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The effect of sediment chemistry on the successful establishment of wild rice (*Zizania palustris* L.) in northern Saskatchewan water bodies

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Abstract

Sediment chemistry of productive and non-productive wild rice sites was measured over 3 consecutive growing seasons. Although productive sites differed from non-productive sites in terms of pH, N and potential N mineralization, redox potential was considered to be the major factor which distinguished these site classes. Productivity of wild rice in commercial stands could not be consistently correlated to sediment nutrients. However, growth appeared to be restricted in strongly reduced sediments and sediment Eh is considered to be a rapid, accurate method of estimating site potential. Good growth is expected if Eh is above −150 mV while poor growth is expected when Eh drops below −200 mV. Eh values of sediment samples changed as storage time increased. It is therefore recommended that Eh is recorded on-site.

Introduction

Lake grown wild rice (*Zizania* sp.) has become a crop of economic significance in Canada with production in 1989 exceeding 1.6 million kg. It is a nutritious cereal, rich in B vitamins and low in fat. Canadian wild rice is marketed as a natural food since it is grown without the aid of fertilizers or other agrochemicals and it is popular in gourmet recipes and in health food stores. In Canada it currently sells for \$10–20 kg^{-1}, but the price may be considerably higher in Europe. To further expand production an increasing number of remote access sites are being test seeded. This is often labour-intensive, wasteful of seed, and the results remain unknown until well into the growing season. Consequently, there is a need to develop a rapid, reliable, and cost-effective method to test the suitability of potential wild rice sites.

Wild rice grows in shallow (<1 m) lakes and slow moving rivers throughout the southern boreal forest region of central and eastern Canada. Many of the site requirements such as water depth, water clarity, plant competition and shelter from wave action (Aiken *et al.*, 1988) can be evaluated quickly. However, at many locations, although conditions appear suitable, wild rice still will not grow. This suggests that sediment conditions may be unsuitable for germination or growth. Past research relating wild rice productivity to sediment chemistry has been inconclusive. Lee and Stewart (1984) suggested that available sediment P and sediment texture were important in the establishment of wild rice. Lee (1986) later concluded that poor growth could result from low P and Zn levels or low organic content. Further study on an established wild rice stand suggested that yields declined due to the decreasing availability of nitrogen (Keenan and Lee, 1988).

One important aspect of sediment chemistry which has received little attention in lake wild rice research is sediment redox potential (Eh).

Oelke *et al.* (1982) reported Eh values ranging from −215 to −315 mV in wild rice paddies in Minnesota: this appears to be the only reference to Eh for this crop. Eh has been studied in several natural vegetation communities (DeLaune *et al.*, 1979; Yamasaki, 1984) and numerous studies in rice (*Oryza* sp.) paddies have demonstrated the effect of soil reduction and anaerobiosis on plant performance (Patrick and Reddy, 1978; Ponnamperuma 1972). As oxygen availability declines there is a sequential reduction of NO_3^- to NH_4^+, Mn(IV) to Mn(II), Fe(III) to Fe(II), SO_4^{2-} to H_2S, and CO_2 to CH_4 corresponding to a drop in Eh from +700 mV to −300 mV (Patrick and Mahapatra, 1968). Ponnamperuma (1978) found that soil reduction could benefit white rice production since low Eh favoured N fixation, increased the solubility of P, Si, Fe, Mn and Mo and suppressed Mn and Al toxicity, although the availability of S, Cu and Zn was lowered. Germination and growth is generally retarded at O_2 concentrations below 0.3% which can occur at Eh_7 +300 mV in submerged soils. The accumulation of toxic decomposition products such as H_2S and CH_4 at very low Eh are also detrimental (Ponnamperuma, 1978).

This study compares sediment nutrient levels, pH and loss of ignition (LOI) at productive and non-productive wild rice in northern Saskatchewan and investigates the relationship between sediment Eh and wild rice growth. The suitability of sediment Eh as a method of new site selection is discussed.

Methods

Field procedure

Field studies were carried out over 3 consecutive growing seasons from 1987 to 1989 at various sites near Meadow Lake (54°8′N, 108°26′W) in northwest Saskatchewan. Sediments from 29 sites were sampled during late August 1987. Both productive (24 sites) and non-productive (5 sites) were selected. Sites were considered productive if they supported a commercial crop of wild rice (>100 kg ha^{-1}) in the previous year. Non-productive sites were those that produced little or no wild rice (<50 kg ha^{-1}) following seeding trials. Thirteen of the sites sampled in 1987 were revisited in May and August 1988 together with 6 additional sites. Of the 19 sites visited in 1988, 10 were productive and 9 were non-productive. Sediment samples collected in May, 1988 were analyzed and compared with those sampled in August, 1987 to determine if sampling date significantly affected nutrient levels. An Ekman dredge was used to collect the top 20 cm of sediment approximately 50 cm from established plants. This provided a composite sample of material from within the rooting zone but beyond the oxygenated microzone adjacent to the roots. Two samples were collected at each site. Each sample was sealed in a plastic bag, packed on ice, transported to the laboratory and placed in a refrigerator to await chemical analysis.

Sediment redox potentials were measured with a platinum electrode (Fisher model 13-620-277) during the early flowering (July) and mature (August) plant stages in 1988. Two readings were taken: one immediately upon collection and the second upon arrival at the laboratory. The probe was held vertically in the sediment and the value was recorded when the reading stabilized. After each reading the probe was rinsed with lake water and wiped clean with a cotton cloth. Eh values were not corrected to pH 7 due to the uncertainty of the correction factor in highly reduced sediments (Baas Becking *et al.*, 1960).

In the third year only Eh measurements were carried out. Eight productive and eight non-productive sites were sampled in mid-May, mid-June, late July and mid-August, corresponding to the preemergent, floating leaf, flowering and mature stages of wild rice development. The Eh procedures were identical to those used in 1988.

To determine the effects of 6 different storage treatments on redox potential sediment collected from a non-productive site was subdivided immediately into 30 plastic bags giving 5 replicates per storage treatment. Treatments included; (i) stored on site for 3 days at air temperature (5—20°C) then stored in the laboratory at room temperature (25°C), (ii) as in treatment (i) except laboratory storage was in a refrigerator (4°C), (iii) placed immediately on ice (0°C) for 3 days then stored in a refrigerator (4°C), (iv) immediately frozen (−20°C) and stored for 7 days, (v) immediately frozen (−20°C) and stored for 14 days, and (vi) immediately frozen (−20°C) and stored for 21 days. Redox potentials were measured after the sediment had been bagged and for unfrozen samples, at 7 day intervals for 21 days. The procedure was the same as that used when measuring the redox potentials at the different lake sites.

The density of the wild rice stands was recorded from twenty five 0.25 m^2 quadrats during the mature plant stage in 1988 and 1989. A sample of 40 plants was collected at random from each productive site. Because wild rice kernels readily shatter when mature, grain production of each head was measured indirectly by counting the pedicel scars left by the female florets. The potential yield of each site was calculated as the product of stand density and number of florets.

Laboratory procedures

Sediments were analysed for available nutrients in their wet state. In 1987 inorganic P and some organic P was extracted using the Bray-P_2 technique (Bray and Kurtz, 1945) and determined with a Technicon Auto Analyzer; in 1988 analysis was by 0.5*M* $NaHCO_3$ extraction and inductive coupled plasma (ICP) spectrophotometry which removed only inorganic P. NH_4 was extracted with 2*N* KCl and read on the Auto Analyzer. Fe, Mn, Zn, and Cu were extracted with 0.1*N* HCl and measured on the ICP spectrophotometer. Ca, Mg, K and Na, extracted with 1*N* NH_4OAc solution, were determined by spectrophotometry. $CaCl_2$ (0.001 *M*) was used to extract SO_4^{2-}; determination was by ion chromatography. Duplicate samples were analyzed for each site at each collection period. Mean values were subsequently used in the statistical analysis. Concentrations of all elements were expressed on a volume basis (1m × 1m × 20cm). Biological N mineralization was estimated by the Waring and Bremmer method (Page *et al.*, 1982) except NH_4 extraction was with 2*N* KCl. Total sediment C and N were measured using a Leco CHN analyzer. An H_2SO_4 digest was used to extract total sediment P and K. Sediment pH was measured by electrode from a 1:1 soil-double distilled water mixture (10 mL each) shaken for 45 minutes. LOI values were determined by igniting 40 mL oven dried sediment for 8 hours in a muffle furnace at 600°C.

Results

The results of the sediment chemical analyses are listed in Tables 1 and 2. The large standard deviations which existed for all variables except pH illustrate the great variation in sediment chemistry between sites in each productivity class. The only variable in 1987 which differed significantly was pH ($p \leq 0.05$) with the non-productive sites measuring 7.2 compared to 6.7 in the productive sites. The 1988 data revealed a significant difference in NH_4 concentrations ($p \leq 0.05$), with the non-productive sites averaging 4.7 g 0.2 m^{-3} compared to 2.6 g 0.2 m^{-3} in the productive sites. Potential N mineralization of the sediment samples collected in the spring of 1988 also showed a significant difference ($p \leq 0.05$), again with the non-productive sites showing higher levels. In addition, the mean Eh of −214 mV measured at the non-productive sites was significantly lower ($p \leq 0.01$) than the −112 mV noted for the productive areas. Eh data for 1989 are presented in Table 3. The seasonal mean Eh for productive sites ranged from −30 mV (site 5) to −204 mv (site 1). However, site 1 did not produce a commercial stand in 1989, but was included in the productive category because it had been successful in previous years. The non-productive stands were less variable with values ranging from −200 mV to −264 mV. The overall mean value for productive sites was −116 mV, this was significantly greater ($p \leq 0.01$) than the −232 mV average for non-productive sites.

A considerable variation in productivity existed among the commercial sites. Stand density averaged 74 stems m^{-2} in 1987 and 101 stems m^{-2} in 1988. In 1989 stand density ranged from 22 to 76 averaging 53 stems. Similarly, potential productivity was highly variable averaging 2411 kernels m^{-2} in 1987, falling to 360 kernels m^{-2} in 1988. An average of 1937 kernels m^{-2} was re-

Table 1. Sediment variables (mean ± SD and range) sampled in 1987 and 1988 at productive (P) and non-productive (N) wild rice sites. Student's t was used to determine significant differences in paired data (n = 24 and 17 for P 1987 and P 1988; n = 5 and 9 for N 1987 and N 1988)

Sediment variable	1987				1988			
	Site	Mean	Range	t	Site	Mean	Range	t
N(as NH_4^+)[a]	P	4.4 ± 3.05	1.0 – 11.1	1.66	P	2.6 ± 1.5	1.2 – 6.6	2.58*
	N	2.2 ± 1.6	0.7 – 4.8		N	4.7 ± 1.3	3.0 – 6.8	
P	P	5.2 ± 6.3	1.0 – 28.0	−2.03	P	0.16 ± 0.09	0.09 – 0.37	1.49
	N	2.4 ± 1.3	1.0 – 4.6		N	0.26 + 0.16	0.13 – 0.55	
K	P	4.1 ± 2.5	0.5 – 9.8	1.41	P	5.1 ± 1.6	2.3 – 7.1	0.21
	N	5.6 ± 1.4	4.1 – 8.2		N	5.0 ± 1.2	2.7 – 6.6	
CA	P	257 ± 95.7	82 – 456	1.26	P	220 ± 89.1	94 – 364	0.88
	N	360 ± 194	185 – 569		N	259 ± 58.4	192 – 342	
Mg	P	34.2 ± 17.4	11 – 98	1.28	P	33.2 ± 12.9	15.6 – 51.6	0.85
	N	45.0 ± 22.2	25.4 – 72.7		N	39.0 ± 11.3	26.4 – 52.7	
Fe	P	228 ± 170	0 – 622	1.62	P	16.7 ± 16.4	0.2 – 47.5	2.07
	N	107 ± 103	1 – 247		N	267 ± 272	0.3 – 721	
Zn	P	0.46 ± 0.42	0 – 1.7	0.72	P	0.93 ± 1.1	0.18 – 4.1	1.04
	N	0.32 ± 0.35	0 – 0.73		N	1.65 ± 1.4	0.0 – 4.3	
Mn	P	14.2 ± 11.4	3.2 – 55.3	−2.06	P	7.9 ± 4.6	2.9 – 18.3	1.85
	N	7.4 ± 5.7	1.2 – 17.6		N	19.3 ± 13.3	4.5 – 39.3	
L.O.I.(%)	P	45.2 ± 16.5	29.8 – 88	0.62	P	49.9 ± 14.5	29.2 – 84.6	0.29
	N	49.8 ± 14.2	30 – 68		N	52.1 ± 12.2	32 – 65.2	
pH	P	6.7 ± 0.5	5.6 – 7.7	2.39*	P	6.6 ± 0.3	6.0 – 7.1	0.94
	N	7.2 ± 0.2	6.8 – 7.5		N	6.7 ± 0.2	6.3 – 7.0	

* $p \leq 0.05$.

[a] Nutrient concentrations in $g\,0.2\,m^{-3}$.

Table 2. Sediment variables (mean ± SD and range) sampled in 1988 at productive (P) and non-productive (N) wild rice sites. Student's t was used to determine significant differences in paired data (n = 17 for P and 9 for N)

Sediment variable	Site	Mean	Range	t
Eh (mV)	P	−112 ± 31.7	−28 – −157	7.50**
	N	−214 ± 31.1	−182 – −275	
Mineralizable N[a]	P	16.5 ± 6.6	9.8 – 25.9	2.79*
	N	29.8 ± 8.7	21.7 – 45.5	
C(%)	P	30.1 ± 6.6	22.4 – 37.7	0.7
	N	27.4 ± 5.9	19.0 – 32.5	
N(%)	P	2.6 ± 0.5	1.9 – 3.24	1.07
	N	2.2 ± 0.5	1.58 – 2.75	
P(%)	P	0.11 ± 0.02	0.08 – 0.14	0.14
	N	0.11 ± 0.02	0.08 – 0.13	
K(%)	P	0.16 ± 0.07	0.09 – 0.24	0.23
	N	0.16 ± 0.04	0.12 – 0.22	
SO_4^{2-}	P	1.06 ± 1.19	0.04 – 2.96	0.86
	N	1.61 ± 1.24	0 – 16 – 3.18	

[a] Nutrient concentrations in $g\,0.2\,m^{-3}$.

** $p \leq 0.01$.

* $p \leq 0.05$.

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- 6.6 - 6.8	2.58*
- 0.37 - 0.55	1.49
- 7.1 - 6.6	0.21
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- 84.6 5.2	0.29
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corded in 1989 representing a range of 700 to 3040 kernels m^{-2}.

Linear correlation coefficients were calculated between sediment chemistry parameters and production (Table 4). Significant negative values ($r = -0.47$, $p \leq 0.05$) resulted between stem density and Fe and Zn in 1987. No significant negative correlations were noted in 1988. Plots were made comparing sediment nutrients to the yield parameters to determine if nonlinear relationships existed; none were dectectable. Correlation between Eh and stem density in 1988 was $r = 0.57$ and midway through the 1989 growing season was $r = 0.72$ ($p \leq 0.05$). However, no significant relationship was noted between Eh and potential production at commercial sites.

Table 5 depicts the response of sediment Eh to various storage treatments over a time period of

Table 3. Mean Eh values (mV ± SE) for productive and non-productive wild rice sites sampled in 1989 (n = 2)

	Site							
	1	2	3	4	5	6	7	8
Productive sites								
Mid-May	−199 ± 24	−206 ± 11	−211 ± 22	−62 ± 25	−51 ± 10	−37 ± 23	−142 ± 26	60 ± 34
Mid-June	−200 ± 14	−147 ± 13	156 ± 14	−84 ± 17	−23 ± 26	−25 ± 26	−160 ± 42	−95 ± 37
Late-July	−204 ± 28	−138 ± 9	−131 ± 14	113 ± 14	−31 ± 17	−71 ± 13	−161 ± 13	−70 ± 20
Mid-August	−212 ± 28	−208 ± 8	−174 ± 27	−94 ± 21	−15 ± 11	−46 ± 20	−134 ± 33	−36 ± 42
Mean	−204 ± 6	−175 ± 37	−168 ± 34	−88 ± 21	−30 ± 15	−47 ± 17	−149 ± 13	−65 ± 24
Non-productive sites								
Mid-May	−206 ± 18	−222 ± 17	−223 ± 18	−217 ± 13	−200 ± 11	−222 ± 19	−215 ± 51	−250 ± 7
Mid-June	−217 ± 21	−210 ± 23	−232 ± 42	−232 ± 75	−238 ± 27	−268 ± 19	−203 ± 21	−241 ± 28
Late-July	−230 ± 16	−217 ± 11	−190 ± 34	−186 ± 10	−205 ± 14	−272 ± 17	−201 ± 10	−301 ± 14
Mid-August	−275 ± 64	−262 ± 22	−267 ± 25	−199 ± 10	−267 ± 25	−284 ± 23	−182 ± 4	−204 ± 33
Mean	−237 ± 31	−228 ± 23	−228 ± 32	−209 ± 20	−228 ± 31	−262 ± 27	−200 ± 14	−264 ± 26

Table 4. Correlation coefficients for sediment chemical variables with wild rice production indices

	1987		1988	
	Stem density (n = 24)	Potential production (n = 20)	Stem density (n = 10)	Potential production (n = 10)
N	−0.18	0.03	−0.17	0.15
P	−0.37	−0.08	−0.25	0.16
K	−0.10	−0.29	−0.48	−0.14
LOI	0.23	0.37	0.24	0.08
Ca	−0.09	0.10	−0.42	0.04
Mg	−0.29	−0.19	−0.50	0.07
Fe	−0.47*	−0.17	0.22	0.06
Zn	−0.47*	−0.41	0.43	0.00
Mn	−0.32	−0.05	−0.50	−0.21
pH	0.17	0.11	0.06	0.22

* $p \leq 0.05$.

Table 5. The effect of time and six storage treatments on mean sediment Eh values (mV ± SD; n = 5)

Time	Treatment					
(days)	i	ii	iii	iv	v	vi
0	−249 ± 31	−246 ± 11	−250 ± 11	−229 ± 12	−219 ± 18	−251 ± 14
7	−271 ± 20	−251 ± 11	−246 ± 16	−255 ± 26	–	–
14	−329 ± 7	−295 ± 11	−277 ± 19	–	−284 ± 5	–
21	−329 ± 17	−298 ± 11	−296 ± 12	–	–	−305 ± 14

21 days. After 14 days all values had dropped significantly ($p \leqslant 0.01$, based on analysis of variance), and Eh continued to fall as storage time increased regardless of the treatment used.

Discussion

Many sites which are seeded with wild rice seem incapable of nurturing the crop. Seeds do not germinate or seedlings die before aerial leaves emerge from the water. Previous research on lake wild rice productivity in Ontario suggests that poor wild rice growth resulted from loose textured sediment which provided inadequate anchorage for the roots, and low levels of organic matter, N, P, and Zn (Keenan and Lee, 1988; Lee, 1986, 1987; Lee and Stewart, 1984). These results contrast with those found in the current study. A comparison of sediment gathered from productive and non-productive sites indicated that no significant difference existed for P or LOI (Table 1). In addition, the non-productive sites possessed more available N in 1988 and recorded significantly higher potential mineralizable N values (Table 2). The higher mineralizable N suggests that there should be an adequate supply of N to the plants throughout the year. The faster liberation of N in the non-productive sites by the soil microbes may reflect the structure and morphology of the plants which inhabit the two site classes (Goodshalk and Wetzel, 1978; Sain, 1984). Thus, despite suitable sediment nutrient levels, high percent organic matter and similar sediment pH, wild rice establishment was still precluded at these non-productive sites. Similarly, productivity within commercial sites could not consistently be correlated to sediment nutrients.

The most significant difference between productive and non-productive sediments was the redox potential. The mean Eh of −214 mV and −232 mV for the non-productive sites in 1988 and 1989 respectively and −112 mV and −116 mV for the productive sites in these same years both describe a highly reduced environment, but the degree of reduction is significantly greater in the non-productive sediments ($p \leqslant 0.01$). Any site which possessed an Eh around −200 mV did not produce wild rice on a commercial scale. As the Eh readings became less negative the likelihood that the site would yield a substantial wild rice crop increased and a significant correlation ($p \leqslant 0.05$) was noted between stand density and Eh in both 1988 and 1989. However, potential productivity was not significantly related to Eh. This could however, be a factor of the site classification or sampling procedures used. Thus, site 1 was not commercially viable in 1989 an the size of the stand at site 2 had greatly diminished over the past two growing seasons. In 1987 wild rice at site 2 covered approximately 5 ha of the lake; in 1989 the stand was less than 0.2 ha. Similarly, the strongly negative value (−211 mV) noted during mid-May at site 3 represented sediment taken from a part of the lake from which no plants subsequently emerged; later sampling was conducted in the productive part of the lake.

Redox values vary with the substrate in which they are measured. Yaname (1978) suggests that when the Eh of a soil is measured the reading should be conducted on a solution extract of the soil. This allows for a quicker determination of a solution Eh as the electrons are more accessible to the electrode than in the case of soil Eh. However, while Ponnamperuma (1972) states that solution Eh is more meaningful and reliable than soil Eh, soil or mud potentials provide a semiquantitative measure of soil reduction and can be used to test the quality of rice paddy soils. Consequently, direct sediment Eh measurements were used in the present study. However, the Eh readings were not stable over long periods of storage. This corresponds with work conducted by Brunskill *et al.* (1971) who found that the Eh of 16 Ontario lake sediments was significantly altered by a 2-week storage period.

The mechanism(s) by which wild rice is affected by highly reduced soils was not tested. However, the range in pH at both the productive and non-productive sites indicates that a buildup of toxic redox products is unlikely due to the insolubility of these products at pH levels of 5.6—7.7 as recorded at these sites. The more probable causes may include; (i) an inability of the roots to respire and take up nutrients due to competi-

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tion with reduced compounds for O_2, (ii) toxicity of microbial respiration gases, and (iii) poor germination resulting from insufficient O_2 if the seed is below the oxidised microzone at the surface of the mud layer (Ponnamperuma, 1965, 1972, 1978; Svare, 1960).

Conclusion

Sediment samples collected from productive and non-productive sites in northern Saskatchewan over a two-year period could not be consistently distinguished in terms of sediment nutrient concentrations, LOI, or pH. *In situ* Eh measurements appear to provide a reliable method for distinguishing productive and non-productive wild rice sites. However, samples collected and stored for subsequent analysis could provide incorrect Eh values. Redox potentials changed over a 2-week time period regardless of the storage method used; preferably, sediment should be disturbed as little as possible, and tested quickly after collection. In addition, sediment conditions are locally quite variable and several samples should be taken from the proposed site to determine uniformity and potential suitability for wild rice. Although such procedures should provide growers with a rapid method of evaluating potential new wild rice sites, actual production at a site cannot be predicted from Eh readings alone, because other factors, such as water depth, can greatly influence plant performance.

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