Effect of Root Oxygen Stress on Phosphorus Uptake by Cattail

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ABSTRACT

The effect of redox conditions or oxygen demand in rooting medium on phosphorus (P) uptake by Typha domingensis was quantified. Phosphorus uptake decreased with decrease in redox potential in the rooting medium. Greatest uptake was measured under the oxidized treatment (+565 mV). Phosphorus uptake was less under the two anaerobic treatments (+277 mV and -200 mV). In the two anaerobic treatments, P uptake was considerably less at -200 mV in which a high oxygen demand was created using titanium (Ti 3+) citrate. Results suggest that P uptake by Typha domingensis in wetland receiving P input from adjacent agriculture areas could be influenced by the oxidation-reduction status of the root environment.

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INTRODUCTION

When roots are under flooded conditions, the required oxygen must reach the roots through internal paths from aerial parts (Armstrong, 1979; Jackson and Drew, 1984). Development of aerenchyma and related internal pathways for oxygen diffusion to roots is a major adaptation mechanism in wetland plants (Hook and Scholtens, 1978; Hochachka and Somero, 1973). Aerenchyma development in plants growing in anaerobic soil environments is important because it facilitates diffusion of oxygen to the roots allowing some aerobic respiration (Armstrong, 1972; Keeley, 1979), reduces the number of respiring cells in the root and help detoxify the reduced rhizosphere (Armstrong, 1972; Williams and Barber, 1961). Aerenchyma formation in some species appear to result from development of hypoxic conditions in the roots followed by enhanced synthesis and accumulation of ethylene (Drew et al., 1979; Drew et al., 1981).

The intensity of reduction (a measure of anaerobiosis) in flooded soil or sediment is measured by determining the decrease in oxidation-reduction or redox potential (Patrick and DeLaune, 1977). Aerated soils have redox potentials (Eh) characteristic in the range of +400 to +700 millivolts; anaerobic soils exhibit redox potentials from +400 mV to as low as -250 to -300 millivolts (Figure 1). The range of redox potential in anaerobic soils is much wider, approximately 700 millivolts as compared to range of approximately 300 millivolts in well drained soils. Second, oxygen is usually absent from most anaerobic soils at redox potential below +400 millivolts. As the result of the large range in redox potential representation of anaerobic conditions, the measurement of lack of oxygen cannot be used as a measure of intensity of anaerobiosis in flooded soil. Studies dealing with responses of hydrophytic vegetation to anaerobic root environment in most instances have been conducted using experiments in which plants were grown hydroponically and nitrogen (N) was passed through the solution to remove oxygen. Such a system would have a redox potential only slightly below that where oxygen disappears on the redox scale (i.e., +400 mV) (DeLaune and Pezeshki, 1991) (Figure 1).

There is little information in the literature to distinguish wetland plant response (including nutrient element uptake) to root oxygen stress in the anaerobic soil environment. It has been shown using titanium citrate as a redox buffer that oxygen-depleted solutions commonly used for evaluating wetland plant response to anaerobic conditions are a poor analogue for wetland soil because such oxygen depleted solution do not create a high oxygen demand or low redox conditions commonly found in soil (DeLaune et al., 1990). A solution of high oxygen demand in reducing environment influences oxygen transit and oxygen release by the root system of wetland plants (Klundze et al., 1993; Kludze and DeLaune, 1996). Creating an oxygen demand in anaerobic rooting medium using titanium citrate also influences photosynthesis in bald cypress (Klundze et al., 1994). The intensity of soil reduction has also been shown to influence photosynthesis and growth of *Typha domingenis* and *Cladium jamaicense* (Pezeshki et al., 1996). In this study,
FIGURE 1. Range of redox potential (Eh) found in aerobic and anaerobic soil environments.

we examine the effect of root oxygen stress [using titanium (Ti^{3+}) citrate] on P uptake by cattail (Typha domingensis).

MATERIALS AND METHODS

*Typha domingensis* (cattail) was collected from the Florida Everglades which is receiving P run-off from sugarcane production. The plants were cultured in pots filled with commercial potting soil (Jiffy Mix Plus, Jiffy Products of America, Chicago, IL). After a 5-week growth period, new ramets were separated from mature plants and transferred to a modified 20% Hoagland's nutrient solution minus P for a period of six weeks in the laboratory conditions with day and night temperatures of 25±1°C and with photon flux density of 1,000 to 1,200 %mol m^{-1}s^{-1} at canopy level 24-h period.

Culture in P-free medium was necessary to decrease internal tissue P concentrations of cattail. The nutrient solution was changed weekly to sufficiently deplete and normalize plant tissue P concentrations. After six weeks culture in P-free
nutrient medium, plants of similar size and apparent vigor were selected for use in the study.

Plants were placed in a 10-L container of distilled, deionized water for 24 hours to flush any remaining P from the roots. Next, the plant roots were surfaced sterilized by immersion into a 1% sodium hypochloride (NaOCl) solution (Chlorox) for five minutes prior to initiation of the uptake experiments. The plant roots were rinsed several times in distilled, deionized water, and patted down with paper towels to remove any adhering solution before being transferred to the P-uptake system.

The system for measuring P uptake consisted of 1-L glass containers covered with No. 13 rubber stoppers. Five holes on the rubber stoppers were drilled for plants (DeLaune et al., 1990). No hole was drilled on the rubber stopper for control (without plant). A hole each for rubber septum, gas inlet and gas outlet and platinum electrode was also provided. Individual plants were placed on the hole and sealed with Silicon Rubber Adhesive Sealant RTV 162 (GE Silicones, Waterford, NY) and transferred to 1-L glass containers. The container contained 600 mL solution of a modified 20% Hoagland's nutrient solution containing 3.22 μM P as potassium dihydrogen phosphate (KH₂PO₄). The pH of the Hoagland's solution was maintained at 4.9-5.0. There were three redox treatments, i) highly reduced conditions, ii) moderately reduced condition, and iii) oxidized condition. Each treatment was replicated three times.

To create an oxygen demand in the rooting medium, titanium citrate was used as a redox buffer (Zehnder and Wuhrmann, 1976; DeLaune et al., 1990). Highly reduced conditions (below -200 mV) was obtained by adding titanium (Ti³⁺) citrate (reduced form), and continuously purging the nutrient solution with helium (He) gas. Moderately reduced condition (+100 to +300 mV) was obtained by continuously purging with He gas. Oxidized condition (+400 to +700 mV) was obtained by bubbling solution with compressed air. Equal amount of oxidized form of titanium (Ti⁴⁺) citrate was added to the oxidized and moderately reducing treatments to maintain an equal concentration of titanium citrate.

Titanium (Ti³⁺) citrate was prepared under argon (Ar)-nitrogen (N₂) atmosphere by adding 50 mL of 19% titanium (Ti³⁺) chloride (Aldrich) to 600 mL of 0.2 M sodium citrate solution and neutralizing to pH 7.0 with saturated sodium carbonate. Titanium (Ti³⁺) citrate is purple-blue in solution. Two hundred mL of titanium citrate were removed and oxidized to clear with slow stream of compressed air. The titanium(Ti³⁺) citrate solution becomes colorless when oxidized to titanium (Ti⁴⁺) citrate. Five mL of the oxidized solution Ti⁴⁺ was injected into the treatment maintained under moderately reduced or oxidized conditions. Five mL of titanium (Ti³⁺) citrate was injected into the highly reduced treatment.

Redox potential (Eh) was monitored every h and immediately after each sampling period. The Eh was monitored by way of platinum electrode and salt bridge (Patrick et al., 1973). Titanium (Ti³⁺) citrate or titanium (Ti⁴⁺) citrate was added again whenever redox potential deviated from desired redox conditions for each treatment. At the end of the study, the means of Eh was reported in mV for each treatment.
### RESULTS AND DISCUSSION

There were differences in P uptake by Typha among the three treatments with Typha plant (Figure 2). All P added remained in the solutions in all treatments without Typha plant. The changes in P concentration represented plant uptake since there was no change in P concentration over the 24 h period of the study in the solutions which contained no plants. T-test paired comparison of P uptake over the sampling periods between highly reduced treatment and moderately reduced treatment was significantly different at 0.05 level, and between the highly reduced treatment and oxidized treatment was highly significantly different at 0.01 level. Average redox level (Eh) of the nutrient solution were +565 mV for the solution oxygenated with compressed air [receiving titanium (Ti4+) citrate], +277 mV for solution purged with He [receiving titanium (Ti4+) citrate] and -200 mV for solution purged with He receiving titanium (Ti3+) citrate. The uptake of soluble reactive P

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Redox Potential (mV) at pH 7

FIGURE 2. Change in phosphorus concentration in nutrient solution maintained under oxidized, moderately reduced, and highly reduced conditions.
(SRP) was measured over a period of 24 h. The concentration of soluble reactive P was depleted with time in all treatments. Correlation coefficients of P uptake observed in these treatments were $R^2=-0.8007$, $-0.9721$, and $-0.7858$ for highly reduced treatment, moderately reduced treatment, and oxidized treatment, respectively. The P uptake by the *Typha* plant was determined by soluble reactive P depleted from the nutrient solution. Greatest P uptake by *Typha* was measured in the oxidized nutrient solution. Both anaerobic treatments (no oxygen) had lower rates of P uptake as compared to the oxidized treatment. Phosphorus uptake was less in the more reducing treatment which had a higher oxygen demand [created with titanium (Ti$^{3+}$) citrate].

CONCLUSIONS

Results of this study suggest that P uptake is influenced by not only oxidation status in the root environment but as demonstrated by the two anaerobic treatments by oxygen demand or capacity of reduction.

Nutrient element uptake by *Typha* and perhaps other wetland plants may be governed by the soil redox intensity and capacity. To predict P uptake by *Typha* would require identifying substrate oxygen demand in which plant grows. From results presented, it is difficult to identify the exact cause of the reduced P uptake. Previous studies (Klundze and DeLaune, 1996; Pezeshki et al., 1996) have shown that plant physiological functions (e.g., photosynthesis oxygen transport) are impacted by creating a strong oxygen demand in anaerobic root environments. Restricted root oxygen exchange and parallel changes in root respiration could influence P uptake.

More comprehension studies are needed to determine the impact of intensity and capacity of soil reduction on P uptake by wetland plant species. Such studies should include P uptake at lower concentration than used in this experiment. Determining the interaction between physiological plant response to anaerobic root environment and P uptake would provide information for predicting competitive abilities for growth and distribution of wetland plant species.

ACKNOWLEDGMENTS

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REFERENCES


ROOT O STRESS ON P UPTAKE BY CATTAIL


