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# WILD RICE PRODUCTION IN MINNESOTA

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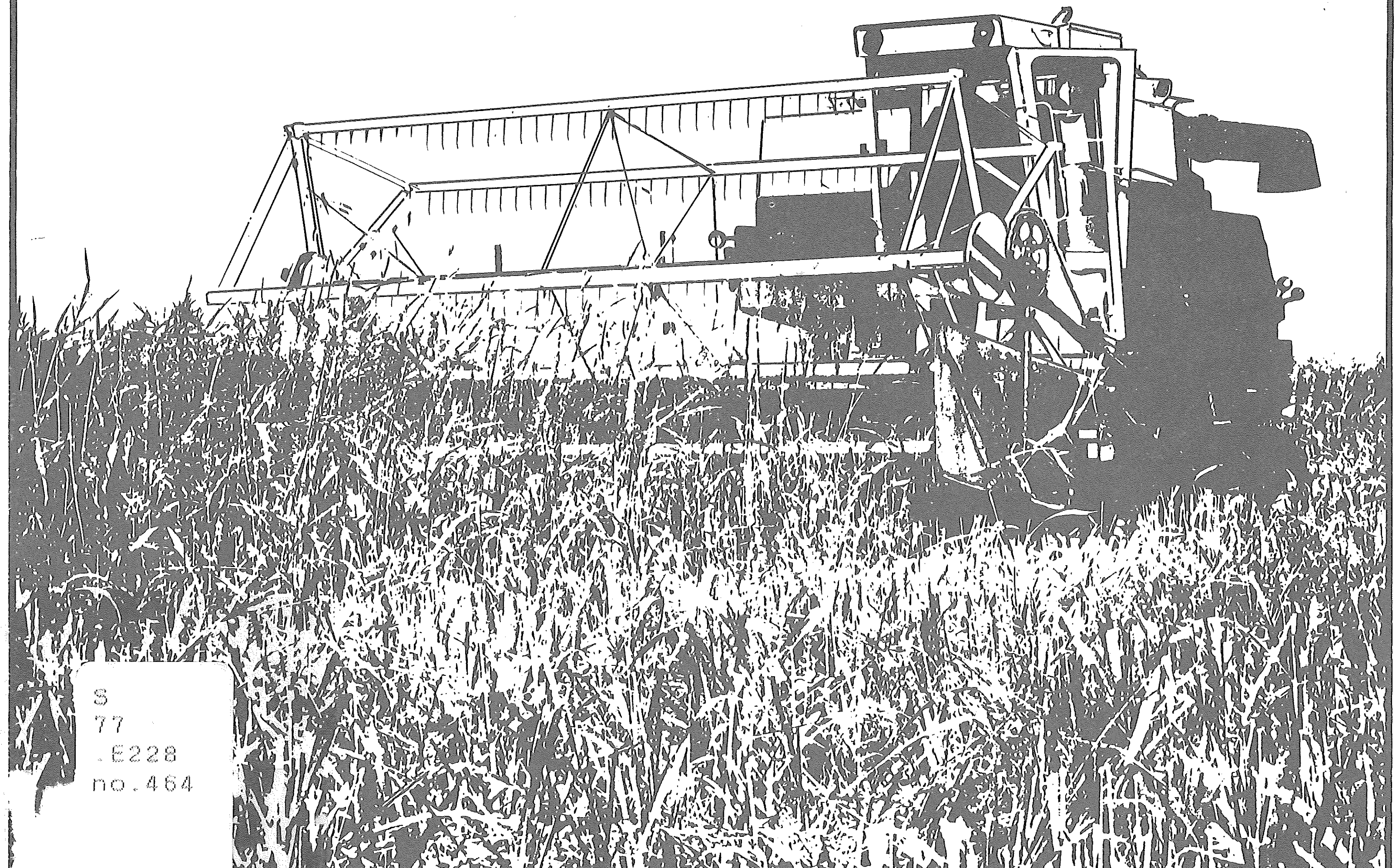



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Colorplate 1. Common waterplantain in flower (top). Floating leaves (bottom) are seedlings that developed seeds while upright leaves (bottom) are plants that developed from rootstocks.

Colorplate 2. Forked seed heads of burreed. Each sharp point is an individual seed.

Colorplate 3. Algae can significantly reduce wild rice stands.

Colorplate 4. Wild rice worm eggs inside the glumes. A few small larvae can also be seen.

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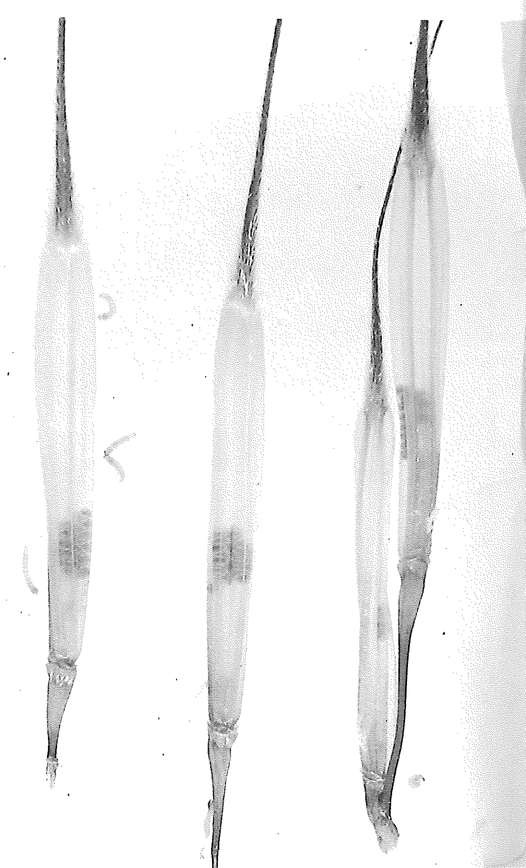

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# Introduction

E. A. Oelke

Wild rice is native to North America. Natural stands are found alongside the tidewater rivers (above the saline zone) in the Atlantic states and in shallow lakes and streams in northern Minnesota, northern Wisconsin, and southern Ontario and Manitoba, Canada. The grain is consumed by wildlife, especially ducks. It was used for human food 10,000 years ago when man moved into central North America. The American Indians harvested the grain from natural stands for food.

Figure 1. Parching wild rice in an iron kettle over an open fire. The grain is constantly stirred during drying.

The American Indian name for wild rice is "Manomin," meaning good berry. Other names given to wild rice were Indian rice, Canadian rice, squaw rice, oats, water oats, blackbird oats, and marsh oats. The name wild rice persisted and it is sold as "wild rice."

The most common harvesting method used by American Indians was the canoe and flail method. One person propelled the canoe with a pole while the other used one stick to bend the stems over the canoe and a second stick to tap the mature grains into the canoe. The stands were harvested several times during the two- to three-week ripening period. Today, the natural stands on reservations can be harvested only by American Indians. The harvesting of natural stands that are not on Indian reservations is controlled by the Minnesota Department of Natural Resources (DNR). DNR specifies when and how natural stands can be harvested and requires a license of anyone harvesting wild rice. The canoe and flail method is the only legal way to harvest natural stands. All Minnesota residents are eligible to purchase a license to harvest natural stands not on reservations.

Originally, wild rice grain was dried by laying the grain on mats placed in the sun or by laying the grain on racks placed above fires. Later, the grain was dried in iron kettles over fires (figure 1) where it was stirred

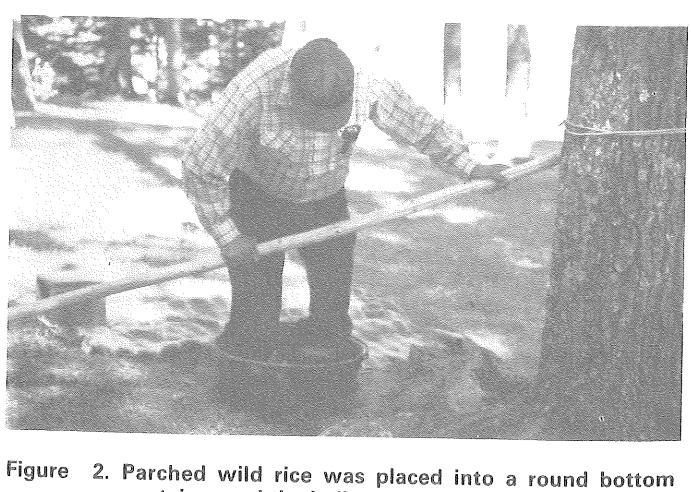


Figure 2. Parched wild rice was placed into a round bottom container and the hulls removed by treading (jigging).

constantly until dry. The hulls were removed by placing the dry grain into a hole lined with skin or into a round bottomed container, and individuals wearing moccasins treaded out (jigged) the grain (figure 2). The chaff was removed by winnowing. Today, nearly all wild rice harvested from natural stands is processed as described in a later section. Approximately 50 pounds per acre of grain (40 percent moisture) can be harvested from natural stands.

Growing wild rice as a field crop was suggested in 1852 by Joseph Bowron of Wisconsin and in 1853 by Oliver Hudson Kelley of Minnesota. However, attempts to grow wild rice as a field crop were not begun until 1950 when James and Gerald Godward grew a 1-acre field at Bass Lake near Merrifield, Minnesota. The first three years the Godwards had good crops, but disease destroyed the crop the fourth year. They continued their pioneering efforts by developing new areas and by 1958 had 120 acres diked for growing wild rice. They still grow wild rice successfully near Aitkin, Minnesota. During the mid-'50s and early '60s others started growing wild rice, and in 1965 Uncle Ben, Inc., began contracting acreage.

Production on new fields during the 1960s was successful, but after two or three years diseases frequently caused low yields. These fields were planted with seed collected from natural stands so the plants had the characteristics of wild plants. Not all of the seed matured at the same time, and it fell from the plant when mature. These characteristics necessitated development of harvest machines that did not destroy the plants but removed only the partially mature kernels. Some harvesting machines floated on the water and others required drainage of fields before harvest. Machines used on the muddy soil had continuous, lugged belting around the wheels for support. Fields were harvested three or four times. Yields were 150-200 pounds per acre of unprocessed grain. When varieties with a nonshattering tendency were introduced in 1968, large combines with tracks were used to harvest wild rice. Yields of 1,000 pounds per acre of unprocessed grain can be obtained with the new varieties.

Minnesota leads the world in wild rice production. In 1979, the state produced approximately 80 percent of the world's supply from natural stands and planted fields. Canada produced 17 percent, Wisconsin 2 percent, and California 1 percent.

Wild rice is grown as a field crop primarily in Minnesota, with a few acres also grown in Wisconsin, northern California, and southern Manitoba and Ontario, Canada.

Acreage and production of wild rice from cultivated fields in Minnesota are given in table 1. Acreage expanded rapidly from 1968 to 1973 but declined to 10,000 in 1977 due to a period of dry years and problems with insects and diseases. Insecticides and fungicides (as well as better and earlier maturing varieties) are available now and acreage is expected to increase. Production from cultivated fields first exceeded that from natural stands in 1971. Today, 60-90 percent of the total wild rice supply comes from cultivated fields.

Wild rice is produced in the northern half of Minnesota. The leading counties are Aitkin, Clearbrook, Polk, Beltrami, and Itasca. Wild rice could be planted on more than 100,000 acres in Minnesota.

**Table 1. Wild rice production from cultivated fields in Minnesota, 1968-80**

| Year | Acreage | Production (1,000 lb)[1] |
|---|---|---|
| 1968 | 900 | 90 |
| 1969 | 2,650 | 400 |
| 1970 | 5,200 | 910 |
| 1971 | 8,700 | 1,520 |
| 1972 | 17,000 | 3,740 |
| 1973 | 18,000 | 3,000 |
| 1974 | 13,000 | 2,700 |
| 1975 | 13,000 | 3,200 |
| 1976 | 13,000 | 3,750 |
| 1977 | 10,000 | 3,000 |
| 1978 | 12,000 | 4,200 |
| 1979 | 14,000 | 4,600 |
| 1980 | 14,000 | 4,300 |

[1]40% moisture; 2½ pounds of harvested grain will give 1 pound of dry processed grain.

# The Wild Rice Plant

E. A. Oelke

Wild rice is in the grass family of plants. It belongs to the genus *Zizania.* Rice belongs to the genus *Oryza.* There are four species of wild rice: *Z. palustris* L., *Z. aquatica* L., *Z. texana* Hitchcock, and *Z. latifolia* (Griseb.) Turcz. ex Stapf. The first three are native to North America and the last is native to Asia. *Z. palustris* and *Z. aquatica* are annuals, the others perennials. *Z. palustris,* the large seeded type, grows in the Great Lakes region, is harvested for food (figure 3), and is the species grown as a field crop. *Z. aquatica* grows in the St. Lawrence River, eastern and southeastern U.S. coastal areas, and in Louisiana. Its seeds are slender and are not harvested for food. *Z. texana* grows in a small area in Texas, has slender seeds, and also is not harvested for food. North American species have a chromosome number of 2n = 30; *Z. latifolia* has 2n = 34.

Wild rice caryopses are the fruits of the plant. The caryopsis is similar to kernels of the cereal grains. A large endosperm is surrounded by a thin layer of pericarp and aleurone. The embryo at one end of the caryopsis contains a cotyledon that can extend to the length of the caryopsis, a coleoptile that surrounds the terminal bud, and a coleorhiza that surrounds the primary root. The lemma and palea (hulls) remain on the seed during harvest but are removed during pro-

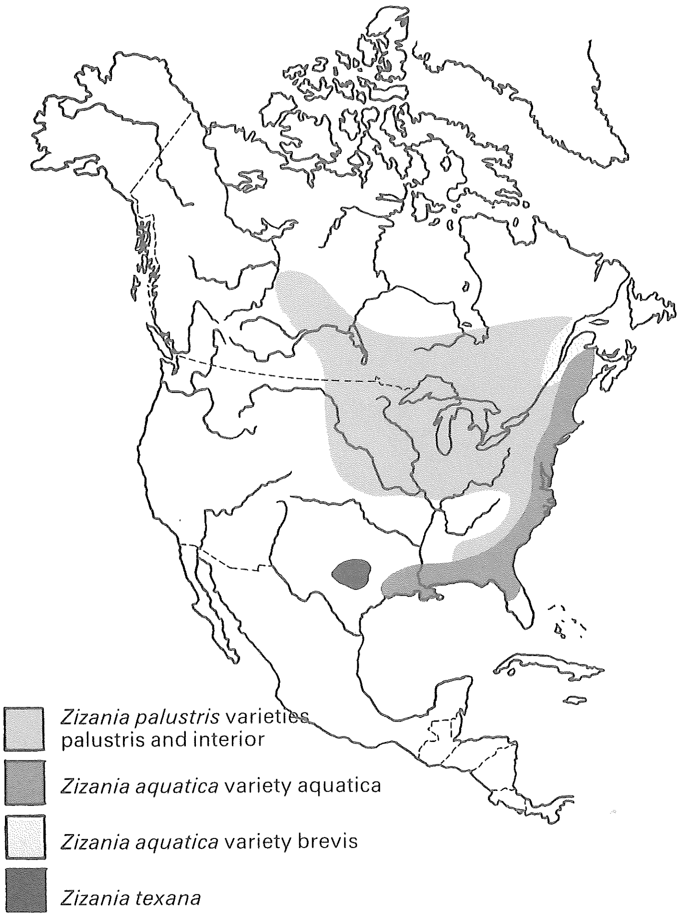



**Figure 3. Distribution of wild rice in North America. Adapted from USDA, Technical Bulletin 634.**

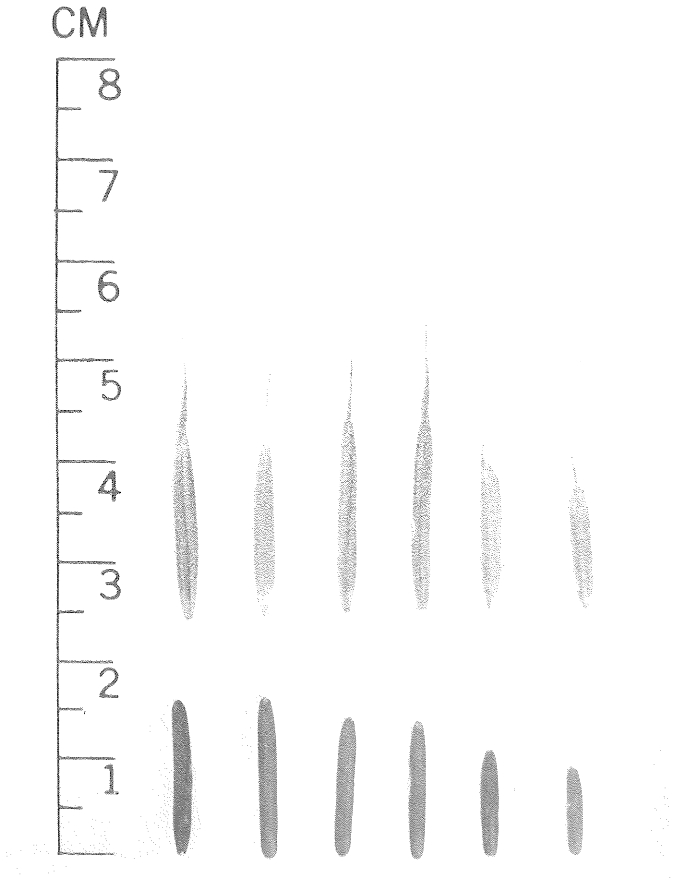



**Figure 4. Wild rice seeds with the hulls (lemma and palea) on (top) and with the hulls removed (bottom). Seeds can vary in length from 1-1½ cm.**

cessing (figure 4). The endosperm, pericarp, embryo, and hulls make up 77, 4, 4, and 14 percent of the seed, respectively.

Wild rice seeds require three to four months of storage in cold (35° F) water before they will germinate. This dormancy is caused by an impermeable and tough pericarp that is covered by a layer of wax and by an imbalance of growth promotors and inhibitors. The growth inhibitor, abscisic acid, was found to be higher in dormant than in nondormant seeds. Freshly harvested seeds, however, can be forced to germinate by carefully removing (scraping) the pericarp from directly above the embryo. Scraped seeds cannot be planted directly, but they can be germinated in water and the seedlings transplanted.

Germination is evident when the coleoptile breaks through the pericarp (figure 5). The primary root

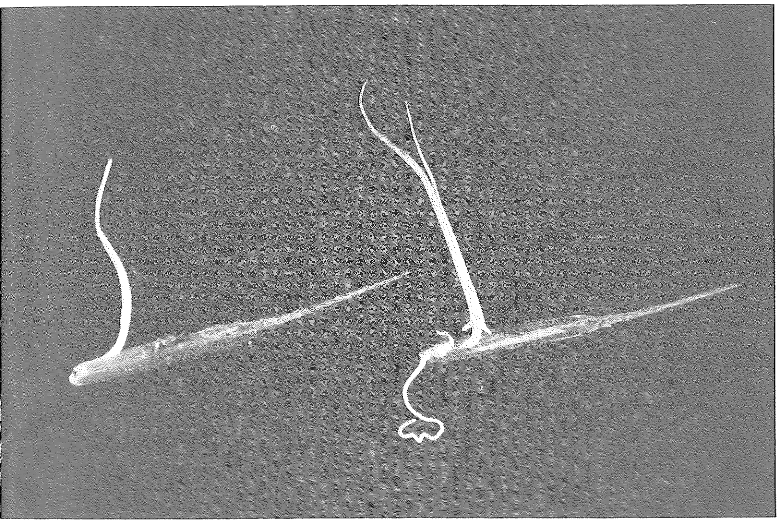


**Figure 5. Wild rice seeds after germinating in water at 68° F for 6 to 10 days (left to right).**

emerges through the pericarp 7 to 10 days after the coleoptile emerges. Within three weeks the seedlings have three leaves but are still submerged (figure 6). The first internode elongates as in corn and oats. Wild rice seedlings can emerge through 3 inches of flooded soil because the first internode can elongate up to 2 inches. The internode elongates very little if the seeds germinate in water. Adventitious roots arise at the first node and also occasionally at the second and third nodes. The terminal bud differentiates nodes and internodes and terminates in an inflorescence (panicle). A leaf sheath with a leaf blade is attached to each node above the coleoptile node.

The first three leaves have no wax on their surfaces, remain submerged, and eventually die. The next two leaves have waxy surfaces and float on the water. The remaining three to five leaves are aerial and have waxy surfaces and blades varying in length from 16 to 30 inches. They vary in width from ¾ to 1 inch. The midrib is a little to one side and more prominent on the lower

**Figure 6. Submerged wild rice seedlings at 14, 18, and 21 days (left to right).**

surface than the upper. A prominent ligule is located at the junction of the blade and sheath. The ligule is ½ inch long, membranous, frayed at the top, and rounded truncate or somewhat acuminate in shape.

The upper three to five internodes of the mature stem are 12-30 inches long and the lower internodes are about 12 inches long. Internodes are hollow but divided into regularly spaced intervals by thin partitions, which are porous and do not impede the diffusion of gases up and down the stem. Stem diameter varies from ¼ to ½ inch depending on variety, plant density, fertility level, and water depth. Up to 50 tillers per plant can be produced from the basal nodes of the main stem and its tillers. Many of the tillers bear panicles (figure 7). In fields with a plant population of four plants per square foot, plants will have three to six tillers.

The adventitious root system of the mature plant is shallow with a lateral spread of 8-12 inches. The roots are straight, spongy, and generally white, but often rust-tinged by iron deposits. Root hairs are lacking.

The monoecious panicle is 18-20 inches long with the seed-bearing part being 10-12 inches and located

Figure 7. A wild rice plant during flowering.

above the male part. The staminate (male) inflorescence has 12 to 15 branches that are widespreading and 4-5 inches long with 50 to 60 staminate florets per branch. A staminate floret has six stamens enclosed by a lemma and palea. The stamens produce a large amount of pollen which is wind-borne. The pistillate (female) inflorescence has 150 to 200 florets on branches which are appressed and vary in length from 1 to 5 inches, with the upper ones being the shortest. Each pistillate floret has a lemma and palea. The lemma has a prominent awn ½-2½ inches long. Each pistillate floret has only one caryopsis and the glumes are not developed, thus harvested seeds are actually spikelets. The pistillate florets emerge from the leaf sheath before the staminate ones. Wild rice is usually cross-pollinated because the stigmas are receptive for three to four days and generally are pollinated from other plants before the stamens of the same stem shed pollen. Sometimes the transition florets between the pistillate and staminate ones have both stigmas and anthers and could be self-pollinated. Fertilization is evident when the stigma has withered, generally 24 hours after pollination. Two weeks after fertilization the caryopsis is visible, and after four weeks it is dark and ready for harvest. Caryopses on a panicle appear to mature at random, and it requires 7 to 10 days for all to mature. The mature caryopsis is purplish black and is surrounded by the lemma and palea before and after harvest.

Wild rice requires from 106 to 130 days to mature in north central Minnesota, depending upon temperatures during the growing season and variety (figure 8). Germination starts when water temperatures reach 42° F, the latter part of April or first part of May. Floating leaves are visible a month later and upright (aerial) leaves 10 days later. Tillering begins after an additional 10 days. Jointing (elongation of internodes) starts 67 days after germination and the boot stage occurs eight days later. Flowering begins in late July and grain formation in August. Fields are harvested during late August and early September. Wild rice requires approximately 2,900 growing degree days to mature (figure 8).

Minnesota wild rice is best adapted to northern latitudès. It is not very productive in southern United States because warm temperatures greatly accelerate growth. Also, the number of florets per panicle are reduced in daylengths shorter than 14 hours. However, fair yields have been obtained in Florida by planting in late February or early March.

| | Stages of Development | Days | Date | GDD |
|---|---|---|---|---|
| Vegetative Growth Phase | Germination | 0 | May | 0 |
| | Emergence | 12 | | 138 |
| | Floating Leaf | 29 | | 468 |
| | Aerial Leaf | 39 | June | 686 |
| | Early Tillering | 49 | | 928 |
| Reproductive Growth Phase | Jointing | 67 | July | 1394 |
| | Boot | 75 | | 1590 |
| | Early Flowering | 83 | | 1834 |
| | Mid Flowering | 91 | | 2078 |
| | Early Grain Formation | 105 | August | 2466 |
| | Maturity | 121 | | 2940 |

Figure 8. Wild rice plant development (K2 variety) in Aitkin County. GDD = growing degree days using 40° F as the base temperature.

## Site Selection

E. A. Oelke and D. D. Barron

Most of the wild rice in Minnesota is grown on low, wet land previously not farmed. Before considering an area for wild rice, a preliminary topographic survey should be made to determine if the site is flat enough to avoid expensive grading; too much grading will expose subsoil. The Soil Conservation Service may assist in making the survey. The site also should have an impervious subsoil so that fields can be flooded during most of the growing season. The site should be above the floodplain so the fields can be drained during late summer for harvest and fall tillage.

An acceptable water source must be available from a stream or lake. Under Minnesota law, permits from the Department of Natural Resources are necessary to use surface or ground water for irrigation. Permits are available only to owners of land next to the water source. Wells can be used if the recharge rate is sufficient. A permit also is needed from the Minnesota Pollution Control Agency for return flow. Application for permits should be started early in the planning stage to assure that they are granted prior to construction.

The majority of wild rice fields have been developed on organic soils, the peat depth varying from several inches to more than 5 feet. Deep peat can pose problems if not properly drained or if equipment is not modified for it. Peat areas in Minnesota generally are flat and slightly above the flood plain, ideal for wild rice. Clay loam soils also are suitable for wild rice.

## Land Preparation and Dike Construction

E. A. Oelke and D. D. Barron

Brush and small trees often are cleared in winter by shearing with a bulldozer and are piled for burning the next summer. Large disks or rotovators are used to till the soil rather than moldboard plows. Plowed organic soils frequently float when flooded.

After the soil is worked, make a detailed topographic survey to establish contour lines for dikes (figure 9). Place dikes so that a maximum water depth of 8 inches can be maintained on the shallow end and 16 inches on the deep end of a field. Locate access roads so they can be used as part of the dike system to divert water, collect water, and divide drainage areas. Grade and crown roads to provide high and dry travel. Where roads cross drainage ways, use culverts or other permanent structures. It is desirable to have access roads to every field for ease of observation and movement of equipment.

Inner dikes should have a minimum top width of 4 feet, but not less than the height of the dike. The steepest side slopes should be 1½:1 (a one foot drop for every 1½ feet of horizontal distance) for most soils. For easily erodible soils the slope should be 3:1, and the height should be 1 foot higher than the water level. Be careful when using organic soil for dikes since peat erodes easily and sometimes will not hold back water. It is best to mix some mineral soil with peat, especially on the side slopes. Avoid burying logs or frozen chunks of peat in dikes.

Seed dikes with bluegrass to retard erosion and weed growth. Bluegrass grows well on both peat and mineral soils and is not a weed in wild rice fields nor an alternate host for wild rice diseases.

Make sure that each field has inner ditches (borrow pits) around the perimeter for rapid drainage before harvest. These ditches often fill in on peat soils and should be kept open.

One irrigation system layout has a central water supply ditch from which the various fields can be flooded (figure 10). Another system allows water to flow from one field into the other. This system, however, prevents individual crop rotation or fallowing for each field.

The amount of water required to grow wild rice ranges from 24 to 30 acre-inches. An experiment conducted with plastic-lined boxes having two plants per square foot showed a water use of 25 acre-inches for the growing season. Most growers have permits for pumping that many acre-inches of water; nearly half of it often is supplied by rainfall. Water systems should be planned to flood a field in 7 to 10 days. A 12-inch pump that delivers 4,000 gallons per minute and runs 24 hours a day provides 5,760,000 gallons per day. Such a system would require approximately 8½ days to flood a 100-acre field to an average depth of 11 inches.

Detailed procedures for designing wild rice fields have been developed by the Soil Conservation Service (SCS) and are outlined in *Irrigation System, Surface and Subsurface* (443), (Minnesota Supplement). It is available from SCS at 200 Federal Building, 316 N. Robert Street, St. Paul, MN 55101.

**Figure 9. A layout of wild rice fields with water supply ditches in the upper right and center. The river from which the water is pumped is in the lower corner. The area covers about 700 acres.**

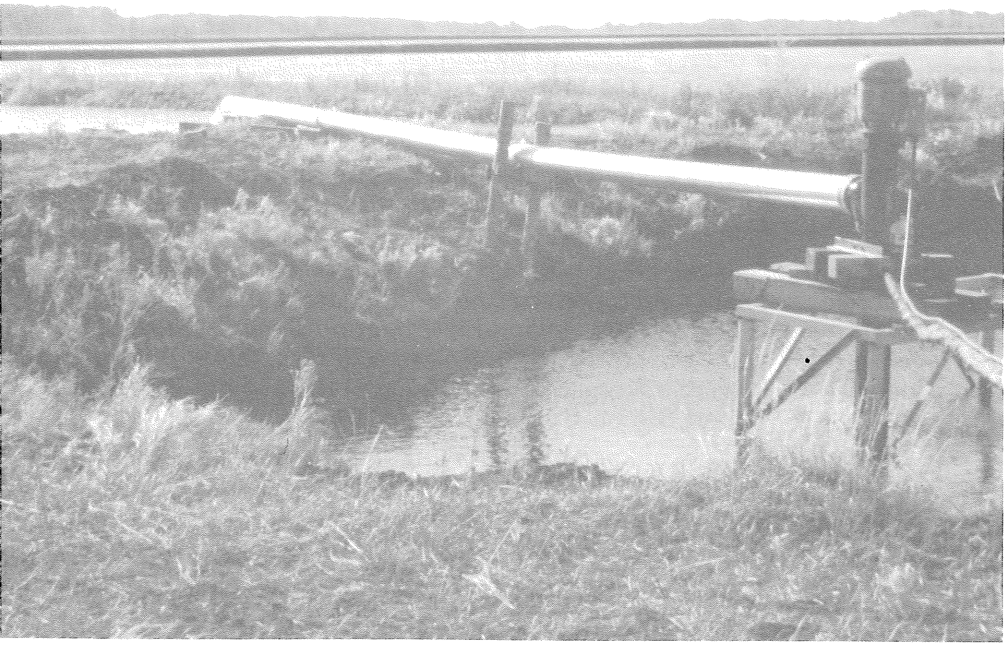


Figure 10. An electrical pump lifting water from a main supply ditch into another supply ditch within the fields.

# Varieties

R. E. Stucker

## HISTORICAL

The first wild rice fields were planted with seed from natural stands. Mature seed from natural stands falls from the plant (shatters) and not all of the seeds on a plant mature at the same time. Populations grown from seeds of natural stands are referred to as the "shattering" varieties. Populations of plants derived from Canadian lakes (Canadian shattering types) and grown in Minnesota are two to three weeks earlier maturing than populations collected from Minnesota lakes (Minnesota shattering types). Shattering type populations are harvested with a multiple-pass procedure that requires harvesting every other day for 10 days and will yield 60 pounds of processed grain per acre. Only a small proportion of wild rice acreage is planted to the shattering types.

In 1963 Dr. Paul Yagyu and Erwin Brooks, who were with the Department of Agronomy and Plant Genetics, University of Minnesota, found some plants in a field of shattering wild rice that retained their seeds longer than other plants. Seeds of the "nonshattering" plants were increased, and in 1968 Algot Johnson—in whose field the plants were found—grew 20 acres of this selection. It is now called the 'Johnson' variety. Subsequently, other plants with some shatter resistance were found in growers' fields and in lakes.

Today, several varieties with some shatter resistance, referred to as "nonshattering," (figure 11) are available. However, mature seed of the nonshattering varieties will fall off if not harvested soon after the stage of maturity called "40 percent dark seed." Consequently, seed shattering is still a major problem in nonshattering varieties. Nevertheless, the resistance to shattering is sufficient to permit a single-pass harvest with rice combines and to substantially increase yield. Yields of 300 pounds per acre of processed grain have been obtained with these varieties.

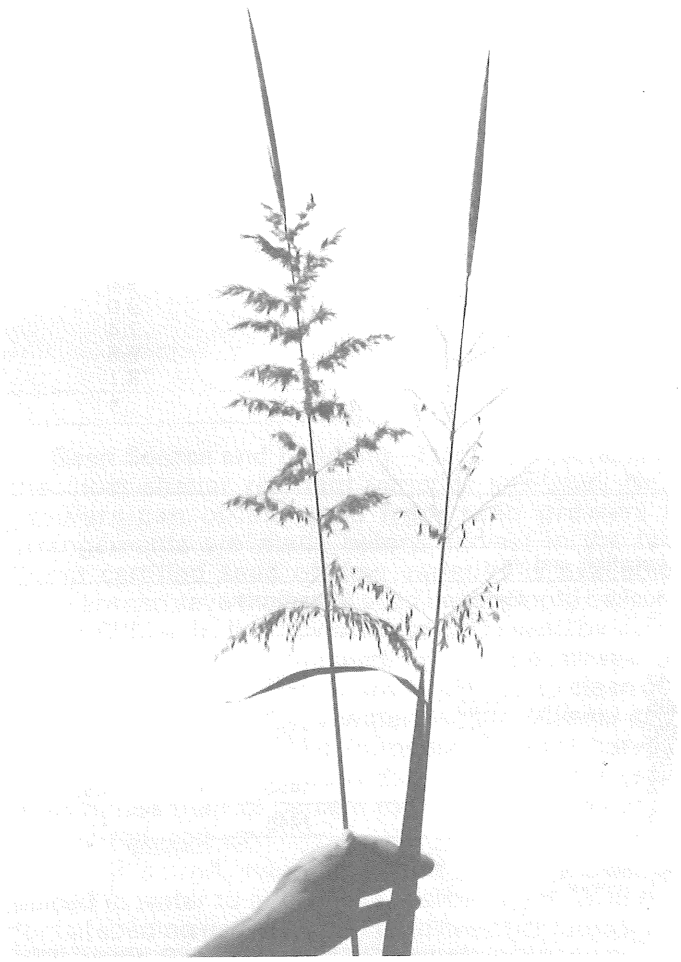


Figure 11. A nonshattering panicle (left) can be identified by the presence of male flowers (lower branched portion) even after pollen shed.

## NONSHATTERING VARIETIES

**Johnson** was the first variety with some shattering resistance. It is tall, late, and has wide leaves with panicle color ranging from pale green to purple. Seed was increased by Algot Johnson and made available in 1969.

**M1** has some shattering resistance, is medium height, and has medium-to-late maturity. It has medium width leaves with panicle color mostly purple. It was developed by Manomin Development Co. in 1970.

**M3** has some shattering resistance, is medium height, and has medium-to-late maturity. It has medium width leaves with a variety of panicle colors and has a mixture of all female and female-male panicles. It was developed by Manomin Development Co. in 1974.

**K2** has some shattering resistance, is medium height, and has early-to-medium maturity. It has medium width leaves with mostly purple panicles. It was developed by Kosbau Bros. in 1972.

**Netum** has some shattering resistance, is medium height, and has early maturity. It has medium to narrow width leaves with a mixture of panicle colors from pale green to purple. It was developed by the Minnesota Agricultural Experiment Station and released in 1978.

Comparative characteristics of the five varieties are shown in tables 2 and 3. The average yields in table 4 probably are not significantly different because of the variability of testing procedures. When the later varieties mature, Netum is likely to be lower in yield than the other varieties. However, the earlier maturity of Netum reduces the hazard of loss from early frost, severe winds, disease, and bird feeding. Growing varieties that differ in maturity spreads the harvest load. The K2 variety is an early-to-medium maturing variety and is probably the most widely grown at this time.

All varieties possess approximately the same degree of shattering resistance and all are susceptible to brown spot and other diseases. They all lodge if too much fertilizer is applied or if grown in deep water.

## VARIETAL IMPROVEMENT

Practically all of the attempts to develop improved varieties of wild rice for paddy production have occurred during the last 20 years. The present breeding program at the Minnesota Agricultural Experiment Station was initiated in 1972. Several characteristics of the wild plant limit progress from breeding. A strong seed dormancy system, shattering mechanisms for seed dispersal, and nonuniform maturation are examples of wild characteristics that must be changed in the domestication process. Seeds need to be stored in water and at 35° F causing difficulty in storing seeds for more than one year. This also limits varietal improvement. Improvements in maturity and height can be made but increased shattering resistance, disease resistance, and yield are more difficult to achieve with the present state of knowledge.

Table 2. Characteristics of five varieties grown at Excelsior in 1979

| Variety | Heading | Harvest | Seed Moisture | Plants/sq ft | Panicles/sq ft |
|---|---|---|---|---|---|
| | July | August | percent | number | number |
| Netum | 16 | 21 | 34 | 1.6 | 7.1 |
| K2 | 24 | 23 | 38 | 1.6 | 7.3 |
| M1 | 25 | 28 | 36 | 1.3 | 7.0 |
| M3 | 25 | 27 | 36 | 1.6 | 7.2 |
| Johnson | 27 | 28 | 39 | 1.4 | 7.0 |
| LSD (5%) | 1 day | 1 day | ns[1] | .2 | ns[1] |

[1]The varieties do not differ for these traits.

Initial breeding efforts have emphasized maturity. Lack of genetic resistance to diseases has inhibited improvement for disease resistance, but continued efforts may result in some improvement. Efforts to improve productivity for yield are limited by testing procedures. Continued research in this area coupled with improvement in maturity, reduced plant height, and increased shattering resistance should result in more productive, stable varieties in the future.

**Table 3. Characteristics of five varieties grown at Grand Rapids in 1979**

| Variety | Heading | Harvest | Seed Moisture | Plants/sq ft | Panicles/sq ft |
|---|---|---|---|---|---|
| | July | Month | percent | number | number |
| Netum | 17 | Aug. 25 | 37.5 | 3.4 | 9.6 |
| K2 | 22 | Aug. 29 | 40.2 | 2.8 | 9.0 |
| M1 | 25 | Sept. 5 | — | 2.3 | 7.4 |
| M3 | 23 | Sept. 5 | — | 3.1 | 9.5 |
| Johnson | 24 | Sept. 5 | — | 2.6 | 8.1 |
| LSD (5%) | 1 day | — | — | .4 | .7 |

**Table 4. Yields of five wild rice varieties, 1978-79**

| | Location and year | | | | | |
|---|---|---|---|---|---|---|
| Variety | Grand Rapids 1978 | Excelsior 1978 | Grand Rapids 1979 | Excelsior 1979 | Clearbrook 1979 | Average[1] |
| | pounds/acre* | | | | | |
| Netum | 1457 | 1055 | 1740 | 1162 | 1326 | 1348 |
| K2 | 1822 | 1485 | 1895 | 1253 | 1614 | 1614 |
| M1 | — | — | 1830 | 1422 | 1351 | 1534 |
| M3 | 1811 | 1828 | 1957 | 1404 | — | 1750 |
| Johnson | 1197 | 1305 | 2072 | 1359 | 1490 | 1485 |
| Average | 1572 | 1418 | 1899 | 1320 | 1445 | — |

[1]The average yields are not significantly different.

*Yields at 40% grain moisture.

# Establishing First Year Stands

E. A. Oelke

**Seed Source and Handling**—Plant new fields with the most shatter resistant varieties available. New growers can obtain seed from seed growers if arrangements are made before harvest in the fall. Some certified seed of new varieties is available. Growers can save their own seed but it should be from weed-free fields. It is advisable to clean seed by air or gravity cleaner before fall seeding or winter storage for spring seeding. It is particularly important to clean out all weed seed, especially waterplantain *(Alisma sp.)*. Seed should be cleaned immediately after harvest before submerging it into water and before the grain dries to less than 28 percent moisture or germination will be reduced severely.

If seed is stored, even for a short time, it should be placed in water to assure later germination. Wild rice for fall seeding usually is placed in livestock tanks filled with water. Seed stored for spring planting can be put into 50-gallon drums perforated with numerous small holes to allow water circulation. Seed also can be placed into plastic mesh bags for storage. The drums or bags are placed in streams below the ice or in water-filled pits 10 feet deep. Mud should not be allowed to cover the seed. Water surrounding the seed should not be allowed to freeze. The seed also can be stored in tanks filled with water kept at 33° to 35° F and the water should be changed every three to four weeks.

**Seedbed Preparation**—If large amounts of vegetation are tilled under in new fields being developed for wild rice, the area should be tilled a year or more before planting. It also may be desirable, particularly on peat soils, to grow small grains such as oats a year or two before planting wild rice. The initial cropping without flooding allows the vegetation to decompose and results in fewer problems with floating peat when the fields are flooded. A rotovator is commonly used to prepare the seedbed. Often a roller or row of tires is attached to the rear of the rotovator to give better flotation on wet soils. Rototilling to a depth of 6 inches is satisfactory. A disk can be used to prepare a seedbed but it is not effective in destroying existing vegetation. A moldboard plow is not satisfactory in peat soil covered with vegetation because the turned-over soil tends to float when fields are flooded. Land-breaking plows cause less floating of soil but they should not be used in shallow peat where underlying clay is brought to the surface. It is difficult to establish wild rice in the clay subsoil. The final seedbed should be devoid of ridges and hollows to assure good drainage.

Seed dormancy prevents germination before three months of cold storage. Germination is determined by placing seeds in a pan of water at room temperature (68° F). The water should be changed every 2 days, and after 21 days high quality seed should have a 70 percent or higher germination rate. Wild rice germinates at 42° F, but optimum temperature is 64° to 70° F (table 5). The viability of dormant seed can be checked by removing the pericarp from above the embryo and placing the scraped seed in a pan of water for germination or by the tetrazolium test.

**Time of Seeding**—Wild rice can be seeded either in the fall or spring. Fall seeding has the advantage of eliminating the need to store wild rice seed over the winter. If seed is not properly stored during the colder months, poor germination can result. In addition, seeding in the fall is desirable because fields generally are dry and ground equipment can be used. However, if the soil is too dry, flooding the fields immediately after fall seeding may be necessary so the seeds won't dry out.

Spring seeding should be done as early as possible and before stored seed begins to sprout. A date of

**Table 5. Germination of wild rice in water at various temperatures**

| Constant temperature | Percent germination | | Alternating temperatures | Percent germination | |
|---|---|---|---|---|---|
| | 1 week | 4 weeks | | 1 week | 4 weeks |
| 42°F | 0 | 2 | 42-68°F[1] | 5 | 67 |
| 46 | 0 | 20 | 42-86 | 16 | 51 |
| 50 | 0 | 54 | 46-72 | 31 | 80 |
| 55 | 8 | 76 | 46-82 | 27 | 65 |
| 59 | 24 | 72 | 50-75 | 35 | 79 |
| 64 | 34 | 84 | 50-79 | 37 | 73 |
| 68 | 52 | 62 | 55-75 | 50 | 77 |
| 72 | 40 | 60 | 55-79 | 53 | 75 |
| 75 | 58 | 66 | 59-72 | 51 | 80 |
| 79 | 50 | 54 | 59-82 | 52 | 69 |
| 82 | 26 | 32 | 64-68 | 38 | 71 |
| 86 | 6 | 6 | 64-86 | 41 | 55 |

[1]Temperature alternated daily; 12 hours at each temperature.

seeding trial at Grand Rapids using the K2 variety indicated that seeding after June 1 was too late to allow the crop to mature.

**Method of Seeding**—Use of a grain drill assures seeding to a uniform depth. Wild rice will not emerge from depths greater than 3 inches. However, the seed may be broadcast over the soil surface using a fertilizer spreader (figure 12) and then incorporated to a depth of 1-2 inches with a disk or harrow. These methods cannot be used in the spring because of wet fields. Spring seeding usually is done over the water with an airplane.

A three-year experiment conducted on mineral soil at the Minnesota Agricultural Experiment Station at Grand Rapids indicated that seeding to a uniform depth gave the best stand (table 6). The simulated drilling method of seeding into 1-inch-deep trenches 12 inches apart produced a higher plant population and yield than the broadcast or water-seeding method.

The seed should not be allowed to dry to less than 28 percent moisture during planting. It is best to drain the water from the seed just before planting and then mix the seed with oats in a ratio of 2 or 3 pounds of oats for each pound of wild rice seed. This allows the seed to flow uniformly through the seeding equipment. Success in seeding depends upon prompt covering of seed with soil or water to maintain viability and reduce losses from birdfeeding.

**Rate of Seeding**—An experiment at the Minnesota Agricultural Experiment Station in Grand Rapids in 1977 indicated that the optimum population was four plants per square foot (figure 13). Higher plant populations resulted in more lodging, particularly for the Johnson variety. Incidence of leaf disease also was more prevalent at higher plant populations.

A seeding rate of 30-45 pounds per acre of good quality seed is needed for a plant population of four plants per square foot. However, the amount of seed needed to

**Table 6. The influence of three planting methods on plant population and yield at Grand Rapids 1973-75**

| Planting method | Plants/sq ft | Yield/acre |
|---|---|---|
| | number | pounds[1] |
| Water seeded | 1.5 | 773 |
| Broadcast onto soil and rotovated | 1.9 | 1438 |
| Seeded into 1 inch deep trenches 12 inches apart | 2.1 | 1676 |
| LSD (5%) | 0.5 | 538 |

[1]40% moisture

Figure 12. Broadcasting the seed onto the soil with a bulk fertilizer spreader. The seed is immediately incorporated into the soil with a disk or harrow.

obtain the optimum plant population varies considerably with seed quality, as shown in table 7. Germination of commercial seed may range from 15 to 95 percent and moisture percentage may vary from 35 to 50 percent. Only 60 percent of the seeds that germinate establish plants when the seed is broadcast over the soil followed by shallow incorporation.

**Table 7. Plant population obtained with six different seeding rates of three nonshattering varieties in 1975 at Grand Rapids**

| Variety | Seeding rate/acre, pounds[1] 5 | 15 | 30 | 45 | 70 | 100 | Germination of each seed lot |
|---|---|---|---|---|---|---|---|
| | ------------- | | plants/sq ft | | | ------------- | percent |
| Johnson | 0.4 | 0.9 | 1.2 | 1.8 | 2.8 | 3.7 | 30 |
| K2 | 1.1 | 2.0 | 3.1 | 4.0 | 5.9 | 8.2 | 65 |
| M1 | 0.8 | 1.3 | 2.0 | 3.0 | 4.5 | 5.8 | 46 |

[1]Weight after winter storage in water and after surface moisture allowed to dry from seeds.

**Plant Populations in Second Year and Older Fields**—Fields planted to both shattering or nonshattering varieties reseed themselves after the first year. Up to 1,000 pounds of seed per acre can fall to the ground before harvest, resulting in a very dense population the second and succeeding years. It is necessary to reduce the plant population for optimum yield. This is done by using an airboat with a series of v-shaped knives spaced 6-8 inches apart on a toolbar attached to the rear of the boat (figure 14). The knives ride on the soil surface and remove rows of plants while the airboat travels approximately 35 miles per hour on the water surface. The plant population in the fields is reduced during the floating leaf stage of growth to two to three plants per square foot. Sometimes it is necessary to thin the fields in two directions.

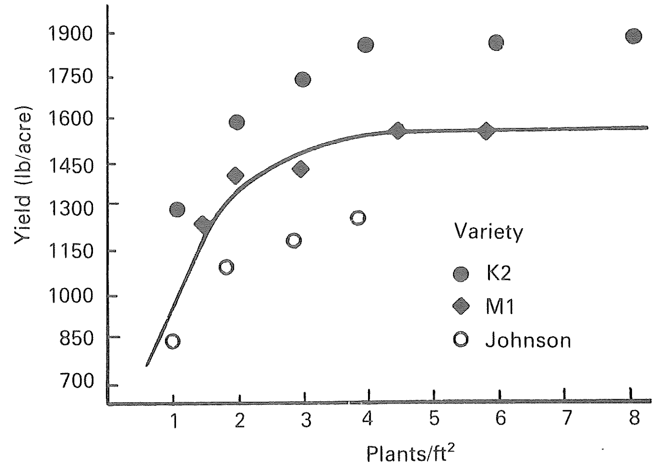



**Figure 13. Relationship of grain yield (40% moisture) and plant density for three varieties grown in Grand Rapids during 1974.**

**Figure 14. The v-shaped knives attached to the airboat are lowered into the water to remove rows of plants while the airboat skims across the field.**

# Soil Fertility

J. Grava

## CHARACTERISTICS OF FLOODED SOILS

Flooding starts biological and chemical reactions that normally do not occur in well-aerated upland soils. As the air in the soil is displaced by water the root zone is transformed from an aerobic (oxygen-rich) to an anaerobic (lacking oxygen) or near-anaerobic environment. Replacing soil air with water and covering the soil with a layer of water results in a drastic decrease in the supply of oxygen in the soil. Within a day or so after submergence, aerobic microorganisms become inactive, adaptive facultative anaerobes are forced to use substances other than oxygen, and true anaerobes become active. An anaerobic condition is created in all of the plow layer of soil except a thin layer that receives a small amount of oxygen from the water.

In the thin aerobic layer, conditions are similar to those in a well-drained soil. Nitrate ($NO_3$) is the common form of inorganic nitrogen in this layer. The aerobic layer of a mineral soil usually is brown, a result of the presence of oxidized forms of iron. Properties of the underlying anaerobic soil are strikingly different. Virtually no oxygen is present in this layer, and the soil is likely to be gray or grayish brown as a result of reduction of the ferric form of iron to the more soluble ferrous form. The stable form of inorganic nitrogen in the anaerobic layer is ammonium ($NH_4$).

The thickness of the aerobic layer is determined by dynamic balance between the rate of oxygen supplied through the water and the oxygen consumption rate of the soil. In mineral soils this layer may be only ¼-½-inch thick. In flooded organic soils there may be no surface oxidized layer since reducing conditions extend all the way to the soil surface.

The disappearance of oxygen from the soil starts a sequence of reactions involving several compounds. These reactions are linked closely to biological changes taking place in the flooded soil, and they require an energy souce. Although there is some overlapping in the reduction of the oxidized compounds in the soil, the process is somewhat sequential, with reduction tending to take place in the following order: oxygen, nitrate, manganese, iron, sulfate, and carbon dioxide. After oxygen has disappeared, nitrate and nitrite N are rapidly reduced to gaseous forms of nitrogen that are unavailable to the crop. Next, manganese and then iron compounds are reduced to the more soluble forms. If reduction becomes intense enough, sulfate is reduced to sulfide, which is extremely toxic to plants.

The intensity of reduction in a flooded soil is commonly measured in terms of the redox potential (Eh). A potential range of 200 to 300 millivolts is considered by some as the dividing line between oxidized and reduced conditions. Redox potentials in several wild rice paddies have ranged from −215 to −315 mV, indicating intensely reduced conditions. The redox potential allows reasonable predictions to be made concerning the behavior of several important nutrients.

Bacterial activity is responsible for the oxygen depletion leading to reduction. This activity is affected greatly by soil temperature, thus the reactions associated with flooding may be at a near standstill at low temperatures in early spring and greatly accelerated as the soils warm up later in the season. Temperature measurements of flooded organic soils near Aitkin have indicated temperatures in the low 40s (° F) during plant emergence in early May. The temperature measured approximately 50° F by mid-May, gradually increased to 65° F by mid-July, and then gradually decreased toward harvest time.

## EFFECTS OF FLOODING ON PLANT NUTRIENTS

Flooding causes marked changes in several chemical systems in the soil that affect the nutrition of wild rice. The pH of most soils tends to change toward the neutral point (pH 7) after flooding, with acid soils increasing and alkaline soils decreasing in pH. Thus the pH as determined on an air-dried sample under laboratory conditions may be different from the soil reaction at the root surfaces of the growing plant.

Flooding the soil affects the behavior of fertilizer nitrogen as well as native soil nitrogen. The unique reactions undergone by nitrogen in flooded soils result in considerable loss of applied nitrogen fertilizer; the utilization of added nitrogen generally is poorer in flooded soils than in well-drained soils.

Microorganisms in the denitrification process convert nitrate and nitrite forms of nitrogen to gaseous forms of nitrogen that are unavailable to plants. Because of reduced conditions in the soil, mineralization of organic nitrogen does not proceed past the ammonium stage. The lack of nitrate in a submerged soil does not appear to affect wild rice adversely, since ammonium forms of nitrogen can be utilized equally well by the plant.

Waterlogging affects phosphate solubility and availability to the plant. Saturation of the soil with water increases the availability of soil phosphorus due to conversion of ferric phosphate to the more soluble ferrous form.

Potassium is affected less by submergence of the soil than are phosphorus and nitrogen. Flooding results in a larger fraction of the potassium ions being displaced from the exchange complex into solution. An increase in the concentration of potassium in soil solution should result in greater availability to the crop, but it also could result in greater leaching loss of potassium, particularly in organic soils.

The solubilities of calcium and magnesium are changed only slightly by flooding but those of iron, manganese, and sulfur greatly increase. The solubility and availability of boron and molybdenum (possibly copper and zinc) should increase slightly in flooded soils.

## NUTRIENT REQUIREMENT AND UPTAKE

The wild rice plant has a relatively high requirement for plant nutrients to produce a pound of dry matter. Of the total nutrients in the plant (table 8), the grain contains 37 percent of the nitrogen, 22 percent of the phosphorus, and 3 percent of the potassium. Nearly 40 percent of the nitrogen, 60 percent of the phosphorus, and 85 percent of the potassium remain in the stems.

Table 8. Plant nutrients in grain, leaves, and stems of a 2,000 pound (dry weight) wild rice crop

| Plant nutrient | Pounds/acre |
|---|---|
| Nitrogen | 105 |
| Phosphorus | 38 |
| Potassium | 260 |
| Calcium | 263 |
| Magnesium | 207 |
| Iron | 2 |
| Manganese | 2 |
| Zinc | 0.5 |
| Aluminum | 0.5 |
| Boron | 0.1 |

The accumulation of nitrogen, phosphorus, and potassium by the wild rice plant in relation to the accumulation of dry matter is illustrated in figure 15. During the vegetative growth phase, wild rice grows rather slowly. At jointing, less than 12 percent of total dry

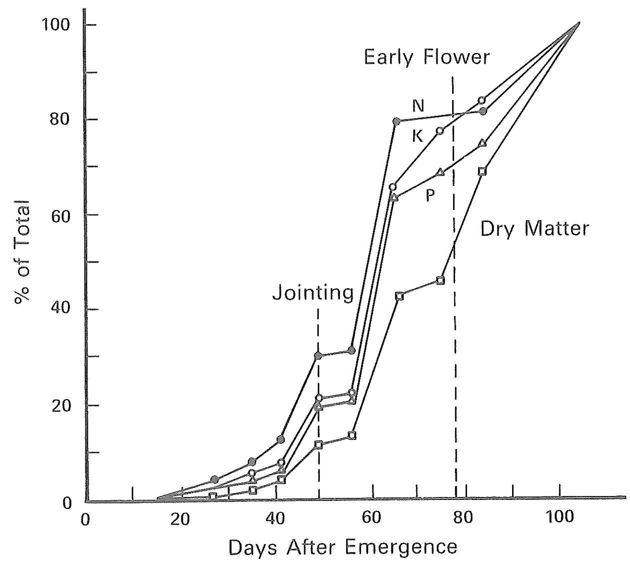



Figure 15. Accumulation of dry matter, nitrogen, phosphorus, and potassium in wild rice during the growing season.

matter is produced. Most growth and dry matter production occurs during the reproductive phase. Thirty percent of the growth occurs over a 10-day period from boot stage to early flower. The remaining 50 percent of dry matter is produced during the last 30 days from mid flowering to maturity. Under favorable conditions, most of the grain is produced during a 15-day period.

Nitrogen uptake by the plant occurs in three distinct steps (figure 15). During the vegetative growth phase, the plant accumulates 30 percent of its total nitrogen. From boot to early flower, 50 percent of total nitrogen is accumulated within a 10-day period. During flowering and grain formation, the remaining 20 percent of nitrogen is taken up. Consequently, the requirement for nitrogen is great during the reproductive phase of growth. The effectiveness of topdress nitrogen application at jointing, observed in the field, is explained partially by the fact that wild rice accumulates 70 percent of its total nitrogen during flowering and grain formation.

The accumulation of phosphorus and potassium by the plant also follows a stepwise pattern. Accumulation of nitrogen, phosphorus, and potassium continues at a relatively rapid rate until maturity.

## SOIL AND TISSUE TESTS

A soil test is the best way to predict how much fertilizer is needed. The best time for collecting soil samples from wild rice fields is after the water has been drained off or during seedbed preparation.

The soil should be sampled to a depth of 6 inches. Approximately 15 cores from each field should be collected and the soil thoroughly mixed in a clean pail; then a sample container should be filled with the mixture. The soils information sheet should be filled out so that reliable recommendations can be given.

Currently, neither liming nor fertilization with micronutrients is expected to be beneficial to wild rice production.

Plant analysis is a diagnostic technique used to determine the nutritional needs of a crop by using the plant itself as an indicator. It involves taking a leaf or some other plant part and determining how much of several essential nutrients it contains. By comparing the results with the amount of each element a normal plant should have, it can be determined whether the sampled plant is getting too much or too little of any nutrient. Table 9 shows the range in concentration of various plant nutrients in wild rice grown in properly fertilized fields.

When sampling wild rice for plant analysis, the second leaf (most recently fully expanded leaf blade) should be collected from 20 plants at the jointing stage. The plant samples should be dried in an oven at 150° to 175° F for 48 hours, or air dried in a well-ventilated room for four days. Several commercial laboratories are providing analytical services to growers.

**Table 9. Concentration of plant nutrients in the dry matter of the second leaf of wild rice at jointing**

| Plant nutrient | Range in concentration |
|---|---|
| | percent |
| Nitrogen | 2.73-3.83 |
| Phosphorus | 0.31-0.63 |
| Potassium | 2.43-4.31 |
| Calcium | 0.26-0.54 |
| Magnesium | 0.11-0.16 |
| | parts/million |
| Manganese | 80-770 |
| Iron | 62-430 |
| Zinc | 7-64 |
| Boron | 5-9 |
| Copper | 1-4 |
| Aluminum | 12-160 |

## FERTILIZATION

The amounts of nitrogen, phosphate, and potassium to apply for wild rice as recommended by the University of Minnesota Soil Testing Laboratory are shown in tables 10, 11, and 12.

A slight deficiency of nitrogen in wild rice is desirable because it results in less lodging and vegetative growth. Plants lacking nitrogen are lighter green in color and shorter than plants receiving sufficient nitrogen, and lower leaves of affected plants have yellow tips and margins. Deficiency symptoms of other plant nutrients have not been observed.

The ammonium form is superior to the nitrate form as a source of nitrogen in wild rice production. The plant uses either form of nitrogen equally well, but it is not possible to maintain the nitrate in a flooded soil. Losses of nitrate through leaching and denitrification account for 20-50 percent, and occasionally as high as 70 percent, of the total applied. In contrast, ammonium properly placed effectively supports the plant as long as the supply lasts.

The commonly used ammonium (as in ammonium phosphate) or ammonium-producing sources (such as urea) are equally effective. Nitrate sources are unsatisfactory for preplant applications and are slightly inferior to ammonium forms when topdressed. Large nitrogen losses occur with nitrates unless taken up rapidly by the plant.

The best response generally is obtained from ammonium nitrogen placed 3-4 inches below the soil surface. This can be achieved by incorporating broadcast fertilizer with a disk or rotovator.

Slow release nitrogen materials, including urea formaldehyde products and various coated materials, have been tested in rice culture. Under ideal conditions these materials have been equal or slightly inferior to conventional fertilizers in grain producing capabilities. In some instances, the release rates were too slow to meet the needs of the growing crop.

For wild rice, all or part of nitrogen (as ammonium phosphate or urea) and all phosphate and potash fertilizer should be applied and incorporated into the soil 3-4 inches deep during seedbed preparation.

Nitrogen topdress applications should be made at jointing when the internodes start to elongate. Urea or ammonium nitrate is a good source of nitrogen for this purpose. Applying phosphorus and potassium into the water in the spring is not very effective and could cause algae problems.

**Table 10. The amount of nitrogen to apply to wild rice fields based on cropping history and soil type**

| Status of field | Amount of nitrogen (N) to apply each year: Mineral soils | Organic soils |
|---|---|---|
| | pounds/acre | |
| 1st year only | 20 | 15 |
| 2nd year and older | 40 | 30 |

**Table 11. The amount of phosphorus to apply to wild rice fields based on soil tests**

| Phosphorus (P) soil test, (pounds/acre) | Amount of phosphate ($P_2O_5$) to apply |
|---|---|
| | pounds/acre |
| 0-15 | 40 |
| 16-30 | 20 |
| over 30 | 0 |

**Table 12. The amount of potassium to apply to wild rice fields based on soil tests**

| Potassium (K) soil test, (pounds/acre) | Amount of potash ($K_2O$) to apply |
|---|---|
| | pounds/acre |
| 0-100 | 60 |
| 101-200 | 40 |
| 201-300 | 20 |
| over 300 | 0 |

## WATER QUALITY

Growers, as well as public control agencies, are interested in the quality of water and each group may have a different viewpoint. Growers are concerned about whether the water is suitable for growing wild rice. Regulatory agencies are concerned about possible detrimental effects on public waters of any water discharged from fields.

Concern about possible detrimental effects of sulfate in the water is based on earlier observations that no large stands of wild rice occur in Minnesota where sulfate concentration in surface water exceeds 10 parts per million. Sulfate at levels commonly found in Minnesota waters does not injure wild rice. Waters in wild rice fields along the Clearwater River range from 22 to 390 parts per million sulfate. Most river and lake waters in other areas contain less than 10 parts per million sulfate. Wild rice has been grown satisfactorily in experiments at sulfate concentrations of up to 250 parts per million.

The growth of wild rice is not affected by two other water characteristics—hardness and pH—although considerable variation is found in the supply and field waters. The Clearwater River water is very hard (300 parts per million $CaCO_3$) and strongly alkaline (pH 8.0). These two properties remain nearly the same in the field water as well. In Aitkin County, the supply water generally is moderately hard (90 parts per million $CaCO_3$) and nearly neutral in reaction (pH 7.0). The water in fields has lost some calcium and magnesium and is relatively soft (22 parts per million $CaCO_3$) and acid (pH 4.2-5.7).

The water in well-fertilized fields may have relatively high concentrations of nitrogen, phosphorus, and potassium with no detrimental effects on the plants.

Among the major nutrient elements, phosphorus has the most potential of exerting a detrimental effect on public waters. Nearly 90 percent of wild rice fields are developed on organic soils. Phosphate retention by peat is low. Organic soils that are fertilized too much can contribute substantial quantities of nutrients to drainage waters, resulting in potential degradation and economic losses of fertilizer. Too much fertilization can be avoided by applying plant nutrients according to recommendations based on soil tests. Incorporate phosphate fertilizer into the soil and avoid topdressing of phosphorus into the water.

Although the potential for loss of plant nutrients from fields appears to be high, actual losses are low. A field is an impoundment. Current thinning methods using airboats do not cause significant soil disturbance. Turbidity and total phosphorus in the water are elevated during thinning but return to normal within an hour. Seepage of field water through dikes does not threaten water quality since relatively small volumes of water are lost, and phosphorus concentration in seepage water is relatively low due to prolonged soil contact.

Annual nutrient losses from fields along the Clearwater River have been estimated to be 1.1 pounds per acre of phosphorus, 5.8 pounds per acre of nitrogen, and 4.2 pounds per acre of potassium.

Field water is released slowly over a period of from one to two weeks. Wild rice field water return flows appear to threaten water quality only where discharges enter relatively small lakes and constitute a significant portion of their critical phosphorus loading. Return flows to large lakes do not contribute a significant percentage of the phosphorus considered to be critical. Flowing waters normally are not as sensitive to nutrient additions as are lakes or reservoirs.

The following management alternatives have been suggested to growers where discharges are suspected of contributing a significant portion of the critical phosphorus loading to lakes: Construct reservoirs for recycling; flood adjacent fallowed fields or low-lying areas; drain fields to areas where phosphorus standards do not apply.

# Water Management

E. A. Oelke

Wild rice will not thrive in unflooded soils. If seeds do germinate in unflooded soils, the seedlings remain small and the plants are yellow. Soils need to be saturated from germination until three to four weeks before harvest for good plant growth but to help control weeds the soil must be covered with 6 inches or more of water for most of the growing season.

Wild rice fields should be flooded as early as possible in the spring. A minimum depth of 6 inches should be maintained on the shallow part of the field and a maximum of 14 inches on the deep part. Water deeper than 14 inches causes lodging. Best weed control, adequate plant populations, no delay in maturity, and good yield were obtained with 13 inches of water in a three-year water depth trial conducted at Grand Rapids (figures 16, 17, 18). Final plant height and tillers per plant were intermediate with a continuous 13-inch depth of water (figures 19, 20). The Johnson, K2, and M1 varieties responded the same to water depth.

The critical period for maintaining at least a 6-inch water depth is during the first 8 to 10 weeks of the season when weeds are more readily controlled by water. Fluctuating the water depth during this time is not desirable. Water should be added daily or as needed to compensate for percolation, evaporation, and transpiration. A continuous flow is not necessary.

The water level in the fields can be allowed to decrease slowly during flowering so that very little, if any, water needs to be drained from the fields two to three weeks before harvest. Care must be taken in some fields, particularly during hot weather and on mineral soils, so they won't dry out before the plants are mature. The soils should remain saturated during most of the grain-filling period.

One of the benefits of wild rice fields to a watershed area is their water-holding capabilities in the spring. Wild rice fields are filled in the spring with runoff water that would otherwise cause flooding by some rivers.

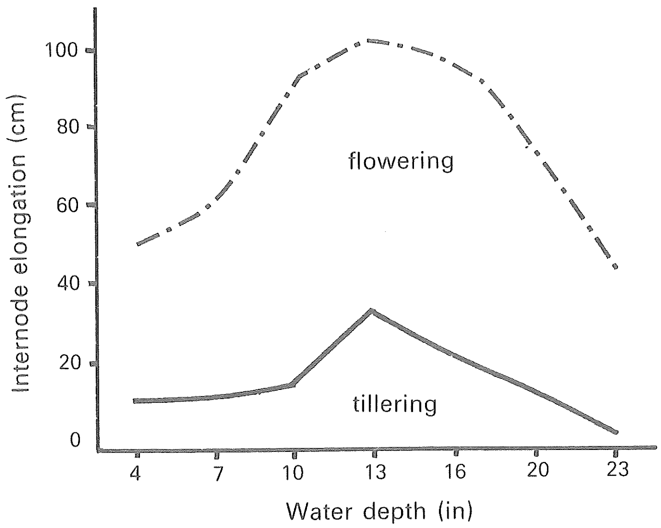



Figure 17. Maturity of wild rice, as indicated by internode elongation of main stem, and water depth relationship.

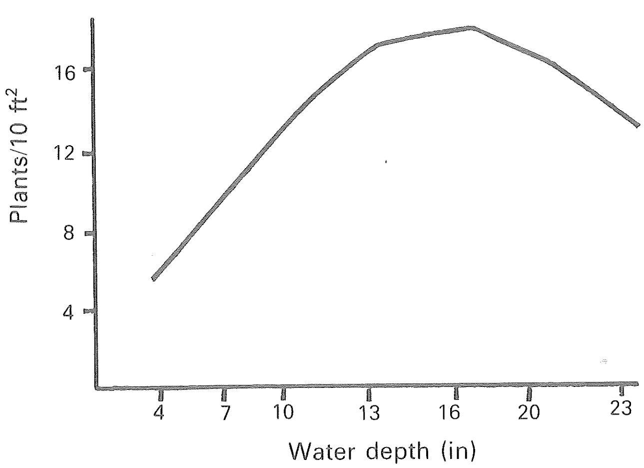



Figure 16. Plant population of Johnson variety wild rice as it varies with water depth.

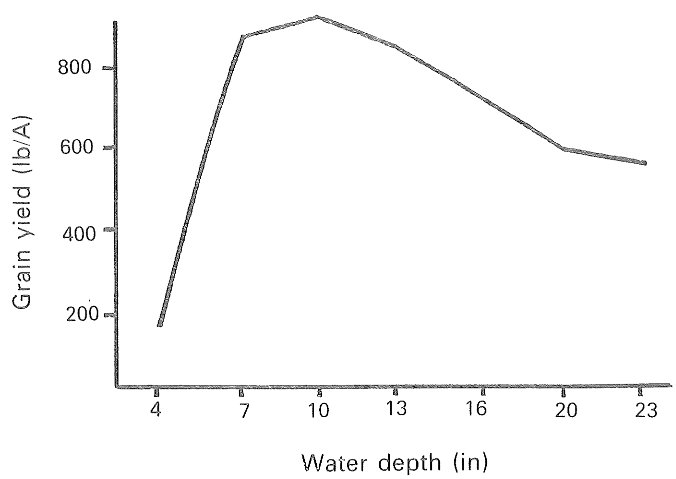



Figure 18. Grain yield at 40% moisture as influenced by water depth.

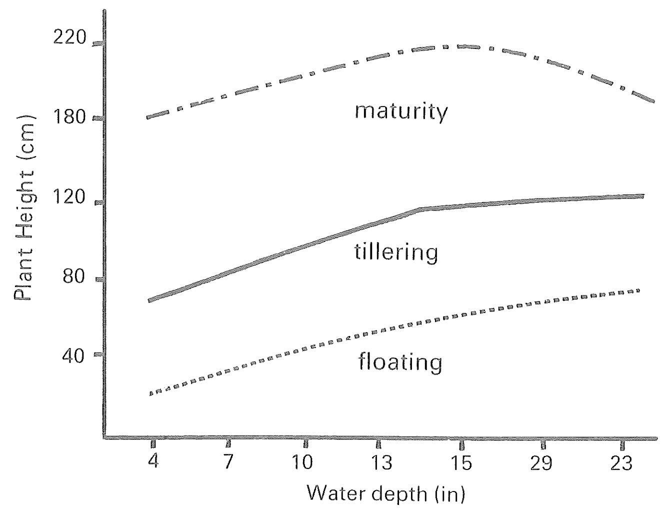



**Figure 19. Plant height of wild rice as it varied with water depth.**

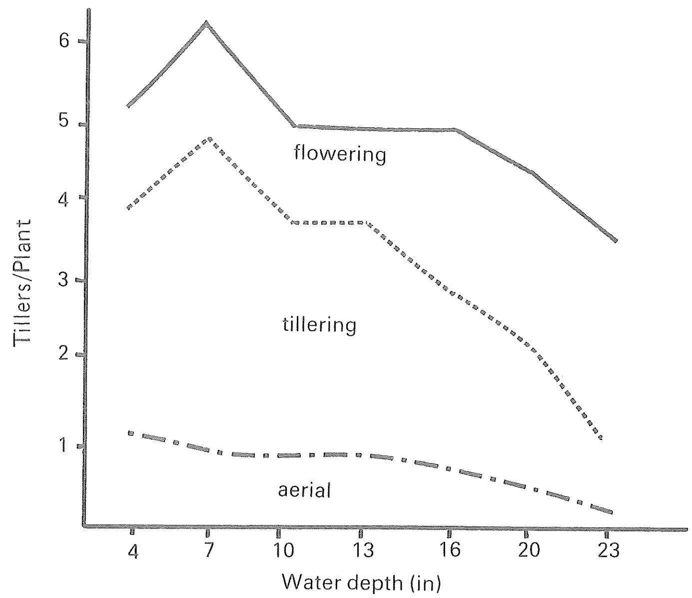



**Figure 20. The influence of water depth on tillering of wild rice.**

## Weeds

**E. A. Oelke**

The weeds in wild rice fields are the common water weeds of Minnesota. Broadleaf weeds are more serious than grass weeds. A description of the most common weeds found in wild rice fields is given below.

### COMMON WATERPLANTAIN

Common waterplantain (*Alisma trivale* Pursh) (colorplate 1) is an emersed, erect, aquatic perennial that reproduces by seed and rootstocks. It may grow 48 inches tall and has elliptical leaf blades 10 inches long and 6 inches wide. The leaves have long petioles. Seeds are round, reddish brown, ⅛-inch long, and remain viable in the soil for many years. Leaves of plants from rootstocks emerge from the water before wild rice to form a dense leaf canopy that shades wild rice. This kills some plants and reduces tillering of wild rice. Seeds germinate during much of the growing season. Seedling waterplantain does not injure wild rice; however, it will produce seed and develop rootstocks. Common waterplantain is more severe in shallow (1-6 inches) water, but will grow in water up to 30 inches deep.

### CATTAIL

Cattails (*Typha latifolia* L.) are perennials that reproduce by rootstocks and by minute airborne seeds that germinate readily in mud and shallow, clear water. Established plants have an extensive rhizome system and erect stems with long, narrow leaves. Flowers are in a long and very dense cylindrical spike terminating the stem. Plants are 4-8 feet tall and usually grow in colonies. Seeds remain viable in soil for more than five years. Cattails grow in shallow water and areas of the field with poor drainage. Fall tillage helps control them. Cattails on edges of dikes are overwintering sites for the wild rice stem borer.

### BURREED

Burreed (*Sparganium eurycarpum* Engelm) is a perennial that reproduces by seeds and spreads by rhizomes. Plants are 3-4 feet tall and erect with a sparingly-branched, leafy stem. Leaves are narrow and upright. Inflorescence is forked with seed heads, bur-like before seeds fall away (colorplate 2). Seeds are pyramidal in shape.

Plants occur in shallow water and can spread rapidly. They are not controlled with ¼ pound per acre of 2,4-D (amine) or rotovating in the fall. Fall plowing helps control, but will not eliminate them.

### COMMON ARROWHEAD

Common arrowhead (*Sagittaria latifolia* Willd) is a perennial that reproduces by seeds, rhizomes, and tubers. Common arrowhead is a rooted aquatic with arrow-shaped leaves. Lower leaves are all basal with petioles as long as the water is deep. Plants are 1-2 feet tall with white flowers. Seeds are flat, ⅛-inch wide with marginal wings, and are clustered into a spherical head. It occurs in shallow water but is not prevalent enough to cause serious problems.

## CURSED CROWFOOT

Cursed crowfoot (*Ranunculus sceleratus* L.) is an annual or short-lived perennial, mostly emersed, with pale yellow flowers on water surface. Lower leaves have long petioles. Seed heads are cylindrical. It usually occurs in shallow parts of field where wild rice stands are poor.

## WATER STARWORT

Water starwort (*Callitriche heterophylla* Pursh) is an aquatic herb with narrow and opposite leaves on a stem below the water. Leaves at top of stem float and are arranged in rosette. Plant reproduces by seeds and can be found in all parts of field where wild rice stands are poor. It can reduce wild rice stands.

of 43 percent with one plant per square foot that developed from rootstocks (table 13). Competition of common waterplantain that develops from rootstocks is greatest after eight weeks of growth, so it is important to control this weed before then.

Weed control should consist of a combination of cultural and chemical methods. Planting weed-free seed is the first step. Seed should be saved from a weed-free field or cleaned before planting. Rotovating in the fall after harvest effectively controls cattails and helps control waterplantain. Plowing in the fall buries common waterplantain rootstocks, thereby reducing it the following year. A water depth of 6-10 inches in the shallow end of a field helps control weeds. It may be

**Table 13. Effect of waterplantain plant density on yield and yield components of wild rice**

| | Wild rice | | | | | |
|---|---|---|---|---|---|---|
| Waterplantain/sq ft | Plants/ sq ft | Panicles/ plant | Seeds/ panicle | Wt/100 seeds | Yield/acre wet[1] | Processed grain |
| number | number | | | grams | pounds | |
| | 3.42 | 1.97 | 54.2 | 2.13 | 1241 | 447 |
| 5 seedlings[2] | 3.43 | 1.77 | 57.1 | 1.93 | 1106 | 407 |
| 10 seedlings | 3.28 | 1.98 | 60.1 | 2.02 | 1180 | 432 |
| 20 seedlings | 3.51 | 1.98 | 68.3 | 1.90 | 1382 | 510 |
| ½ rootstock[3] | 3.24 | 1.52 | 62.5 | 1.95 | 1966 | 347 |
| 1 rootstock | 3.48 | 1.22 | 48.6 | 1.98 | 661 | 237 |
| 2 rootstock | 2.90 | 1.20 | 35.4 | 1.81 | 517 | 184 |
| 4 rootstock | 2.36 | .80 | 24.2 | 1.68 | 145 | 42 |
| LSD (5%) | .66 | .38 | 13.2 | .20 | 202 | 74 |

[1]As harvested wet weight.
[2]Waterplantain developed from seeds.
[3]Waterplantain developed from rootstocks.

## SMALL PONDWEED

Small pondweed (*Potamogeton pusillus* Fern.) is an aquatic perennial that reproduces by seeds and underground buds. Its stems are slender with numerous branches toward the top. Leaves are all submersed, narrow, and with three veins. Flowers in elongated spikes are borne on axillary stalks. Whorls of egg-shaped, beaked seed (achenes) develop in spikes.

Small pondweed can be found in shallow areas of a field where wild rice stands are poor. Often it can be found in interior drainage ditches.

Other weeds found in wild rice fields are water parsnip (*Sium suave* Walt.), nodding beggarsticks (*Bidens cernua* L.), marsh cress [*Rorippa palustris* var. glabrata (Lunell); Vict.], barnyardgrass (*Echinochloa crusgalli* L.), spikerush (*Eleocharis* spp.), duckweed (*Lemna minor* L.), chara (*Chara* spp.), naiad (*Najas* spp.), American sloughgrass [*Beckmannia syzigachne* (Steud.) Fern.], and reed-meadow grass (*Glyceria grandis* S. Wats.).

Serious losses can result from weeds in wild rice. The most troublesome weed is common waterplantain; experiments conducted showed an average yield loss

necessary to fallow a field for a year to help control weeds. During this year, however, the field should be flooded in the spring to insure weed growth and after six weeks the field should be allowed to dry so it can be tilled.

2,4-D (amine) at ¼ pound per acre active ingredient is the only herbicide recommended for weed control in wild rice. It should be applied when wild rice is in the tillering stage of growth. Considerable injury to wild rice can result from later applications. Overlaps should be avoided since ½ pound per acre can injure wild rice. Common waterplantain developed from rootstocks will be in the flowering stage when wild rice is in the tillering stage of growth. 2,4-D (amine) at ¼ pound acre does not give complete control but it helps reduce next year's infestation. Spot spraying areas of dense common waterplantain infestations rather than overall spraying is recommended.

Algae can reduce the plant population in areas of fields (colorplate 3) by forming a mat on the water surface before wild rice emerges. Copper sulfate at 15 pounds per acre helps control algae. Retreatment is often necessary for complete control. County agents or extension specialists should be contacted for up-to-date herbicide recommendations.

# Insects and Other Animals

D. M. Noetzel

## WILD RICE WORM

Nearly everyone associated with wild rice is familiar with the larval stage of the wild rice worm [*Apamea apamiformis* (Guenee)]. Both harvesters and processors find the crawling larvae in harvested wild rice. Adult moths begin to appear in late June and early July when wild rice begins to flower. They mostly feed on milkweed blooms after emergence, which continues through August.

The female moth lays from 2 to more than 150 pearly white eggs per wild rice floret (colorplate 4). The eggs are inserted past the stigma, which extrudes between the lemma and palea (hulls) of the floret. Egg laying is continuous over four to six weeks so that larval growth stages from early instars to nearly fully developed larvae are present. The early larval stages feed within the hulls and then eat their way through the hulls either before or shortly after the first molt. The infested florets do not form seeds. The larvae then spin a webbing that permits them to be carried by the wind to other plants. This is called ballooning.

After larvae become established in the panicle, they feed mostly on the wild rice kernels but also on male florets. During the feeding process, they create a webbing that is coated with white excrement.

There may be as many as eight larval stages (colorplate 5). Many larvae reaching the seventh stage show a strong tendency to migrate and bore into either wild rice stems or stems of other plants bordering the fields. The winter is passed in the seventh stage and the final larval molt occurs in the spring. Pupation takes place in early June and lasts for approximately three weeks.

Wild rice worm control has been successful with several insecticides; however, only malathion at 1 pound of active ingredient per acre is labeled. Malathion should be applied 14 to 21 days after eggs become visible in the hulls. One larva per plant will reduce yields by 11 percent. Table 14 provides guidelines on when to treat for wild rice worm, however, processors want to reduce wild worm numbers to near zero because processing plants are food processors.

**Table 14. Calculated losses in dollars per acre from wild rice worms as based on expected yields, numbers of larvae per 100 panicles and a selling price of $1.25 per pound of unprocessed grain**

| Worms/ | Expected yield in pounds/acre | | | | | | |
|---|---|---|---|---|---|---|---|
| panicle | 100 | 200 | 300 | 400 | 600 | 800 | 1000 |
| number | dollars | | | | | | |
| 10 | $ 1.36 | 2.72 | 4.08 | 5.44 | 8.15 | 10.87 | 13.59 |
| 15 | 2.04 | 4.08 | 6.11 | 8.15 | 12.23 | 16.31 | 20.38 |
| 20 | 2.72 | 5.44 | 8.15 | 10.87 | 16.31 | 21.74 | 27.18 |
| 30 | 4.08 | 8.15 | 12.23 | 16.31 | 24.46 | 32.61 | 40.76 |
| 40 | 5.44 | 10.87 | 16.31 | 21.74 | 32.61 | 43.48 | 54.35 |
| 60 | 8.15 | 16.31 | 24.46 | 32.61 | 48.92 | 65.22 | 81.53 |
| 80 | 10.87 | 21.74 | 32.61 | 43.48 | 65.22 | 86.96 | 108.70 |
| 100 | 13.59 | 27.18 | 40.77 | 54.35 | 81.53 | 108.70 | 135.88 |

## MIDGE

A variety of midges in the families Chironomidae and Dixidae use the flooded fields for larval development. One of the Dixid midges, *Cricotopus* spp. has caused severe injury to first year fields. The *Cricotopus* adult is a small, delicate, dusky, mosquito-like fly. It lacks scales on its wings and does not have functional mouthparts. It is so inconspicuous that most growers will not see it. Its eggs are laid in gelatinous masses in moist soil and hatch when the field is flooded.

The larvae spin a delicate but tough silken webbing attached to the developing wild rice plant and hide within it. The webbing can become covered with mud. Larval feeding consists of both scraping up algae and abrading the leaf margins The leaves often curl and cannot emerge from the water. The presence of midge can be observed by the frayed leaf edges, curling of leaves, and the mud-covered webbing. Algae growth is also associated with fields showing high midge numbers.

More severe effects from midge activity have been noted during warmer than normal springs. Fields with shallow water suffer more injury than when flood water is deeper because of the earlier warm temperatures in shallow fields. Within a field, however, more damage occurs in wheel tracks and borrow pits—probably because the plants take longer to emerge from the deeper water, thus allowing more time for midge damage.

Midge control with malathion often is necessary in first year fields where stand is critical. Second-year and older fields often have enormous numbers of midge larvae, but plant population is high and control usually is not necessary.

## RICE STALK BORER

Surveys of rice stalk borers (*Chila plejadellus* Zincken) were taken in the middle '70s. It was found that in some fields 90 percent of the stems were infested. Occasionally, up to 15 larvae per stem were observed just before harvest. The insect overwinters as a larva primarily in rice stems, cattails, and pigweed.

Light tan-colored adults can be collected in light traps between the middle of June and early August. Egg laying begins toward the end of June. The circular, flat, cream-colored eggs are laid in overlapping rows on floating rice leaves. Eggs hatch in approximately one week with the larvae initially feeding on the leaf and leaf sheath (colorplate 6). Later they bore into the main stem to complete their development. Visible damage such as white panicles, dead heart, and stem breakage showed no correlations with stalk borer infestation levels and yield was not affected. However, there may be more poorly filled grains in borer infested plants.

There appears to be little if any economic injury from stalk borer. No attempts have been made to obtain approval for use of insecticides. However, diazinon, carbaryl, and chlordimeform all gave good to excellent control. *Bacillus thuringiensis,* difluroenzuson, and malathion were relatively ineffective.

Present control is obtained by activity of a braconid wasp, *Chelonus knabi* Vier. It parasitizes the eggs, infesting from 30 to 80 percent of the overwintering larvae. In addition, weed-free fields and clean dikes reduce winter sites for the larvae.

## RICE WATER WEEVIL

Two species (*Lissorhoptrus oryzophilus* Kuschel and *L. buchanani* Kuschel) of these snout beetles are found in wild rice. They overwinter as adult weevils along the field ditch bank and feed on bluegrass before moving to wild rice late in May. On wild rice plants they chew elongated but narrow holes between the leaf veins. The beetle crawls down to the roots where egg laying and larval development take place. Larvae are abundant in the wild rice roots in July and August, but no economic damage has been demonstrated in Minnesota. Pupation and adult emergence also occur in August.

## RICE LEAFMINER

Two kinds of tiny leafmining flies [*Hydrellia ischiaca* Loew and *H. girseola* (Fallen)] can be found in wild rice in Minnesota. Each lays its eggs on the floating or erect leaf of the plant. The maggot burrows into the leaf consuming the mesophyll or center of the leaf. Leafminers have been a problem in small research boxes but have not been economically important in fields. Malathion does not provide control.

## RICE STEM MAGGOT

Occasionally, plants will be observed that have the male floral parts and sometimes the entire panicle broken over. If leaf perforations exist that coincide with the position of the damaged panicle when it was in the boot, it is rice stem maggot [*Eribolus longulus* (Loew)] injury. The fly itself is delicate, yellowish black, and lays its eggs inside the rolled leaf sheath. When the egg hatches, the tiny larva burrows through the rolled leaves into the developing head. The head will sometimes stay attached to the sheath, or it may break off. Rarely will such damage reach the 1 percent level.

## CRAYFISH

Stand reduction in wild rice has been observed due to the activities of the crayfish species *Orconectes virilis* (Hagen). It is probable that they are carried into wild rice fields with flood water. Once established they maintain and increase their numbers within the field. *O. virilis* is an excellent "chimney builder," drilling a hole in the moist field soil and throwing mud up around it. The crayfish is capable of both survival and reproduction in these burrows between periods of field flooding.

Crayfish injury to wild rice is due primarily to eating the seedling plants. Burrowing damage to dikes or other structures has not been observed. The amount of damage from an industry standpoint has been important in the central wild rice producing areas. To the industry as a whole, however, crayfish are not a major problem.

## BLACKBIRDS

Blackbirds are one of the major pest problems in wild rice production. Ditch banks containing emergent vegetation provide nesting sites adjacent to the wild rice fields. Flooding greatly aids establishment of such nests. The blackbird population in the wild rice growing areas is enormous.

Blackbird depredation on wild rice begins when the first kernels are in the milk stage. It is not known whether these are resident or migrant birds. At this stage, the bird does not consume the entire seed. Rather, it squeezes the hulls and forces the soft kernel out through the split between the hulls. As in other crops, the birds appear to display both long and short term habituation to feeding areas. To be effective, control procedures should be started at the first appearance of black birds.

Virtually every method of bird management has been attempted by wild rice producers. Shooting, use of carbon dioxide "guns," Av-Alarm records, and continual over-flight with aircraft have been tried or are in use now. Continued concern by growers probably indicates unsatisfactory control with all of these methods.

The chemical, methiocarb, has been investigated for its effectiveness as a bird repellent but is not yet cleared for use. The chemical causes illness and induces conditioned aversion in blackbirds. Wild rice seeds that have the chemical on them are strongly aversive. Similar uniform applications of methiocarb to the crop under field conditions is rather variable however. Hence, bird repellency often is inconsistent.

### WATER BIRDS

Wild rice fields serve as resting, foraging, nesting, and brood rearing sites for both migratory and resident water birds.

At least four species of ducks—mallards, blue-wing teal, green-wing teal, and pintail—use the fields during nesting season. Data suggest that a 20-acre wild rice field often supports one to two nesting pairs of ducks. Thus waterfowl production in wild rice fields compares favorably with that in potholes, making them a prime duck-producing area.

More than 35 species of shorebirds and wading birds have been observed using wild rice fields. Many are resident birds that use the flooded fields for foraging areas; several species also nest on the dikes.

Waterfowl damage to early season wild rice is observed occasionally. However, the damage rarely is of economic significance and growers look with considerable favor on the waterfowl-wild rice relationship.

### MAMMALS

Raccoon, mink, and skunk forage for food on dikes and in ditches. Both deer and moose have been seen in the fields. Large animal activity occasionally damages the crop, but seldom is it economically important. Muskrats can be observed during the summer, but drainage of the fields for wild rice harvest renders them unsuitable for permanent muskrat residence. Thus, muskrats do not pose a risk for the dikes.

## Diseases

**J. A. Percich**

Diseases of wild rice usually are not destructive in natural stands, but in field grown wild rice they can be devastating. Severe epidemics of brown spot were common during the early years of commercial production, completely destroying some fields. Although wild rice is not closely related to rice, it shares common diseases that are caused by the same pathogens. The following pathogens have been demonstrated to be present in wild rice.

### BROWN SPOT

This is the most serious disease affecting field grown wild rice and was previously called *Helminthosporium* brown spot.

The disease is caused by *Bipolaris oryzae* Luttrell (*Helminthosporium oryzae* B. de Haam) and *B. sorokiniana* Luttrell (*H. sativum* P.K. and B.). These fungi may cause similar symptoms and both can be found on infected plants; therefore, these two fungi presently are considered to cause the same disease.

Both fungi can survive on many wild and domestic grasses and on wild rice stubble, and fungi, *B. oryzae* has been found on seed. The infective fungal spores (conidia) are produced in spring and are windborne.

All varieties of wild rice at all stages of growth are susceptible to the disease. The disease often is most severe when day temperatures are 77° to 95° F and night temperatures are 68° F or warmer. Relative humidity of more than 89 percent and the presence of free water on leaf surfaces for 11 to 16 hours also favor infection.

Symptoms: All parts of a plant, are susceptible. Leaf spots are oval, approximately the size and shape of sesame seeds (colorplate 7). They are uniform and evenly distributed over the leaf surface. Spots are brown, often with yellow margins. As the disease progresses individual spots may grow together forming large brown diseased areas covering the leaves, leaf sheaths, and panicles. Severe infection can result in weakened and broken stems, infected florets, and reduced quantity and quality of seed production. Yield losses may vary from slight to 100 percent.

Control:

1. Sanitation is an essential part of a control program. Initial inoculum can be reduced through soil incorporation of crop residue, seeding clean seed in new fields, use of brown spot resistant rotation crops, fallow, and the use of nonhost plants on dikes.
2. Chemical control may be necessary. The protectant

fungicide Dithane M-45 at 2 pounds per acre of the powdered material, applied four times at 7 to 10 day intervals during flowering and grain filling, is used. Dithane M-45 is approved for use on wild rice in Minnesota only.

3. Recommended applications of fertilizer reduce severity of the disease.

### STEM ROT

This disease is the second most prevalent one found in field grown wild rice.

Cause: Two different fungi, a *Sclerotium* sp. and *Helminthosporium sigmoidium* Cav., may cause this disease. Both pathogens produce dark structures called sclerotia in the culms, leaf sheaths, and stems (colorplate 8). The sclerotia survive in infected plant debris or float in the water and are deposited on the soil surface during paddy drainage. Sclerotia germinate in the spring and produce infective spores (conidia) that are wind-borne, or the sclerotia themselves may float to plants and infect at the water level.

Symptoms: Small, oval, purplish lesions initially develop on stems or floating leaves at the water level. Later in the season as the fields are drained the infected plant stems become necrotic, dry, and brittle. This may cause lodging. The effect of stem rot infection on yield in nonlodged plants is not known. However, in almost all cases, lodged plants show signs of stem rot infection.

Control:

1. Plant residue should be removed or tilled into the soil.
2. Plant only clean seed.
3. Use a nonsusceptible rotation crop to reduce survival of overwintering sclerotia.
4. No effective chemical control is available.

### STEM SMUT

This disease has been reported to cause economically serious yield reductions in managed natural stands in Canada, but it has not been a serious problem in cultivated fields.

Cause: The disease is caused by the fungus *Entyloma lineatum* (Cke.) Davis.

Symptoms: On mature plants, glossy black lesions occur on the heads, culms, and stems. The lesions on the head can elongate and ultimately girdle the stem, thus reducing seed production significantly. Spores are produced under the surface of the lesions and are released to the air for dispersal.

### ERGOT

This disease is rare in Minnesota's cultivated fields but can be a serious problem in natural stands.

Cause: *Claviceps zizaniae* (Fyles) is the causal fungus. Overwintering structures called sclerotia drop off infected wild rice plants and can survive for years. During flowering the sclerotia germinate and produce wind-borne ascospores that infect the flowers. After infection, a sweet, sticky liquid that attracts insects is produced. Insects carry the spores to other nearby plants. Hard, dark, sclerotia are formed in place of the grain.

Symptoms: Large sclerotia are present in place of the kernels. They are pink to light brown but eventually turn black. Ergot sclerotia may be harmful if consumed, but since they are larger than healthy kernels they can be separated easily from the grain.

Control: No control except by removing ergot bodies from grain before consuming.

### BACTERIAL LEAF STREAK

This disease is found in most natural stands and cultivated fields, but yield losses have not been determined.

Cause: The causal organism is the bacterium, *Pseudomonas syringae.*

Symptoms: Lesions on the leaves are characterized by long, narrow, dark green, water-soaked streaks that expand lengthwise along the leaf blade (colorplate 9). Water-soaked tissues eventually turn brown or black and may be covered with a glistening crust of bacterial exudate.

Control: None.

## Time of Harvest

E. A. Oelke

Harvesting of shattering types of wild rice should begin when some of the seeds are in the hard dough stage before they fall from the plant. Harvesting can start in early July for the early types from Canada and in late July for the types from Minnesota lakes.

Most of the cultivated acres of wild rice are planted to nonshattering types. The kernels on individual panicles ripen unevenly and seed shattering occurs before all of the kernels are ripe. This uneven ripening and shattering necessitates harvesting nonshattering wild rice before all the kernels are mature.

Maximum yield of processed grain occurs when 35-40 percent of the kernels are dark rather than green in color. Moisture percent of the grain and percent recovery also will be approximately 35-40 percent at this time. This generally occurs when some of the seeds have fallen from the main stem but very few from the tillers of the same plant. A grower may not always be able to wait for the potential maximum yield. Harvesting early may be necessary if high winds, storms, or frost are imminent. Some fields may have to be harvested early if enough combines are not available to harvest all the acreage in a short time. Harvesting of nonshattering varieties starts in mid-August.

## Harvesting

C. E. Schertz

### SHATTERING TYPES

Fields that have been seeded with a shattering type wild rice are harvested with a multiple-pass-harvest procedure. The harvester has finger-like troughs mounted on a special chassis (figure 21). The troughs are spaced to permit the stems of wild rice to pass between them as the machine moves forward. The fixed bat reel over the troughs knocks ripe kernels from the plant. As the harvester moves forward, the stems bend and pass beneath the chassis. The immature kernels remain on the plants and are gathered when the harvester makes another pass in two to three days. The harvester is driven in the same path on succeeding harvests so the least number of plants are destroyed. Unloading is accomplished by tilting the troughs to the rear. Instead of the multiple-pass harvester, a combine may be used for the final clean-up operations.

### NONSHATTERING VARIETIES

Shatter resistance and uniformity of maturing have improved sufficiently so that direct harvest by cutter for combines is practiced.

Field conditions impose severe machine limitations that normally are not found in the harvest operations of other crops. High capacity combines are needed to harvest wild rice directly because the plants are still green. Ground conditions are extremely wet even though fields are drained two to three weeks before harvest. Wild rice is a poor sod former; thus the stubble provides little support for the combines. In addition, much wild rice is grown on organic soils that have lost most of their fiber strength from tillage.

The self-propelled rice combine was first used to harvest wild rice in 1967. Growers have made innovative modifications to various components such as reels, grain divide points, draper systems, and track-type support systems (figure 22). A description of these modifications follows.

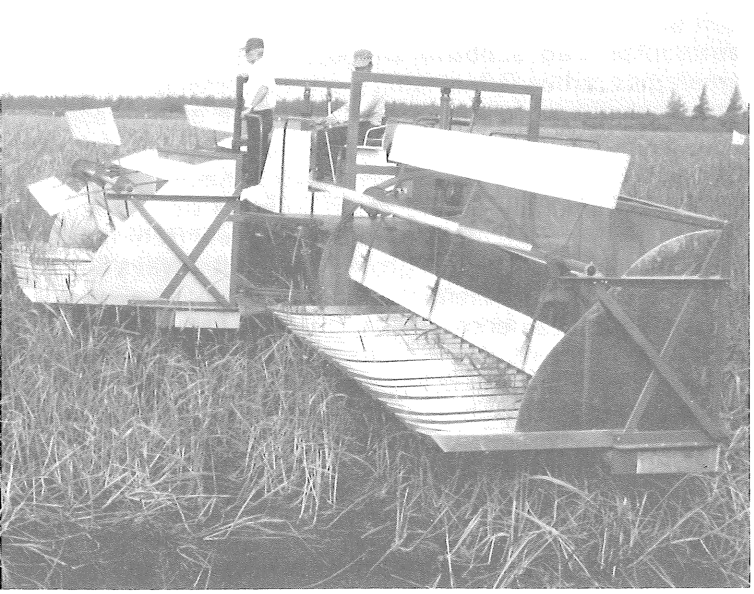


Figure 21. Multiple-pass harvester used to harvest shattering types of wild rice. The machine does not cut off the plants but only dislodges the mature kernels.

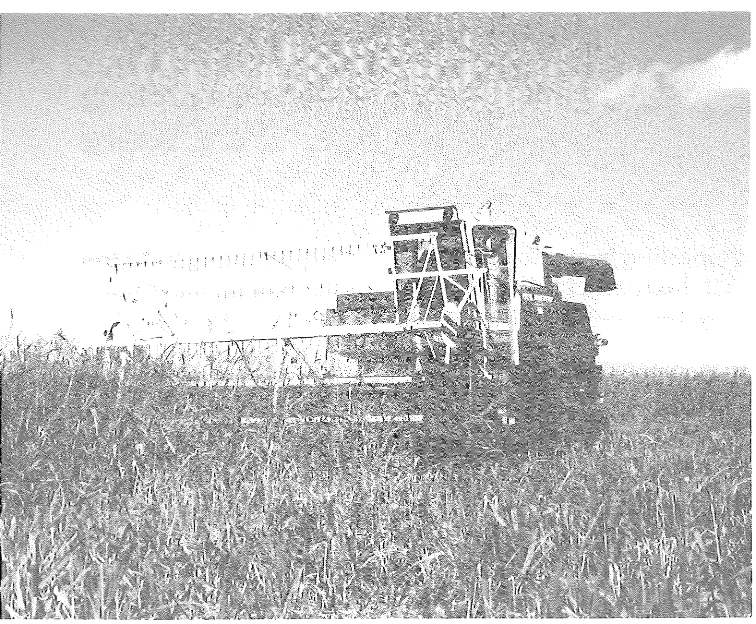


Figure 22. Harvesting wild rice with a modified rice combine.

### LARGE DIAMETER REEL

A large diameter reel is needed to permit the reel bats to enter the crop without pushing the crop forward. Reels 7 feet in diameter are used, though even larger diameters are preferred. The pickup type reel, where the bats remain parallel to the original position as they rotate, is considered necessary to reduce shattering.

### DRAPER EXTENSION

Because of the height of wild rice plants, it is advisable to use a header equipped with a draper extension between the sickle and the crossauger. This provides a space for the plants to fall before entering the crossauger as well as a "live" surface to assist in moving plant material to the crossauger chamber. This helps provide uniform feeding of the combine and fewer lost stems in the front of the combine. Draper extensions are standard on some combines.

### CYLINDER AND CONCAVE

Most combines used in wild rice harvest have a spike-tooth cylinder and concave. Spike-tooth cylinders are especially effective in processing heavy clumps of crop material. Rasp-bar cylinders are especially effective in separating a large percentage of grain through the concave rather than passing it to the walkers for separation. Rasp-bar cylinders leave straw in larger pieces that make it easier to separate straw and grain on the walkers and sieves. Tests show that the rasp-bar system can accomplish threshing without increasing discharge losses compared to the spike-tooth combines in wild rice.

### GRAIN DIVIDE POINT

Most combine grain heads do not have an adequate divide point to handle a wild rice crop without modification. To avoid having stems hairpin and cause an accumulation of straw on the end of the header, larger and different divide points are added. If the crop is standing adequately, a large, pointed, harpoon-like divider works satisfactorily. If the crop is lodged excessively, a bow type of divider is used to depress the crop at the end of the sickle instead of trying to pull it apart.

### SUPPORT SYSTEMS

An extensive support system is necessary because extremely soft soil conditions are encountered at harvest time. Combine support systems range from conventional half-tracks and guide wheels (figure 23) to full-track systems with 45-inch pads bolted to each track shoe (figure 24). Early draining is undesirable because it could reduce yields and allow weed growth; however, closely spaced interior ditches and shaping of fields are effective in reducing the need for full-track systems. Half-track systems are standard attachments for most combines. The addition of planking to reduce ground support pressure is not difficult.

The conversion to a full-track system is a major undertaking. In this system, the rear of the combine is carried

Figure 23. Combine with a modified half track for wild rice harvesting.

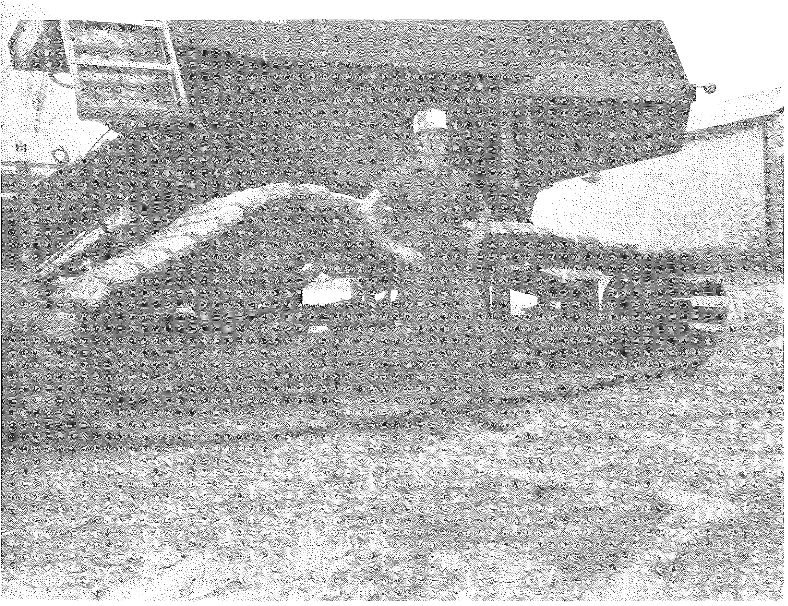


Figure 24. Combine with a full track system for wild rice harvesting.

on a walking beam instead of guide wheels. The walking beam, in turn, is supported on the channel frames of the two tracks. The original combine steering system is not adequate with a full-track system because there are no guide wheels and the brakes designed for the wheel unit are not capable of satisfactorily turning a full-track system. Braking of one axle of a differential speeds up the other side putting additional strain on all drive components.

For most conversions to full-track, the differential spider gears of the combine are welded solid and steering clutches are installed in both the left and right drive shafts. These have been installed so that the conventional steering of the combine controls the clutches and the conventional brakes of the combine control the brakes. Installation of these steering clutches requires widening the tread, but allows use of wider pads on the tracks.

The preferred situation is to have access to a combination of full-track and half-track machines. This permits use of the half-track to open fields and harvest on firmer areas while having the full-track's capability to harvest where half-tracks are unable to operate.

## COMBINE ADJUSTMENTS AND OPERATION

The height of the reel should be adjusted so it does not go into the crop any more than necessary to sweep the crop back onto the draper extension. Excessive insertion of the reel bats into the crop will cause hairpinning of the rice straw over the reel bats, increase the opportunity for the tall heads to be contacted by the central structural members of the reel, and increase the chances for forward push of the stems as the bat enters the crop (figure 25). The height of cut should be low enough to harvest most of the grain but high enough to reduce the amount of straw going into the combine.

Tines on the reel should point down or somewhat to the rear to provide a lifting action. This tines adjustment is depicted as positive pitch of pickup teeth in figure 25. The reel peripheral speed should be sufficient to control the crop and press it slightly to the rear. Generally, the reel peripheral speed should be 1¼ to 1¾ times the travel speed of the combine.

The speed of the cylinder and the closeness of the cylinder to the concave influence discharge losses. The aggressiveness of the cylinder, its speed, and the closeness of the concave should be only enough to thresh the kernels. Excessive aggressiveness of the cylinder increases the break-up of straw, which in turn reduces the capability of the walkers and sieves to separate grain from straw. The tailings return is provided on combines to permit recycling of the material that needs rethreshing and the material that was not adequately separated at the sieves. In wild rice harvest, there is no need for rethreshing. Any material that was not threshed in the first pass through the cylinder is attached to the straw and passes out the discharge over the walkers with the straw. In wild rice harvest, the function of the tailings return is to separate material that was not adequately separated in its first pass over the sieves. The sieves and air should be adjusted to permit only a small amount of tailings return material.

Adjustment of the air settings is critical to the separation of grain and straw on the sieves. Too much air blows the lighter kernels out the rear of the machine, whereas too little air permits too much light, chaffy material to accumulate with the clean grain. Air passages should be checked frequently for collection of light, chaffy material that may cause plugging.

The "quick-kill" procedure is useful in determining the distribution of material on the walkers and sieves. This involves having the combine operate normally, then very quickly stopping the engine with the machine still engaged, and applying the brakes. When the machine is stopped abruptly an inspection of the material on the sieves and walkers reveals how uniformly it was distributed. The machine can be restarted by disengaging header and machine drives, starting the engine, and then starting the threshing portion. When the threshing portion is started, the header can be re-engaged.

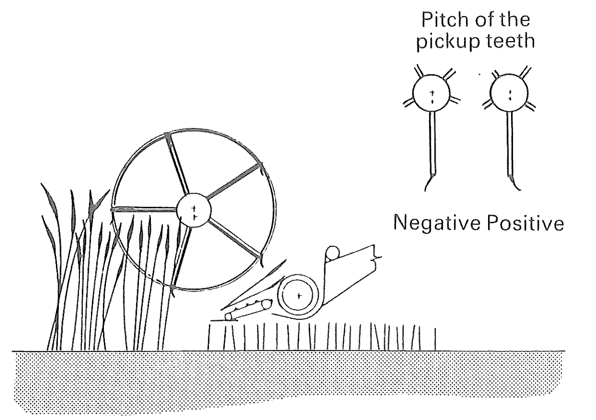



Figure 25. Schematic showing reel and crop interaction (approximately to scale). If the reel is too small a diameter or too low when a reel bat is in front of the reel axis it pushes forward on the stalks, but later when they are pushed rearward they encounter the center tube and associated brace members.

# Fall Tillage and Crop Rotation

E. A. Oelke

Plant residue should be incorporated into the soil or burned to reduce leaf diseases the following year. Wet weather often prevents burning so fall tillage is needed. Tillage is necessary for weed control, especially of cattails, and for seedbed preparation and incorporation of fertilizer. The rotovator is commonly used and it is modified by adding extra flotation for soft peat soils. A plow can be used if fields are dry enough and infertile subsoils are not turned up. Fall plowing in second year and older fields can reduce the amount of thinning necessary to decrease the plant population.

Most growers will keep fields fallow during the third year and clean soil out of the ditches surrounding the fields. Peat soil often slides into the ditches while fields are flooded. The plugged ditches cause poor drainage that interferes with harvesting and tilling. Other crops can be planted the third year if fields are drained to avoid saturated soils during the growing season. Crops grown in rotation with wild rice are buckwheat, rye, wheat, mustard, and forage grasses for seed production. Barley grows well but it is susceptible to brown spot, so is not a good crop for rotation.

Changing fields to new varieties is difficult because wild rice seeds survive in the soil for several years. Eradication of seeds of an old variety is started by omitting fall tillage. Seeds left on the soil surface during the winter will dry out and lose viability. The following spring, the field should be flooded to allow germination, and after four to six weeks the field should be drained and then tilled to eliminate volunteer wild rice plants. A short season crop like buckwheat could be planted after tillage. Two years of this system should eliminate most of the wild rice seed of the old variety.

Another system that has had some success is plowing 20-24 inches deep in the fall to bury most of the seed deep enough so seedlings cannot emerge. This is successful only when the peat layer is more than 24 inches deep. Some growers have switched fields to a new variety in one year using this system.

# Processing

J. Strait

Before commercial production started, many low volume processing plants used a variety of homemade devices. Plants existed throughout northern Minnesota, northern Wisconsin, and southern Canada. The development and rapid growth of commercial production resulted in construction of processing plants having annual processing capacities of more than a million pounds per year.

Steps in processing consist of separation of immature kernels, fermentation or curing, parching, dehulling, cleaning, grading, and packaging. With the exception of separation of immature kernels and packaging, the steps listed are common to all major processing plants. The equipment and processing details used vary among the plants.

## SEPARATION OF IMMATURE KERNELS

Combined wild rice seed delivered to a processing plant is nonuniform in kernel maturity, moisture content, and potential yield of finished product.

Immature kernels in wild rice are undesirable because of the low yield of finished product obtained. The University of Minnesota Agricultural Engineering Department developed a separator that removes most of the immature kernels from wild rice upon delivery to the processing plant. The machine separates three fractions designated as heavy, medium, and light.

The heavy fraction contains predominantly mature, plump, large diameter kernels. The light fraction contains mostly small diameter, immature kernels. The medium fraction is composed principally of kernels in the intermediate stages of maturity. The separator includes an optional rerun feature allowing borderline material between the medium and light collection compartments to be recirculated through the machine for resorting.

Moisture content varied considerably among the fractions (table 15). The yield of finished wild rice from the heavy fraction was approximately 50 percent of the green weight and accounted for more than 60 percent of the total finished wild rice. The yield of the light fraction was so low as to make it uneconomical to process and was discarded.

The column headed "On total volume basis" shows that without rerun approximately 23 percent of the wild rice was sorted into the light fraction and with rerun 32 percent was sorted into the light fraction. This removal of the light fraction is important because the capacity of the processing plant is limited. Removing 25-30 percent of the volume prior to processing increases seasonal processing capacity. Some processors parch the heavy, mature fraction directly without fermentation.

**Table 15. Characteristics of three fractions of wild rice. Fractions produced by the separator developed to remove immature kernels from combined wild rice**

| | | | Percentage of separated fraction | | | |
|---|---|---|---|---|---|---|
| Separated fraction | Rerun feature | Moisture | On total wt. basis | On total vol. basis | From individual fractions | Of total recovered |
| | | percent | | | | |
| Heavy | W/O[1] | 38 | 51 | 39 | 50 | 65 |
| Medium | W/O | 44 | 36 | 38 | 37 | 34 |
| Light | W/O | 61 | 13 | 23 | 4 | 2 |
| Heavy | W[2] | 37 | 46 | 34 | 51 | 61 |
| Medium | W | 45 | 35 | 34 | 41 | 37 |
| Light | W | 60 | 18 | 32 | 4 | 2 |

[1]Borderline material between medium and light not rerun through separator.
[2]Borderline material between medium and light rerun through separator.

## FERMENTATION

Fermentation or curing is a chemical and biological process involving respiration, heat and moisture transfer, and a large number of microorganisms. Most processors of wild rice consider fermentation necessary for color and flavor development as well as hull degradation. During the fermentation process the wild rice kernels change color from greenish to brown. Flavor changes considered desirable by some consumers also develop during the fermentation process. Hull degradation occurring during fermentation results in more efficient dehulling. Fermentation results in extension of the processing season beyond the end of harvest.

Research at the University of Wisconsin showed that dry matter losses occur during fermentation. The losses increased with the length of the fermentaton period (table 16) and were due to respiration of the grain and microbes.

**Table 16. The amount of processed grain recovered from wet grain stored at 70°F up to 10 days**

| Length of storage and turning | Processed grain recovered |
|---|---|
| Days | % |
| 0 | 100 |
| 1 | 100 |
| 2 | 97 |
| 3 | 98 |
| 4 | 93 |
| 5 | 92 |
| 6 | 93 |
| 7 | 89 |
| 8 | 89 |
| 10 | 79 |

Fermentation is achieved by placing the wild rice in windrows in an open field (figure 26). The windrows may be 4-6 feet wide and 8-12 inches deep. The windrows are periodically agitated and watered to

Figure 26. Wild rice grain curing in windrows and being turned and watered.

prevent the wild rice from getting too dry and to prevent a temperature build-up that encourages the growth of molds and accelerates dry matter losses.

A fermentation period of four to seven days is considered desirable. This allows sufficient time for color and flavor development and hull degradation, but is not so long as to cause high dry matter losses. However, some wild rice is kept in the fermentation field for as long as three weeks because of lack of processing capacity.

## PARCHING

Moisture removal is the primary objective of the parching process (figure 27). The moisture content of wild rice from the fermentation field is approximately 40-45 percent (wet basis) and it is dried in the parcher to a moisture content of 7 percent. Most processors operate the parcher so that a slightly toasted flavor is imparted to the wild rice. It is important to achieve a high degree of gelatinization of the starch in the wild rice kernels during this process.

A batch rotary drum parcher consists of a drum approximately 4 feet in diameter, 6-8 feet long, and supported on rollers at the front and rear for continuous rotation. Propane gas burners, located below the drum, heat the exterior surface. Heat is transferred through the drum to the wild rice while the drum rotates and the grain is in tumbling and sliding contact with the inner surface. Wild rice usually is parched for two hours.

One processing plant uses a continuous parcher consisting of four 30-foot long drums set side by side with each external surface heated by a gas flame. The wild rice passes consecutively from one drum to the next, and by the time it is discharged from the fourth drum parching has been completed.

## DEHULLING

Following parching, the wild rice is passed over a cleaning screen to remove stalk fragments or other debris that may be present. Then it is conveyed directly to the huller. During parching, shrinkage of the kernels loosens the hull from the kernel.

Two types of hullers are used. The barrel huller is an enclosed drum with rotating paddles that knock off the hulls. Double roll hullers (figure 28) are more widely used. The wild rice kernels fall between two closely spaced rubber covered rollers that impart a rubbing action by operating one roller at a higher peripheral speed than the other.

## SCARIFICATION

Most processors scarify the product after dehulling to remove a portion of the outer layer of the kernel. Scarification reduces cooking time, which is particularly desirable when wild rice is mixed with rice. The typical scarifier is a continuous flow device that consists of a cylindrical container with a shaft extending longitudinally of the drum and carrying several rubber paddles. The axis of the scarifier is tipped slightly down in the direction of flow. The degree of scarification is controlled by the inclination of the scarifier and by the speed and clearance of the rubber paddles.

## CLEANING, GRADING, AND PACKAGING

Cleaning operations are performed on the wild rice at several steps in the processing sequence. The first cleaning operation to remove stalk fragments and metal particles has been described. Various types of aspirating devices are employed between the huller and the scarifier and after the scarifier to remove hulls from the mixture as it proceeds through the processing line. Weed seeds are removed either at the first screening or any subsequent aspiration. Small pebbles are removed by the gravity separator.

The grading or sorting of the finished wild rice kernels varies among plants and marketing organizations. The characteristics of finished wild rice at the end of processing, as well as the grading and sorting required, are shown in figure 29.

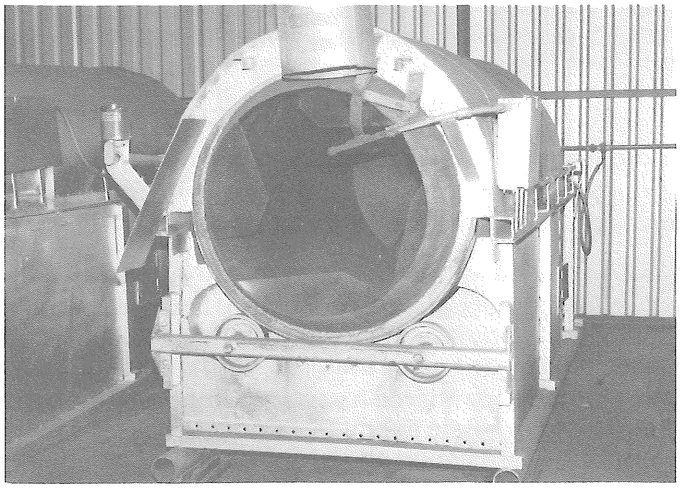


**Figure 27. Wild rice parcher. The inner drum rotates while heat is applied by gas to the bottom of the parcher.**

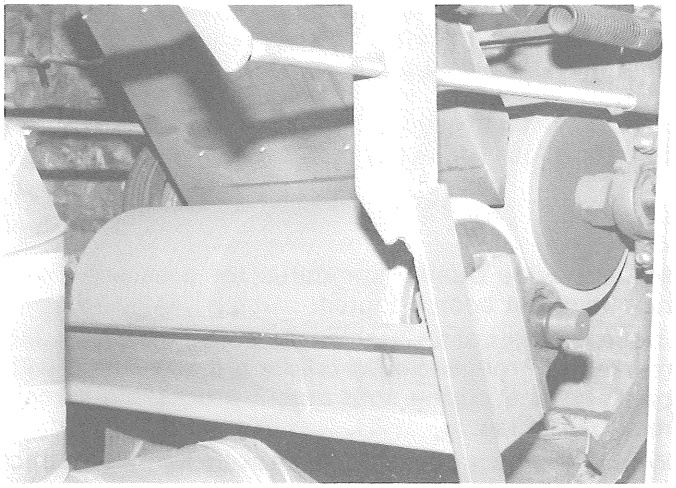


**Figure 28. Huller showing counter-rotating huller rolls and distribution chute above rolls.**

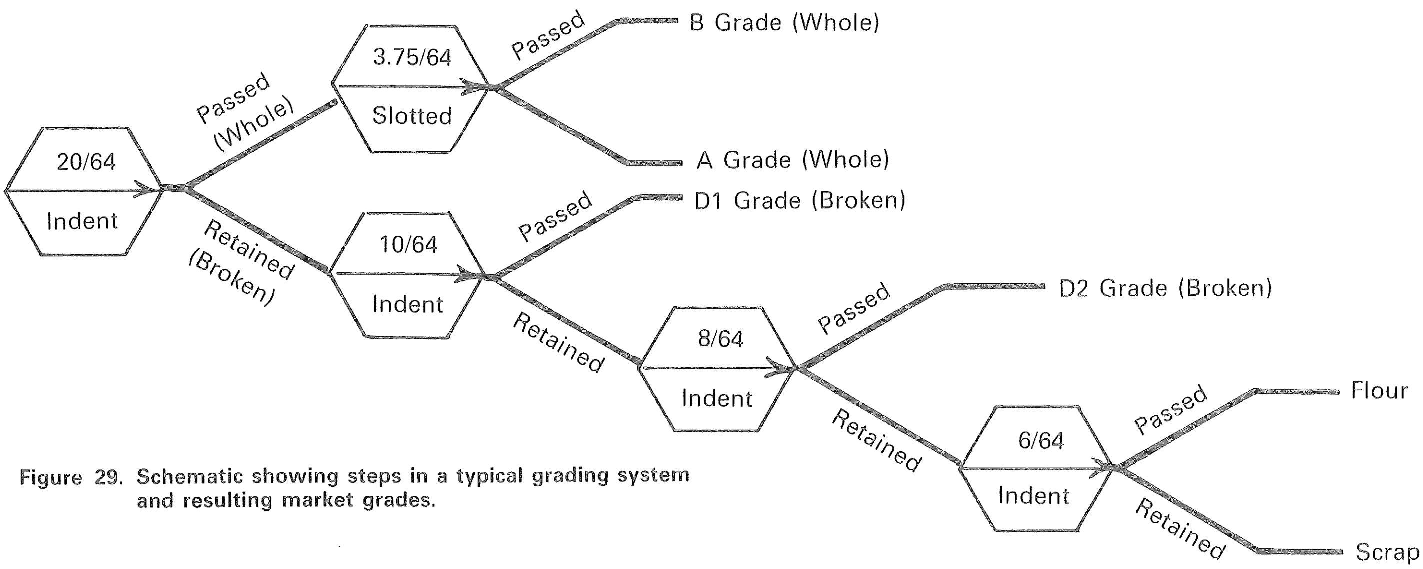



**Figure 29.** Schematic showing steps in a typical grading system and resulting market grades.

A combination length and width grader is used to grade wild rice. The length grader has a rotating cylinder with closely spaced indents that resemble an element of a sphere. As the cylinder rotates, rice kernels of less than a particular length are carried in the indents to a higher elevation and dropped in a trough and discharged from the grader. Kernels too long for the indents are discharged at the opposite end of the machine. In the figure 29 diagram, a cylinder with indents of $^{20}/_{64}$ inch is used. Those kernels carried in the indents are classed as broken kernels. The remainder are classed as whole kernels. A kernel can be broken in such a way that one part is separated as a broken kernel and the remainder as a whole kernel.

A second sorting device is positioned immediately below the indent grader. The lower grader is equipped with a cylindrical sieve having slotted openings. The slotted openings in the grading cylinder used are $^{3.75}/_{64}$ inches wide and 1¼ inches long. Sorting of kernels by this sieve is based on kernel diameter. Kernels passing through the slotted opening are classified as "B" grade and those retained are classified as "A" grade. The broken kernels are further processed through indent graders as indicated in the diagram to produce two market grades of broken kernels and material for grinding into wild rice flour.

Whole kernels separated on the first pass through the indent grader are collected into bins for subsequent passage over a gravity separator. The gravity separator sorts out unhulled kernels and small rocks. Unhulled kernels are returned to the huller for another pass through the processing equipment. Large diameter wild rice kernels removed with the rocks are separated from the rocks on a vibrating sorter.

Packaging of wild rice normally is done after the rush of harvesting and processing. Wild rice usually is packaged in 1-pound plastic bags or boxes. Wild rice also is sold to some customers in bulk without packaging.

## Quality Considerations

J. Strait

Industry-wide quality standards for processed wild rice have not been adopted.

Broken kernels are a problem to both processors and marketing groups. Stress cracks are associated with parching and during subsequent processing kernels may be broken.

White centers noticeable in broken kernels detract from the overall appearance of processed wild rice. Conditions causing white centers are not fully understood. One theory is that white centers are caused by gases trapped within the kernel during parching.

Most processors try to produce a finished product having a slightly toasted flavor. Off flavors usually are associated with molds and microorganisms.

Cooking time standards have been imposed upon the industry to a certain extent by large purchasers of wild rice. Both scarification and a high degree of gelatinization of the starch during processing contribute significantly to a reduction in cooking time. Puffing and precooking can reduce preparation time drastically.

# Marketing

E. A. Oelke

The marketing system for wild rice consists of five principal groups: harvesters or growers, buyers, processors, wholesalers, and retailers.

The wild rice harvested from natural stands often is bought by buyers at the harvest site who buy the grain on a commission basis for a processor or wholesaler. Some buyers are brokers, other buyers buy the grain and then process it themselves.

Some harvest-site buyers buy wild rice from growers, but most of the field grown wild rice is sold as processed grain to wholesalers. Some grower groups wholesale their grain cooperatively. One of the cooperative groups owns a processing plant. The price paid to growers per pound of processed grain has varied from $1.75 to $4.50 since 1968 with the highest paid in 1979. The amount of grain harvested from natural stands in the United States and Canada influences prices paid.

Nearly half of the wild rice produced is sold to firms such as Uncle Ben for mixing with rice. The other markets are restaurants, hotels, caterers, grocery chains, and specialty shops. Most of the grain is sold in the United States but a small amount is exported to Europe. Retail prices per pound range from $5.00 in Minnesota to $25.00 in Europe.

# Food Value and Uses

E. A. Oelke

The composition of wild rice grain resembles that of oats. The protein percent is high and the fat percentage low compared with other cereals (table 17). Except for polished white rice, the ash values for wild rice are comparable with those of other grains. The crude fiber percentage of wild rice is similar to that of brown rice and oats but is half that of wheat and corn. The total carbohydrate percentage of wild rice is similar to that of other grains except rice, which has a slightly higher percentage. Wild rice appears to be comparable in nutritive value with the common cereals.

The amino acid composition of the protein in wild rice is similar to that of oat groats (table 18). Often the sum of lysine, threonine, and methionine amounts (SLTM value) is used as an indication of the nutritional quality of cereal grains. The higher the value the better the protein quality.

Fat percentage in wild rice is less than 1, but the lipids are unique compared with those of rice, wheat, and oats because those in wild rice contain a high level of linolenic acid (table 19). Linoleic and linolenic make up 67.7 percent of the total fatty acids; thus, rancid odors could develop in wild rice because these acids may oxidize. Wild rice contains more of the mineral elements, except calcium, than brown or polished rice (table 20). Removing the pericarp from polished rice

**Table 17. Composition of wild rice and other selected cereal products[1]**

| Component | Wild rice | Brown rice | Polished white rice | Oats | Hard red winter wheat | Corn |
|---|---|---|---|---|---|---|
| | percent | | | | | |
| Moisture | 7.9-11.2 | 12.0 | 12.0 | 8.3 | 12.5 | 13.8 |
| Protein | 12.4-15.0 | 7.5 | 6.7 | 14.2 | 12.3 | 8.9 |
| Fat | 0.5-0.8 | 1.9 | 0.4 | 7.4 | 1.8 | 3.9 |
| Ash | 1.2-1.4 | 1.2 | 0.5 | 1.9 | 1.7 | 1.2 |
| Crude fiber | 0.6-1.1 | 0.9 | 0.3 | 1.2 | 2.3 | 2.0 |
| Total carbohydrate | 72.3-75.3 | 77.4 | 80.4 | 68.2 | 71.7 | 72.2 |

[1]Data from "Wild Rice: Nutritional Review" by R.A. Anderson, 1976, *Cereal Chemistry* 53:945-955.

**Table 18. Amino acid composition of processed wild rice, rice, oat groats, and wheat**

| Amino Acid | Wild rice[1] Minn. | Wild rice[1] Wisc. | Brown rice[2] | Polished rice[2] | Oat groats[2] | Whole wheat[2] |
|---|---|---|---|---|---|---|
| | g per 100 g recovered amino acids | | | | | |
| Alanine | 6.2 | 5.9 | 6.3 | 5.4 | 5.0 | 3.5 |
| (Ammonia) | — | 2.0 | 2.4 | 2.8 | 2.7 | 3.9 |
| Arginine | 8.2 | 7.3 | 9.3 | 8.1 | 6.9 | 4.7 |
| Asparatic acid | 10.6 | 10.1 | 10.6 | 9.2 | 8.9 | 5.1 |
| Cysteine | 0.2 | 1.4 | 1.2 | 2.7 | 1.6 | 2.3 |
| Glutamic acid | 19.5 | 19.2 | 22.9 | 17.6 | 23.9 | 30.8 |
| Glycine | 4.9 | 5.0 | 5.2 | 4.5 | 4.9 | 4.0 |
| Histidine | 2.8 | 2.6 | 2.7 | 2.2 | 2.2 | 2.3 |
| Isoleucine | 4.4 | 4.4 | 3.8 | 4.6 | 3.9 | 3.9 |
| Leucine | 7.5 | 7.4 | 8.8 | 8.1 | 7.4 | 6.8 |
| Lysine | 4.5 | 4.4 | 4.0 | 3.4 | 4.2 | 2.6 |
| Methionine | 3.1 | 2.6 | 1.9 | 2.7 | 2.5 | 1.7 |
| Phenylalanine | 5.1 | 5.2 | 5.6 | 5.3 | 5.3 | 4.6 |
| Proline | 4.0 | 4.3 | 4.6 | 4.5 | 4.7 | 9.5 |
| Serine | 5.5 | 5.6 | 5.9 | 5.0 | 4.2 | 4.9 |
| Threonine | 3.3 | 3.6 | 3.8 | 3.5 | 3.3 | 3.0 |
| Tyrosine | 3.9 | 3.1 | 3.5 | 4.5 | 3.1 | 3.1 |
| Valine | 6.2 | 5.9 | 5.4 | 6.5 | 5.3 | 4.8 |
| SLTM[3] | 10.9 | 10.6 | 9.7 | 9.6 | 10.0 | 7.3 |
| | percent | | | | | |
| Total protein | 14.2 | 13.5 | 12.8 | 7.3 | 17.1 | 12.0 |

[1]Total Data from University of Minnesota, Agricultural Experiment Station and University of Wisconsin—Madison, Agricultural Experiment Station.

[2]Data from table in "1975 Report on Wild Rice Processors' Conference" by University of Wisconsin—Madison.

[3]Sum of lysine, threonine, and methionine.

removes a considerable portion of the minerals. However, scarifying (partial removal of the pericarp) during processing of wild rice does not result in much loss of minerals.

Processed wild rice grain contains no vitamin A but is an excellent source of the B vitamins—thiamine, riboflavin, and niacin (table 21). The grain is especially rich in riboflavin.

When only wild rice harvested from natural stands was available, it was an expensive gourmet food. It was traditionally served with wild game. Market expansion has accompanied growth of wild rice as a field crop. Wild rice is marketed alone or in combination with rice of various types and is generally available at food stores. There has been extensive activity in the development and publication of recipes utilizing wild rice in the home. Wild rice is used in place of potatoes or rice and in preparation of casseroles, soups, and salads.

**Table19. Fatty acid composition of hexane extracts of wild rice, rice, oats, and wheat[1]**

| Fatty acid | Wild-rice | Brown rice | Polished rice | Oat groats | Wheat |
|---|---|---|---|---|---|
| | percent of total fatty acids | | | | |
| Palmitic | 14 | 20 | 4 | 16 | 24 |
| Stearic | 1 | 2 | 4 | 2 | 1 |
| Oleic | 6 | 41 | 43 | 41 | 2 |
| Linoleic | 8 | 34 | 18 | 9 | 56 |
| Linolenic | 30 | 1 | 1 | 2 | 4 |

[1]Data from "Wild Rice: Nutritional Review" by R. A. Anderson, 1976, *Cereal Chemistry* 53:949-955.

**Table 20. Minerals in wild rice and other cereals[1]**

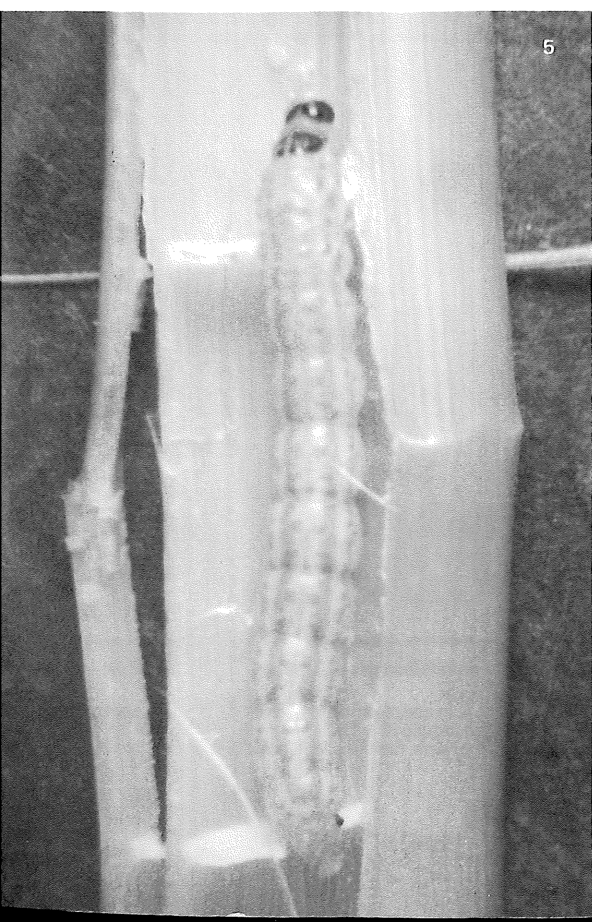
| Mineral | Wild rice | Brown rice | Polished rice | Oat groats | Hard red winter wheat | Corn |
|---|---|---|---|---|---|---|
| | mg per 100 g | | | | | |
| Calcium | 17-22 | 32 | 24 | 53 | 46 | 22 |
| Iron | 4 | 2 | 1 | 4 | 3 | 2 |
| Magnesium | 80-161 | — | 28 | 144 | 160 | 147 |
| Potassium | 55-344 | 214 | 92 | 352 | 370 | 284 |
| Phosphorus | 298-400 | 221 | 94 | 405 | 354 | 268 |
| Zinc | 3-6 | — | 1 | 3 | 3 | 2 |

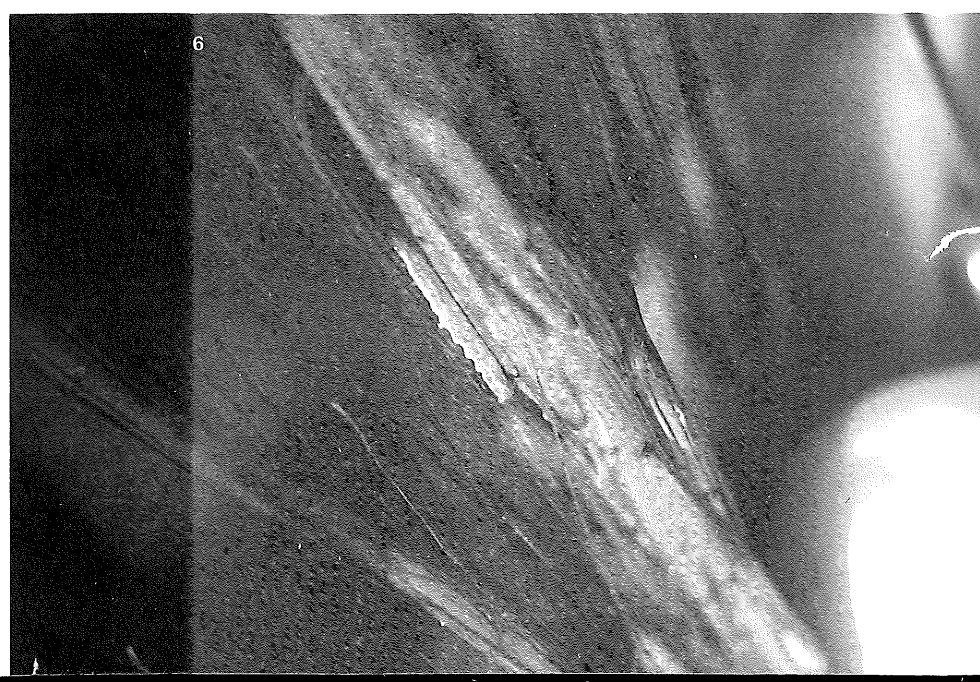
[1]Data from "Wild Rice: Nutritional Review" by R. A. Anderson, 1976, *Cereal Chemistry* 53:949-955.

**Table 21. Vitamin content of wild rice and other cereals[1]**

| Vitamin | Wild rice | Brown rice | Polished rice | Oat groats | Hard red winter wheat | Corn |
|---|---|---|---|---|---|---|
| | mg per 100 g | | | | | |
| Thiamine | 0.45 | 0.34 | 0.07 | 0.60 | 0.52 | 0.37 |
| Riboflavin | 0.63 | 0.05 | 0.03 | 0.14 | 0.12 | 0.12 |
| Niacin | 6.2 | 4.7 | 1.6 | 1.0 | 4.3 | 2.2 |
| Vitamin C | 0 | 0 | 0 | 0 | 0 | 0 |
| | I.U. | | | | | |
| Vitamin A | 0 | 0 | 0 | | 0 | 490 |

[1]Data from "Wild Rice: Nutritional Review" by R. A. Anderson, 1976, *Cereal Chemistry* 53:949-955.





Colorplate 5. Wild rice worm larvae.

Colorplate 6. Larva of rice stalk borer in the stem of wild rice.

Colorplate 7. Individual brown spot lesions (top) showing typical yellow edges. Some lesions have coalesced on leaves in bottom photo.

Colorplate 8. Dark spots on the inside of stems are sclerotia produced by stem rot fungi.

Colorplate 9. Water-soaked lesions caused by bacterial leaf streak bacteria.

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