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Mineral Deficiencies of Wild Rice Grown in Flocculent Sediments

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ABSTRACT

Wild rice production was examined in nutrient deficient flocculent sediments. Plants grown in these sediments were characterized by purple coloration of the leaves and slower maturation. Controlled experiments revealed that growth and development was enhanced in these sediments when P was added singly, but best improvement occurred when P, N and K were added together. Mineral deficiency symptoms of wild rice for N, P, K, Ca, Mg, Fe, and a mixture of various micronutrients (Bo, Mn, Zn, Cu and Mb) were compared to the appearance of wild rice grown in the problem flocculent sediments. Phosphorus deficient plants, which had purple leaves and culms, most closely resembled wild rice plants from flocculent sediments. Although either N and/or K were also affecting production in these sediments, only the visual symptom for the initial limiting element of P was evident in the field-grown plants.

Key words: *Zizania aquatica,* production, phosphorus.

INTRODUCTION

Wild rice, *Zizania aquatica* L., is commercially grown in Canada using lake-culture techniques (Aiken *et al.* 1988). An important part of this technique is to select potential wild rice producing lakes. For a lake to be commercially successful, it must be shallow (less than 1 m), have a paucity of competing perennial plants, and a suitable sediment.

The sediments of wild rice lakes can be classified as organic, clay, flocculent, organic/clay, organic-clay, or organic-flocculent (Day and Lee 1989). Best production occurs in organic, organic/clay and organic-clay sediments. Production is extremely poor in flocculent and organic-flocculent sediments which are characterized by their light brown color, soft texture and low (<0.1 $g.cm^{-3}$) bulk densities. These sediments are extremely high in organic content with loss on ignition values generally greater than 55%. Since shallow lakes with this type of sediment are quite common and often several thousand hectares in size, it would be highly beneficial economically if they could be put into commercial production.

A previous study compared wild rice production and seasonal nutrient trends in flocculent sediments to a productive organic/clay sediment (Day and Lee 1990). Plants from organic-flocculent sediments were smaller, matured slower, and had purple foliage. It was suggested that nutrient deficiencies were reducing wild rice growth. This hypothesis was examined in this study by the application of fertilizer to flocculent sediments under controlled conditions, and the identification of specific mineral nutrient deficiency symptoms.

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METHODS

Fertilizer Trials. Fertilizer trials were conducted by culturning wild rice in cultivation rafts described by Stevenson and Lee (1987). Plastic tubs (28 cm by 35 cm by 14 cm) containing sediment from three organic-flocculent lakes were suspended at a water depth of 45 cm. The sediment sources were Tag, Collins, and No-name lakes, located near Ignace, Ontario, Canada and previously described by Day and Lee (1990).

The experimental procedure was similar to that outlined by Lee (1987). Three cultivation rafts (Figure 1), one for each sediment source, were used in a randomized block experimental design with two replicates of nine fertilizer treatments in each raft. Slow release fertilizers manufactured by the Sierra Chemical Company, Milpitas, California were uniformly mixed with each of the three sediments in high (H) and low (L) concentrations in all but the control treatment (Table 1).

Five seedlings were planted in each tub. Rafts were designed to accommodate 24 tubs; therefore six additional control tubs were used on each raft to ensure that each tub in the experiment was bracketed on at least two sides by other tubs containing wild rice. This created equal shade for all plants in the experiment. The plants within these six additional tubs were not used in the analysis. At maturity, the plants were removed, sediment was rinsed from

TABLE 1. FERTILIZER RATES UNIFORMLY MIXED WITH ORGANIC FLOCCULENT SEDIMENT FROM TAG, COLLINS, AND UNNAMED LAKES, PLACED IN 35 CM × 28 CM × 14 CM PLASTIC TUBS, AND SUSPENDED FROM WILD RICE CULTIVATION RAFTS.

Treatment	Fertilizer Rate
C	no fertilizer
+P, H	120 $kg.ha^{-1}$ P of 0-4-0
+P, L	30 $kg.ha^{-1}$ P of 0-4-0
+NPK, H	800 $kg.ha^{-1}$ N, 268 $kg.ha^{-1}$ P, 532 $kg.ha^{-1}$ K of 18-6-12
+NPK, L	200 $kg.ha^{-1}$ N, 67 $kg.ha^{-1}$ P, 133 $kg.ha^{-1}$ K of 18-6-12
+N, H	800 $kg.ha^{-1}$ N of 40-0-0
+N, L	200 $kg.ha^{-1}$ N of 40-0-0
+M, H	200 $kg.ha^{-1}$ of micronutrients*
+M, L	100 $kg.ha^{-1}$ of micronutrients*

*(12% Fe, 2.5% Mn, 1% Zn, 0.5% Cu, 0.1% Bo, 0.05% Mo, 15% S)

LEGEND

C	+P(H)	+P(L)	+NPK(H)
+M(H)		+N(L)	
+N(L)	+P(L)		C
	+NPK(L)	+M(L)	+M(L)
+NPK(H)	+P(H)		+N(H)
+M(H)		+N(H)	+NPK(L)

Figure 1. Wild rice cultivation raft used with Collins Lake sediment. The suspended plastic tubs contained the sediment and fertilizer treatments. Two replicates of each of the nine fertilizer treatments were added to the sediment in either high (H) or low (L) concentrations. Wild rice matured faster in the +NPK and +P treatments (shown in the aerial-leaf stage) than in the +N, +M and control (C) treatments (shown in the floating-leaf stage). The same results were observed for Tag and No-Name Lakes.

the roots, and the height, dry weight, and number of seeds determined for each plant.

Skewness and kurtosis statistics were calculated for the plant variables measured. The normality of the variables was improved with a square root transformation. Analyses of variance (SPSS Inc. 1985) tested for statistical differences among the nine fertilizer treatments for wild rice height, dry weight, and number of seeds per plant.

Foliar Mineral Deficiency Symptoms. Wild rice plants were initially grown in organic soil to the aerial leaf stage (4-5 weeks) in a greenhouse using culture tanks described by Lee 1984. To ensure that the plants had adequate nutrients, 10 g of slow release Osmocote 18-6-12 fertilizer (Sierra Chemical Company, Milpitas, California) was mixed into the organic soil. The plants were not grown in nutrient solution during the earlier development stages since it is impossible to physically control for algae while the plants are still in the submerged and floating leaf stages, and the use of chemicals for algal control might modify the mineral concentrations. A 16 hour photoperiod was used for the entire experiment. Day temperatures were kept at 23 C, while night temperatures were maintained at 15 C.

Once the plants reached the aerial leaf stage, they were removed from their pots and the soil was gently washed from the roots. The roots were kept wet at all times prior to transfer to the test solutions.

Modified Hoagland solutions (Hoagland and Arnon 1950) were used in the experiment. N, P, K, Ca, and Mg were mixed at half strength (50% Hoaglands); Fe and the mixture of other micronutrients (Bo, Mn, Zn, Cu, and Mo) were 2.5 times normal strength to approximate sediment values (Lee 1984). A complete solution (control) and solutions lacking N, P, K, Ca, MG, Fe, and the micronutrient mixture were prepared for a total of 8 treatments. The pH range of the solutions (5.5 to 6.5) was similar to that found in productive lake sediments (Day and Lee 1989).

Five wild rice plants were used for each of the eight different treatments. Individual plants were placed in 2 L glass jars that had been washed with double distilled water. The jars were filled with the appropriate nutrient solution and placed in culture tanks. Nutrient solutions were replenished daily. In order to impede light penetration and prevent algal growth, the tanks were covered with two layers of black plastic. The leaves of the plants were left uncovered, and the stems were supported with clamps to prevent the plants from falling. The plants were monitored daily for a 30 day period and visual foliar symptoms were recorded.

RESULTS

Raft Experiments. Phenological development of wild rice, as well as growth performance, was affected by the different fertilizer treatments (Figure 1). Wild rice plants in the NPK and P treatments were in the advanced aerial leaf stage, while plants in the N, micronutrients, and control treatments were still in floating leaf or early aerial leaf stage. Analyses of variance showed statistically significant differences among treatments (wt/plant $F=_{(2,8)}17.0$, $p<0.01$; ht/plant $F=_{(2,8)}14.0$, $p<0.01$; seeds(pedicels)/plant $F=_{(2,8)}87.1$, $p<0.01$). The various fertilizers affected wild rice similarly in all three lake sediments. Values for height, seeds per plant and dry weight were highest in the NPK and P treatments (Figure 2). N and micronutrient treatments did not significantly increase plant performance for these variables relative to the control.

Nutrient Deficiency Symptoms. The leaves of some of the plants displayed chlorosis when first transplanted into the nutrient solutions. These chlorotic leaves were removed since these symptoms were believed to be the result of transplant shock. The first visible nutrient deficiency symptoms were recorded at day 10 of the experiment. As time progressed, the symptoms became more severe, affecting more leaf area and often the stalks.

Plants in the complete solution remained green and healthy for the duration of the experiment (Figure 3).

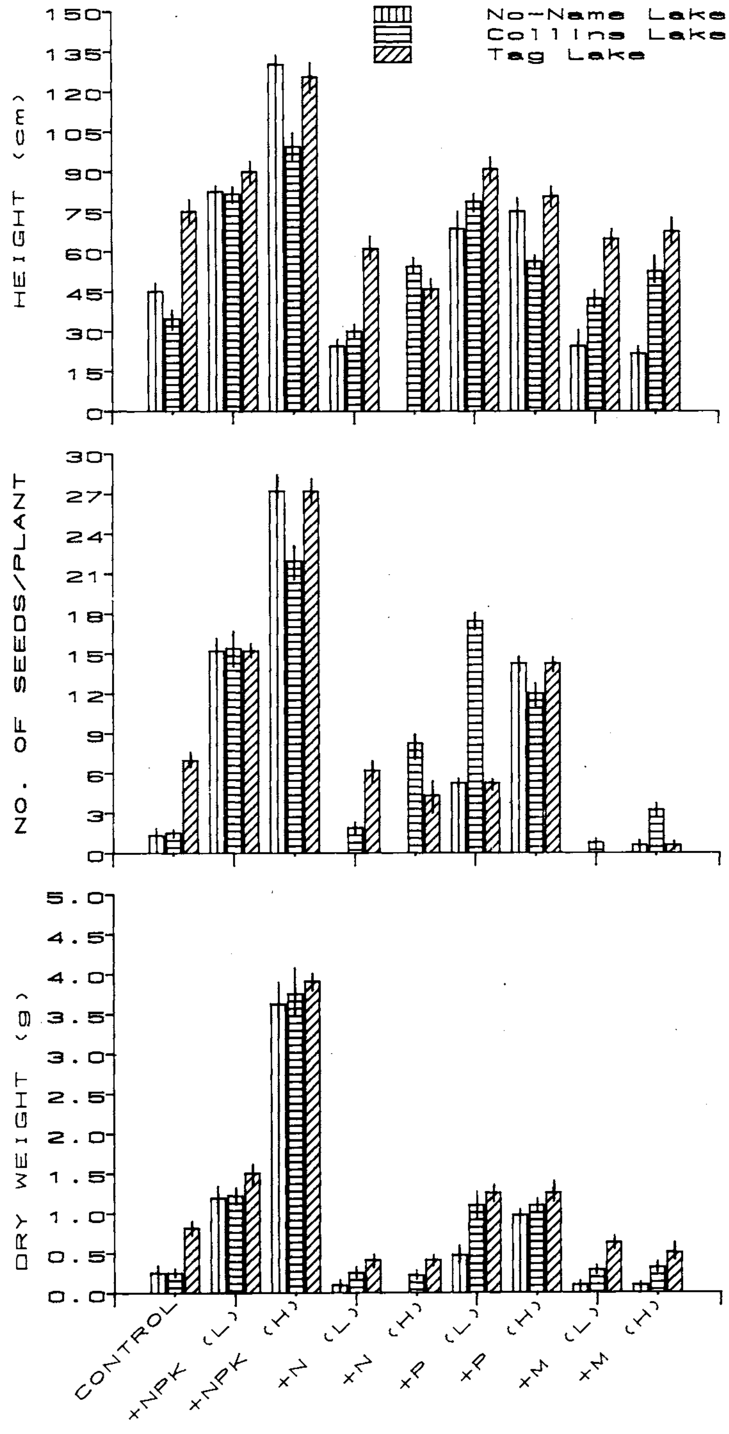

Figure 2. Mean height, mean number of seeds per plant, and mean dry weight response of wild rice grown in sediment from Collins, Tag, and No-Name Lakes to the nine fertilizer treatments. Error bars indicate one standard deviation from the mean.

Plants grown in the –P solution most closely resembled wild rice grown in organic-flocculent sediment (field). These plants displayed purple coloration along the margins, interveinally, and on the stalks of the more recently affected leaves, while older leaves were necrotic. In the –N treatment, chlorosis first appeared at the tips and margins

Figure 3. Comparison of the mineral deficiency symptoms of wild rice grown in the field (organic-flocculent sediments) to wild rice grown in complete solution and in solutions deficient in N, P, K, Fe, Mg, Ca, and the micronutrient mixture.

of the older leaves, and then progressed towards the base. Plants in the –K solution were scorched at the tips and margins of the most recently matured leaves. The –Fe plants displayed interveinal chlorosis in the younger leaves. The –Fe plants displayed interveinal chlorosis of the older leaves. After 10 days, the plants grown in the micronutrient deficient (–micro) solution, displayed marginal and interveinal chlorosis and a slight purple color along the margins and sheaths of the older leaves. These leaves later turned an orange-brown color, and became necrotic after

20 days. After a 30 day period all the above symptoms still prevailed for the respective treatments. Many of the earlier leaves that were affected became necrotic.

DISCUSSION

The fertilizer trials and the nutrient deficiency results point to phosphorus as the primary limiting nutrient in organic-flocculent lakes. Plants subjected to fertilizer regimes that included P were characterized by early maturation, good production and no chlorosis (Figure 1). By contrast, wild rice plants grown in +M (micronutrients), +N, and C (control) treatments (i.e. lacking P) displayed both slow maturation and purple foliage. Plants from organic-flocculent lakes (Figure 3) most closely resembled the P deficient treatment. P deficient plants were characterized by purple coloration of the leaves, and a slower maturation rate. Similar symptoms have been observed in other plants that are deficient in this element (Hale and Orcutt 1987).

The observation of P deficiency seems reasonable when the composition of the sediments is considered. Although studies have indicated that high organic content is generally correlated to high P values within lake sediments (Trojanowski et al. 1985; Golachowski 1984; Trisal and Kaul 1983; Peltier and Welch 1970), organic-flocculent sediments are characterized by high organic content but low P values (Day and Lee 1989). This discrepancy may be due to the more decomposed organic matter in flocculent sediments which release less nutrients (Twilley et al. 1985; Jordana 1983; Twinch and Ashton 1983; Malsner and Nihlgard 1980). Another possibility is that the low bulk densities of these sediments make them subject to turbulent mixing which is known to accelerate nutrient release (Bostrom 1984; Zicker at al. 1956).

However, although P seems to be the element which causes an initial increase in wild rice growth, the results (Figure 1 and 2) showed that the greatest response occurred when NPK were added jointly. This concurs with the standard practice of adding all three nutrients to wild rice paddies to increase production (Oelke et al. 1982) and suggests that nitrogen and/or potassium were in less than optimum concentration in the organic-flocculent sediments. The visual symptoms indicated only the problem with P and imply that just the initial limiting element (in this case P) was a problem. The plants did not exhibit combined nutrient deficiencies as Newman and Haller (1988) hypothesized could occur with waterhyacinth (*Eichhornia crassipes*). Therefore, although the coloration of wild rice indicated only a phosphorus deficiency, there were also other non-obvious deficiencies. In future, caution should be exercised in interpreting the presence of visual deficiency symptoms of a particular mineral nutrient as the only nutrient problem.

In conclusion, wild rice production in the organic-flocculent sediments of the lakes studied, was initially limited by P, but other elements (either N and/or K) were also in less than optimum concentrations. P deficiency in wild rice was characterized by slow maturation and purple coloration of the culms and leaves. When only P was added, production was enhanced, but optimum growth in these sediments required the addition of P in combination with N and K. Future studies will involve *in situ* fertilizer experiments that assess the environmental effects of fertilizing natural organic-flocculent lake sediments in order to bring them into commercial production.

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LITERATURE CITED

Aiken, S. G., Lee, P. F., Punter, D., and J. M. Stewart. 1988. Wild rice in Canada. N.C. Press, Toronto. 130 pp.

Bostrom, B. 1984. Potential mobility of phosphorus in different types of lake sediments. Int. Revenue ges. Hydrobiol. 69:457-474.

Day, W. R. and P. R. Lee. 1989. Ecological relationships of wild rice, *Zizania aquatica* L. 8.Classification of sediments. Can J. Bot. 67:1381-1386.

Day, W. R. and P. F. Lee. 1990. Ecological relationships of wild rice, *Zizania aquatica* L. 9.Production in organic-flocculent sediments. Can. J. Bot. 68:(in press).

Golachowski, J. 1984. Phosphorus in bottom sediments of some lakes of the world. Polish Archives of Hydrobiology. 31:175-206.

Hale, M. G. and D. M. Orcutt. 1987. The physiology of plants under stress. Wiley, New York. 206 pp.

Hoagland, D. R. and D. I. Arnon. 1950. The water-culture method for growing plants without soil. Circular 347. Calif. Agr. Exp. Sta., Univ. of California, Berkely, 32 pp.

Jordana, J. C. C. 1983. Physical, chemical, and metabolic characteristics of a peat bog in the depression of Padul (Granada, Spain). Acth. Hydrobiol. 25:253-266.

Lee, P. F. 1984. The aquaculture of wild rice. Progress year 3. Special Publication. Lakehead Univ., Thunder Bay, Ont. 229 pp.

Lee, P. F. 1987. Ecological relationships of wild rice, *Zizania aquatica* L. 5.Enhancement of wild rice production by *Potamogeton robbinsii*. Can. J. Bot. 65:1433-1438.

Newman, S. and W. T. Haller. 1988. Mineral deficiency symptoms of waterhyacinth. J. Aquat. Manage. 26:55-58.

Oelke, E. A., Grava, J., Noetzel, D., Barron, D., Percich, J., Schertz, C., Strait, J., and R. Stucker. 1982. Wild rice production in Minnesota. Univ. of Minn. Ext. Bull. 464. St. Paul, Minn. 39 pp.

Peltier, W. H. and E. B. Welch. 1970. Factors affecting growth of rooted plants in a reservoir. Weed Sci. 18:7-9.

SPSS Inc. 1985. SPSSx User's Guide. 2ed. McGraw-Hill. Montreal. 988 pp.

Stevenson, S. and P. F. Lee. 1987. Ecological relationships of wild rice, *Zizania aquatica* L. 6.The effects of increases in water depth on vegetative and reproductive production. Can. J. Bot. 65:2128-2132.

Trisal, C. L. and S. Kaul. 1983. Sediment composition, mud-water interchange and the role of macrophytes in Dal Lake, Kashmir. Int. Revue ges. Hydrobiol. 68:671-682.

Trojanowski, J., Trojanowska, C., and H. Ratajczyk. 1985. Chemical characteristics of the bottom sediment top layer in Szeytno Male Lake (Poland). Polish Archives of Hydrobiology. 32:99-112.

Twilley, R. R., Brinson, L. R., and J. D. Davis. 1985. Biomass production and nutrient cycling in aquatic macrophyte communities of the Chawen River, North Carolina (U.S.A.). Aquat. Bot. 22:231-252.

Twinch, A. J. and P. J. Ashton. 1983. Wetlands as accreting systems: nutrient cycling in wetlands. J. Limnol. Soc. Sth. Afr. 9:104-109.

Zicker, E. L., Berger, K. C., and A. D. Hasler. 1956. Phosphorus release from bog lake muds. Limnol. Oceanogr. 1:293-303.