aspen	Other hardwoods	Conifers	Hybrid poplar
				-------Yield(green tons/year)-------			
Stearns	CRP	6,294	62	1.57	1.20	1.34	6.66
Steele	Crops	136,118	87	1.61	1.21	1.36	9.33
Steele	Grass Private	4,277	76	1.59	1.21	1.35	8.10
Steele	Grass Public	473	74	1.59	1.21	1.35	7.91
Steele	CRP	2,470	79	1.59	1.21	1.35	8.42
Stevens	Crops	138	92	1.61	1.22	1.36	9.84
Stevens	Grass Private	0	-	-	-	-	-
Stevens	Grass Public	0	-	-	-	-	-
Stevens	CRP	0	89	1.61	1.21	1.36	9.49
Swift	Crops	2,874	81	1.60	1.21	1.35	8.63
Swift	Grass Private	1,226	59	1.57	1.20	1.33	6.25
Swift	Grass Public	141	60	1.57	1.20	1.33	6.36
Swift	CRP	1,398	59	1.57	1.20	1.33	6.26
Todd	Crops	47,494	74	1.59	1.21	1.35	7.89
Todd	Grass Private	157,211	64	1.57	1.20	1.34	6.78
Todd	Grass Public	442	48	1.55	1.19	1.33	5.11
Todd	CRP	4,881	67	1.58	1.20	1.34	7.15
Traverse	Crops	1,549	94	1.62	1.22	1.36	10.01
Traverse	Grass Private	246	51	1.55	1.19	1.33	5.43
Traverse	Grass Public	0	-	-	-	-	-
Traverse	CRP	25	87	1.61	1.21	1.35	9.24
Wabasha	Crops	70,993	83	1.60	1.21	1.35	8.90
Wabasha	Grass Private	53,368	72	1.58	1.21	1.34	7.70
Wabasha	Grass Public	492	58	1.57	1.20	1.33	6.21
Wabasha	CRP	4,416	76	1.59	1.21	1.35	8.15
Wadena	Crops	16,286	44	1.55	1.19	1.32	4.72
Wadena	Grass Private	53,407	47	1.55	1.19	1.32	5.00
Wadena	Grass Public	329	42	1.54	1.19	1.32	4.50
Wadena	CRP	387	46	1.55	1.19	1.32	4.91
Waseca	Crops	104,271	88	1.61	1.21	1.36	9.41
Waseca	Grass Private	2,677	65	1.58	1.20	1.34	6.97
Waseca	Grass Public	165	75	1.59	1.21	1.35	8.00
Waseca	CRP	1,271	77	1.59	1.21	1.35	8.24

County	Current land use	Acres	Crop Productivity Index	-------Yield(green tons/year)------- Aspen	Other hardwoods	Conifers	Hybrid poplar
Washington	Crops	15,518	73	1.59	1.21	1.34	7.78
Washington	Grass Private	59,944	59	1.57	1.20	1.33	6.31
Washington	Grass Public	2,365	61	1.57	1.20	1.34	6.50
Washington	CRP	131	53	1.56	1.20	1.33	5.71
Watonwan	Crops	7,661	85	1.60	1.21	1.35	9.04
Watonwan	Grass Private	47	82	1.60	1.21	1.35	8.78
Watonwan	Grass Public	0	-	-	-	-	-
Watonwan	CRP	24	70	1.58	1.20	1.34	7.45
Wilkin	Crops	4,563	89	1.61	1.21	1.36	9.51
Wilkin	Grass Private	13	87	1.61	1.21	1.35	9.24
Wilkin	Grass Public	0	-	-	-	-	-
Wilkin	CRP	42	81	1.60	1.21	1.35	8.68
Winona	Crops	51,544	84	1.60	1.21	1.35	8.95
Winona	Grass Private	80,758	65	1.57	1.20	1.34	6.94
Winona	Grass Public	1,520	70	1.58	1.20	1.34	7.51
Winona	CRP	4,143	67	1.58	1.20	1.34	7.15
Wright	Crops	107,240	85	1.60	1.21	1.35	9.04
Wright	Grass Private	79,960	73	1.59	1.21	1.34	7.81
Wright	Grass Public	1,421	66	1.58	1.20	1.34	7.01
Wright	CRP	3,410	71	1.58	1.20	1.34	7.59
Yellow Medicine	Crops	6,485	86	1.61	1.21	1.35	9.22
Yellow Medicine	Grass Private	1,291	55	1.56	1.20	1.33	5.83
Yellow Medicine	Grass Public	41	66	1.58	1.20	1.34	6.99
Yellow Medicine	CRP	510	78	1.59	1.21	1.35	8.32