# A study of the growth of wild rice (*Zizania aquatica*) in Iowa

by

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# INTRODUCTION

Since wild rice (*Zizania aquatica* L.) is considered a culinary delicacy and a particularly good waterfowl food (Moyle, 1944), it is generally accepted as an asset wherever it grows and produces seed.

The primary purpose of this research project was to determine whether or not wild rice would grow in a variety of types of wetland areas of present-day Iowa. Another purpose of the study was to determine if the grain would overwinter and produce new plants the next year.

Also, I hoped to determine at least one environmental factor which could be used as a basis for predicting the suitability of a site for growing wild rice. In order to do this, I measured various parameters at two week intervals at each of several sites in central Iowa and compared the measurements to a figure representing the number and height of wild rice plants produced at each site. Finding such a predictable environmental factor influencing growth would save the expense of time, energy, and money which has been used previously in trial-and-error plantings.

# LITERATURE REVIEW

## History in Iowa

Shaw and Fredine (1956) reported that Iowa had 1,196,392 acres of wetlands in 1850. From 1906 until 1922, the wetlands area decreased from 930,000 acres to 368,000 acres; a decrease from 78 to 31 percent. By 1956, they reported that the wetlands had dwindled to 117,000 acres; 10 percent of the original wetland acres. The decrease was due to drainage yielding agriculturally productive land and impoundment making some wetlands into deep water areas. Either way, many sites were made unsuitable for growth of wild rice.

Records of populations of wild rice were evaluated by Beal and Monson (1954) in their review of the angiosperms of Iowa. They reported that wild rice had been found in 29 Iowa counties at various times. Herbarium vouchers exist at Iowa State University and the University of Iowa from 17 of the 29 counties. Those are from Lyon, Dickinson, Emmet, Clay, Palo Alto, Hancock, Cerro Gordo, Allamakee, Fayette, Sac, Hamilton, Hardin, Story, Linn, Johnson, Muscatine, and Ringgold counties. For the 12 other counties, Kossuth, Winnebago, Worth, Black Hawk, Clayton, Winneshiek, Harrison, Pocahontas, Page, Taylor, Decatur, and Woodbury, there are reports of wild rice but no herbarium vouchers. Other reports indicate wild rice in Wright (Pammel, 1908) and Louisa counties (Davidson, 1959).

The herbarium at Iowa State University has herbarium vouchers from 16 of the 17 counties reported by Beal and Monson (1954). Only Hancock County is not represented. Of the 22 collections from those 16 counties, 13 (over half) were collected before 1910, and six more were collected before 1930. In the 1930's two collections were made. From the 1940's there is one collection from a site artificially sown previously.

Following the report by Beal and Monson, two population vouchers have been stored in the Iowa State University herbarium. Both collections were made from Big Wall Lake in Wright County. One was made by Monson in 1956; the other by Riggins in 1969.

Since 1954, there have been a few other reports of wild rice, but no voucher specimens were found. Huggins (1968) reported wild rice at DeSoto Bend in Harrison County. Roosa (personal communication)[1] reported wild rice growing along the Iowa River in Hancock County in 1971. Also in 1971, Landers (personal communication)[2] reported wild rice present on the Simonson farm northeast of Ames, Iowa.

Over the past few years many attempts have been made to establish populations of wild rice in Iowa. The State Conservation Commission has been particularly interested and active in this regard. Plantings have not thus far been especially successful over a span of several years. For many persons, it has been a rather frustrating experience because at many of the sites there seems to be no evident reason for the failures.

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[1]Dean Roosa, Goldfield, Iowa. 1971.

[2]Dr. Roger Q. Landers, Department of Botany and Plant Pathology, Iowa State University, Ames, Iowa. 1971.

## Summary of General History

When Linnaeus named *Zizania aquatica* in 1753, "for centuries it had fed many tribes of wild men and for nearly 200 years had supplied the food wants of many European adventurers" (Chambliss, 1940). Chambliss (1922, 1940) relates how the Indians of Minnesota, Wisconsin, and Canada harvested the wild rice. During the growing season, they would survey the new crop noting its condition and evaluating the possibilities of good harvest sites. As the wild rice became mature, the Indians gathered for the harvest and a coinciding festival. When about one quarter of the potential grain yield was mature, the harvest began. Using canoes or narrow, flat-bottomed boats, the Indians moved gently through the populations of wild rice. Each boat contained two persons; one pushed the boat through the water, the other gently bent the stalks over the side of the boat with one hand while gingerly beating the heads of the grain with the other so that the mature grains fell to the bottom of the boat. Since all of the grains of each inflorescence do not reach maturity simultaneously, the Indians passed through the same area two or three times at intervals of about two to four days to complete the harvest. When the gathered rice was returned to the campsite, it was spread out on blankets and skins in the shade to dry off the excess water. Later the rice was dried completely by parching over a slow fire, and it was dumped into a hole lined with a clean animal skin. Then a young Indian "danced" or "jigged" on the rice to loosen the hulls. In some tribes, the grain was beaten by poles to remove the hulls (Moyle, 1944). Later, the hulls were separated from the rice grains, generally on a windy day. The hulls blew away as the mixture was thrown into the air, and the rice fell back into the container. There were some persons of the tribes who were skilled at separating out the hulls even on a calm day by special movements made in throwing the rice into the air and catching the grains. The wild rice was then stored to be used as food during the winter.

Moyle (1944) indicated that by 1944 these traditional methods of processing the grain after the harvest had been replaced by use of modern mechanical equipment. The new processing methods along with increased demand for wild rice among those who could not harvest the grain themselves influenced the Indians to increase the harvest beyond that needed by the tribes for food. Since the demand is generally much greater than the supply, the Indians, the processors to whom they sell, and retailers get rather high prices. In some areas, particularly Minnesota, wild rice is currently being grown on private land in artificial paddy impoundments to make it more available. In 1970, 7,000 acres of wild rice were grown in the paddies of Minnesota (Smith, 1971). At the University of Minnesota a type of wild rice plant has been developed which retains the earlier maturing grains until all are mature (Oekle and Brun, 1969). When this is generally available, one of the main harvesting problems should be alleviated.

Along the Atlantic Coast and in the southern part of the United States, wild rice is generally not harvested due to the small size of the grains and the poor percentage of seed set.

## General Description of Wild Rice

*Zizania aquatica* L. is an annual aquatic species of the grass family (Chambliss, 1940; Dore, 1969; Fassett, 1956; Hitchcock, 1935; Moyle, 1944;

Oelke and Brun, 1969). Its most frequent common name is wild rice, but it is also known as Indian rice, Canadian rice, water oats, water rice, tuscarora, and manomin (Dore, 1969). Chambliss (1922) indicated that it is also called squaw rice in the northern areas and marsh oats in the southern areas of the United States.

Wild rice is found growing wild in the northern United States, southern Canada, along the Atlantic coast in the United States and along the coast of the Gulf of Mexico from Florida to Louisiana (Chambliss, 1940; Fassett, 1956; Hitchcock, 1935). In Canada, the range is from southern New Brunswick west to southern Manitoba. In the United States, the natural range in the north is from Maine west to North Dakota, then south to Nebraska, Missouri, Illinois, Indiana, Michigan, and New York.

Wild rice grain can be sown in the fall since it survives well when submersed in water through the winter (Dore, 1969), or it can be sown in early spring (Oelke and Brun, 1969). The time of germination depends on the location. In the Washington, D.C. area germination occurs in early April (Chambliss, 1922). In northern Minnesota and Canada seeds germinate from late April to the middle of May (Chambliss, 1940; Oelke and Brun, 1969). Grains which are planted later in the year germinate soon after they are sown if they were properly stored. In natural stands or established plantings, grains which mature during the growing season fall into the water and become the source of plants the following growing season.

The 11 or 12 leaves produced by each plant are of three types: submerged, floating, or aerial (Weir and Dale, 1960). These authors found that the leaf type and the number of each depended upon the water depth.

When no standing water was present, they found only aerial leaves. As the water depth increased, more submerged and floating leaves were produced. Weber and Simpson (1967) reported that plants grown in water with a level decreasing throughout the growing season matured sooner than those grown at a constant or increasing water level. Moyle (1944) indicated that shorter plants matured earlier.

A study of wild rice development by Weir and Dale (1960) provided an extensive description of leaf anatomy. The submerged leaves have little supportive tissue, but a large amount of air space keeps them suspended in the water. They are thin and ribbon-like and yield to the movement of the water. There is no cuticle over the leaves and there are no stomates. The midrib is inconspicuous. The epidermal cell walls are smooth rather than wavy. The floating leaves, which are generally produced in May and June (Moyle, 1944), have more supportive tissue. The midrib is more conspicuous. The leaves are thicker and long enough to float on the water surface. The upper surface has a cuticle which repels water allowing the leaves to remain afloat. The cells of the upper epidermis have wavy cell walls and are interspersed with stomates. Portions of the upper epidermis are thickened and look somewhat like blisters. The lower epidermis is much like that of the submerged leaves. As the floating leaves appear, the wild rice plants become subject to dislodging. If heavy wave action develops, the plants are pulled out by the roots and float away. Chambliss (1940) reported that often many acres of wild rice have been destroyed in this way. The aerial leaves generally appear in June (Dore, 1969) or July (Chambliss, 1940; Moyle, 1944). As is common in grasses, the lower part of the leaf (the sheath) surrounds the stem. Chambliss (1940) indicated that this particularly strengthens the stem once it is above water. The upper part of the leaf (the blade) is flat and narrow, from 0.3 to 1.2 m long (Chambliss, 1922). The leaf blade varies in width from 0.5 to 6.0 cm. Anatomically, the aerial leaves are much like those of terrestrial grasses in having stomates, a covering of cuticle, relatively small amounts of air space, and a great deal of supportive tissue. The midrib of the blade is prominent and off-center. There are siliceous epidermal hairs along the edge of the leaf. The epidermis of the upper surface is much like the upper surface of the floating leaves, including the blister-like thickenings.

The height of wild rice plants depends on the extent to which the internodes lengthen (Weir and Dale, 1960) and varies from 0.6 to 3.0 m (Dore, 1969). In deep water, the internodes generally lengthen more than those of plants growing in shallow water; therefore, plants in deeper waters are most frequently taller than those of shallow water (Weir and Dale, 1960). The hollow, buoyant stems are divided by thin partitions at several places between the nodes. These allow the passage of gases but not water, apparently acting as air locks. Thus, in case of a break in one part of the plant the inner stem is protected from being filled with water because the partitions allow water to enter only part of the stem (Dore, 1969). Plants can grow up to five or six branches called tillers (Moyle, 1944). The tillers do not grow as tall as the main stems (Dore, 1969).

Relatively little is reported on the roots. Oelke and Brun (1969) stated that a single root is produced as the seed germinates. Later, roots arise from the lower nodes of the stem (Dore, 1969). The many fibrous roots do not grow deeply into the substate (Chambliss, 1940; Dore, 1969). Dore (1969) stated that root hairs are absent in wild rice.

Chambliss (1940), Dore (1969), Hitchcock (1935), and Moyle (1944) have described the flowers and pollination biology. Flowers appear in late July or early August in a terminal panicle arrangement growing through the sheath of the last leaf. Pistillate flowers on stiff, ascending branches appear first and are ready to be pollinated because the lemma and palea (which together are later termed the hull) have separated slightly allowing the feathery stigmas to protrude. After pollination, the stigmas are withdrawn and the palea and lemma again close tightly. The staminate flowers appear later since they are below the pistillate ones on the stem and remain enclosed in the sheath of the last leaf as the pistillate flowers appear. The drooping staminate flowers grow on spreading branches. The lemma and palea enclose six bright yellow stamens. Wild rice plants are usually cross pollinated since the pistillate flowers of an inflorescence have generally been pollinated and the stigmas withdrawn before anthesis of the male flowers on the same plant. However, some flowers of an inflorescence may be self-pollinated since the stigmas of the lower pistillate flowers may remain receptive to pollination until after pollen from the upper staminate flowers is released.

After pollination and fertilization, the rather tiny ovule (Chambliss, 1940) begins to develop and reaches maturity in approximately 10 days (Moyle, 1944). At maturity the embryo extends the full length of the dark brown grain on the side next to the lemma. When mature, the grains which range from 8 to 18 mm in length, are dislodged from the plant each with its surrounding lemma and palea. Dore (1969) indicated that the stiff hairs on the long awn of the lemma help to dislodge the grain since they catch on other parts of the plant and put pressure on the joining point between the grain and the pedicel. These bristles may also help the seed to lodge in the substrate (Chambliss, 1940).

In order to keep grain viable through the winter, it must be kept cool and wet (Chambliss, 1922; Dore, 1969; Moyle, 1944). To prevent fermentation and to break the dormancy period, temperatures must be maintained close to freezing. Seed which is left at the growing site will naturally be under these conditions since it falls directly through the water to the substrate. Chambliss (1922) suggested keeping grain which has been harvested to plant at other sites in cold storage or in large, tightly covered cans which have small holes for water circulation and have been securely fastened to the bottom of a stream in enough water to cover the rice well. Moyle (1944) suggested placing the rice in double burlap sacks surrounded by wire mesh to prevent destruction by muskrats, then submerging it in a lake.

## Taxonomy Review

Fassett (1956) separated *Zizania aquatica* L. into four varieties: *Z. aquatica* var. *aquatica* L., *Z. aquatica* var. *angustifolia* Hitchc., *Z. aquatica* var. *brevis* Fassett, and *Z. aquatica* var. *interior* Fassett. He separated var. *aquatica* from var. *angustifolia* and var. *interior* by using characters of the lemma and palea. The pistillate lemmas of *Z. aquatica* var. *aquatica* are "thin and papery, dull," (Fassett, 1956) and roughened over the entire surface. The sterile florets are thread-like. The pistillate lemmas of the other two varieties are "firm and tough, straw-like," (Fassett, 1956) and are smooth except for the roughened nerves. The sterile florets are flattened. The other two varieties are separated by other morphological characters. Z. aquatica var. angustifolia generally is a smaller plant, 0.7 to 1.5 m with much narrower leaves, 4 to 12 mm, and shorter ligules, 3 to 5 mm. The lower pistillate branches have two to six spikelets, and the lower to middle staminate branches have one to fifteen spikelets. The grains of this variety are generally larger than those of the other varieties (Moyle, 1944). Z. aquatica var. interior grows from 0.9 to 3 m tall. The leaves are from 1 to 4 cm wide with ligules from 1 to 1.5 cm long. The lower pistillate branches have 11 to 29 spikelets, and the lower and middle staminate branches have 30 to 60 spikelets.

Z. aquatica var. aquatica grows along the Atlantic coast and inland to northern Indiana and eastern Wisconsin. Z. aquatica var. angustifolia grows in southern New Brunswick south to northern Massachusetts, then west to northern Minnesota and northern Indiana. Z. aquatica var. interior grows from Indiana and southern Minnesota to Nebraska and Texas.

The fourth variety Z. aquatica var. brevis Fassett grows in estuaries along the St. Lawrence River. The plants of this variety are from 0.2 to 1.0 m tall with narrow leaves from 3 to 9 mm wide. The lemmas of the pistillate flowers are much like those of var. aquatica; however, the awn is much shorter, approximately 1 cm, and the grains are smaller.

Dore (1969) explained that at times the varieties may be difficult to discern. When var. interior is crowded, the plants produce shorter stems, narrower leaves, and fewer grains; thus, var. interior may appear to be var. angustifolia.

## Environmental Requirements

Frequently chemical characteristics of water along with water depth and movement are mentioned in descriptions of conditions favorable for wild rice growth. Moyle (1944) maintained that the water must be clear and can vary from 0.3 to 0.9 m deep at the start of the growing season with less than 0.15 m change in level throughout the summer. Dore (1969) stated that wild rice will grow in water which is as shallow as 2.5 cm but no deeper than 0.6 m at the beginning of the growing season. The alkalinity should be greater than 40 ppm (Moyle, 1944). Stoddard (1957) stated that alkalinity should not be greater than 200 ppm. He also advocated that the water must have a pH of 6.8 to 8.8. The water should not have an amount of salt which can be tasted (Dore, 1969; Chambliss, 1922). The water also should contain neither certain sewage and industrial wastes which kill all aquatic plants nor detergents to which wild rice is apparently sensitive (Dore, 1969). There should be some amount of current over the site (Moyle, 1944).

In addition to water quality, substrate characteristics have been included in describing favorable sites for wild rice growth. Moyle (1944) recommended at least 0.15 m of organic soil which contains some calcareous material. The soil should be low in available potassium and phosphate and have a pH approaching neutrality (Stoddard, 1957). Dore (1969) found that wild rice plants appear more commonly in areas with heavy deposits of sediment which have buried any perennial plants present, thus eliminating competition which wild rice does not generally survive. Such sites are commonly found at inlets and outlets of shallow lakes and in rivers with extreme spring flooding which subsides during the summer season. Dore (1969) and Chambliss (1922) claimed that the soil type is of little importance and can be mud, sand, or gravel so long as the substrate has sufficient dissolved oxygen and there is an opportunity for roots to establish adequate support for the plants.

Even though wild rice generally grows in water, some authors maintain that the nutrients used by the plants come from the sediments instead of the surrounding water. This is intuitively evident based on the fact that wild rice plants grow well even without standing water (Thomas and Stewart, 1969). No studies on the source of nutrient uptake have been made using wild rice; however, valuable information comes from studies of other rooted aquatic plants. Peltier and Welch (1969) compared the growth of *Potamogeton pectinatus* L. in sediments with the growth in sand. The study involved adding graduated amounts of nutrients to each substrate. They found that the sediments were the source of nutrients. They indicate, however, that more research is needed before the relative importance of sediment nutrients, light, and temperature can be determined. Boyd (1967) says, "It appears likely that the roots of aquatic plants play an important role in mineral uptake; however, this role probably varies greatly in magnitude between species and environmental conditions."

Further information concerning nutrient requirements is available from studies of plant growth after the addition of nitrogen, phosphorus, and potassium. Rogosin (1957) showed that the yield of grain on shattering wild rice was increased by adding a fertilizer of 60 percent nitrogen, 20 percent phosphorus, and 20 percent potassium. Smith (1971) claimed that in fertilizing experiments using nonshattering wild rice plants no significant differences in height, tiller number, flag leaf weight, potential floret number, percent sterility, and lodging were found when phosphorus or potassium were added. In addition, there was no significant difference in yield (grams per 0.83 sq m) with added potassium. However, he found that increased nitrogen quantities produced plants which were taller with larger leaves and had larger heads of grain exhibiting increased sterility. Because the plants grew larger, Smith concluded that they could be blown over more easily, thus reducing the crop if a wind storm occurred between the time of heading and harvesting. If no wind occurred, there was generally a greater yield, particularly since larger heads were produced even though the sterility percentage was high (Smith, 1971). In addition, infestations of wild rice worm reduced yield of these larger plants destroying a greater percentage of the larger heads (Smith, 1971). Smith postulated that this was true because the larger heads had a larger number of florets for egg deposition. In conclusion, Smith made no specific fertilizer recommendations due to the inconclusive results he obtained.

## Special Considerations in Planting Wild Rice

In reference to time and techniques of sowing grains, there are several conflicting views. Dore (1969) and Chambliss (1922) both recommended spring sowing so that diving ducks would not eat the grains before they germinated.

Dore (1969) claimed that besides being more convenient, spring sowing prevents seed from being covered by sediments deposited by spring floods. Spring planting could, however, be delayed for the same reasons that spring work can be delayed for other crops (Smith, 1971). In rice paddies where flood-deposited sediments are of little concern, Smith maintained that fall planting is better, especially if the seed is covered by soil. Fall seeding eliminates the need to store the seed through the winter under artificial conditions which usually reduce the viability. Burying the seed prevents loss to birds and helps prevent "floaters," rice plants which do not root into the soil. Following fall planting, Smith recommended fall flooding for several reasons. 1) The seed is kept moist, so that in a cold, dry winter it would not lose viability. 2) The water may be more available in the fall. 3) The numbers of floaters are further reduced.

Smith (1971), in his experiments using nonshattering wild rice, further found that the density of the planting is important. He recommended one to three plants per square foot. Under these less dense conditions the plants have the most grain per unit of dry matter, nutrients are conserved, and there is increased light penetration for photosynthesis (Smith, 1971). Also there is greater air circulation which dries the plants earlier in the day thus limiting the amount of time when plants are most susceptible to disease invasion. For regular (shattering) wild rice, Chambliss (1922) maintained that branching in less dense stands may produce uneven grain maturation which would be an advantage in attracting and feeding wildlife but a disadvantage if the wild rice was to be harvested.

There are at least two problems in growing wild rice inherent in the plant itself--sterility and shattering. The problem of shattering has been solved by workers at the University of Minnesota since they have developed the nonshattering strains (Oelke and Brun, 1969; Smith, 1971). These strains retain matured grains instead of dropping them as soon as they are ripe. The problem of sterility of the pistillate florets is particularly disconcerting because it increases as the size of the panicles of grain increase. Thus, whereas one might expect larger yield, the yield may actually decrease. Smith (1971) maintained that flowers of larger panicles showed increased percentages of sterility due to the fact that the wind-carried pollen did not reach the stigmas of the florets located in the center of the inflorescence because pollen entry was blocked by layers of outer florets.

Besides problems inherent in the plants, problems arise as animals destroy plants and consume grain. Muskrats cut off the plants at the waterline and eat them. They can be eliminated by trapping and selling the furs to create additional income from the property. Red-winged blackbirds can be chased away by putting up the eye-catching, twirling, flashing metal devices used by gasoline stations and car dealers (Stoddard, 1957). In cases where the wild rice is meant for human use, perhaps waterfowl can also be frightened away by the devices. The presence of carp in the area is a liability because they stir up the bottom sediments and increase the turbidity of the water (Dore, 1969). The larval stage of rice worm (*Apamea apamiformis*) can cause major destruction of wild rice beds. Dore (1969) recommended spraying with an insecticide at flowering time before eggs and larvae become protected by the hulls. Smith (1971) stated, however, that insecticides have not been approved for use on wild rice in Minnesota. Perhaps use of early maturing strains of wild rice could solve this problem since earlier maturing plants tend to escape rice worm damage.

Another problem is the diseases, such as ergot, smut, stem smut, leaf spot, and culm rot caused by various fungi. Leaf spot can be controlled by burning the remaining plant material after harvest--with due regard for not setting peat afire also--or the plant material can be plowed under (Oelke and Brun, 1969).

Another cause of crop failure can be exclusion of wild rice by competition of perennial plants. Oelke and Brun (1969) advised rototilling the areas after harvest to control cattails (Typha spp.). Other plants can be controlled by keeping the water at least 0.15 m deep (Oekle and Brun, 1969).

Also, certain environmental conditions are a hazard to a wild rice crop. Long periods without rain can cause the water level to decrease below that necessary to maintain the plants. In cases of rapid increase or decrease in water level, plants can become dislodged or may fall over due to lack of usual support (Dore, 1969). Violent storms with heavy waves and winds can dislodge plants or drown the aerial part. Hail can also be the cause of crop loss (Stoddard, 1957).

Finally, people can cause damage to wild rice populations. Indirectly, their motor boats can cause waves which dislodge plants (Dore, 1969). When plantings are made on public property for the purposes of attracting waterfowl or muskrats, the crop may be taken by people for food.

# METHODS AND MATERIALS

## Growth Plots

To observe the growth of wild rice, grain was planted in 1 m square plots constructed of fiber glass screen supported by 2.5 by 5.0 cm pine boards each 1.2 m long. The screen was attached to the boards by wire cloth staples. The bottom of the screen was worked into the substrate to a depth of approximately 5.0 cm for two reasons. 1) If the rice did not grow in a given plot, it was known that the rice seed planted there did not move to another site; and 2) this prevented seed intrusion from any other area.

The growth plots were located at various sites in central Iowa. The 1971 sites were Spring Lake, Greene County; Hendrickson's Marsh, Story County; Hickory Grove Park, Story County; tertiary treatment ponds, Ames Municipal Sewage Treatment Plant, Story County; Big Wall Lake, Wright County; and Little Wall Lake, Hamilton County. These locations included an abandoned quarry, a deep artificial lake, a shallow artificial marsh, and a dredged lake. The 1972 sites were expanded to include a gravel pit in Wright County near Big Wall Lake and the Kimberley and Smith farm ponds, Story County, in addition to the 1971 locations.

The grains used for planting were collected from Big Wall Lake, Wright County, and purchased from Wildlife Nurseries, Oshkosh, Wisconsin. They were scattered over the surface of the water in the plots and sank directly to the substrate as long as there was no obstruction. In 1971, all first plantings took place in early June. Replanting was done in early July at Little Wall and Hickory Grove Lakes. To test the ability of the wild rice to survive through the winter and produce plants the following year, fall plantings were made at the Big Wall Lake site and at two sites in Hickory Grove Lake. At Little Wall Lake, grain which fell from the 1971 plants remained on the substrate over winter. It should be noted that this seed was subject to drying and freezing since there was no water at the site. In 1972, plantings were made from April into July.

In 1971, the visits to sites to check growth were made approximately every two weeks starting in June and ending in November. In 1972, visits were made monthly in April and May and at two week intervals from June into October.

The height of the plants was measured from the base of the stem to the highest point of the inflorescence after the staminate flowers had emerged.

## Water Analyses

While in the field, temperature and depth of the water were measured. Also, water samples were taken approximately 10 cm below the water surface. The pH was measured from these samples in the field in 1972. The water samples were taken back immediately to the laboratory.

Upon returning to the laboratory, analyses were made for phosphate, turbidity, pH, ammonia, nitrate, nitrite, sulfate, chloride, and hardness. Phenolphthalein alkalinity and total alkalinity were added parameters analyzed during 1972. In 1971, some samples were frozen for later analyses of some parameters. In 1972, most samples were analyzed the same day. In the few cases when a slight delay was unavoidable all tests were completed within 24 hours of the time the samples were taken.

For turbidity determinations, the Hellige Turbidimeter was used. The average of three readings was compared to the graphs accompanying the turbidimeter to determine the amount of silicon dioxide to be suspended in the water to produce the same readings.

Two different methods were used in determining pH. In 1971 the samples were brought back to the laboratory where the pH was measured on the Beckman Zeromatic II pH meter. In 1972, pH was measured at the sites on a Leeds and Northrup 7417 pH/specific ion/mV field meter.

The remaining factors were measured using the methods outlined by Hach Chemical Company, Ames, Iowa, in their manual Water and Wastewater Analysis Procedures (Catalog No. 10, October 1968): Phosphate, ammonia, nitrate, nitrite, and sulfate were measured on a Hach DR (direct reading) photoelectric colorimeter which determines the amount of color change in a sample after adding specified reagents. Chloride, hardness, phenolphthalein alkalinity, and total alkalinity were measured by using titration methods.

## Soil Analyses

Soil samples were taken at each plot to a depth of approximately 20 cm. After these samples were air dried in the laboratory, a portion of each was sent to the soil analysis laboratory at the University of Wisconsin, Madison, Wisconsin, for determinations of pH, magnesium, manganese, potassium, organic matter, calcium, nitrate, and phosphorus.

The procedures used in the soil analyses are generally more complex than those used in the water analyses. The procedures used are described in the manual: Wisconsin Soil Testing and Plant Analysis Procedures by Schulte and Olsen, 1970.

# RESULTS

Before looking at results of data collections, I would like to emphasize that the conditions inside the plots might in some cases differ from those outside the plots. The screens cast shadows over the site, especially during early morning and late afternoon hours, thus reducing light intensity considerably. They also confine algae and other plants either inside or outside the plot. Because the current is retarded, chemical parameters within the plots could be different from outside waters since parameters might build up or decrease rather than be continually changing. Plantings in the surrounding area, therefore, might not give the same results as those inside the plots. However, experimental studies such as these give indications of results one might obtain in varied field situations. In interpreting the results and applying the information to new areas, one must duplicate the factors critical for growth.

Results of the measurements of various parameters are recorded in this section. Table 1 shows the number of stalks, the average height reached by the plants, and the amount of growth index. The amount of growth index for each site was established by multiplying the number of stalks at each site by the average height of the stalks. This was done because height alone would diminish the importance of plots with large numbers of small plants, and the number alone would favor the importance of many, short stalks over a few, large stalks. The data in Table 1 are presented in decreasing size of the amount of growth index produced in 1972. Due to the difficulty in counting the larger numbers of stalks, those counts are approximate.

Table 1. Number of stalks of plants within various populations, the average height of the plants, and the calculated amount of growth index for 1971 and 1972

| Location | Site no. | 1971 No. of stalks per $m^2$ | 1971 Av. height m | 1971 Amount of growth index | 1972 No. of stalks per $m^2$ | 1972 Av. height m | 1972 Amount of growth index |
|---|---|---|---|---|---|---|---|
| Little Wall Lake | 1 | 80 | 1.5 | 120.0 | 100 | 1.5 | -[a] |
| Little Wall Lake | 1 | -[a] | -[a] | -[a] | 75 | 2.5 | 337.5 |
| Hendrickson's Marsh | 1 | 25 | 0.4 | 10.0 | 100 | 2.2 | 220.0 |
| Hendrickson's Marsh | 2 | 0 | 0.0 | 0.0 | 100 | 2.2 | 220.0 |
| Big Wall Lake | 2 | 0 | 0.0 | 0.0 | 100 | 1.6 | 160.0 |
| Gravel pit | 1 | -[b] | -[b] | -[b] | 100 | 1.5 | 150.0 |
| Hickory Grove Lake | 1 | 100 | 1.0 | 100.0 | 25 | 1.7 | 42.5 |
| Smith Farm | 1 | -[b] | -[b] | -[b] | 60 | 0.7 | 42.0 |
| Spring Lake | 2 | -[b] | -[b] | -[b] | 30 | 1.3 | 39.0 |
| Twin Anchors | 1 | -[b] | -[b] | -[b] | 35 | 0.8 | 28.0 |
| Spring Lake | 1 | 6 | 0.4 | 2.4 | 25 | 0.9 | 22.5 |
| Hickory Grove Lake | 2 | 34 | 1.2 | 40.8 | 2 | 1.5 | 3.0 |
| Tertiary treatment | 1 | 4 | 0.5 | 2.0 | 0 | 0.0 | 0.0 |
| Tertiary treatment | 2 | 3 | 0.5 | 1.5 | -[b] | -[b] | -[b] |
| Tertiary treatment | 3 | -[b] | -[b] | -[b] | 0 | 0.0 | 0.0 |
| Little Wall Lake | 2 | 7 | 1.7 | 11.9 | -[b] | -[b] | -[b] |

[a]Information for 1972 is based on data from two groups of plants.

[b]Indicates unplanted sites.

Other characteristics and measurements given in Table 2 include planting and blooming dates, average seed weights, average seed lengths, average number of female florets on the lower branches, and percentage of seed set (not percentage of mature grain). In addition, the average height of the plants is presented again so that comparisons between height and the other measurements can be easily made. There are two entries for Little Wall Lake, Site 1, because the plants had two distinctly different maturation times and resulting average plant sizes. The plants from grain overwintering at this site were shorter and matured earlier than those from grain planted at the site in the spring. Information from the Smith farm is missing because muskrats destroyed the crop before it could produce mature grain.

The results of analyses of water samples are shown in Table 3. Turbidity is given in parts per million equivalent to the amount of silicon dioxide causing the same amount of turbidity. Other parameters given in parts per million are orthophosphate, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, sulfate, and chloride. The parameters total hardness, total alkalinity and phenolphthalein alkalinity are given in parts per million calcium carbonate.

The results of soil sample analyses are given in Table 4. All measurements are given in parts per million except pH.

Table 2. Planting and blooming dates, average plant height, average seed weight, average seed length, average number of female florets per lower branch, and the percentage of seed set (not percentage of maturing grain), 1972

| Location | Site no. | Planting date | Blooming date | Av. plant height m | Av. seed weight gm | Av. seed length mm | Av. no female florets/ branch | Percent seed set |
|---|---|---|---|---|---|---|---|---|
| Little Wall Lake | 1 | Fall 1971 | June 28 | 1.5 | 0.039 | 12.8 | 14 | 97 |
| Little Wall Lake[a] | 1 | May 16 | July 10 | 2.5 | 0.020 | 11.9 | 8 | 99 |
| Hendrickson's Marsh | 1 | April 13 | July 11 | 2.2 | 0.017 | 12.3 | -[b] | 93 |
| Big Wall Lake | 2 | Fall 1971 | June 28 | 1.5 | -[b] | -[b] | 8 | 99 |
| Gravel pit | 1 | May 16 | July 14 | 1.5 | -[b] | -[b] | 4 | 94 |
| Hickory Grove Lake | 1 | Fall 1971 | July 11 | 1.7 | 0.068 | 14.9 | 12 | 85 |
| Smith Farm | 1 | June 29 | -[b] | 0.7 | -[b] | -[b] | -[b] | -[b] |
| Twin Anchors | 1 | June 29 | Aug. 4 | 0.8 | 0.058 | 19.2 | 5 | 94 |
| Spring Lake | 2 | May 11 | July 11 | 1.3 | 0.044 | 14.9 | 2 | 97 |
| Spring Lake | 1 | May 11 | July 11 | 0.9 | 0.024 | 13.1 | 2 | 74 |
| Hickory Grove Lake | 2 | Fall 1971 | Aug. 4 | 1.5 | 0.050 | 14.0 | 9 | 94 |

[a]Information for 1972 is based on data from two groups of plants.

[b]Indicates no data available.

Table 3. Results of analyses of water samples

| Date | Temp. °C | Depth cm | pH | Turbid. ppm | $PO_4$ ppm | $NH_3$-N ppm | $NO_3$-N ppm | $NO_2$-N ppm | $SO_4$ ppm | Cl ppm | Hard. ppm | Ph.alk. ppm | Alk. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Twin Anchors, 1972 | | | | | | | | |
| 6-29 | 25.5 | 46 | -[a] | 6.0 | 0.1 | 0.1 | 1.1 | .088 | 14.0 | 11.0 | 162.0 | 44.0 | 102.0 |
| 7-11 | 25.0 | 34 | 7.5 | 1.7 | 0.2 | 0.6 | 0.0 | .078 | 9.0 | 12.0 | 142.0 | 0.0 | 122.0 |
| 8-4 | 21.5 | 46 | 8.3 | 19.3 | 0.0 | 0.1 | 0.0 | .017 | 33.0 | 13.0 | 180.0 | 18.0 | 148.0 |
| 8-18 | 27.5 | 39 | 8.5 | 4.0 | 0.3 | 0.0 | 0.0 | .027 | 12.0 | 15.5 | 186.0 | 14.0 | 142.0 |
| 8-31 | 24.0 | 39 | 8.7 | 5.0 | 0.3 | 0.0 | 1.5 | .005 | 22.0 | 15.0 | 162.0 | 20.0 | 164.0 |
| | | | | | Big Wall Lake, Research Site, 1971 | | | | | | | | |
| 6-3 | 25.0 | 38 | 8.4 | - | 0.4 | 0.5 | 3.0 | .000 | 11.0 | 10.0 | 122.0 | - | - |
| 6-16 | 26.0 | 36 | 9.7 | 8.5 | 0.5 | 0.6 | 1.0 | .006 | 5.0 | 11.5 | 134.0 | - | - |
| 7-9 | 20.5 | 40 | 8.6 | 5.7 | 0.9 | 0.8 | 0.0 | .007 | 9.0 | 7.5 | 172.0 | - | - |
| 7-20 | 20.0 | 35 | 7.5 | 4.2 | 0.5 | 0.9 | 0.8 | .007 | 5.0 | 8.0 | 158.0 | - | - |
| 8-3 | 23.0 | 22 | 8.0 | 4.0 | 0.4 | 0.3 | 0.0 | .003 | 4.0 | 6.0 | 126.0 | - | - |
| 8-19 | 28.5 | 6 | 8.2 | 5.1 | 0.3 | 1.2 | 0.0 | .002 | 5.0 | 7.8 | 140.0 | - | - |
| 9-3 | 29.0 | 4 | 7.4 | 9.0 | 0.7 | - | 1.4 | .000 | 14.0 | 22.2 | 164.0 | - | - |
| 9-17 | 22.0 | 4 | 8.6 | 9.0 | 0.5 | 1.2 | 1.5 | .000 | 9.0 | 18.0 | 160.0 | - | - |
| 9-25 | 14.0 | 2 | 7.7 | 11.8 | 0.3 | 0.9 | 0.0 | .004 | 4.0 | 30.5 | 176.0 | - | - |
| 10-8 | 18.0 | 2 | 8.4 | 15.0 | 0.4 | 0.8 | 0.0 | .004 | 3.0 | 17.0 | 167.0 | - | - |
| 10-25 | 13.0 | 2 | 7.8 | 8.3 | 0.3 | 1.0 | 0.8 | .007 | 12.0 | 11.5 | 226.0 | - | - |
| 11-6 | 1.0 | 9 | 7.9 | 21.5 | 0.2 | 0.3 | 0.0 | .002 | 12.0 | 14.0 | 170.0 | - | - |
| | | | | | Big Wall Lake, Research Site, 1972 | | | | | | | | |
| 4-27 | 12.5 | 22 | - | 10.3 | 0.3 | 0.8 | 0.0 | .000 | 11.0 | 7.0 | 318.0 | 0.0 | 206.0 |
| 5-16 | 23.0 | 24 | - | 2.8 | 0.6 | 0.2 | 0.0 | .003 | 2.0 | 6.5 | 204.0 | 0.0 | 184.0 |
| 6-13 | 22.5 | 26 | 8.8 | 3.0 | 0.6 | 0.7 | 3.2 | .003 | 5.0 | 5.0 | 294.0 | 0.0 | 174.0 |
| 6-28 | 22.5 | 20 | 8.4 | 4.0 | 0.7 | 0.6 | 6.0 | .008 | 8.0 | 3.5 | 206.0 | 0.0 | 152.0 |
| 7-14 | 22.5 | 27 | 7.2 | 2.7 | 0.4 | 0.6 | 0.0 | .004 | 2.0 | 4.5 | 180.0 | 0.0 | 146.0 |
| 7-27 | 21.5 | 28 | 6.8 | 6.0 | 0.4 | 0.8 | 0.7 | .000 | 6.0 | 3.5 | 192.0 | 0.0 | 172.0 |
| 8-8 | 18.5 | 30 | 6.9 | 3.3 | 0.4 | 0.7 | 3.5 | .000 | 5.0 | 4.5 | 216.0 | 0.0 | 214.0 |
| 8-23 | 20.5 | 27 | 6.9 | 9.3 | 0.5 | 0.8 | 0.5 | .000 | 13.0 | 3.5 | 194.0 | 0.0 | 204.0 |

[a]Hyphen indicates no data available.

Table 3. (Continued)

| Date | Temp. °C | Depth cm | pH | Turbid. ppm | $PO_4$ ppm | $NH_3$-N ppm | $NO_3$-N ppm | $NO_2$-N ppm | $SO_4$ ppm | Cl ppm | Hard. ppm | Ph.alk. ppm | Alk. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hickory Grove, Site 1, 1971 | | | | | | | | | | | | | |
| 6-17 | 28.0 | 24 | 8.4 | 2.0 | 0.1 | 0.3 | 0.7 | .125 | 38.0 | 23.0 | 178.0 | - | - |
| 7-2 | 30.5 | 24 | 10.3 | 2.0 | 0.1 | 0.2 | 0.0 | .088 | 38.0 | 24.0 | 160.0 | - | - |
| 7-16 | 26.0 | 22 | 9.6 | 1.5 | 0.1 | 0.0 | 0.7 | .118 | 31.0 | 23.0 | 188.0 | - | - |
| 7-29 | 22.0 | 18 | 9.4 | 5.0 | 0.1 | 0.3 | 0.0 | .042 | 28.0 | 23.0 | 174.0 | - | - |
| 8-10 | 26.0 | 14 | 8.6 | 5.5 | 0.3 | 0.4 | 0.0 | .034 | 26.0 | 19.2 | 142.0 | - | - |
| 8-26 | 21.0 | 3 | 8.5 | - | 0.3 | 0.5 | 0.4 | .011 | 45.0 | 28.5 | 174.0 | - | - |
| 9-10 | 31.0 | 6 | 9.1 | 14.0 | 0.1 | 0.2 | 0.8 | .023 | 36.0 | 19.8 | 139.0 | - | - |
| 9-26 | 20.0 | 2 | 8.8 | 9.0 | 0.1 | 0.0 | 0.0 | .007 | 30.0 | 20.0 | 152.0 | - | - |
| 10-11 | 14.0 | 1 | 7.8 | 16.0 | 0.1 | 0.2 | 0.0 | .000 | 27.0 | 20.5 | 162.0 | - | - |
| 10-22 | 16.0 | 2 | 7.8 | 12.0 | 0.2 | 0.4 | 0.0 | .004 | 26.0 | 11.5 | 166.0 | - | - |
| 11-5 | 9.0 | 6 | 8.4 | 10.8 | 0.2 | 0.5 | 0.0 | .024 | 27.0 | 20.0 | 164.0 | - | - |
| 11-25 | 6.0 | 6 | 8.4 | 3.8 | 0.2 | 0.2 | 0.6 | .011 | 22.0 | 16.6 | 187.0 | - | - |
| Hickory Grove, Site 1, 1972 | | | | | | | | | | | | | |
| 4-5 | 7.0 | 19 | - | 7.0 | 0.3 | 0.2 | 1.5 | .035 | 25.0 | 18.0 | 200.0 | - | - |
| 5-9 | 14.5 | 24 | - | 1.5 | 0.3 | 0.0 | 0.5 | .068 | 32.0 | 23.0 | 262.0 | 0.0 | 184.0 |
| 6-12 | 25.0 | 22 | 9.4 | 5.0 | 0.1 | 0.0 | 1.4 | .115 | 36.0 | 24.5 | 245.0 | 34.0 | 142.0 |
| 6-27 | 25.5 | 22 | 8.7 | 4.0 | 0.2 | 0.2 | 5.4 | .135 | 10.0 | 12.5 | 248.0 | 0.0 | 146.0 |
| 7-11 | 27.5 | 24 | 8.7 | 2.7 | 0.2 | 0.2 | 2.4 | .326 | 27.0 | 18.0 | 212.0 | 0.0 | 110.0 |
| 8-4 | 20.0 | 28 | 7.5 | 4.0 | 0.2 | 0.0 | 2.4 | .093 | 17.0 | 14.5 | 250.0 | 0.0 | 172.0 |
| 8-18 | 28.5 | 24 | 7.6 | 1.7 | 0.2 | 0.0 | 2.9 | .070 | 24.0 | 20.0 | 248.0 | 0.0 | 182.0 |
| Hickory Grove, Site 2, 1971 | | | | | | | | | | | | | |
| 6-17 | 27.5 | 54 | 8.9 | 0.8 | 0.1 | 0.3 | 1.9 | .108 | 37.0 | 22.5 | 172.0 | - | - |
| 7-2 | 30.8 | 50 | 9.5 | 2.0 | 0.0 | 0.2 | 0.0 | .093 | 42.0 | 24.0 | 120.0 | - | - |
| 7-16 | 28.5 | 51 | 10.0 | 2.5 | 0.3 | 0.0 | 0.0 | .078 | 33.0 | 24.0 | 142.0 | - | - |
| 7-29 | 23.5 | 48 | 9.4 | 6.0 | 0.0 | 0.2 | 0.0 | .035 | 22.0 | 23.5 | 182.0 | - | - |
| 8-10 | 26.0 | 42 | 9.3 | 3.0 | 0.0 | 0.0 | 1.0 | .026 | 28.0 | 23.0 | 148.0 | - | - |
| 8-26 | 23.0 | 37 | 8.8 | 16.5 | 0.1 | 0.2 | 0.6 | .000 | 24.0 | 23.0 | 174.0 | - | - |
| 9-10 | 27.0 | 26 | 9.0 | 15.0 | 0.1 | 0.2 | 1.0 | .007 | 28.0 | 19.5 | 148.0 | - | - |
| 9-26 | 18.5 | 24 | 8.9 | 8.5 | 0.0 | 0.3 | 0.0 | .017 | 29.0 | 20.5 | 148.0 | - | - |

Table 3. (Continued)

| Date | Temp. °C | Depth cm | pH | Turbid. ppm | $PO_4$ ppm | $NH_3$-N ppm | $NO_3$-N ppm | $NO_2$-N ppm | $SO_4$ ppm | Cl ppm | Hard. ppm | Ph.alk. ppm | Alk. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hickory Grove, Site 2, 1971 (Continued) | | | | | | | | | | | | | |
| 10-11 | 15.0 | 20 | 8.2 | - | 0.2 | 0.5 | 0.0 | .003 | 27.0 | 21.5 | 156.0 | - | - |
| 10-22 | 16.0 | 27 | 8.1 | 4.7 | 0.1 | 0.3 | 0.0 | .006 | 22.0 | 16.0 | 140.0 | - | - |
| 11-5 | 10.0 | 30 | 8.8 | 4.2 | 0.2 | 0.6 | 0.0 | .033 | 27.0 | 20.0 | 160.0 | - | - |
| 11-25 | 5.0 | 25 | 8.3 | 1.5 | 0.3 | 0.3 | 0.8 | .023 | 25.0 | 20.5 | 187.0 | - | - |
| Hickory Grove, Site 2, 1972 | | | | | | | | | | | | | |
| 4-5 | 7.0 | - | - | 6.5 | 0.3 | 0.2 | 0.5 | .027 | 22.0 | 16.5 | 192.0 | - | - |
| 5-9 | 14.5 | 47 | - | 2.0 | 0.3 | 0.0 | 0.0 | .054 | 32.0 | 23.0 | 262.0 | 0.0 | 182.0 |
| 6-12 | 25.0 | 50 | 9.2 | 7.0 | 0.2 | 0.0 | 0.9 | .113 | 42.0 | 25.0 | 215.0 | 26.0 | 118.0 |
| 7-11 | 27.5 | 55 | 9.5 | 1.7 | 0.1 | 0.1 | 4.4 | .153 | 26.0 | 16.5 | 172.0 | 38.0 | 98.0 |
| 8-4 | 20.0 | 50 | 7.7 | 2.7 | 0.1 | 0.0 | 0.4 | .044 | 17.0 | 15.0 | 242.0 | 0.0 | 188.0 |
| 8-18 | 30.0 | 54 | 7.4 | 2.7 | 0.2 | 0.0 | 2.0 | .023 | 24.0 | 17.5 | 230.0 | 0.0 | 174.0 |
| Smith Farm, 1972 | | | | | | | | | | | | | |
| 6-29 | 29.5 | 24 | - | 11.5 | 0.0 | 0.3 | 9.4 | .112 | 21.0 | 22.0 | 244.0 | 22.0 | 110.0 |
| 7-11 | 27.5 | 20 | 8.1 | 9.0 | 0.2 | 0.2 | 6.1 | .416 | 24.0 | 23.0 | 264.0 | 0.0 | 154.0 |
| 8-4 | 22.5 | 19 | 7.5 | 6.0 | 0.1 | 0.2 | 2.9 | .210 | 22.0 | 20.0 | 226.0 | 0.0 | 234.0 |
| 8-19 | 29.5 | 14 | 7.7 | 8.3 | 0.4 | 0.0 | 9.9 | .260 | 26.0 | 25.0 | 276.0 | 0.0 | 232.0 |
| 8-31 | 25.0 | 20 | 7.8 | 8.5 | 0.1 | 0.0 | 8.2 | .316 | 29.0 | 24.5 | 224.0 | 0.0 | 240.0 |
| Hendrickson's Marsh, Site 1, 1971 | | | | | | | | | | | | | |
| 5-28 | 21.0 | 28 | 7.5 | - | 0.3 | 0.5 | 0.7 | .105 | 32.0 | 19.0 | 240.0 | - | - |
| 6-17 | 24.5 | 24 | 8.4 | 9.8 | 0.3 | 0.1 | 0.0 | .198 | 37.0 | 23.0 | 266.0 | - | - |
| 7-2 | 24.5 | 26 | 7.4 | 5.6 | 0.9 | 0.1 | 0.0 | .059 | 16.0 | 20.0 | 246.0 | - | - |
| 7-16 | 25.0 | 24 | 7.8 | 5.2 | 0.4 | 0.1 | 0.0 | .044 | 33.0 | 24.0 | 370.0 | - | - |
| 7-29 | 16.0 | 16 | 7.5 | 7.2 | 0.3 | 0.5 | 0.0 | .002 | 30.0 | 23.5 | 344.0 | - | - |
| Hendrickson's Marsh, Site 1, 1972 | | | | | | | | | | | | | |
| 4-13 | 23.0 | 4 | - | 1.2 | 0.0 | 0.0 | 0.0 | .005 | 46.0 | 16.0 | 284.0 | 6.0 | 226.0 |
| 5-9 | 17.0 | 18 | - | 2.5 | 0.3 | 0.0 | 0.0 | .020 | 22.0 | 8.5 | 292.0 | 0.0 | 242.0 |
| 6-12 | 21.5 | 19 | 7.4 | 7.0 | 0.4 | 0.0 | 0.0 | .138 | 26.0 | 19.5 | 370.0 | 0.0 | 284.0 |

Table 3. (Continued)

| Date | Temp. °C | Depth cm | pH | Turbid. ppm | $PO_4$ ppm | $NH_3$-N ppm | $NO_3$-N ppm | $NO_2$-N ppm | $SO_4$ ppm | Cl ppm | Hard. ppm | Ph.alk. ppm | Alk. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Hendrickson's Marsh, Site 1, 1972 (Continued) | | | | | | | | | |
| 6-27 | 22.0 | 18 | 7.3 | 4.0 | 0.3 | 0.4 | 3.9 | .135 | 18.0 | 20.0 | 404.0 | 0.0 | 326.0 |
| 7-11 | 23.5 | 11 | 7.2 | 36.0 | 0.6 | 0.8 | 0.5 | .000 | 9.0 | 19.5 | 362.0 | 0.0 | 376.0 |
| 8-4 | 16.5 | 20 | 6.7 | 8.3 | 1.2 | 0.3 | 0.0 | .005 | 12.0 | 11.0 | 326.0 | 0.0 | 302.0 |
| 8-18 | 26.5 | 14 | 6.8 | 41.5 | 1.7 | 1.4 | 0.0 | .000 | 13.0 | 12.5 | 348.0 | 0.0 | 396.0 |
| 8-31 | 21.0 | 17 | 6.3 | 13.0 | 1.4 | 0.8 | 1.0 | .000 | 9.0 | 12.5 | 320.0 | 0.0 | 374.0 |
| | | | | Hendrickson's Marsh, Site 2, 1971 | | | | | | | | | |
| 6-17 | 24.0 | 34 | 8.1 | 8.5 | 0.3 | 0.2 | 1.0 | - | 37.0 | 22.5 | 254.0 | - | - |
| 7-2 | 24.0 | 36 | 7.4 | 28.5 | 0.4 | 0.2 | 0.4 | .124 | 38.0 | 19.5 | 241.0 | - | - |
| 7-16 | 24.0 | 32 | 8.0 | 15.8 | 0.1 | 0.0 | 0.0 | .145 | 41.0 | 24.0 | 330.0 | - | - |
| 7-29 | 18.5 | 22 | 7.8 | 18.8 | 0.2 | 0.6 | 0.0 | .000 | 37.0 | 22.5 | 226.0 | - | - |
| 8-10 | 24.5 | 8 | 7.6 | - | 0.3 | 0.7 | 1.6 | .000 | 22.0 | 22.0 | 236.0 | - | - |
| | | | | Hendrickson's Marsh, Site 2, 1972 | | | | | | | | | |
| 4-13 | 20.0 | 12 | - | 3.3 | 0.1 | 0.1 | 0.0 | .001 | 73.0 | 18.0 | 276.0 | 0.0 | 192.0 |
| 5-9 | 16.0 | 28 | - | 5.5 | 0.1 | 0.3 | 0.0 | .003 | 19.0 | 6.5 | 244.0 | 0.0 | 220.0 |
| 6-12 | 20.5 | 27 | 7.4 | 14.0 | 0.2 | 0.0 | 0.0 | .185 | 30.0 | 21.5 | 354.0 | 0.0 | 292.0 |
| 6-27 | 22.5 | 22 | 7.4 | 5.0 | 0.2 | 0.2 | 2.2 | .187 | 27.0 | 21.5 | 336.0 | 0.0 | 316.0 |
| 7-11 | 24.0 | 21 | 7.2 | 5.0 | 0.6 | 1.2 | 0.0 | .012 | 8.0 | 19.5 | 346.0 | 0.0 | 380.0 |
| 8-4 | 16.5 | 28 | 6.7 | 30.5 | 0.8 | 0.3 | 0.0 | .075 | 16.0 | 12.5 | 274.0 | 0.0 | 334.0 |
| 8-18 | 22.5 | 25 | 7.0 | 12.7 | 1.8 | 0.7 | 0.0 | .000 | 9.0 | 11.5 | 364.0 | 0.0 | 368.0 |
| 8-31 | 20.5 | 22 | 6.8 | 9.5 | 1.7 | 0.5 | 1.0 | .003 | 7.0 | 11.5 | 292.0 | 0.0 | 344.0 |
| | | | | | Gravel pit, 1972 | | | | | | | | |
| 4-27 | 10.5 | 38 | - | 6.0 | 0.1 | 0.1 | 1.0 | .006 | 9.0 | 4.0 | 194.0 | 0.0 | 160.0 |
| 5-16 | 19.5 | 45 | - | 10.2 | 0.3 | 0.1 | 0.0 | .003 | 9.0 | 2.5 | 178.0 | 0.0 | 158.0 |
| 6-13 | 22.5 | 49 | 8.6 | 4.0 | 0.0 | 0.3 | 3.2 | .000 | 7.0 | 3.0 | 166.0 | 0.0 | 124.0 |
| 6-28 | 23.5 | 46 | 8.4 | 4.0 | 0.1 | 0.2 | 3.0 | .003 | 6.0 | 2.0 | 154.0 | 0.0 | 112.0 |
| 7-14 | 24.0 | 49 | 7.5 | 3.8 | 0.1 | 0.3 | 0.0 | .000 | 5.0 | 2.5 | 120.0 | 0.0 | 98.0 |
| 7-27 | 23.5 | 42 | 7.9 | 2.7 | 0.1 | 0.2 | 1.0 | .000 | 6.0 | 2.5 | 140.0 | 0.0 | 98.0 |
| 8-8 | 19.0 | 57 | 7.4 | 1.3 | 0.1 | 0.2 | 1.5 | .000 | 4.0 | 3.0 | 157.0 | 0.0 | 118.0 |
| 8-23 | 22.0 | 50 | 7.3 | 2.7 | 0.1 | 0.0 | 0.0 | .000 | 12.0 | 1.5 | 136.0 | 0.0 | 118.0 |

Table 3. (Continued)

| Date | Temp. °C | Depth cm | pH | Turbid. ppm | $PO_4$ ppm | $NH_3$-N ppm | $NO_3$-N ppm | $NO_2$-N ppm | $SO_4$ ppm | Cl ppm | Hard. ppm | Ph.alk. ppm | Alk. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Tertiary Treatment Ponds, Site 1, 1971 | | | | | | | | | |
| 6-3 | 21.0 | 28 | 8.0 | - | 1.4 | - | 0.0 | - | 199.0 | 53.0 | 300.0 | - | - |
| 6-15 | 21.0 | 18 | 7.9 | 3.2 | 1.9 | - | 0.0 | - | 120.0 | 41.2 | 194.0 | - | - |
| 6-30 | 22.0 | 24 | 7.8 | 9.5 | 2.2 | - | 5.1 | - | 148.0 | 53.5 | 224.0 | - | - |
| 7-16 | 22.0 | 26 | 7.5 | 2.5 | 1.7 | 2.0 | 1.3 | - | 190.0 | 55.0 | 296.0 | - | - |
| 8-5 | 19.0 | 6 | 6.9 | 2.0 | - | - | 1.9 | .052 | 170.0 | 73.5 | 302.0 | - | - |
| 8-26 | 21.0 | 21 | 7.1 | 2.0 | 2.7 | - | 1.5 | .146 | 160.0 | 54.0 | 236.0 | - | - |
| 9-10 | 23.0 | 22 | 7.1 | 11.3 | - | 1.3 | 0.9 | .005 | 185.0 | 52.5 | 194.0 | - | - |
| 9-26 | 21.0 | 24 | 7.1 | 20.5 | - | - | 0.0 | .027 | 180.0 | 47.8 | 180.0 | - | - |
| 10-17 | 21.0 | 38 | 7.4 | 17.0 | - | - | 1.1 | .003 | 210.0 | 24.8 | 168.0 | - | - |
| | | | | Tertiary Treatment Ponds, Site 1, 1972 | | | | | | | | | |
| 7-14 | 22.5 | 47 | 7.3 | 4.0 | 22.8 | 8.2 | 0.8 | .206 | 104.0 | 57.5 | 292.0 | 0.0 | 230.0 |
| 8-2 | 21.5 | 40 | 7.0 | 14.0 | 19.5 | 13.0 | 4.7 | .310 | 110.0 | 43.0 | 298.0 | 0.0 | 220.0 |
| 8-19 | 24.5 | 36 | 7.2 | 5.0 | 17.5 | 5.0 | 3.2 | .334 | 176.0 | 70.0 | 344.0 | 0.0 | 244.0 |
| 9-2 | 21.5 | 40 | 7.3 | 2.7 | 21.8 | 4.5 | 3.7 | .528 | 174.0 | 80.0 | 320.0 | 0.0 | 226.0 |
| | | | | Tertiary Treatment Ponds, Site 2, 1971 | | | | | | | | | |
| 7-16 | 22.0 | 28 | 7.5 | 2.1 | 2.9 | 2.0 | 3.8 | .199 | 220.0 | 51.0 | 290.0 | - | - |
| 8-5 | 19.0 | 12 | 6.8 | 0.5 | 4.7 | - | 0.8 | .046 | 135.0 | 61.5 | 278.0 | - | - |
| 8-26 | 21.0 | 27 | 7.0 | 1.5 | 1.4 | - | 1.8 | .156 | 177.0 | 51.0 | 240.0 | - | - |
| 9-10 | 23.0 | 26 | 7.1 | 11.8 | - | 1.8 | 0.7 | .004 | 185.0 | 48.0 | 183.0 | - | - |
| 9-26 | 21.5 | 32 | 7.2 | 15.0 | - | - | 0.0 | .005 | 185.0 | 48.0 | 183.0 | - | - |
| 10-17 | 21.0 | 34 | 7.3 | 20.5 | - | - | 1.3 | .004 | 180.0 | 48.0 | 184.0 | - | - |
| | | | | Tertiary Treatment Ponds, Site 3, 1972 | | | | | | | | | |
| 7-14 | 23.5 | 38 | 7.3 | 17.5 | 23.8 | 7.5 | 1.0 | .006 | 110.0 | 59.0 | 300.0 | 0.0 | 254.0 |
| 8-2 | 22.0 | 36 | 7.1 | 14.0 | 31.8 | 8.2 | 3.8 | .004 | 124.0 | 58.0 | 288.0 | 0.0 | 242.0 |
| 8-19 | 23.0 | 36 | 7.3 | 6.0 | 16.4 | 6.2 | 1.8 | .230 | 170.0 | 58.0 | 342.0 | 0.0 | 264.0 |
| 9-2 | 22.0 | 36 | 7.4 | 4.0 | 19.5 | 6.8 | 1.9 | .608 | 184.0 | 57.0 | 320.0 | 0.0 | 224.0 |

Table 3. (Continued)

| Date | Temp. °C | Depth cm | pH | Turbid. ppm | $PO_4$ ppm | $NH_3$-N ppm | $NO_3$-N ppm | $NO_2$-N ppm | $SO_4$ ppm | Cl ppm | Hard. ppm | Ph.alk. ppm | Alk. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Little Wall Lake, Site 1, 1971 | | | | | | | | | | | | | |
| 6-4 | 26.0 | 33 | 8.9 | - | 0.4 | 0.6 | 0.0 | .000 | 10.0 | 29.4 | 248.0 | - | - |
| 6-16 | 29.5 | 30 | 9.7 | 3.2 | 0.1 | 0.2 | 0.1 | .004 | 3.0 | 28.0 | 208.0 | - | - |
| 7-9 | 21.0 | 34 | 9.5 | 6.0 | 0.2 | 0.6 | 0.0 | .007 | 13.0 | 17.0 | 166.0 | - | - |
| 7-20 | 23.0 | 21 | 9.5 | 5.5 | 0.2 | 0.7 | 3.2 | .006 | 4.5 | 30.0 | 164.0 | - | - |
| 8-3 | 29.5 | 15 | 9.7 | 3.3 | 0.1 | 0.5 | 0.3 | .006 | 7.0 | 35.0 | 222.0 | - | - |
| 8-18 | 34.0 | 4 | 9.5 | 8.8 | 0.1 | 2.1 | 0.2 | .000 | 9.0 | 40.5 | 247.0 | - | - |
| Little Wall Lake, Site 1, 1972 | | | | | | | | | | | | | |
| 4-27 | 15.0 | 9 | - | 6.0 | 0.1 | 0.3 | 2.2 | .005 | 8.0 | 26.5 | 280.0 | 22.0 | 136.0 |
| 5-16 | 33.5 | 9 | - | 7.0 | 0.1 | 0.4 | 2.0 | .000 | - | 25.0 | 278.0 | 46.0 | 264.0 |
| 6-13 | 27.5 | 8 | 10.2 | 14.0 | 0.2 | 0.7 | 3.5 | .002 | 2.0 | 12.5 | 176.0 | 68.0 | 132.0 |
| 6-28 | 24.5 | 10 | 9.5 | 14.0 | 0.1 | 0.6 | 0.7 | .005 | 7.0 | 2.5 | 196.0 | 54.0 | 152.0 |
| 7-14 | 22.5 | 6 | 8.2 | 17.5 | 0.4 | 0.8 | 0.0 | .004 | 1.0 | 7.5 | 190.0 | 0.0 | 172.0 |
| 7-27 | 22.5 | 4 | 7.0 | 3.7 | 0.9 | 1.0 | 1.6 | .000 | 20.0 | 8.5 | 316.0 | 0.0 | 264.0 |
| 8-8 | 16.5 | 16 | 6.9 | 6.5 | 0.9 | 0.6 | 0.5 | .000 | 14.0 | 3.5 | 201.0 | 0.0 | 178.0 |
| 8-23 | 23.0 | 15 | 7.0 | 2.7 | 1.5 | 0.2 | 0.3 | .000 | 8.0 | 28.5 | 330.0 | 0.0 | 242.0 |
| 9-9 | 17.5 | 15 | 7.1 | 6.0 | 1.2 | 0.1 | 2.2 | .000 | 12.0 | 21.5 | 256.0 | 0.0 | 224.0 |
| Little Wall Lake, Site 2, 1971 | | | | | | | | | | | | | |
| 6-16 | 31.0 | 19 | 9.4 | 10.2 | 0.2 | 0.3 | 0.4 | .000 | 9.0 | 23.8 | 214.0 | - | - |
| 7-9 | 24.5 | 32 | 8.7 | 15.5 | 0.3 | 0.7 | 1.0 | .000 | 10.0 | 13.5 | 154.0 | - | - |
| 7-20 | 25.5 | 20 | 9.2 | 5.0 | 0.3 | 0.9 | 4.3 | .003 | 9.0 | 24.0 | 176.0 | - | - |
| 8-3 | 27.0 | 8 | 9.4 | 8.5 | 0.8 | 1.2 | 5.0 | .000 | 8.0 | 37.5 | 195.0 | - | - |
| Spring Lake, Site 1, 1971 | | | | | | | | | | | | | |
| 6-10 | 26.0 | 46 | 7.6 | 1.0 | 0.0 | 0.1 | 1.0 | .013 | 94.0 | 24.2 | 208.0 | - | - |
| 7-6 | 27.0 | 38 | 8.4 | 4.0 | 0.1 | 0.2 | 0.7 | .004 | 93.0 | 23.0 | 212.0 | - | - |
| 7-19 | 24.5 | 47 | 8.8 | 2.0 | 0.1 | 0.1 | 2.0 | .007 | 97.0 | 23.0 | 228.0 | - | - |
| 8-3 | 21.5 | 24 | 7.8 | 3.3 | 0.1 | 0.0 | 1.5 | .006 | 98.0 | 21.5 | 204.0 | - | - |
| 8-19 | 25.5 | 16 | 7.8 | 2.5 | 0.3 | 0.4 | 0.0 | .000 | 115.0 | 23.8 | 228.0 | - | - |
| 9-1 | 24.0 | 9 | 7.8 | 9.0 | 0.1 | 0.1 | 5.0 | .003 | 105.0 | 24.0 | 216.0 | - | - |
| 9-25 | 14.5 | 2 | 7.4 | 18.0 | 0.2 | 0.1 | 0.0 | .004 | 97.0 | 26.0 | 228.0 | - | - |

Table 3. (Continued)

| Date | Temp. °C | Depth cm | pH | Turbid. ppm | $PO_4$ ppm | $NH_3$-N ppm | $NO_3$-N ppm | $NO_2$-N ppm | $SO_4$ ppm | Cl ppm | Hard. ppm | Ph.alk. ppm | Alk. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Spring Lake, Site 1, 1971 (Continued) | | | | | | | | | |
| 10-17 | 20.0 | 0 | 7.8 | 18.2 | 0.0 | 0.5 | 1.0 | .005 | 160.0 | 23.0 | 250.0 | - | - |
| 11-6 | 7.0 | 15 | 7.3 | 5.5 | 0.1 | 0.0 | 4.2 | .004 | 115.0 | 22.2 | 261.0 | - | - |
| | | | | Spring Lake, Site 1, 1972 | | | | | | | | | |
| 4-18 | 15.5 | 38 | - | 8.5 | 0.2 | 0.0 | 0.0 | .004 | 140.0 | 20.0 | 284.0 | 0.0 | 194.0 |
| 5-11 | 17.5 | 40 | - | 8.0 | 0.2 | 0.0 | 2.0 | .012 | 160.0 | 21.5 | 304.0 | 0.0 | 186.0 |
| 6-1 | 19.5 | 30 | 8.0 | 5.0 | 0.2 | 0.0 | 0.0 | .005 | 130.0 | 21.5 | 338.0 | 0.0 | 206.0 |
| 6-16 | 21.0 | 40 | 7.7 | 6.0 | 0.0 | 0.0 | 0.0 | .001 | 130.0 | 19.5 | 265.0 | 0.0 | 170.0 |
| 6-30 | 26.0 | 36 | 8.2 | 2.5 | 0.2 | 0.2 | 1.8 | .004 | 120.0 | 19.5 | 332.0 | 0.0 | 140.0 |
| 7-18 | 25.0 | 36 | 7.8 | 5.0 | 0.3 | 0.1 | 1.2 | .003 | 105.0 | 19.5 | 256.0 | 0.0 | 142.0 |
| 8-2 | 23.5 | 48 | 7.3 | 10.5 | 0.2 | 0.0 | 0.0 | .002 | 75.0 | 16.0 | 222.0 | 0.0 | 154.0 |
| 8-17 | 29.5 | 38 | 7.8 | 5.0 | 0.1 | 0.1 | 0.5 | .000 | 93.0 | 19.0 | 232.0 | 0.0 | 148.0 |
| 9-2 | 21.0 | 33 | 8.1 | 4.0 | 0.1 | 0.0 | 0.2 | .002 | 110.0 | 18.5 | 236.0 | 0.0 | 146.0 |
| 9-15 | 22.0 | 38 | 9.0 | 2.7 | 0.1 | 0.2 | 0.0 | .001 | 76.0 | 18.0 | 226.0 | 0.0 | 146.0 |
| | | | | Spring Lake, Site 2, 1972 | | | | | | | | | |
| 4-18 | 16.0 | 48 | - | 3.0 | 0.1 | 0.0 | 0.0 | .003 | 140.0 | 17.5 | 292.0 | 0.0 | 176.0 |
| 5-11 | 17.5 | 48 | - | 8.0 | 0.0 | 0.0 | 3.3 | .002 | 130.0 | 17.0 | 258.0 | 0.0 | 150.0 |
| 6-1 | 20.0 | 44 | 8.5 | 4.0 | 0.0 | 0.0 | 0.0 | .003 | 145.0 | 16.0 | 230.0 | 0.0 | 130.0 |
| 6-16 | 21.5 | 50 | 8.0 | 5.0 | 0.0 | 0.2 | 1.5 | .000 | 115.0 | 17.0 | 228.0 | 0.0 | 118.0 |
| 6-30 | 26.5 | 46 | 7.8 | 6.0 | 0.2 | 0.2 | 1.0 | .003 | 125.0 | 18.0 | 268.0 | 0.0 | 122.0 |
| 7-18 | 24.5 | 44 | 7.3 | 6.0 | 0.2 | 0.2 | 0.5 | .001 | 115.0 | 18.0 | 220.0 | 0.0 | 126.0 |
| 8-2 | 23.0 | 60 | 7.2 | 2.7 | 0.2 | 0.0 | 1.8 | .000 | 77.0 | 15.5 | 210.0 | 0.0 | 120.0 |
| 8-17 | 29.5 | 50 | 7.5 | 7.0 | 0.3 | 0.2 | 0.0 | .002 | 93.0 | 17.0 | 220.0 | 0.0 | 130.0 |
| 9-2 | 20.5 | 44 | 7.7 | 4.0 | 0.0 | 0.0 | 1.1 | .004 | 125.0 | 16.0 | 212.0 | 0.0 | 134.0 |
| 9-15 | 21.0 | 48 | 8.2 | 3.5 | 0.0 | 0.2 | 0.0 | .004 | 110.0 | 15.5 | 196.0 | 0.0 | 116.0 |

Table 4. Results of analyses of soil samples with calcium, magnesium, and organic matter readings divided by 100, 10, and 1,000 respectively to facilitate table preparation

| Location | Site no. | pH | P ppm | K ppm | Ca ppm/100 | Mg ppm/10 | Mn ppm | $NO_3$-N ppm | O.M. ppm/1000 | Muck depth cm |
|---|---|---|---|---|---|---|---|---|---|---|
| Hickory Grove Lake | 1 | 7.2 | 2.5 | 97.5 | 42.5 | 50.0 | 18.5 | 48 | 18 | 10 |
| Hickory Grove Lake | 2 | 7.4 | 3.0 | 87.5 | 35.5 | 34.0 | 21.5 | 49 | 23 | -[a] |
| Hendrickson's Marsh | 1 | 6.8 | 50.0 | 200.0 | 80.0 | 110.0 | 20.0 | 34 | 90 | 6 |
| Hendrickson's Marsh | 2 | 6.8 | 48.0 | 195.0 | 70.0 | 105.0 | 20.0 | 22 | 80 | 6 |
| Tertiary treatment | 1 | 5.0 | 200.0 | 325.0 | 18.0 | 49.0 | 16.5 | 22 | 18 | 0 |
| Tertiary treatment | 3 | 5.6 | 120.0 | 350.0 | 23.5 | 65.0 | 33.0 | 130 | 28 | -[a] |
| Spring Lake | 1 | 6.9 | 6.5 | 75.0 | 27.0 | 21.0 | 46.5 | 3 | 16 | 0 |
| Spring Lake | 2 | 6.9 | 7.0 | 67.5 | 17.5 | 15.0 | 75.0 | 2 | 16 | -[a] |
| Twin Anchors | 1 | 7.1 | 5.0 | 150.0 | 45.0 | 77.5 | 31.0 | 1 | 33 | 28 |
| Big Wall Lake | 2 | 6.6 | 13.0 | 210.0 | 55.0 | 120.0 | 15.0 | 18 | 100 | 29 |
| Little Wall Lake | 1 | 7.1 | 20.0 | 350.0 | 77.5 | 220.0 | 5.5 | 77 | 100 | 17 |
| Little Wall Lake | 2 | 7.2 | 14.0 | 270.0 | 48.0 | 160.0 | 5.5 | 78 | 100 | 35 |
| Gravel pit | 1 | 7.1 | 11.0 | 182.5 | 70.0 | 87.5 | 39.5 | 13 | 43 | 20 |
| Smith farm | 1 | 7.4 | 22.5 | 187.5 | 45.0 | 80.0 | 11.0 | 25 | 48 | 20 |

[a]No data available.

## ANALYSES AND DISCUSSION

This study has shown that wild rice will grow in water and soil of the quality presently existing in Iowa emanating from a variety of sources (Tables 1 and 2). In 1971, the wild rice planted grew at all sites except Hendrickson's Marsh, Site 1, and Big Wall Lake, Research Site. Wild rice grew everywhere it was planted in 1972 except in the tertiary treatment ponds at the Ames Municipal Sewage Treatment Plant.

Separating out any factor(s) which control this growth is complex because so many parameters are present and interacting. In addition, these factors continually change in amount and in relative percentage to all other factors. From field data, the influence of each factor can best be studied by evaluating the effect of each separately as it changes in amount measured. To determine which parameter might be exerting major control over the growth of wild rice, the amount of growth indices (Table 1) were related to the quantitative measures of each tested environmental parameter (Tables 3 and 4) by using graphs (Figures 1-21). Each water parameter was measured several times; therefore, there are several points on each graph for every site or amount of growth index.

If the parameter promotes growth, the amounts of the parameter should continuously increase as the amount of growth indices increase. Thus, for a small amount of growth index there will be a small amount of the parameter present; and for a large amount of growth index, a large amount of the parameter. Additionally, the amounts of a parameter measured for a specific amount of growth index should be larger than the amounts of the parameter measured for smaller amount of growth indices. Likewise, the

Figure 1. Analyses of soil potassium from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 2. Analyses of soil magnesium from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 3. Analyses of soil nitrate nitrogen from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

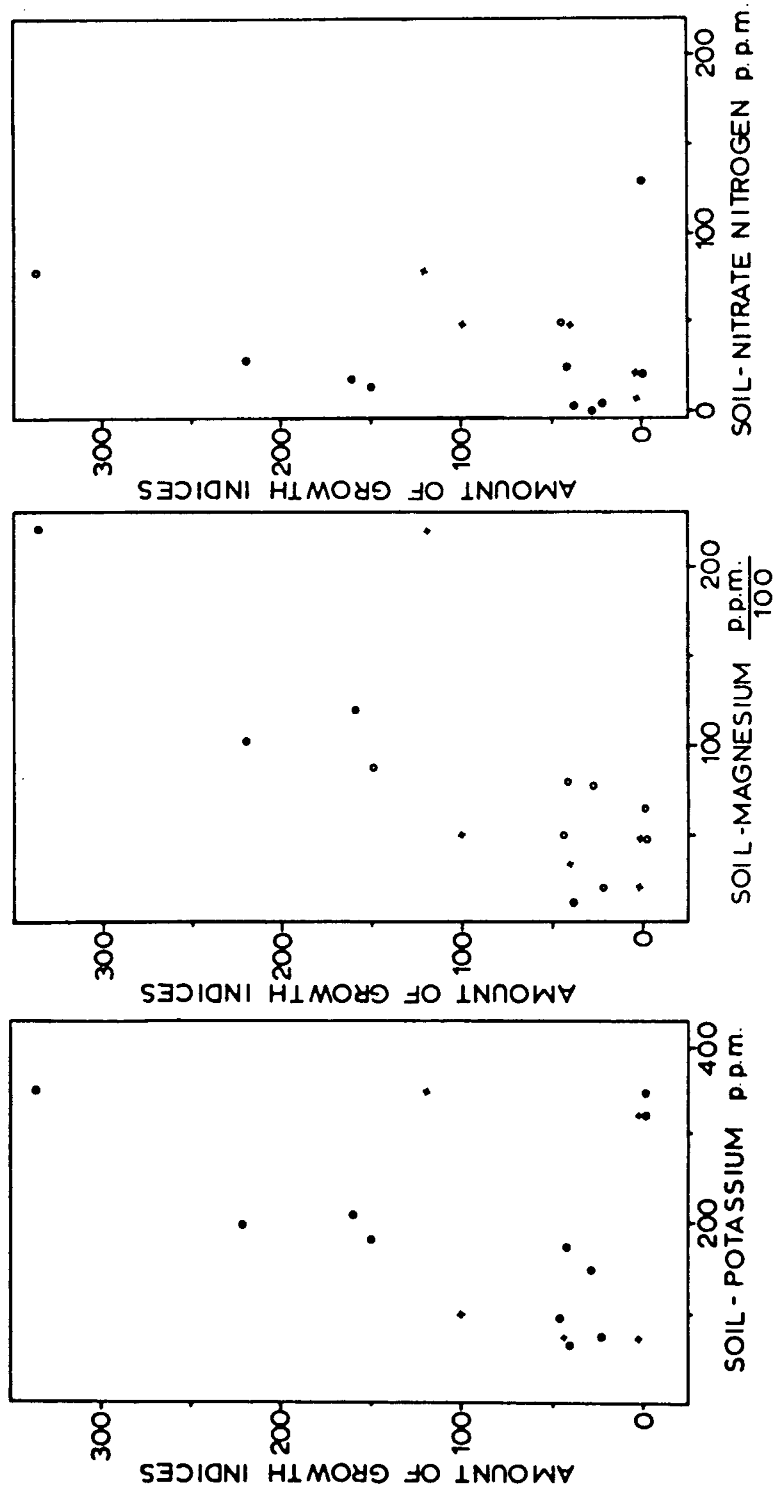

AMOUNT OF GROWTH INDICES
SOIL-NITRATE NITROGEN p.p.m.
AMOUNT OF GROWTH INDICES
SOIL-MAGNESIUM p.p.m./100
AMOUNT OF GROWTH INDICES
SOIL-POTASSIUM p.p.m.

Figure 4. Analyses of soil calcium from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 5. Analyses of muck depth from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 6. Analyses of the amount of organic matter in the soil from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

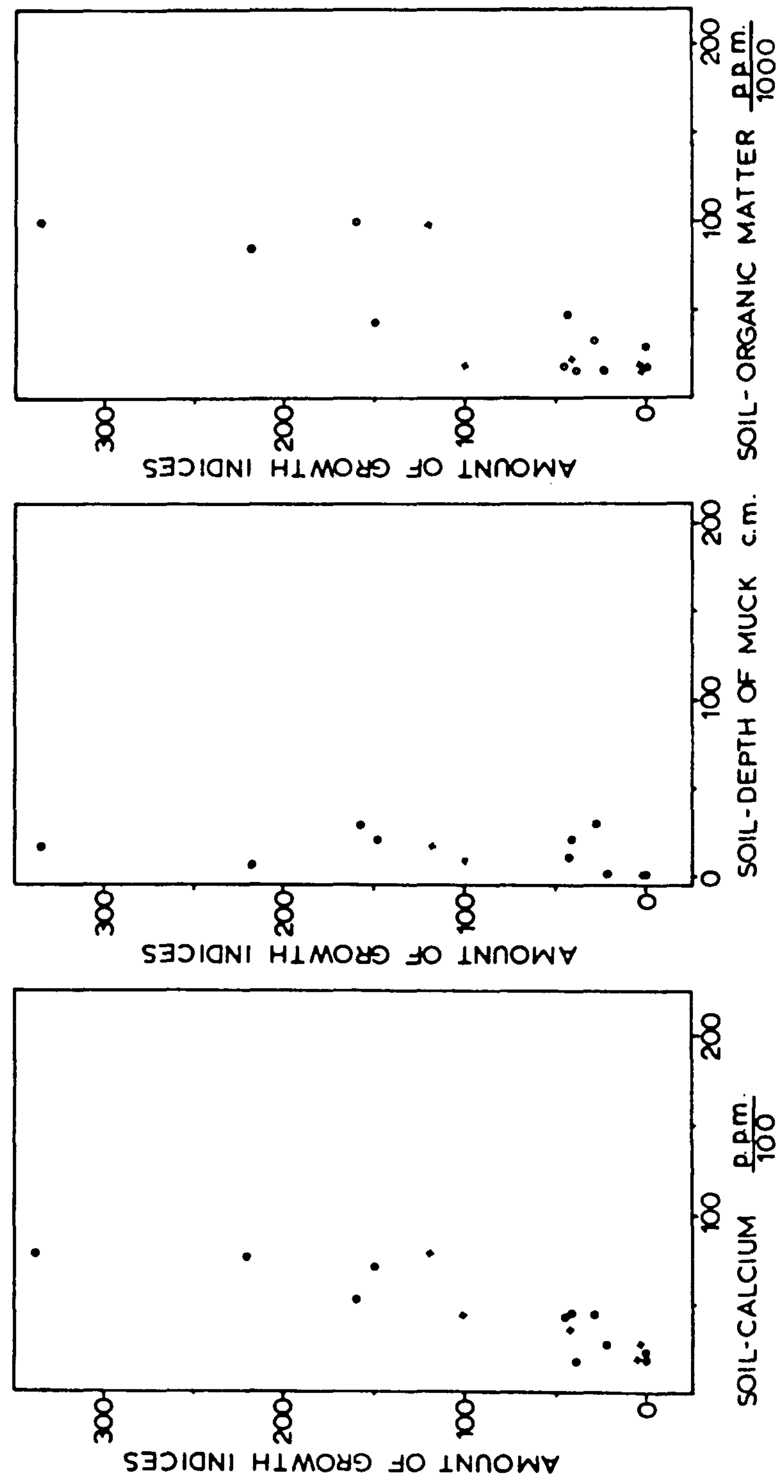

AMOUNT OF GROWTH INDICES
300
200
100
0
SOIL-ORGANIC MATTER p.p.m./1000
0
100
200
AMOUNT OF GROWTH INDICES
300
200
100
0
SOIL-DEPTH OF MUCK c.m.
0
100
200
AMOUNT OF GROWTH INDICES
300
200
100
0
SOIL-CALCIUM p.p.m./100
100
200

Figure 7. Analyses of soil pH from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 8. Analyses of soil phosphorus from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 9. Analyses of soil manganese from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

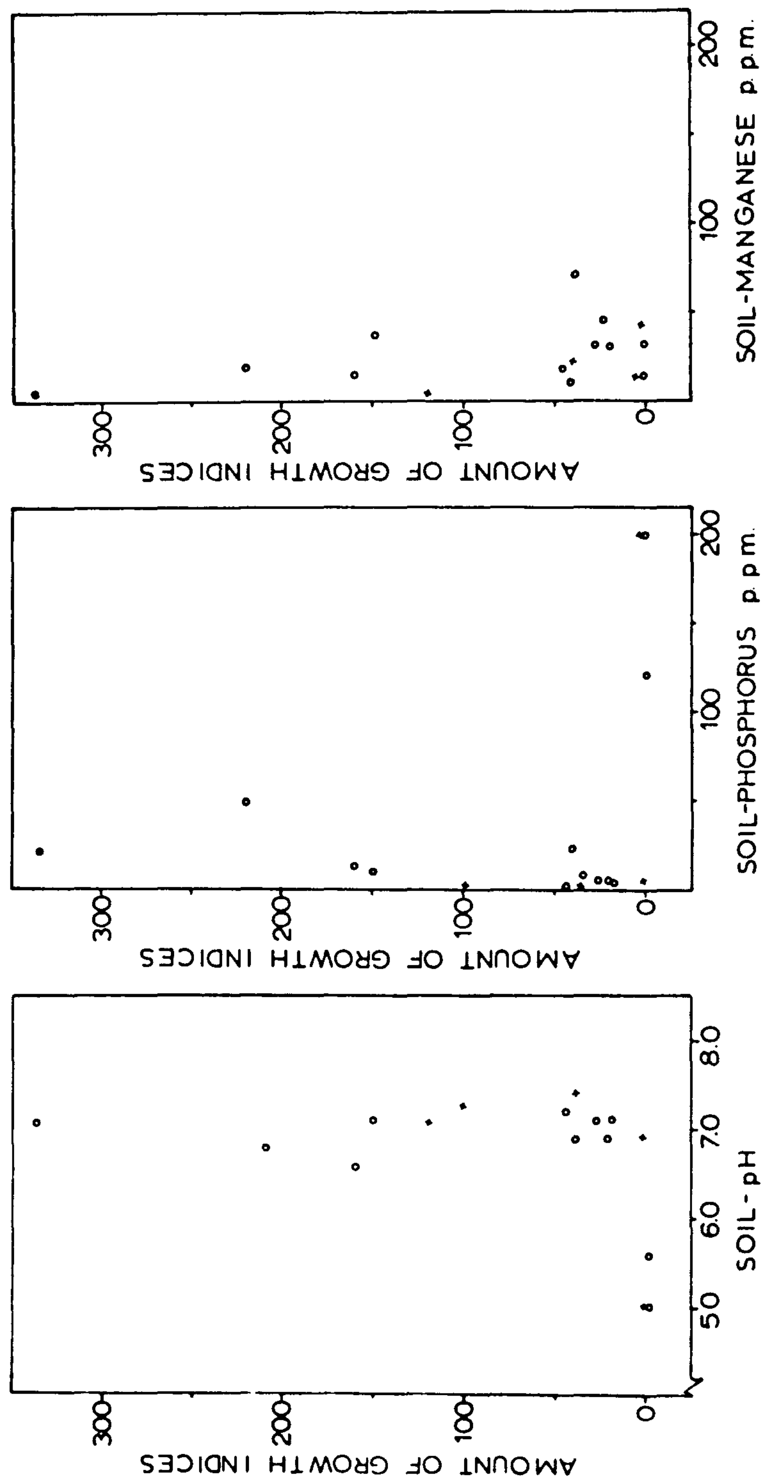

AMOUNT OF GROWTH INDICES
300
200
100
0
SOIL-MANGANESE p.p.m.
100
200
SOIL-PHOSPHORUS p.p.m.
100
200
SOIL-pH
5.0
6.0
7.0
8.0

Figure 10. Analyses of water pH from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 11. Analyses of water sulfate from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 12. Analyses of water ammonia nitrogen from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

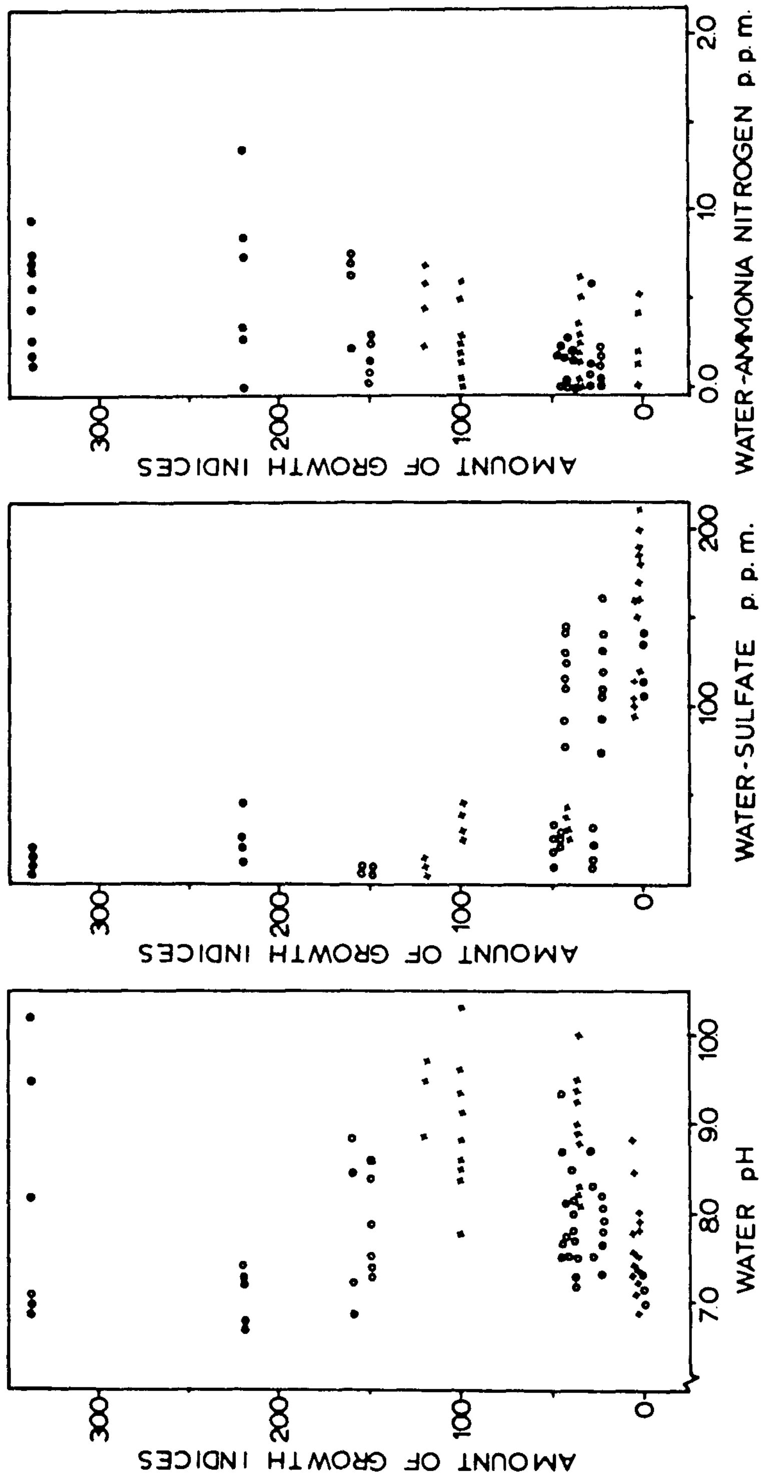

AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-AMMONIA NITROGEN p.p.m.
0.0
1.0
2.0
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-SULFATE p.p.m.
100
200
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER pH
7.0
8.0
9.0
10.0

Figure 13. Analyses of water phosphorus from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 14. Analyses of turbidity of the water from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken. Readings taken when the wild rice plants were in the submerged-leaf stage are given special indicators: the crosses are surrounded by circles and the circles contain a dot.

Figure 15. Analyses of water depth from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

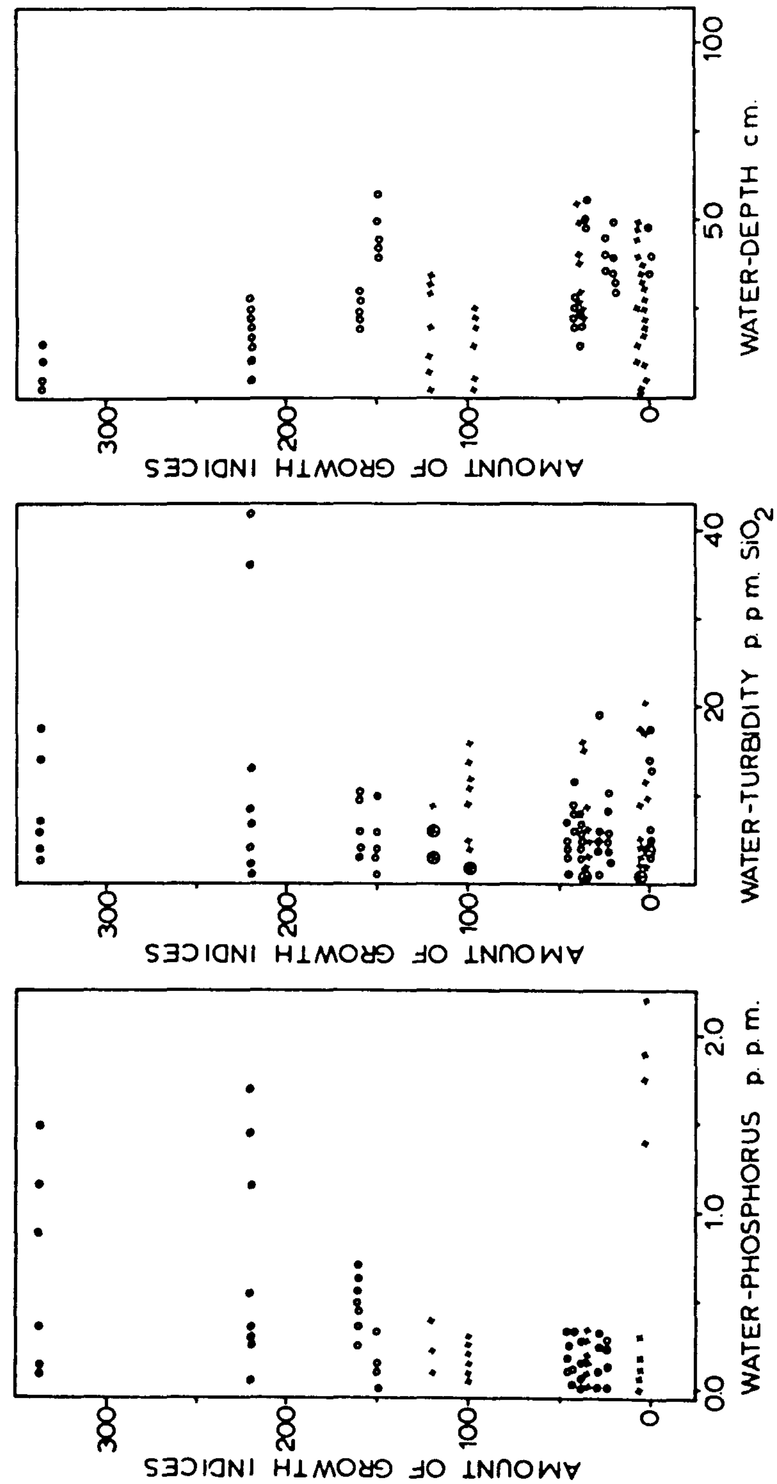

AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-DEPTH cm.
50
100
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-TURBIDITY p. p. m. $SiO_2$
20
40
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-PHOSPHORUS p. p. m.
0.0
1.0
2.0

Figure 16. Analyses of chloride in the water from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 17. Analyses of water temperature at experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 18. Analyses of phenolphthalein alkalinity and total alkalinity of the water from experimental growth sites. The horizontal axis indicates the amount of growth indices. The phelophthalein alkalinity amounts are indicated by x's and the total alkalinity amounts are indicated by o's. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken. All measurements are for 1972.

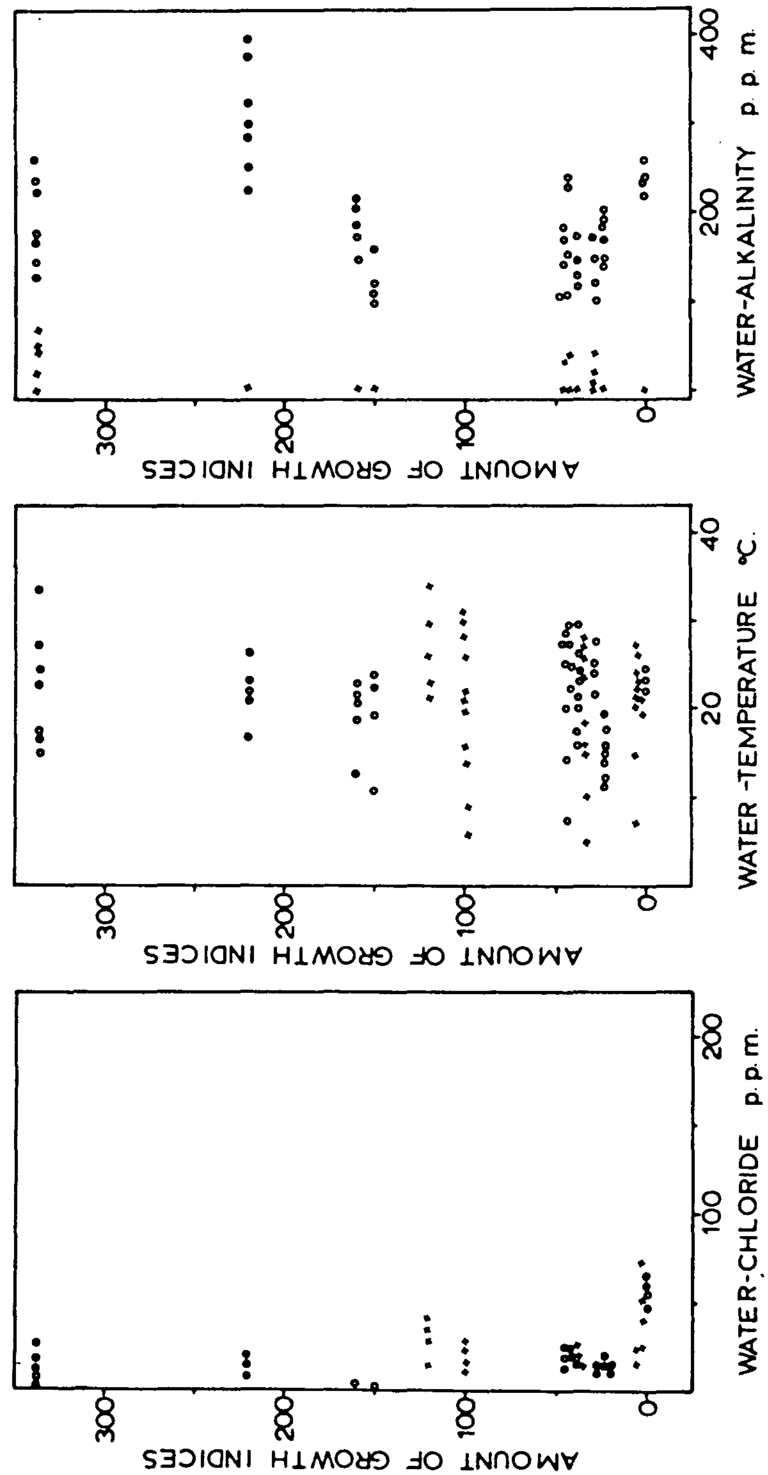
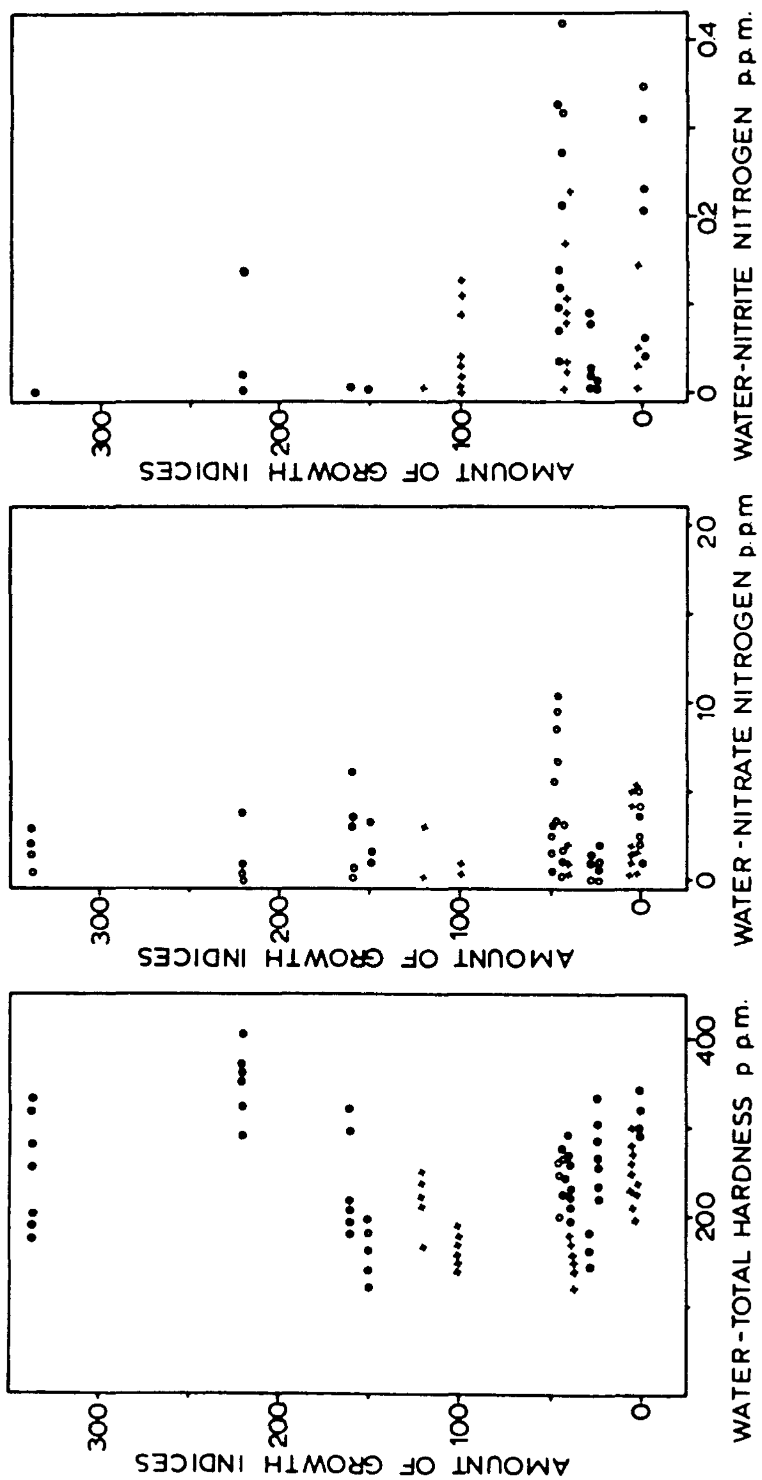

AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-ALKALINITY p.p.m.
200
400
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER -TEMPERATURE °C.
20
40
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-CHLORIDE p.p.m.
100
200

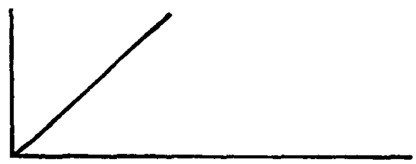
Figure 19. Analyses of total hardness of the water from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

Figure 20. Analyses of nitrate nitrogen in the water from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.

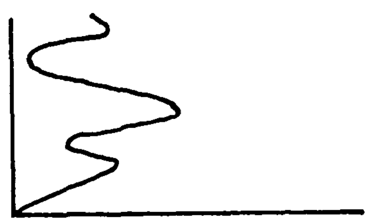
Figure 21. Analyses of nitrite nitrogen in the water from experimental growth sites. The horizontal axis indicates the amount of growth indices with x = 1971 values and o = 1972 values. Each "x" or "o" indicates the resulting measurement of the parameter at each site for each time a sample was taken.


AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-TOTAL HARDNESS p.p.m.
200
400
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-NITRATE NITROGEN p.p.m
0
10
20
AMOUNT OF GROWTH INDICES
300
200
100
0
WATER-NITRITE NITROGEN p.p.m.
0
0.2
0.4

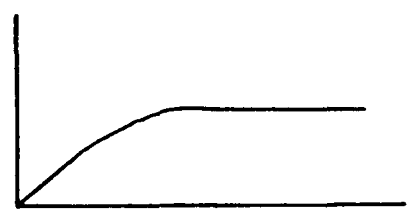
amounts of the parameter measured for larger indices should be larger than the amounts of the parameter for any smaller specific index. Ideally the result would look much like the following drawing.



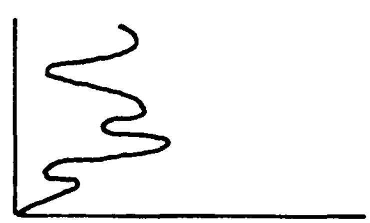
There are some situations which need special interpretation. If one of the parameters inhibits growth of wild rice, increased amounts of the parameter might not further reduce growth and decreased amounts might not allow greater growth. It is difficult to separate this situation from one in which the factor has no particular affect on plant growth because neither would show a definite pattern. The following drawing shows how this might look. The controlling parameter might be an unmeasured one in which



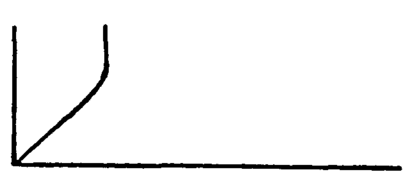
case it would not be found by graphing other factors. Undetected amounts may be influencing growth, and these would be found only with more sensitive techniques designed to measure smaller quantities of environmental parameters. Interaction between parameters probably occurs so that the amount of one factor affects the response of wild rice to another factor. Such interactions can be determined only, if at all, by very carefully executed laboratory experiments. Also, there may be a maximum amount of a parameter which promotes growth, and amounts greater than this have no added affect. In this case, the amount of growth index and the amount of the parameter should increase up to this point. Then the amount of growth index would not increase, but the quantity of the parameter present would. The following drawing shows this situation. Certain substances



might increase in amount and be taken in by the plant but not used. The resulting graph would depend on the relationship of this parameter to the one controlling growth. If they were positively correlated, the graph would appear much like the one for the growth-controlling factor. Otherwise the following drawing shows how this could appear. The parameter



might be growth-promoting up to a certain amount, then increased amount of growth would not be dependent on increased amounts of that parameter. This drawing shows how this would look.

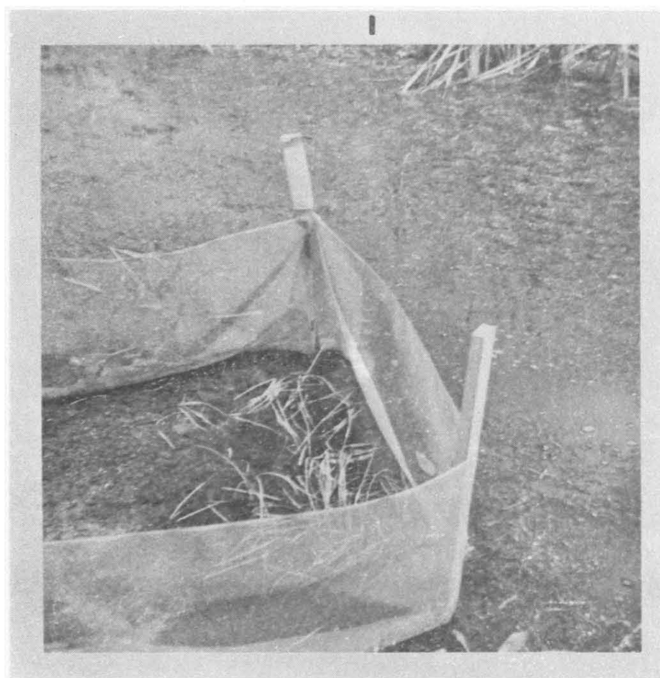


Results for the following sites are not plotted on the graphs: Hendrickson's Marsh, Site 2, 1971; Big Wall Lake, Research Site, 1971; Little Wall Lake, Site 2, 1971; and Hickory Grove, Site 2, 1972. The very reduced amount of light penetrating underwater at these sites seemed to be a dominant controlling factor. An example can be seen pictorially in a view from Little Wall Lake shown in Figure 22. The plants in the east half of the plot were removed before planting wild rice seed evenly throughout the plot. As can be seen, many more plants grew in the cleared side of the plot than in the uncleared portion. To plot points from these sites on the graphs would attempt to attribute the results to parameters which were secondarily, if at all, involved since field observations convinced me that light was probably the primary controlling factor. This conclusion agrees with the stipulation by Moyle (1944) that the water be clear.

The results obtained from the plot at the Smith farm are graphed. Due to the fact that the plants were destroyed by muskrats before they reached full growth, this information is interpreted with some care.

The difference between the amount of growth indices at the same plot for the two different years is generally large (Table 1). From field observations, it was evident that the weather for the two years was very different. Statements issued by the state climatologist substantiate the field observations. June, 1971, was the hottest June since 1934 with less precipitation than normal; August, 1971, was the driest August in Iowa in 99 years; June, 1972, was both cooler and drier than a normal June; the summer of 1972 was cool with precipitation greater than normal (Waite, 1971,

Figure 22. View of Site 2 at Little Wall Lake in summer of 1971 showing that east (right) side of plot which was cleared of other plant species before planting wild rice has produced many more wild rice plants.



1972). Therefore, the results of the two years are separated by designation on the graphs to attempt to eliminate whatever influence the difference in weather might have exerted. The results for 1971 are designated by crosses; and those for 1972, by circles, except for alkalinity measurements where crosses indicate phenolphthalein alkalinity.

As the information from these graphs is interpreted, it is important to realize that large amounts of growth indices need not necessarily be accepted as the "best" growth. The shorter plants which frequently contributed to smaller indices generally produced larger grains (Table 2) which are preferred for harvest for human consumption, whereas the taller plants which contributed more frequently to larger indices provided generally smaller grains but contributed a greater amount of cover for waterfowl and more food for those animals which eat the stems and leaves.

In comparing the amount of growth indices with tested soil parameters, it was found that the quantity of several of the measured parameters showed an increase as the amount of growth indices increased. This was generally the case for potassium (Figure 1), magnesium (Figure 2) and nitrate nitrogen (Figure 3) for both 1971 and 1972. The amounts of potassium in soils from the tertiary treatment ponds are rather high and amount of growth indices of 2.0 for 1971 and 0.0 for 1972 are low values. Since this location produced the only exception in the relationship of amount of potassium present to the growth index, it was somewhat discounted based on the statements by Dore (1969) that detergents and certain industrial wastes are detrimental to wild rice growth. These would very likely be present in tertiary treatment pond waters. Yet, Stoddard (1957) indicated that the amounts of potassium should be low for good growth of wild rice. Magnesium was not referred to as a critical parameter in determining wild rice growth in any of the literature examined. Smith (1971) found that increased amounts of nitrogen fertilizer seemed to increase the size of wild rice plants; however, the fertilizer was added as urea which would be an ammonia form easily oxidized to nitrate.

Other soil parameters increased in amount as the growth index increased in only one of the two years. Calcium measured in 1971 showed this tendency (Figure 4). But in 1972 the amount of calcium increased only up to an amount of growth index of 220.0, then did not increase in amount as the amount of growth index increased. It appears that all available calcium is being used at the highest amount of growth index. Also, as the muck depth increased in 1971, the growth index increased; but this tendency was not evident in 1972 (Figure 5). Although the amount of organic matter did not show a consistent tendency to increase with the growth index in 1971, there is such a tendency evident in 1972 (Figure 6). Moyle (1944) indicated that all of these might be important growth factors since he recommended at least 0.15 m of organic soil containing some calcareous material.

The tendency for parameter amounts to increase with the growth index was not apparent for either year with soil pH (Figure 7), and soil phosphorus (Figure 8) or for soil manganese (Figure 9) in 1972. In 1971, the quantity of manganese present tended to decrease as the amount of growth index increased. Stoddard (1957) indicated that available phosphate should be low and that the pH should be close to neutral, but no mention was found in the literature concerning manganese amounts in relation to ideal growth sites for wild rice.

Comparing tested water parameters with the amount of growth indices, there is one which increased with an increase in the growth index. The pH in 1971 was higher when greater amount of growth indices occurred; yet, pH values for the amount of growth indices 40.8 and 100.0 are much the same (Figure 10). The pH measurements in 1972 are generally between 7.0 and 9.0 up through amount of growth index 160.0, then they drop for amount of growth index 220.0 with all readings between 6.5 and 7.5. For the highest amount of growth index, the pH readings vary from 6.5 to 10.0. Thus, there is no discernible tendency in 1972 to show a relationship between the pH readings and the growth indices. Stoddard (1957) stated that the pH of the water should be between 6.8 and 8.8.

Considering sulfate in the water, all plots with large amount of growth indices have low concentrations of sulfate; however, low sulfate concentrations are not always associated with a large amount of plant growth (Figure 11). High amounts of sulfate appeared within these experimental plots only in conjunction with small amounts of growth indices. For the greatest amount of growth index, the sulfate concentration was less than 50 ppm. This information agrees somewhat with the recommendations of Moyle (1944) that the sulfate concentration be low; however, he mentioned that concentrations less than 10 ppm are best for producing wild rice.

Ammonia nitrogen concentrations in three out of four plots with large amounts of plant growth have points on the graph showing concentrations much higher than those with small amounts of growth (Figure 12). Within the fourth plot all concentrations are at the same level as those with smaller amounts of growth. Also, the concentrations at the tertiary treatment ponds were very high ranging in 1972 from 4.5 to 13.0 ppm. The same situation was found with phosphorus (Figure 13). At the tertiary treatment ponds the concentrations ranged from 2.7 ppm to greater than 8.0 ppm in 1971 and from 16.4 to 31.8 ppm in 1972. No references were found in the literature which made recommendations regarding the requirements for either ammonia nitrogen or phosphorus in water.

Turbidity readings show no definite trend to correspond with the amount of growth indices. Although measurements were made for the entire plant growing season, only those made before the floating-leaf stage are crucial (Figure 14). Special symbols mark these readings for easy evaluation. The crosses for 1971 reading are enclosed with circles, and the circles marking 1972 readings contain a dot. During the submerged-leaf stage the plants are dependent on light penetration. Generally the more shallow the water, the greater are the chances of receiving enough light to ensure growth. The measurements for tubidity are somewhat misleading because: 1) in shallow plots, sediments are stirred up while taking samples and increase the turbidity measurements and 2) the differences in water depths at the sites are not taken into account. Deeper water must be clearer than shallower water in order for submersed plants to receive adequate light. In other words, if the turbidity is the same at two different sites, the plants in deeper water will receive less light due to the absorption and diffusion by suspended materials plus the normal characteristics of light beams in water. As shown previously, the amount of light received at the substrate level is a definite controlling factor (Figure 22 and page 51).

The depth of the water shows no general tendency to correspond to the amount of growth indices (Figure 15). However, at the two sites with the highest indices and tallest plants the water was the shallowest. This contrasts with the data of Weir and Dale (1960) showing that plants tend to be taller in deeper water.

The amounts of chloride measured in water are approximately the same for all amounts of growth indices throughout 1971 and 1972 (Figure 16). The same is true for water temperature (Figure 17). Specifications for wild rice growth requirements for these two parameters were not found in the literature.

At all sites except Hendrickson's Marsh the total alkalinity was less than 270 ppm (Figure 18). At Hendrickson's Marsh with an amount of growth index of 220.0 the total alkalinity quantities ranged from 220 ppm to 400 ppm. Moyle (1944) specified that the alkalinity of the water be greater than 40 ppm. This specification is met at all sites. Stoddard (1957) felt that alkalinity should not be greater than 200 ppm. At Hendrickson's Marsh that specification was exceeded; yet the plant growth was very good. This information on amounts of total alkalinity at the sites is for 1972, the only year such measurements were made.

The amounts of phenolphthalein alkalinity vary considerably from site to site (Figure 18) with very low values being interspersed among the growth indices with higher values. There was no consistent relation between the amounts of phenolphthalein alkalinity and the growth indices. None of the literature references mentioned amounts of phenolphthalein alkalinity in regard to the requirements for good wild rice growth.

Total hardness measurements in 1971 were equal for both the highest and lowest amount of growth indices (Figure 19) and equal at the indices of 40.8 and 100.0. In 1972, the measurements were approximately the same for considerably different amounts of growth indices: 22.5, 39.0, 42.0, 42.5, 160.0 and 337.5. In addition, the hardness was approximately equal and lower in quantity at the indices of 28.0 and 150.0 and approximately equal and higher at the indices of 0.0 and 220.0. Thus, there is no consistent relation between the hardness of the water and the amount of growth indices. No information was found in the literature concerning the total hardness measurements required for good wild rice growth.

For nitrite nitrogen (Figure 21) the measurements showed no consistent relationship to the growth indices in 1971. The measurements in 1972 were less than 0.02 ppm for indices ranging from 22.5 to 337.5; yet, interspersed are indices of sites where the measurements are much higher. At the index of 220.0, measurements were as high as 0.14 ppm; and at the indices of 42.0 and 42.5 the measurements were as high as 0.42. At the tertiary treatment ponds with an amount of growth index of 0.0 the quantities of nitrite nitrogen measured up to 0.53 and 0.61 ppm. Therefore, there was no constant relation between the measurements and the indices. No references in the literature read referred to requirements for nitrite nitrogen in wild rice stands.

# CONCLUSIONS

The conclusion regarding the possibilities of growing wild rice in Iowa appears to be that wild rice will grow in aquatic habitats of present day Iowa at a variety of different sites. Of those sites tested, only the tertiary treatment ponds at the Ames Municipal Sewage Treatment Plant did not produce a satisfactory crop in at least one of the two years the tests were conducted.

In testing the possibilities of overwintering wild rice, the conclusion based on these studies is that overwintering is possible. All sites at which wild rice was left to overwinter produced plants the following spring.

In regard to growth-controlling parameters, it appears, as was expected, that more than one parameter is involved. Any obstruction of light, whether by turbidity or heavy cover from competing vascular plants, is of major importance in preventing plant growth thus reducing a stand which in the absence of turbidity or competing plants would produce a larger crop or eliminating a stand which would at least have shown some productivity. Coincident with this parameter, is the depth of the water in which the wild rice is growing. This is important because deeper water reduces available light for plant growth during the submerged-leaf stage. High amounts of sulfate in the water appear to inhibit growth. However, low amounts do not insure production of large plants nor a large number of plants. As long as plants are not growing in water containing extremely high concentrations of phosphorus and ammonia nitrogen such as found at the tertiary treatment ponds these parameters in larger amounts may enhance growth. Magnesium, potassium, and nitrate nitrogen in the substrate appear to increase the amount of growth of the wild rice plants as amounts of the parameters increase. Increased amounts of calcium in the soil also appear to enhance growth of wild rice.

## RECOMMENDATIONS

I would encourage further studies of water and soil parameters at the projected sites of any further plantings of wild rice. This would help to determine whether or not the parameter quantifications made during this two year study represent true tendencies toward controlling plant growth. I do not encourage full-scale plantings based exclusively on the conclusions made in this paper that 1) the amount of light at the substrate level; and 2) the amounts of magnesium, potassium, and nitrate nitrogen in the soil are the most crucial in determining the suitability of a site for the growth of wild rice. It is possible that a factor was not measured which is more responsible for controlling growth and that the apparent correspondence of these parameters with that factor might be a coincidence. Evidence thus far evaluated shows that the amount of light at the substrate level and the amounts of magnesium, potassium, and nitrate nitrogen in the substrate should be considered before making plantings at any site.

I would also advocate laboratory experiments to compare the influence these parameters have on growth under controlled conditions with that occurring under field situations. By varying only one parameter at a time, the growth-controlling parameters could better be estimated.

At this stage, I would recommend destruction of all late maturing wild rice at sites planted for this project that has been infested by the rice worm. Recall that plants maturing earlier were not attacked so these can be saved to continue plant growth within stands. The later maturing plants could be reintroduced after assurance that the wild rice worm is no longer present.

It seems that there are many problems to be solved before wild rice could be of major importance in Iowa as either a crop for human consumption or as food and shelter for wildlife. However, those who relish the taste of wild rice and who recognize its value to waterfowl heartily recommend its planting. This indicates that it may be well worth solving the problems in order to have populations in Iowa.

It should also be noted that a crop failure one year need not be interpreted to mean that wild rice will not grow and flourish in subsequent years. Rather a second planting should be attempted. Recall that the amounts of growth were very different in the two years of this study (Table 1); and the conclusions would have been much different with only one year's information.

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