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Wild Rice

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I. History:

Wild rice (*Zizania palustris* L.) is native to North America and grows predominantly in the Great Lakes region. This large-seeded species, one of four species of wild rice, is in the grass family (*Poaceae*) and has been eaten by people since prehistoric times. Early North American inhabitants, especially the Ojibway, Menomini, and Cree tribes in the North Central region of the continent, used the grain as a staple food and introduced European fur traders to wild rice. Manomin, the name they gave wild rice, means good berry. Early English explorers called this aquatic plant wild rice or Indian rice, while the French saw a resemblance to oats and called it folle avoine. Other names given to wild rice include Canadian rice, squaw rice, water oats, blackbird oats, and marsh oats. However, the name "wild rice" persisted and today it is the common name for the genus *Zizania*, even though the wild type of rice (*Oryza*) is also called wild rice.

Prior to 1965 most wild rice in the United States was produced in natural stands in lakes, rivers, and streams. In Canada most wild rice is still produced in lakes and streams that are leased from the government. Growing wild rice as a field crop was first suggested in 1852 by Joseph Bowron from Wisconsin, and in 1853 by Oliver H. Kelley of Minnesota. Efforts to grow wild rice as a field crop did not begin until 1950. James and Gerald Godward grew wild rice in a one-acre diked, flooded field (paddy) near Merrifield, Minnesota. By 1958 they had 120 acres of paddies for growing wild rice. Additional growers started paddy production during the mid-1950s and early 1960s, and in 1965, Uncle Ben, Inc. started contracting acreages. These initial efforts to commercialize wild rice production resulted in an organized effort to domesticate this crop using plant breeding.

Development of more shatter-resistant varieties was largely responsible for the rapid expansion of field production in the late 1960s and early 1970s. Production in Minnesota increased from 900 acres in 1968 to 18,000 acres in 1973. Most wild rice from natural stands was harvested by hand prior to this time using the traditional canoe-and-flail method. Mechanical harvesting of wild rice on private lands began during 1917 in Canada. Harvesting with more efficient grain combines was possible with the discovery of shattering resistance. Wild rice is currently produced commercially as a field crop in Minnesota and California, which account for most of the acreage (20,000 and 8,000 acres, respectively, in 1991). Additional amounts are grown as a field crop in Idaho, Wisconsin and Oregon. In Canada, there has been much recent effort to increase total production from lakes by seeding lakes that were without wild rice. The lakes are then mechanically harvested by airboats equipped with collecting troughs. Researchers in Europe are currently investigating the possibility of wild rice production there.

II. Uses:

Wild rice is a nutritional grain that serves as a substitute for potatoes or rice, and is used in a wide variety of foods such as dressings, casseroles, soups, salads, and

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desserts. In recent years, wild rice has been used in breakfast cereals, and mixes for pancakes, muffins, and cookies. Blends of wild rice and long-grain regular rice (*Oryza*) that were introduced in the early 1960s increased the popularity of wild rice among consumers. Wild rice from natural stands is popular among health-food enthusiasts.

This grain has a high protein and carbohydrate content, and is very low in fat (Table 1). The nutritional quality of wild rice appears to equal or surpass that of other cereals. Lysine and methionine comprise a higher percentage of the amino acids in the protein than in most other cereals. The SLTM value (sum of lysine, threonine, and methionine contents) often serve as a measure of the nutritional quality of cereals, and is a little higher for wild rice than for oat groats, which is one of the better cereals for humans. Amino acid composition of processed and unprocessed wild rice is similar, which indicates little reduction in nutritional quality during processing. Wild rice contains less than one percent fat, of which linolenic and linoleic acids together comprise a larger proportion of the fatty acids (68%) than in wheat, rice, or oats. Although these two fatty acids are easily oxidized and make wild rice prone to develop rancid odors, the high levels of linolenic acid make the fat in wild rice highly nutritious.

Mineral content of wild rice, which is high in potassium and phosphorus, compares favorably with wheat (Table 1), oats, and corn. Processed wild rice contains no vitamin A, but serves as an excellent source of the B vitamins: thiamine, riboflavin, and niacin.

III. Growth Habit:

Wild rice is an annual, cross-pollinated species. In Minnesota, it matures in about 110 days, and requires about 2,600 growing degree days (40° F base). Plants are five to six ft tall and can have up to 50 tillers per plant. In cultivated fields that have four plants/sq ft, plants usually have three to six tillers. Stems are hollow except at nodes where leaves, tillers, roots, and flowers appear. Internodes are separated by thin parchment-like partitions. The shallow root system has a spread of 8 to 12 in. Mature roots are straight and spongy. Ribbon-like leaf blades vary in width from ¼ to 1½ in. Mature plants have five or six leaves per stem or tiller above the water.

Table 1. Nutritional composition of wild rice, cultivated brown rice, and wheat.

Nutritional Component	Wild Rice	Cultivated Brown Rice	Wheat
Protein	13.8 (12.8 - 14.8)[a]	8.1	14.3
Ash (%)	1.7 (1.4 - 1.9)	1.4	2.0
Fat (%)	0.6 (0.5 - 0.8)	1.9	1.8
Fiber (%)	1.2 (1.0 - 1.7)	1.0	2.9
Carbohydrate (%)	(72.5 - 75.3)	77.4	71.7
Ether Extract (%)	0.5 (0.3 - 1.0)	2.1	1.9
Phosphorus (%)	0.28	0.22	0.41
Potassium (%)	0.30	0.22	0.58
Magnesium (%)	0.11	0.12	0.18
Calcium (ppm)	20	32	46
Iron (ppm)	17	10-17	60
Manganese (ppm)	14	30-39	55
Zinc (ppm)	5	24	—
Copper (ppm)	13	4-7	8
Nitrogen (free % extract)	82.4	87.4	78.9

[a] Numbers in parentheses indicate ranges in values.

Source: Handbook of Cereal Science and Technology, Chp. 10, Oelke and Boedicker, 1991; and Wild Rice: Nutritional Review, R.A. Anderson, 1976.

Flowers are in a branching panicle with female (pistillate) flowers at the top and male (staminate) flowers on the lower portion. Cross pollination usually occurs since female flowers emerge first and become receptive and are pollinated before male flowers shed pollen on the same panicle. Sometimes the transition florets, which are located between the pistillate and staminate florets on the panicle, have both stigmas and anthers (pollen), and can therefore be self-pollinated. Two weeks after fertilization the wild rice seeds are visible, and after four weeks, it is ready for harvest. This seed is a caryopsis that is similar to the grain of cereals. The caryopsis has an impermeable pericarp, large endosperm, and small embryo. The grains with the palea and lemma (hulls) removed, range from 0.3 to 0.6 in. in length, and from 0.06 to 0.18 in. in diameter. Immature seeds are green, but turn a purple-black color as they reach maturity. Seeds on any tiller will mature at different times, and on secondary tillers they mature later than on main tillers. There is little shattering resistance in natural stands.

Seeds will not germinate for at least three months after reaching maturity, even if environmental conditions are satisfactory for growth. An after-ripening period is required in water at freezing or near-freezing temperatures (35° F) before the embryo breaks dormancy and develops into a new seedling. This seed dormancy is caused by the impermeable pericarp that is covered by a layer of wax, and by an imbalance of endogenous chemical growth promotors and inhibitors. In the spring, seeds will start to germinate when the water temperature reaches about 45° F. Freshly harvested seeds can be made to germinate by carefully scraping off the pericarp directly above the embryo. These seeds cannot be planted directly, but must first be germinated in water, and then the seedlings transplanted later.

IV. Environment Requirements:

A. Climate:

Wild rice is well adapted to northern latitudes. It is not very productive in the southern United States since warm temperatures accelerate plant growth, and as a result, plant heights are shorter with an accompanying lower number of florets. The number of florets per panicle also decreases when the daylength is shorter than 14 hours. However, moderate yields have been produced in southern climates when planted in late February or early March. Northern California, Idaho and Oregon have recently been other areas where wild rice has produced good yields.

B. Soil:

Wild rice in Minnesota and Wisconsin is usually produced on low, wet land that has never or seldom been farmed. The paddy site should be flat enough to avoid expensive or excessive grading that would expose the subsoil. This crop grows well on shallow peat soils, and clay or sandy loams. The site should have an impervious subsoil, such as clay, which prevents seepage during most of the growing season and is a solid footing for heavy field equipment. The majority of wild rice fields have been developed on organic soils with a peat depth ranging from several inches to more than 5 ft. Peat areas in Minnesota, except for acid bogs which are low in fertility, are ideal for growing wild rice since they are generally flat and slightly above the flood plain. Peats with pH 5.5 as well as sphagnum bogs should be avoided. Ideally, the soil should contain 20% mineral matter and have a carbon to nitrogen ratio less than 16.

C. Land Preparation and Dike Construction:

Brush and small trees on a new paddy site are usually removed during winter by shearing with a bulldozer, and then burned the following summer, if weather conditions permit. Large disks or rotovators are used to till the soil rather than moldboard plows. When sod peats are turned over with a moldboard plow the rotting vegetation can produce enough carbon dioxide and methane to cause the soil to float when flooded. A detailed topographic survey is needed to help determine the dike height, location of culverts, and portions of the paddy that should be levelled.

Small fields will have a perimeter dike and water outlet at the lower side. Fields that are 30 or more acres in size will have cross dikes with water gates, as well as the larger perimeter dike. A slight slope of less than one-half percent (six in. per 100 ft) within the paddy promotes preharvest drainage. Tiling of larger fields is common now to promote drainage and fall tillage.

Dikes must be impervious to water. Clay soil is ideal for dike construction. The dikes must be wider if peat soil is used. The top width of the main dike should be eight ft, while the inner dike should have a minimum top width of four ft, but never less than the height of the dike. The steepest side slopes should be 1.5:1 (1.5 ft of horizontal distance for every one ft drop) and the height should be one-half to one ft above the water level. On highly erodible soils, the slope should be 3:1, and the height of the dike should be one to two ft higher than the water level. Use of organic soil for dikes may cause problems since peat erodes easily and may not hold back water. The sides of the dike may need to be flatter than the minimum recommended height to provide wave protection and fill stability. A mixture of mineral soil with peat soil may reduce erosion problems, especially on the sides of dikes. Place dikes so that a maximum water depth of 8 in. can be maintained in the shallow end and 16 in. in the deep end of the field.

Access roads should be located so they can serve as part of the dike system to divert or collect water and to divide the drainage areas. Culverts or other permanent structures should be positioned where roads cross the drainage channels to provide access to every field for easy observation and movement of equipment. The location and size of culverts, water gates, and pumps should be determined prior to construction so the desired water control can be achieved.

D. Water:

Wild rice in natural stands grows in water with a concentration of less than 10 parts per million (ppm) of sulfate. Research has found that wild rice can grow satisfactorily in water with sulfate concentrations of up to 250 ppm. The growth of wild rice is also tolerant to a wide variation in the hardness (22 to 300 ppm calcium carbonate) and pH (5.0 to 8.0) of the water.

This crop will thrive only in flooded soils. Flood the fields as early as possible in the spring. If seeds germinate in unflooded soils, the seedlings are stunted and yellow in color probably due to lack of iron. Soils should be saturated from germination until 2 or 3 weeks before harvest to ensure vigorous plant growth. A constant water depth of at least 6 in. is important to help control weeds during the first 8 to 10 weeks after seeds germinate. Variable water depths during this period can damage wild rice plants. Water deeper than 14 in. causes weak stems and lodging during water drawdown. A 3-year study conducted in northern Minnesota indicated that a 13-in. water depth resulted in adequate plant populations, no delay in maturity, good yields, and the best weed control during the early portion of the season. To maintain the proper depth, water should be added as needed to compensate for soil percolation, evaporation, and plant transpiration. The water level can be permitted to decrease slowly during flowering so that little water needs to be drained 2 or 3 weeks prior to harvest.

An acceptable water source must be available from a stream or lake. Permits are required in Minnesota from the Department of Natural Resources to use surface or ground water for irrigation, and from the Pollution Control Agency for the drainage of water from paddies. These permits are available only to landowners whose fields are next to the water source. Wells can also be used if the recharge rate is sufficient. Applications for these permits should begin early in the planning stage to assure they are granted prior to construction.

One possible plan for an irrigation system has a central water supply ditch from which numerous fields can be flooded. A second system allows water to flow from one field to another. However, this system does not allow crop rotation or fallowing of individual fields. The amount of water needed to grow this crop varies from 24 to 30 acre-in. Research conducted by the University of Minnesota found that wild rice with a plant density of two plants/sq ft required 25 acre-in. during the growing season. Most growers have water-use permits that allow them to pump this amount of water, but nearly half is often supplied by rainfall. The water system should flood a field in 7 to 10 days. A 30-acre field requires about 15 million gallons of water for the initial flooding. A 12-in. pump that delivers 4,000 gallons per minute, and operates for 24 hours a day, will deliver 5,760,000 gallons per day. This pump would take 2½ days to flood a 30-acre paddy to a depth of 11 in. Less water would need to be pumped in subsequent years when the winter snow and spring rains are retained after the water gates of paddies are closed following the harvest in the fall.

E. Seed Preparation and Germination:

Plant new fields with the most shatter-resistant varieties. New producers should make arrangements to buy seed from seed growers 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. Seed should be cleaned immediately after harvest with an air or gravity cleaner before fall planting or winter storage that precedes spring planting. If the seed will be stored, even if for a short time, it must be placed in water to assure germination. Seed used for fall planting is usually placed in tanks filled with water. Seed for spring planting can be stored in 50-gallon drums that are perforated with many small holes or plastic-mesh bags to permit water circulation. The drums or bags are placed below the ice in lakes or streams, or in water-filled pits that are 10 ft deep. Do not let mud cover the seed or allow water surrounding the seed to freeze. Seed can also be stored in tanks where the water is kept at 33 to 35° F and it should be changed every three to four weeks.

Seed dormancy will prevent germination until after three months of cold (33 to 35° F) storage in water. The percent germination is determined by placing seeds in a pan of water at room temperature (68° F). The water should be changed every two days, and after 21 days, high quality seed should have a 70% or higher germination rate. Seed germinates at 42° F, but the optimum temperature is between 64 to 70° F. Viability of dormant seed can be checked by removing the pericarp above the embryo and then placing the seed in a pan of water, or by performing the tetrazolium test.

V. Cultural Practices:

A. Seedbed Preparation:

A new wild rice field that has a large amount of vegetation should be tilled one or more years before planting. Small grains such as oats or winter rye can also be grown for one or two years prior to planting wild rice. This initial cropping, prior to flooding the fields, allows vegetation to decompose and reduces problems with floating peat when fields are flooded. Frequently, a rotovator is used to till the soil to a six-in. depth. A roller or row of tires is often attached to the rear of the rotovator for better floatation on peat soils. A disk can be used to prepare the seedbed, but it is not as effective as a rotovator in destroying and incorporating the existing vegetation. Moldboard plows are not satisfactory for primary tillage of peat soils with vegetation since the turned-over soil may float when the field is flooded. Land-breaking plows will cause less soil flotation, but should not be used in shallow peat where the underlying mineral soil is brought to the surface. Wild rice is difficult to establish on clay subsoil. The final seedbed should be free of ridges and depressions to ensure good water drainage.

Fall tillage is recommended for seedbed preparation, weed control, fertilizer incorporation, and covering plant residue to decrease the severity of leaf diseases in the following year. Growers often fallow fields during the third year. Soil is removed from ditches in the perimeter of fallow fields to maintain good drainage and ease of tillage and harvesting. Other crops can be grown in rotation with wild rice, such as buckwheat, rye, wheat, mustard, canola, or forage grasses for seed production. Barley should not be in the rotation because it is an alternate host of brown spot which is a severe disease in wild rice.

Changing a field to a new variety is not easy since wild rice seeds survive in the soil for several years. The eradication of seeds from the old variety begins by not doing the fall tillage. Seeds that remain on the soil surface during the winter will die. The field should be flooded in the spring to permit germination, and after four to six weeks, the field should be drained and tilled to eliminate any plants. A short-season crop like buckwheat could be planted following the summer tillage. After two years this system should eliminate most of the seed from the old variety. Another method for changing varieties has been successful in areas with a peat layer that is more than 24 in. thick. The field is plowed 20 to 24 in. deep in the fall to bury the seed so seedlings are unable to emerge. This system has allowed some growers to change a field to a new variety in one year.

B. Seeding Date:

Wild rice can be seeded in the fall or spring. Fall planting is preferred since it is the natural seeding time, and eliminates the need to store seed over winter. Other advantages of fall seeding are that the weather is mild, and fields are usually dry so heavy field equipment can be used. However, if the soil is too dry, the fields may need to be flooded immediately after planting to prevent the seeds from drying out. Spring seeding should occur as early as possible before the seeds begin to sprout. A seeding trial at Grand Rapids, Minnesota found that planting the variety K2 after June 1 was too late in the growing season to allow the crop to mature.

C. Method and Rate of Seeding:

Do not allow the wild rice seed to dry during planting. Drain the water from the seed just before planting and then mix it with oats in a ratio of 2 or 3 lb of oats per lb of wild rice. This combination allows the wild rice seed to flow uniformly through the seeding equipment. Successful planting requires that the seed is covered promptly with soil or water to maintain viability and minimize feeding losses from birds.

Wild rice should be planted at a depth of one to three in. Seedlings will not emerge when planted deeper than 3 in. Mineral soils require a shallower planting depth than peat soils. Wild rice may be planted by using a bulk-fertilizer spreader to broadcast the seed, which is followed by using a disk or harrow to incorporate it to a depth of 1 to 2 in. A grain drill may also be used. These seeding methods cannot be used in the spring due to wet field conditions. Seed is usually sown directly into the water from an airplane or broadcasting equipment in the spring. Seeding rates that are 15 to 20% higher should be used when planting directly into water.

A plant density of 4 plants/sq ft is recommended. Higher plant populations have lodging and leaf-disease problems. Planting rate with good quality seed should be 30 to 45 lb/acre. The amount of seed needed to obtain the optimum plant density varies with the seed quality, which is reflected by the germination rate. Germination rates of commercial seed can vary from 15 to 95%.

In second-year and older fields, varieties will reseed themselves. A very high plant population will result since up to 1,000 lbs of seed per acre can shatter before harvest. Reducing the plant population is necessary to produce higher yields. Plants are thinned at the floating-leaf stage. The thinning is done by an airboat with a series of V-shaped knives set six to eight in. apart on a toolbar attached to the rear of the boat. The boat travels at a speed of 35 m.p.h. with the knives riding on the soil surface, and removes approximately 70% of the plants.

Table 2. Fertilizer recommendations for wild rice[1].

Nitrogen	Criteria	Amount to Apply (lb/acre)	
		Mineral Soils	Organic Soils
Nitrogen	Status of Paddy:	Incorporated	Incorporated
	First year only	70	25
	Second year and older	70	50
Phosphorus	Soil Test Results (ppm)	Amount to Apply (lb/acre)	
(P_2O_5)	0 - 7	40	
	8 - 15	20	
	16+	0	
Potassium			
(K_2O)	0 - 50	60	
	51 - 100	40	
	101 - 150	20	
	151+	0	

[1] Source: Fertilizer Recommendations for Agronomic Crops in Minnesota. 1990. George Rehm and Michael Schmitt, University of Minnesota, Minnesota Extension Service, AG-MI-3901, 1990.

The plant density should then be 4 plants/sq ft. Sometimes it is necessary to thin fields with a second series of passes that are perpendicular to the first series.

D. Fertility and Lime Requirements:

Flooding a field to grow wild rice causes changes in several chemical systems of the soil that affect plant nutrition. The only form of nitrogen that is stable in flooded soils is ammonium. Nitrate nitrogen is rapidly lost due to the formation of dinitrogen gas. Consequently, only ammonium based fertilizers, including urea, should be used on wild rice. Also, fall testing for nitrate nitrogen, as is done in small grains, is not useful in making fertilizer recommendations in wild rice. Ammonium nitrogen near the surface of a flooded soil can be oxidized to nitrate then lost by being transformed to dinitrogen gas. To minimize this type of loss nitrogen should be plowed under with a moldboard plow or injected to a depth of 6 to 8 in.

Phosphorus and potassium are both more highly available in peat soils than in mineral soils and tend to be more highly available in flooded mineral soils than nonflooded mineral soils. Leaching losses are possible but in well managed wild rice paddies leaching is not much of a problem. Phosphorus in the flood water enhances algae growth which can be a problem especially in the early stages of wild rice growth. Phosphorus fertilizers should be injected or plowed in.

The availability of iron and manganese increase greatly upon flooding. Wild rice does not have the ability to obtain sufficient iron in nonflooded soils and iron availability is one of the major reasons wild rice must be grown in flooded soils.

The wild rice plant has a relatively high requirement for plant nutrients for each pound of dry matter produced. This crop grows rather slowly during the vegetative phase, so that by jointing, less than 12% of total dry weight is produced. Most plant growth and dry matter accumulation occurs during flowering and grain maturation. Consequently, the nitrogen requirement for wild rice is greatest during the reproductive phase when 70% of the total nitrogen is assimilated by the plant. Growers often apply 30 to 50 lb/acre of urea nitrogen by air at the late boot stage to supply sufficient nitrogen for grain fill. Assimilation of phosphorus and potassium follow a similar pattern during crop development.

Plants that are nitrogen-deficient are shorter and have a lighter green color than plants with a sufficient amount. Lower leaves of nitrogen-deficient plants have yellow tips and margins. A slight deficiency of nitrogen results in less lodging, vegetative growth, and damage from brown spot disease. In addition, yields are higher and harvesting with a combine is easier. Sulfur deficiency can also result in a yellowing that looks similar to nitrogen deficiency. Experiments with sulfur application have not yielded consistent results but the data are suggestive of a response to fertilization for some acid peats with pH less than 6.

Soil testing and plant analysis are the best methods to determine how much fertilizer may be needed by a wild rice crop. The amounts of nitrogen, phosphate, and potassium fertilizer that are recommended for wild rice by the University of Minnesota Soil Testing Laboratory are summarized in Table 2. Tissue nitrogen concentrations of less than 3.5% in the boot stage suggest that fly-on nitrogen, in addition to that normally applied, is needed. Liming has not been effective and liming of acid peats can result in gas production and floating of the soil. If lime is applied the soil should be fallowed or used for an upland crop for one more season. Fertilization with sulfur may be helpful in some acid peats but there is no documented evidence of response to other micronutrients.

Much of the nitrogen can be applied in the fall if it is incorporated to a depth of 6 to 8 in. All ammonium sources, anhydrous ammonia, aqua ammonia, ammonium phosphate, and urea, work equally well. Urea ammonium nitrate, UAN, has 29% of the nitrogen in the nitrate form which will be lost to the atmosphere. This source can be used for wild rice but only 71% of the nitrogen that is applied will be available for wild rice. The phosphorus fertilizer should also be incorporated into the soil to help control algae. Application of phosphorus in the spring should be avoided. If conditions do not permit fall application of fertilizer it is better not to apply phosphorus in the spring. In fields that have been cropped for several years, the buildup of phosphorus from previous fertilization will probably supply the crop with sufficient P.

Under some conditions, losses of fall applied nitrogen can be high. In drained soils ammonium is converted by soil microbes into nitrate which will be lost after flooding in the spring. The rate of the process is slower at lower temperatures and fall fertilization is not recommended until the temperature at 6 to 8 in. depth is less than 50°F. Even at this temperature much of the ammonium can be converted to nitrate within 2 to 3 weeks if the soil is well drained. Fall flooding, within 5 days after nitrogen application, will stop nitrification and result in a better efficiency for fall nitrogen fertilization. Topdress applications of urea should be made at the boot stage or very early flowering.

E. Variety Selection:

Most of the paddy-grown wild rice in Minnesota and Wisconsin is produced using varieties that have a non-shattering tendency. All the following varieties shatter somewhat and are susceptible to lodging and diseases. The most popular variety is K2.

Table 3. Yield and other characteristics of wild rice varieties evaluated in Minnesota.

	Yield			Shattering		Harvest Date	Height	
Variety	1981-1986	1989[1]	19901	1989[1]	1990[1]	1981-1986	1981-1988	Seeds
	------- lb/acre[2] -------			----- %[3] -----			(in.)	(no/lb[4])
K2	1,578	1,083	796	37	59	Aug. 23	72	7,300
M3	1,613	649	720	55	59	Aug. 27	74	9,460
Meter	1,078	1,070	—	21	—	Aug. 2	53	6,880
Netum	1,497	728	—	27	—	Aug. 17	68	8,300
Voyager	1,500	1,082	—	31	—	Aug. 18	66	8,600

[1] Data for 1990 was from Grand Rapids, Minnesota, and for 1989 it was from on-farm site and Grand Rapids combined.

[2] Green weight of harvested grain adjusted to a 40% moisture content.

[3] Shattering expressed as percent of total possible yield (sum of the harvested and shattered grain).

[4] Number of seeds per pound based on wet, stored seed. Seed size will vary among years and seed lots.

Source: 1991 Varietal Trials of Selected Farm Crops, Minnesota Agricultural Experiment Station, Minnesota Report 221-1991.

K2- has a medium height, early to medium maturity, and medium to high yield. Developed by Kosbau Brothers in 1972.

M3- has a medium height, medium to late maturity, high yield, and variable plant and panicle type. Developed by Manomin Development Co. in 1974.

Meter- has a shorter height, very early maturity, low to medium yield, and large seed size. Reduced foliage in the canopy compared to other varieties. Released by the Minnesota Agricultural Experiment Station in 1985.

Netum- has a medium height, early maturity, and low to medium yield. Released by the Minnesota Agricultural Experiment Station in 1978.

Voyager- has a short to medium height, early maturity, and medium to high yield. Should equal or exceed K2 in yield and mature a few days earlier. Released by the Minnesota Agricultural Experiment Station in 1983.

Yield and other agronomic characteristics are shown in Table 3.

Certified seed is not available of the above varieties except during the first year of release. Growers maintain and sometimes select their own seed and new growers need to make arrangements for seed with current growers during harvest. Because of cross-pollination variety integrity is difficult to maintain in a field, thus most seed is not the same as the original variety unless reselection has been done. The breeding program at the University of Minnesota is continuing to develop varieties for future release.

F. Weed Control:

The common broadleaf water weeds of the Upper Midwest are a more serious problem than aquatic grassy weeds. Common waterplantain (*Alisma plantago-aquatica* L.), an aquatic perennial weed, is the most troublesome weed in wild rice fields. Research conducted by the University of Minnesota found that waterplantain which developed from corms caused yield losses of 43% when one weed/sq ft was present. Early control of waterplantain is critical since competition with wild rice is greatest after 8 weeks of growth. First-year seedlings of waterplantain are usually too small and late in appearance to compete with wild rice. Weed seedlings should be controlled since they will cause problems in succeeding years. Consult the Minnesota Extension bulletin on wild rice production for a discussion of other weeds that are present in paddies, yet are usually not economically significant.

Control of weeds should consist of a combination of cultural and chemical methods. Fall tillage after harvest will control cattails (*Typha latifolia* L.) and reduce plant numbers of common waterplantain. Other effective methods to control aquatic weeds include the use of weed-free seed, maintenance of the water depth at six to ten in. especially during the first 6 weeks, and to fallow weedy fields for a year. The fallow fields should be flooded in the spring for 6 weeks to ensure the growth of weeds, and then drained, so they can be tilled to destroy weeds.

Presently, the only herbicide that can be used in Minnesota for controlling weeds in wild rice is 2,4-D (amine) at one-quarter pound of active ingredient per acre. No herbicides are cleared for use in Wisconsin. 2,4-D should be applied when wild rice is in the tillering stage since considerable injury can occur with later applications. Avoid spray overlaps in the field because one-half pound of active ingredient per acre can injure the crop. This herbicide does not give complete control of waterplantain, but will reduce the infestation in the following year. Algae can form a mat on the water surface before wild rice emerges, which will reduce the stand in some areas of the field. Copper sulfate applied at 15 lb/acre into the flood water may help to control algae. Retreatment is often necessary for complete control. Consult your Extension agent or specialist for current herbicide recommendations.

G. Diseases and Control:

Diseases in natural stands of wild rice are not usually destructive, but in field-grown wild rice they can cause serious losses. In the early years of commercial production, severe epidemics of brown spot destroyed entire crops in some locations. Almost every disease pathogen of wild rice has been observed previously on rice (*Oryza*).

Brown spot (formerly called *Helminthosporium* brown spot) is the most serious disease affecting wild rice that is grown in fields. This disease is caused by *Bipolaris oryzae* Luttrell (*Helminthosporium oryzae* B. de Haan) and *B. sorokiniana* Luttrell (*H. sativum* P.K. and B.). These fungi are considered to cause brown spot since both are found on infected plants and cause similar symptoms in wild rice plants. Every variety of wild rice, at each stage of development, is susceptible to brown spot. This disease is most severe when day temperatures range from 77 to 95° F and nights are 68° F or warmer. High relative humidity (greater than 89%), and the continuous presence of free water on leaf surfaces for 11 to 16 hours, can also favor infection. All parts of the plant are susceptible to infection. The brown, oval leaf spots usually have yellow margins and are about the size of sesame seeds. These spots are uniform and evenly distributed over the leaf surface. Severe infections cause weakened and broken stems, damaged florets, and a reduced quantity and quality of grain. Yield reductions can vary from insignificant to 100%.

Sanitation and appropriate cultural methods are important parts of a program to control disease. Disease problems are reduced by the incorporation of crop residue into the soil after harvest, planting disease-free seed in new fields, using rotation crops resistant to brown spot or fallowing fields, and planting grass or other plants on dikes that are not alternate hosts. Barley and reed canarygrass are alternate hosts. Application of a balanced fertilizer can also reduce the severity of disease problems by avoiding nutrient deficiencies which can predispose plants. Higher plant densities than 4 plants/sq ft can also lead to more disease. Use of propiconazole (Tilt), a fungicide, may be necessary. Apply 6 oz/acre at the boot stage followed by an additional 6 oz 14 to 17 days later at early flowering. This fungicide is approved for use on wild rice in Minnesota.

Stem rot is the second most common disease in field-grown wild rice. Two fungi, *a Sclerotium sp.* and *Helminthosporium sigmoidium* Cav., may cause this disease. These fungi produce dark structures called sclerotia in culms, leaf sheaths, and stems. Sclerotia survive in infected plant debris or float in the water until deposited on the soil surface when paddies are drained. In the spring, sclerotia germinate and produce conidia (infective spores) that are spread by the wind or by sclerotia themselves, which can float to new plants and infect at the water level. Small, oval, purple lesions develop initially on stems or leaves at the water surface. Extensive lodging may result after the fields are drained prior to harvest, since the infected stems become necrotic, dry, and brittle. Control of stem rot is achieved most effectively by appropriate sanitation and cultural practices such as burning the residue. Plant residue must be removed or tilled into the soil, only clean seed should be used, and resistant crops or fallow should be in the rotation. There is no fungicide available for effective control.

Stem smut is caused by the fungus *Entyloma lineatum* (Cke.) Davis. Economic losses from this disease have not been a problem in cultivated fields.

Ergot is rarely found in cultivated fields of Minnesota, but can be a serious problem in natural stands. This disease is caused by the fungus *Claviceps zizaniae* Fyles, which is a different species than the one causing ergot in cereal grains. Wind-borne ascospores infect flowers and hard, dark sclerotia eventually develop in place of the grain. No specific control is recommended, but poisonous ergot bodies should be removed from harvested grain by flotation, or by screening.

Bacterial leaf streak caused by (*Pseudomonas syringae* pv. *zizaniae*) and *Xanthomonas oryzae*, as well as bacterial leaf spot (*P. syringae* pv. *syringae*) have been found in cultivated wild rice in Minnesota. The wheat streak mosaic virus-wild rice (WSMV-WR) is the only one known to infect wild rice. The eriophyid mite vector, *Aceria tulipae* Keif., which is commonly found on wild rice, retains WSMV-WR for several days and can be transported long distances by wind. Economic losses for grain yield, if any by these diseases, have not been determined. No control measures are known.

H. Insects and Other Pests:

The rice worm (*Apamea apamiformis* Guenee), which is the larval stage of the noctuid moth, is the most serious insect pest of wild rice in the Upper Midwest. Significant yield losses have been caused by this insect. Its life cycle is coordinated closely with the growth and development of wild rice. Adult moths begin to emerge at about the same time as flowering begins in wild rice during late June or early July. Nectar from milkweed flowers serves as the primary food source for adult moths through August. Eggs are deposited in wild rice flowers over a period of 4 to 6 weeks. Larvae hatch and develop through several instars or stages, and feed as they grow. Yield potential is reduced by the initial feeding activity on the glumes of the spikelet and subsequent feeding on kernels. Rice worms bore into stems of wild rice or migrate to plants that border the production area as their growth and development nears completion. Rice worms overwinter inside the stems in the seventh instar. After a final molt and some additional feeding in the spring, the larvae usually pupate in early June, and develop into the adult moth. Research in Minnesota found that one larva per plant reduces yield by 10%. Control of the rice worm has been effective with several insecticides; yet only malathion at one pound of active ingredient per acre is approved for use in Minnesota. Malathion should be applied 14 to 21 days after eggs become visible in the bracts at the base of florets. Control is only economical if there are 10 or more larvae per 100 panicles.

A number of midges use the flooded paddies for larval development. Eggs are laid in the moist soil and hatch when the fields are flooded. One of the midges, *Cricotopus spp.*, has caused severe damage to first-year fields. The mosquito-like adults are so small that most growers will not see them. Algal growth is associated with paddies showing high midge numbers. A slow emergence of seedlings results in greater damage by midges since it allows more time for feeding activity. The larvae feed on leaf edges and cause frayed leaf edges with subsequent curling of leaves. The leaf curling and webbing that midges produce will interfere with seedling emergence above the water. As a result, the damaged seedlings fail to reach the floating-leaf stage and the stand is thinned severely. Midge control with malathion is often necessary in first-year fields. In the following years control is not usually necessary since there is no economic loss. This is not the result of a lack of midges, which actually increase in number, but due to higher plant numbers so the damage goes unnoticed.

Rice stalk borers (*Chilo plejadellus* Zincken), rice water weevils (*Lissorhoptrus spp.*), rice leafminer (*Hy-*

drellia spp.), rice stem maggot (*Eribolus longulus* Loew), and other insects will feed on wild rice plants. Research in Minnesota did not reveal any economic injury from these insects.

Crayfish (*Orconectes virilis* Hagen) are carried into paddies by flood waters where they forage and may cut back the seedlings. Once crayfish are established in a field, they persist and can increase in number. They survive in production fields by burrowing into moist soil between periods of paddy flooding. Severe stand reductions have occurred in some fields in Minnesota. No chemicals are cleared for their control.

Blackbirds are a major pest. These birds use the paddy dikes as nesting sites and are present in large numbers in the growing areas. Birds begin feeding on wild rice when the kernels are in the milk stage. Control measures should start when blackbirds are first observed in the area. Numerous methods of bird management have been used by commercial growers. Shooting, carbon-dioxide guns or bangers, Av-Alarm records, and continuous overflights by aircraft have been tried or are now used by producers. Oats have been planted around the perimeter of fields to draw the birds away from the wild rice. Methiocarb (Mesurol) has been investigated as a chemical bird repellent, since it causes illness and conditions an aversion to wild rice. This repellent must be applied uniformly on hulls of wild rice grains to be effective. It is difficult to apply methiocarb uniformly to the grain under field conditions, which results in an inconsistent effectiveness in repelling birds. However, methiocarb has not yet been approved for this use. There is no method that has been completely effective in keeping blackbirds away from production fields.

Wild rice fields are also ideal sites for resting, foraging, nesting, and raising broods of migratory and resident water birds. Four species of ducks (mallard, pintail, blue-wing teal, and green-wing teal) and more than 35 species of shorebirds and wading birds inhabit wild rice paddies. Economic damage from waterfowl is rarely observed. Paddies are excellent areas for duck production.

Raccoon, mink, and skunk search for food on the dikes and in ditches. Deer and moose occasionally cause some damage in the fields, but it usually has no economic importance. Muskrats can cause problems by feeding on plants and by burrowing holes in the sides of dikes. However, since muskrats are not permanent inhabitants due to the annual drainage of the paddies for the harvest, they do not pose a threat to the dikes.

I. Harvesting:

Paddies should be drained gradually in late July and early August during grain fill. It usually takes about two to three weeks for paddies to drain and become dry, but will vary with soil type and if drain tiles have been installed. Drainage allows the soil to dry so it can support harvest machinery. Peat soils must be drained completely, although harvesting is possible on mineral soils with some standing water.

Maximum yields of processed wild rice are obtained when about one-third of the grain at harvest time is greenish brown or black, rather than green in color. The grain at this time has the consistency of firm dough and contains 35 to 40% moisture. This moisture content usually occurs when some of the seeds have fallen from the main stem, but very few have dropped from tillers on the same plant. Growers may not always be able to wait until this time to harvest due to imminent climatic conditions such as frost, high winds, and hail. Some paddies may need to be harvested early if enough combines are not available to do all the fields in a short time. The harvest of nonshattering varieties usually begins in early to mid-August.

Direct harvest with a combine is possible since shatter resistance and uniformity of maturation have been improved compared to the original lake types. Field conditions result in severe limitations of machinery that are not found usually in the harvest of other crops. High capacity combines are required to harvest wild rice because the plants are still green. Ground conditions are extremely wet even though fields are drained 2 to 3 weeks before harvest. The crop stubble provides little support for combines since wild rice is a poor sod former and the organic soils on which this crop is usually grown lose most of the fiber strength from tillage.

Growers have made innovative changes to various components of combines such as reels, grain divide points, draper systems, and track-type support systems. Reels seven feet or more in diameter are needed to allow the reel bats to enter the crop without pushing it forward. Extended bats on the reel and crop-divide points prevent the straw from wrapping around rotating parts of the combine. The pickup-type reel is considered necessary to reduce shattering since the bats remain parallel to the original position as they rotate. Reel tines should be adjusted to point downward or somewhat rearward to provide lifting action. This adjustment, which gives a positive pitch to the pick-up teeth, also prevents a pressing action on the crop.

A header equipped with a draper extension between the sickle and crossauger is used due to the height of wild rice plants. This extension provides a space in which plants fall before entering the crossauger and a "live" surface to assist in moving plant material to the crossauger. The divide point of combine grain header is usually modified to handle this crop. Larger and different divide points are used to avoid the hairpining of stems and accumulation of straw on the end of the header. Spike-tooth cylinders are effective for threshing heavy clumps of crop material. Rasp-bar cylinders effectively separate a large portion of the grain through the concave

concave rather than passing it to the walkers. Rasp-bar cylinders leave straw in larger pieces, which results in easier separation of straw and grain on the walkers and sieves.

The very soft soil of paddies requires an effective support system. Extensive support systems for combines range from conventional half-tracks with dual guide wheels to full-track systems with 45-in. pads bolted to each track shoe. Half-track systems are standard attachments for most combines. The addition of planking to reduce ground support pressure is fairly quick and easy to accomplish. This modification places the ground support pressure of paddy soils in the range of an individual's foot. A full-track system must be used in more difficult situations. Conversion to a full-track system is a major project that is usually done by the grower. Guide wheels are removed and the rear of the combine is mounted on a "walking beam" that is supported on the channel frames of the two tracks. The original steering and brake systems must also be changed since there are no guide wheels. A steering clutch is installed in the right and left drive shafts so the original steering and brake systems can continue to control these operations. The steering clutches require widening the track tread, but allow the use of wider pads on the tracks. Growers find it advantageous to have access to both half- and full-track combines. Half-track combines are used to open fields and harvest on firmer areas. Full-track machines are useful on soft ground where half-tracks cannot operate.

The height of the cut should be adjusted low enough to harvest most of the grain, yet high enough to reduce the amount of straw entering the combine. The peripheral speed of the reel should be 1¼ to 1 3/4 times the travel speed of the combine. Rethreshing wild rice with the tailings return in the combine is not needed. Any material that was not threshed in the first pass is still attached to the straw and passes out the discharge over the walkers. The sieves and air flow should be adjusted to allow only a small amount of material in the tailings-return.

Adjustment of the air setting is critical for the separation of grain and straw on the sieves. Excessive air flow will blow the lighter kernels out the rear of the machine, whereas a low air flow permits too much light, chaffy material to accumulate with the clean grain. Check the air passages often for plugging by plant material. The distribution of material on the walkers and sieves is examined by quickly stopping a combine that is operating normally by turning off the engine with the machine engaged and applying the brakes. Clumps of dense plant material on the walkers indicate an inadequate air flow. A problem may occur in unloading the grain from the combine due to the high moisture content. Kernels may interlock and cause a bridge in the grain tank. Growers remove obstructions in the grain tank to reduce bridging.

J. Postharvest Handling and Processing:

Freshly harvested grain has a moisture content of 35 to 45% and proper handling of the grain is necessary prior to drying to maintain grain quality by preventing heating and mold growth. Freshly harvested grain should be delivered to the processing plant as soon as possible. If the grain cannot be transported immediately, it should be kept cool by refrigeration or adding water and stirring. The expanded commercial production of wild rice has led to great changes in the processing sector of this industry. Before commercial production of wild rice began, there were many small processing plants located in the Great Lakes area that used a variety of homemade devices. Today, most of the larger processing plants are in Minnesota with additional ones located in California and southern Canada. Some of the newer plants are capable of processing more than 6 million pounds of wild rice during the several weeks of the harvest season.

Most wild rice is processed on a custom basis. Processing fees and the method of charging for this procedure vary. Some processors charge on a freshly harvested (green) basis and others on a finished (processed) basis. Charging for processing on a green basis is potentially disadvantageous to the grain owner since it gives processors little incentive to maximize the yield of finished grain. Alternatively, charging on a finished basis can penalize processors if grain yield is lower than expected. Processing charges range from 18.5 to 85 cents/lb of finished grain, with the average price being between 40 to 50 cents/lb. The wide range in processing fees is due to the variation in processing efficiency. Large operations can handle greater volumes than small plants, which will still process quantities as small as 100 lb.

The steps in processing involve the separation of immature kernels, fermentation or curing, drying or parching, hulling, scarification, cleaning, grading, and packaging. Fermentation is necessary to partially degrade the hulls to permit easier hulling, impart some of the characteristic flavor of wild rice, and change the immature kernels from a green to a brown color. Scarification removes part of the outer impermeable layer, which reduces the cooking time, so it is similar to that of rice. Uniformity of cooking times is important for wild rice and rice marketed as blends. These processing steps are common to all major plants with the exception of the separation of immature kernels and the packaging. Most plants store processed wild rice in 100 lb sacks in clean, dry warehouses. Several processors put wild rice in small packages and some make blends of wild rice and rice according to customer specifications. For more detailed

VI. Yield Potential and Performance Results:

One hundred pounds of unprocessed wild rice will usually yield 40 lb of processed grain. Yields of unprocessed grain from shattering types grown in paddies have ranged from 150 to 200 lb/acre. With shattering-resistant varieties, yields as high as 1,500 lb/acre of unprocessed grain have been reported in Minnesota. Average yields of varieties from experimental trials in Minnesota during 1981 to 1986 ranged from 1,078 to 1,613 lb of unprocessed grain per acre (Table 3).

VII. Economics of Production and Markets:

The cost of preparing a site for wild rice production will vary considerably depending on the amount of trees and brush that needs to be removed before ditching and diking. In addition, the amount of land leveling will vary. Preparation costs, which include the water pumping and control system can range from $500 to $1,500 an acre.

The cash production costs will vary for each field depending on the year of production. The cash costs for a new field are higher because of the initial seed cost which is about $80 an acre (40 lb/acre seed). However, there are added costs such as airboat thinning and more nitrogen fertilizer for second and third year fields. First year fields will often yield more, thus compensating for the increased seed cost. The cash costs for the first year are approximately $360 with a return of $508 (290 lb/acre of processed grain X $1.75). Some growers sell their grain before processing for about $0.60/lb giving a return of $435 (725 lb/acre X $0.60), thereby eliminating the processing cost.

The marketing system for wild rice consists of five major groups: harvesters and growers, buyers, processors, wholesalers, and retailers. Wild rice from natural stands is often purchased by buyers at the harvest site on a commission basis for a processor or wholesaler. Some buyers are brokers, while other buyers purchase the grain and process it themselves. Over 80% of the cultivated wild rice produced in Minnesota is marketed by three cooperatives: United Wild Rice, Minnesota Wild Rice Growers (MRG), and New Frontier Foods, Inc. They either sell unprocessed or processed grain directly to processors, wholesalers or food companies. Two major buyers are Busch Agricultural Resources, Inc. and Uncle Bens, Inc.

Wild rice was an expensive gourmet food when the only source was from natural stands. The growth of wild rice as a field crop coincided with the market expansion, which resulted in lower prices and a more consistent supply. Since 1968 the wholesale price of processed wild rice per pound has ranged from a low of $2.10 in 1987 to a high of $5.15 in 1978. Price variations between 1968 and 1977 were due to limited and erratic supplies from lake harvests and the initial years of paddy production. The high prices during 1978 to 1980 were due to attempts by marketers to withhold supply, and were short-lived since high prices encouraged increased production. Production expansion in Minnesota was moderate during 1978 to 1980, while in California, production doubled annually through 1981. High costs of grain storage forced the sale of stocks by 1981, and consequently, prices returned to market-determined levels. Production increased 26% each year between 1982 to 1984, yet markets were able to absorb this increase with only a slight drop in price. In 1985, California production more than doubled over the 1984 level, and prices have since declined sharply. In 1991 the price to growers for processed grain averaged $1.75/lb.

Markets for wild rice have expanded at a vigorous rate since 1978, especially during 1982 to 1984 when the demand increased 52%. Market expansion has been due in large part to the introduction of wild rice blends. Although the blends usually contain only 15% wild rice, they make up over two-thirds of the total sales of wild rice. If blends had not been introduced, perhaps the industry for field-grown wild rice would not have developed. Sales in the blend market have increased an average of 15% each year since 1961 when the first blend of wild rice, long-grain rice, and herbs was sold. Pure wild rice and blends have seasonal and geographic sales trends. Consumers purchase more pure wild rice in Minnesota than elsewhere due to a greater familiarity with this food, lower prices, and shipment out of the state as gifts. The demand for wild rice is expected to increase substantially in the future as prices stabilize and production expands.

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