Table 2. Effect of postemergence CDEC rates and amounts of water carrier 10 days after seeding on lettuce yields and weed control.

Water Carrier (gal/A)	CDEC (lb ai/A)	No. weeds/ 90 ft^2	Marketable (lbs)	No. heads harvested	Mean head wt. (lbs)	% Heads harvested
30	0	10	135.4	50	2.7	96
	2	7	141.7	50	2.8	98
	4	6	134.0	50	2.6	99
60	0	15	132.1	50	2.6	97
	2	7	133.9	50	2.6	99
	4	4	128.6	49	2.6	96
90	0	11	134.0	48	2.7	93
	2	7	137.6	51	2.7	98
	4	6	134.6	50	2.7	99
Sources of variation						
gal/A water		NS	NS	NS	*	NS
CDEC rate		*	NS	NS	NS	*
gal/A water x CDEC rate		NS	NS	NS	NS	*

*Significant at .05 level of probability.

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WILD RICE—A PROMISING GOURMET CROP FOR THE EVERGLADES[1]

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Additional key words. Zizania; aquatic crops; soil subsidence.

Abstract. **In our first paper on aquatic vegetable trials, we mentioned the possibility of growing wild rice on flooded Everglades farmlands, and it now appears that it may be especially desirable for rotation with vegetables, providing extra income for the farmer while permitting spring/summer flooding for pest control.**

Until 1960, this cereal was harvested from the wild, mainly in Minnesota, Wisconsin and Canada, except for a commercial "farm" in Manitoba. Successful efforts at domestication in the U. S. resulted in 900 cultivated acres (364 ha) in Minnesota in 1968 and 15,000 acres (6,073 ha) in 1980, with yields 4 to 14 times higher than those from natural stands, partly due to the selection of types semi-resistant to shattering.

Following lysimeter trials in 1977 and 1978, wild rice was field grown in small plots at the AREC-Belle Glade in 1979 and 1980. Several named selections received from the University of Minnesota were planted in February, March and April and immediately flooded to a depth of 2 to 8 in (5 to 20 cm). The grain generally was ready for harvest 70 to 75 days later, with yields ranging up to ca. 900 lb/acre (roughly 1,000 kg/ha) at ca. 9% moisture. In addition to problems such as bird loss, shattering and foliar diseases which are also observed in traditional wild rice growing areas, Everglades producers will have to acquire the equipment and knowledge needed for harvesting, processing and marketing. These requirements may not be unreasonable in view of the return that may be expected from this high-revenue, gourmet product.

Over 100,000 acres (40,500 ha) of organic soils in the Everglades Agricultural Area are fallowed each summer as part of the normal winter vegetable and sugarcane cultural system. Many growers flood this land to control soil-borne diseases and insects, and to improve soil tilth. Flooding also reduces microbial oxidation of the organic soils, the major cause of soil subsidence. Already in some places in the EAA there is insufficient organic soil over bedrock to support traditional crops, and this acreage will increase in the future (10). For these reasons, we are interested in crops which can be grown on flooded organic soils of the Everglades (5). Wild rice appears to be such a crop.

Botanical Identification

The wild rice famed as American Indian fare and as a gourmet accompaniment for wild duck and game meats has generally been identified in the literature as *Zizania*

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aquatica L. It is now clear that Linnaeus recognized and named two species, *Z. aquatica* and *Z. palustris,* though his distinctions were not accepted, were lost sight of, and then confused in the 1908 edition of *Gray's Manual.* In 1925, Linnaeus' two species were correctly discussed in the *Flora of the Cayuga Lake Basin, New York.* This publication received little notice in non-botanical circles and most writers reflected the single species concept until the appearance of William Dore's book on wild rice in 1969 (2).

In Dore's work, the typical northern wild rice ("lake rice"), inhabiting parts of rivers and lakes up to a 4-ft (1.2 m) depth across southern Canada from New Brunswick to Manitoba and in neighboring areas of the United States, is identified as *Z. palustris* var. *palustris.* Its slender stems rise 2 to 4 ft (0.6 to 1.2 m) above the water; the leaves are ¼ to ½ in (6.25 to 12.5 mm) wide; the panicle is slender and few-flowered—only 2 to 6 female florets (on the upper part) and usually less than 15 male florets (beneath) per branch. Seeds are relatively large but not many set per head.

Interior wild rice ("river rice"), *Z. palustris* var. *interior,* is shown as occurring naturally on muddy shores and in water to 1 ft (30 cm) deep along rivers in southeastern Manitoba and Ontario, but more plentiful in the North Central States of the U.S. It was long ago introduced into New Brunswick and Nova Scotia. Its stems are 4 to 8 ft (1.2 to 2.4 m) tall; leaves ½ to 1½ in (12.5 to 37.5 mm) wide; the panicle broad and branched, with 10 to 30 female florets and more than 30 male per branch. Seeds are shorter and plumper than those of var. *palustris* and produced in abundance.

Both varieties of *Z. palustris* are cultivated, and hybrids occur where they overlap in the wild.

Southern wild rice, *Z. aquatica* var. *aquatica,* native to muddy banks of streams from Quebec to southern Ontario and extending south to Louisiana and Florida (Colombia, Duval, Escambia, Levy, Marion, Sumter and Suwannee counties (8)); grows to a height of 8 ft (2.4 m) with stalks to 1 in (2.5 cm) thick at the base. Leaves are 1 to 2 in (2.9 to 5 cm) wide; the panicles 10 to 20 in (25 to 50 cm) long, much-branched, with numerous flowers, though many are sterile (up to 80%). The seeds are slenderer and thinner than those of northern wild rice.

(The name "southern wild rice" is sometimes given to *Zizaniopsis miliacea,* a marsh grass also known as giant cutgrass, ranging from Maine to Florida, Oklahoma and Texas.)

Estuarine wild rice, *Z. aquatica* var. *brevis* is limited to the tidal, freshwater flats of the St. Lawrence River where it is abundant over many miles. It is 1 to 3 ft (0.3 to 0.9 m) tall, with slim stalks, leaves under ½ in (1.25 cm) in width, and panicles 4 to 10 in (10 to 25 cm) long, sparsely branched, with few flowers. Blooming is earliest near the shore and progressively later away from the shore, so seed maturity extends over a long season. The seed kernels are relatively small and have never been exploited commercially.

Neither variety of *Z. aquatica* is cultivated as a cereal (2).

Harvesting of Wild Grain

Traditionally, northern wild rice for domestic use and for sale has been harvested from wild stands by American Indians, early white settlers and their successors in southern Canada and the northern U. S. (mainly Minnesota and Wisconsin), using canoes or flat-bottomed boats. Armfuls of heads would be bent over and tapped with sticks so that most of the ripe grain would fall onto stretched-out blankets. Because it is found in shallow water, interior wild rice can be harvested on foot, rapping the heads against the inside of the collecting bucket. However, in Minnesota it must by law be harvested by the canoe and flail method.

After return to shore and bagging, the wild rice was dried in the sun, or on a platform above a slow, smoking fire, or, better still, while being constantly stirred over a wood fire—to preserve it and loosen the hulls.

The hulls could then be removed by hand, by shaking in baskets, pounding in sacks, or by treading (jigging) followed by winnowing and fanning. The hulled kernels were then packed in birchbark, hide, or cedar containers for sale or storage (1, 3, 9, 11, 12).

In more modern times, home-made harvesting machines have been used on privately-owned lands in Canada but prohibited on crown lands, and the perishable grain has been conveyed out of remote areas by truck, railway or airplane to processing factories (2). Today in Minnesota natural stands not on American Indian reservations are controlled by the Department of Natural Resources. Anyone can harvest wild rice from these stands, but a license is required and harvesting is restricted to certain days. The canoe and flail method must be used for gathering the grain.

Domestication

In spite of protective measures by the federal governments of Canada and the U. S. and the states of Minnesota and Wisconsin, natural stands were seriously diminished by 1951 because of over-harvesting which steadily reduced the amount of seed falling to the bottom to germinate, and harvesting methods which caused unnatural shedding of immature grains which could not germinate (11). Seeds had been widely distributed into appropriate habitats by Indians for their own needs and by conservationists for the purpose of increasing stands to provide food for wildlife (2) (sowing by boat, raft or airplane); and a mechanized wild rice "farm" in eastern Manitoba, since 1917, was supplying Canadian and U. S. markets (12), but systematic cultivation as a cereal crop was not achieved in the U. S. until 1960 (7).

Successful domestication in Minnesota resulted in 900 cultivated acres (362 ha) in 1968 and 15,000 acres (6,073 ha) in 1980, with yields 4 to 14 times higher than the average 50 lb/acre (roughly 50 kg/ha) from wild stands, partly due to the selection of types with some resistance to shattering. In 1979, Minnesota produced 80% of the world supply; Canada 18%; and Wisconsin 2%. In 1979, Minnesota's annual crop was about 5.5 mill. lbs (2.5 mill. kg). The cultivated shattering types are harvested with a mechanical-picker, the less shattering by modified rice combines (7).

For the past 6 years, some rice growers in California have experimented with wild rice as an off-season crop in their irrigated rice fields in the Sacramento Valley. One grower, operating near Yuba City, has achieved per acre yields of 1,500 lbs (1680 kg/ha). In 1980, there were about 500 acres (200 ha) grown in California.

Cultural Requirements

Water: Wild rice seedling plants are completely aquatic and require free water at least 1 to 2 inches (2.5 to 5 cm) deep for development. However, if the water is too deep the seedling leaves are unable to reach the surface. This reduces or prevents formation of aerial stems and permanent leaves, which form from the base of the plant (2). Shallow water promotes tillering and good development of lateral roots, although weeds can become a problem in water less than 6 inches (15 cm) deep. Where water levels can be regulated, at least a 6 inch (15 cm) depth should be maintained during the early part of the season, but it can be lowered during grain filling so that the fields are well drained by harvest. Under natural conditions northern wild rice is usually found in water 2 to 3 feet (60 to 90 cm) deep, whereas interior wild rice does better in shallow water, not over 2 feet (60 cm) deep in the spring and diminishing to a few inches or less in mid-summer (2). Alkaline water in limestone areas is more favorable for development than soft water low in minerals. Optimum pH is between 7.5 and 8.0, although wild rice is grown in water with a pH of 5 to 6. Sulfate ion concentrations should be less than 10 ppm, even though wild rice can tolerate 20 to 30 ppm. Wild rice is occasionally found where the salinity level is 0.1755% or slightly higher (11).

Soil: Wild rice seems fairly indiscriminate as to soil type. It is found in waters with mud, sand, gravel or rocky bottoms, but generally stands are best in soft silt. Much of the cultivated wild rice in Minnesota is grown in peat soil. Although wild rice requires flooding for good germination and growth, adequate oxygen is necessary. "Aeration" of mud by the running feet of a moose has been seen to stimulate and enhance plant growth (2). The pioneer Manitoba grower claimed that the use of a paddle-wheel boat for harvesting served to "cultivate" the bottom, extend the distribution of the fallen seeds and improved quality and size of the grain (9).

Light: Wild rice prospers in full sun. Shade from other vegetation and the presence of surface algae or scum which prevent sunlight from reaching the bottom are highly detrimental (2).

Seed viability and storage: Wild rice seeds remain dormant for at least 3 months after maturity. The seeds steadily lose viability in storage unless kept moist and held at near-freezing temperatures. If the seed is to-be held more than 2 weeks before planting, it is scattered in moist sphagnum moss or sawdust and kept refrigerated between 30 and 35°F (−1.1 and 1.6°C) to avoid fermentation and molding. Some northern growers layer the seed in sphagnum or sand, box it, and leave the container submerged in a pond or stream over the winter. In Minnesota, for winter storage the seed is kept in perforated drums sunk in water-filled pits. If the seed is to be planted in the fall before freezing, it is kept above-ground in tanks filled with water which is changed every 2 to 3 weeks. Freezing the seed in water lowers the germination rate. In Canada, seeds of northern and interior wild rice kept outside in containers of frozen mud maintained full viability all winter, and viable seeds have been gathered in spring from the upper soil of riverbanks subject to extremes of freezing and thawing throughout the winter. Fully mature seeds encased in mud and placed under water over winter gave 100% germination in the spring. Dry seeds lose 55% viability in one month, 86% in 6 weeks and 99% in 7 weeks (2). Sundrying causes rapid loss of viability and leaving the seeds on the soil surface during winter is detrimental to germination (2, 7).

Natural Enemies, Diseases and Insects

Muskrats deplete wild rice stands by eating the tips of young seedlings. Seedlings are easily uprooted by strong winds and agitated waters or waves. A flood will erase an entire stand for a season. Red-winged blackbirds, bobolinks and sparrows feed on the mature grain and cause loose seeds to fall into the water (1, 11).

In the North, the ripening grain is attacked mainly by the wild rice worm, the larva of the noctuid moth, *Apamea apamiformis*. The wild rice midge, *Cricotopus*, chews on the young plants under water. Rice stalk borers, aphids, and leafminers are sometimes found in numbers. There are two serious diseases in Canada—ergot, *Claviceps zizaneae* (Fyles) Pantidou, and smut, *Entyloma lineatum* (Cke.) Davis, and some lesser fungal problems. Ergot has been found in the native stands in Minnesota but not in cultivated fields. Smut is of little concern. Helminthosporium leaf blight caused by *Bipolaris oryzae (H. oryzae)* and *B. sorokiniana (H. sativum)* makes minor inroads on wild stands but may devastate cultivated fields. Complete control is difficult. Four airplane applications of zinc ion-maneb complex at 2.25 lb/acre (2.25 kg/ha) have greatly reduced losses.

Helminthosporium sigmoideum and *Sclerotium* spp. may cause considerable stem rot in cultivated paddies. A bacterial streak (*Xanthomonas translucens* L. R. Jones, A. G. Johnson & Reddy) was reported in Minnesota in 1975. Leafspots are caused by *Mycosphaerella zizaniae* (Catt.) I. Miyake (2, 4, 7).

Low Weed Potential

Wild rice is not apt to become a weed problem in Florida because its ability to spread is limited. Seeds which fall when mature are not distributed by wind nor carried by currents but descend directly to the bottom and are anchored in position by their barbs or bristles. They are not carried away and dropped intact by birds because they are highly digestible (2).

Experimental Culture in Florida

Lysimeter Trials: Seeds received from the University of Minnesota were planted in a 4.5 x 9.0 ft (1.37 x 2.75 m) concrete tank of Pahokee muck soil at the AREC Belle Glade on February 11, 1977, at the rate of 35.6 lb/acre (40 kg/ha). The seeds were placed on the soil surface and a 2-3 in (5 to 7.5 cm) flood was maintained. Germination was noted over the next 2 weeks. However the seedlings often floated to the water surface because the emerging roots failed to anchor securely into the soft, loose soil. For this reason, the water was drained off and floating seedlings were pushed into the muck by hand. By March 18 the seedlings were better established and the tank was reflooded. At that time an apparent leafspot disease was noted. Three days later the wild rice was sprayed with a fungicide (Benlate). One week following the spray, the plants appeared improved and no disease was noted on newly emerged leaves.

On April 1 the plants were about 2 ft (60 cm) tall and some heads were present. Not all the grain ripens simultaneously. Hand-harvesting extended over a 2-week period (May 10-24) and yielded 256 lb/acre (288 kg/ha). After air drying, samples sent to the University of Minnesota were visually evaluated as equal in quality to grain produced in the North (Fig. 1). Although the tank was abandoned it was left flooded. By October 6, 1977 some apparent volunteer plants had developed and produced mature seed.

On February 20, 1978 another planting was made in one-half of the concrete tank, at twice the previously used rate. The seeds were surface-sown and a ½ to 1 inch (1.25 to 2.5 cm) flood was maintained until the seedlings were observed to be securely anchored. Then the water level was raised to 2-3 in (5-7.5 cm). By April 25 the wild rice was flowering. It was harvested from May 15 to June 1 and produced a total yield of 432 lb/acre (485 kg/ha).

Field Trials: In 1979 two plantings were made in the field using 4 selections received from the University of Minnesota: 'Netum', 'K2', 'Johnson' and 'Canadian'. The first planting was made in 4.1 ft (1.25 m) square, 12-inch (30 cm) deep plastic-lined boxes filled 6 inches (15 cm) deep with Pahokee muck, and buried 6 inches (15 cm) deep in a field planted to rice (*Oryzae sativa* L.). The seed was planted approximately 1 inch (2.5 cm) deep in rows 8 inches (20 cm)

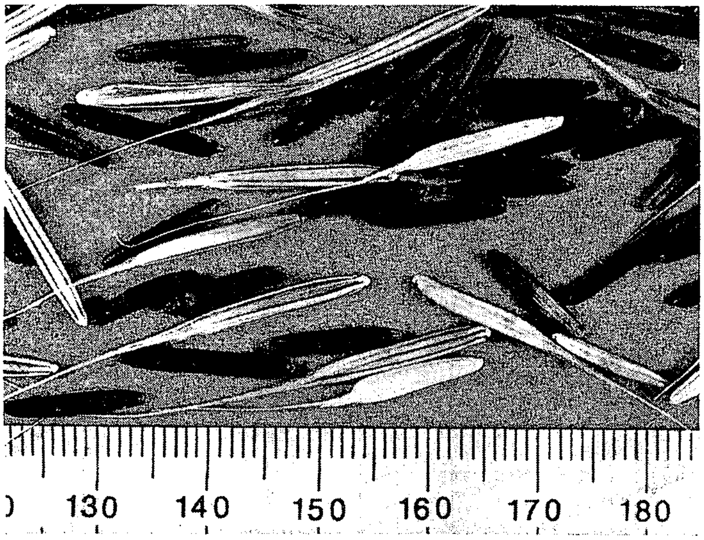

Fig. 1. Florida grown wild rice, of high quality, unhulled and hulled. Note the long awns which anchor fallen seeds in place. Hulling reduces harvested grain weight by 60%. (Scale in millimeters). Photo by AREC-Belle Glade.

apart with seed spaced approximately 1 inch (2.5 cm) apart in the row. This gave a planting rate of 111 lb/acre (125 kg/ha). Prior to planting, P, K, Mg, Fe, Mn, Zn, Cu, B and Mo were applied at 17.8, 89.0, 17.8, 8.9, 8.9, 3.6, 0.9, 0.2 and 0.2 lb/acre (20, 100, 20, 10, 10, 4.0, 1.0, 0.2 and 0.2 kg/ha), respectively. There were 2 replications. Hand harvests were conducted from May 4 to June 6. Total yields were: 'Johnson' 69, 'Netum' 30, 'K2' 20 and 'Canadian' 2 lb/acre (78, 39, 22 and 2 kg/ha), respectively.

On April 3, 1979, these 4 selections were field planted at ca. 1 inch (2.5 cm) depth, using 6-row plots 19.7 ft (6 m) long, spaced at 10 inches (25 cm). The moist seeds were mixed with twice their weight of oat seed (*Avena sativa* L.) and drill-seeded at 71 lb/acre (80 kg/ha). There were 2 replications. The area was immediately flooded to a depth of 3-4 inches (7.5-10 cm). A rather poor stand was observed in this planting. Although 1,800 seeds were planted per plot, the best plot contained only 41 plants. Harvests were made from June 13 to 21, 1979. Total yield for 'Johnson', 'Netum', 'K2' and 'Canadian' was 64, 38, 96, and 3 lb/acre (72, 42, 108 and 3 kg/ha), respectively.

These 1977-79 tests were conducted primarily to determine whether wild rice could be grown successfully in the subtropical Everglades. This question was answered in the affirmative, since well-developed mature grain was produced in all 3 years (Fig. 2). The yield figures probably do not reflect the actual potential of this crop since plots were small, no border rows were provided, and stands were thin.

Three field tests were conducted in 1980 (Fig. 3). Plots were similar to the 6-row plots used in 1979, and the same fertilization rate was used. Seeds freshly received from the University of Minnesota were placed in the furrow by hand at the rate of 83 lb/acre (93 kg/ha), or ca. 1 seed per 0.8 inch (2 cm) in the row; covered, rolled, and flooded. A 13-ft (4-m) section of the center 2 rows was harvested for yield over a period of 1 week (Fig. 4). Two selections ('Johnson' and 'Netum') were replicated 4 times. The results of these trials are presented in Table 1.

Although plant counts were not made, the stands of the March and April plantings were observed to be thinner than the excellent stand obtained in the February planting. This decline in stand, and subsequent decline in yield over the planting dates, probably was due to a decline in seed viability. No germination was observed in a planting made

Fig. 2. Two wild rice heads, partly shattered, and grain harvested at AREC, Belle Glade, May 15, 1980. Photo by Julia Morton.

on May 15, and seed placed on moist filter paper in a petri dish in early June failed to germinate. The seed was stored in water maintained at 45°F (7°C). An as yet unidentified leafspot disease was observed in all lysimeter and field trials.

All field trials required less than 90 days from planting to harvest (Table 2). In most cases, Florida-grown wild rice would be fully harvested before the September southward migration of bobolinks, but the crop might be vulnerable when these birds migrate northward in April-May.

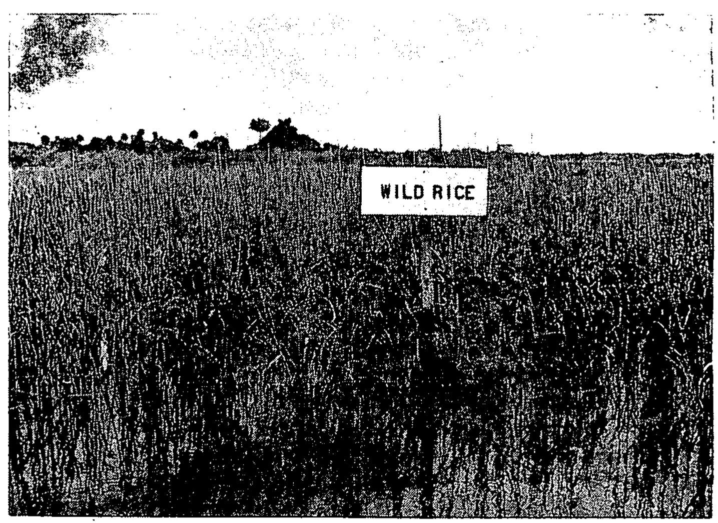

Fig. 3. Wild rice field-planting at AREC, Belle Glade, nearly ready for harvest. Photo by Julia Morton.

Fig. 4. Wild rice harvesting extends over a week or more; some heads are shattering or already bare while others are still maturing. The leafspot evident on these plants was observed in all lysimeter and field trials. Photo by Julia Morton.

Table 1. Planting and harvesting dates and yields (ca. 9% moisture) obtained in the 1980 tests.

Planting date	Harvest dates	Total yield 'Johnson'		'Netum'	
		lb/acre	kg/ha	lb/acre	kg/ha
Feb. 20	May 2, 5 and 9	714	803	942	1,059
Mar. 26	May 27, 30, June 3	224	252	251	282
Apr. 17	June 17, 18, 24	218	245	186	209

Table 2. Time from planting to harvest for the 5 field plantings.

Planting date	Mid-point of harvest	Elapsed days
Feb. 16, 1979[z]	May 15, 1979	88
April 3, 1979	June 18, 1979	76
Feb. 20, 1980	May 5, 1980	75
March 24, 1980	May 30, 1980	68
April 17, 1980	June 20, 1980	64

[z]Planted in frames buried in the field.

Needed Technology

Everglades producers will have to acquire the equipment and knowledge needed for harvesting, processing and marketing. These requirements may not be unreasonable in view of the return that may be expected from this high-revenue, gourmet product.

Processing and Packing

Modern processing is fairly simple. Freshly harvested wild rice has about 40% moisture. When delivered to the processing plant it is spread out in long piles (rows) about 2 feet (60 cm) deep and 3 feet (90 cm) wide. These rows of seed are mechanically stirred each day for a period of 7 days. Water is added daily to keep the grain moist. This step is called fermentation. It gives the grain a more uniform color and deteriorates the hulls for easier removal. During this period any slightly unripe (green) seeds will ripen and assume the normal purplish-brown or blackish hue. Then the grain is transferred to parching "ovens"—stationary drums with internally revolving arms, or metal cylinders rotating over heat—until it ceases to give off steam, but it must not be overheated. When dry (7% moisture) it can be stored without hulling, or it can be hulled immediately by two rubber rollers, one rotating faster than the other. An aspirator system removes the hulls after dehulling. The grain then proceeds over vibrating sieves or gravity tables for size separation; and it is finally bagged or packaged for marketing (2, 11). Unhulled, freshly harvested seeds weighing 250 lb (113 kg) will yield 100 lb (45 kg) of kernels (11).

Market Value

In a current mail-order catalog, wild rice from either Minnesota or California is offered at $15 per lb (0.5 kg). The Minnesota kind is described as relatively soft and cooking in 30 minutes; the California as being nuttier in texture and requiring 45 minutes' cooking. The California grower receives 90 cents per lb (0.5 kg) unhulled grain, wholesale. Minnesota farmers receive $4.00/lb ($8.80/kg) processed grain after paying $0.45/lb ($1.00/kg) for the processing operation.

Food Value

Wild rice affords double the protein of most cultivars of commonly grown rice. In northern wild rice, the protein content ranges from 11.79 to 16.39%. The average for wheat (*Triticum aestivum* L.) is 17.1%; oats, 16.5%. The 9 essential amino acids represent 45.1% of the total amino acids in wild rice; 32.1% in wheat. Wild rice has nearly twice as much alanine, arginine, asparatic acid, lysine and methionine as wheat; half as much cystine, glutamic acid and proline amino acids. Lysine content, 0.225 to 0.286 g/g N, is slightly higher than that of rice. Wild rice is a good source of thiamine, riboflavin and nicotinic acid (6, 13).

Our experience with wild rice in Florida has shown that a crop can be expected in less than 3 months after planting. For this reason, wild rice appears suitable for spring/summer rotation with winter vegetables in Everglades farmlands.

As the dietary value of wild rice becomes more widely recognized, cultivation is foreseeable in many appropriate areas in this country and abroad, and the grain will become more widely available at more reasonable but still "premium" prices. Further efforts should be made to determine its commercial feasibility in Florida.

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IMPORTANCE OF WATER CONTROL FOR TOMATO PRODUCTION USING THE GRADIENT MULCH SYSTEM[1]

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Additional index words. moisture gradient.

Abstract. **Limited field observations along with an understanding of the gradient-mulch system supports the concept that moisture—both level and control—could be a primary limiting factor in the functional efficiency of the system. Within a commercial tomato field, moisture gradient variations were associated with yields from 24 to 42 lbs/plant. The % moisture contained in the 0-2, 2-4, and 4-8 inch depths of the soil bed at Site A was 7.5, 10.5, and 14.8, respectively. Levels at Site B were 9.9, 12.2, and 18.3, and at Site C were 10.8, 12.9, and 19.0. Yields at Site B were 42 lbs/plant, 24.2 at Site A, and 31.6 at Site C. After rains, Site C tended to retain an excess of moisture whereas Sites A and B were relatively stable. The 42 lbs/plant or 1,960 30-lb units/acre reflects an intensity of production that is associated with the best in water use efficiency, as well as production efficiency.**

Concept

The gradient-mulch system has been presented as a sophisticated gathering of technology which can be used to increase production (2, 3, 4, 5). Most tomato growers in Florida now use a full bed mulch and average yields have increased about 60% to a level of 800 marketable units/acre (1). However, it is possible to attain yield levels of 2000/acre by exploiting the full potential of the concept (5). In order to identify limiting factors, the gradient-mulch system should be evaluated with relevance to the integration of the functional components.

Gradient-Mulch System

The system is designed to provide a minimal stress root environment, stabilized as such for the entire growing season. This is accomplished by placing a reservoir of nutrients at the soil bed surface with a constant water table serving as a moisture reservoir and covering with a full bed mulch (Fig. 1).

(A) *Nutrient gradient*: By this procedure it is possible to establish a range of concentrations decreasing gradientwise with distance from the surface source (3, 4, 5). The balance of ions contained in these gradients is altered by equilibration with both soluble and insoluble ions in the soil. The composition of the gradient is relevant to the composition of the applied fertilizer as well as the ionic components in the soil. Gradient steepness tends to be maintained by the upward movement of moisture. A variance in moisture movement can alter stability of the gradient.

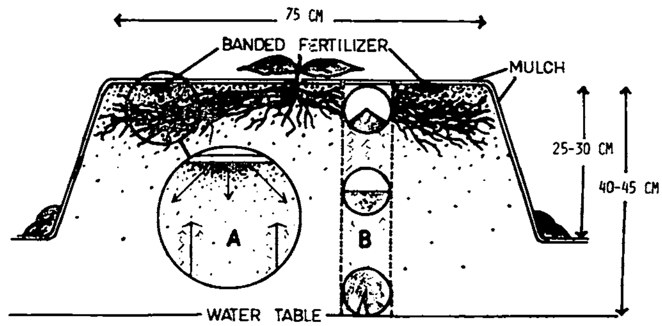

Fig. 1. Gradient-mulch system, minimal stress root environment. A. Nutrient gradient (3-dimensional). 1. Salts diffuse outward from level of highest concentration. 2. Salts move upward with moisture. B. Moisture-air gradient (2-dimensional). 1. Moisture movement upward.

(B) *Moisture gradient*: Moisture seeps upward from the water table providing a moisture/air ratio which increases gradientwise with depth. Moistures range from saturation (28-30%) in the subsoil to a minimal at the surface. A measure of the % moisture in the top 2 inches of the soil bed has been found to vary from 5 to 15% in research plots as well as growers' fields or portions thereof. Evaluation of such variations with regard to crop response has been rather broad and, for the most part, limited. Fluctuation of the water table during the growing season might change the direction of water movement through the soil profile and thus alter the composition of both the nutrient and moisture gradients.

(C) *Root environment*: Roots will develop in that portion of the soil bed where the most favorable increments (rootwise) of both gradients coincide.

Functional Design Concept

Nutrients removed by the root from the root environment are replaced by diffusion from the soil surface or by equilibration with ions distributed throughout the soil (3, 4, 5). Moisture similarly moves from the water table to replace that removed by the roots. When the system is functioning normally the root can obtain nutrients and moisture from one portion of the soil without significantly altering the composition of the soil solution (3, 4, 5). Thus, this design provides functional stability, theoretically, for the entire season.

The key to root environment stability is the constant water table. In Florida with periodic rains, a constant water

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