CHAPTER 38

Efficiencies of Substrates, Vegetation, Water Levels and Microbial Populations

38a Relative Radial Oxygen Loss in Five Wetland Plants

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INTRODUCTION

Drainage from coal mining and washing facilities frequently has a pH as low as 2.2, high concentrations of dissolved metals such as iron (Fe) and manganese (Mn), and high suspended solid concentrations. Precipitation that falls on coal piles and slurries leaches ions from the exposed rock. These pollutants contaminate streams where hydrogen and metal ions reduce water quality and inhibit plant and animal life.

Recently, it has been demonstrated that constructed wetlands can be used to improve water quality. The combination of chemical, hydrological, and biological processes in wetlands are able to precipitate Fe, Mn, and other metal ions, to reduce suspended solids and moderate pH. Constructed wetlands can be built to mimic biogeochemical characteristics of natural wetlands that perform these functions.

Oxygen (O₂) diffusion to root tips is one of the physiological characteristics that permit wetland species to exist in flooded conditions. Diffused O₂ not only supplies the roots but can oxidize the surrounding soil; this process is termed radial oxygen loss (ROL). Increasing evidence suggests that O₂ transport provides a unique environment that can oxidize phytotoxic compounds such as ferrous iron. This characteristic could be used to mitigate the concentration of toxic compounds in mining-related effluent. Theoretically, plants with the largest oxygenated rhizosphere and largest population of metal-oxidizing microbes would maximize the wetland's potential to remove toxic metals from the water column by oxidation. This research investigates the ability of five wetland plant species to diffuse O₂ into wetland soils.

Objectives of this study were (1) to develop a method to test for the presence
of O₂ diffusion from plants' roots, (2) to determine species differences in O₂ loss to sediments and (3) to recommend plant species to use in constructed wetlands to maximize O₂ concentrations in the root zone.

MATERIALS AND METHODS

Plant Selection

Plants were obtained from a constructed wetland, TVA's Impoundment One, which receives effluent from a slurry pond. Total Fe concentration averaged 30 mg/L, Mn often exceeded 10 mg/L, dissolved oxygen (DO) was less than 2 mg/L, pH was 6.0, and suspended solids exceeded 98 mg/L.² Cattail (Typha latifolia), burreed (Sparganium americanum), spikerush (Eleocharis quadrangulata), woolgrass (Scirpus cyperinus), and rush (Juncus effusus), perennial emergent wetland plants, were selected because they were well established, healthy, and reproducing. Mature plants were collected during July and August 1987 from the third and fourth ponds of Impoundment One. T. latifolia and S. americanum grow in shallow to deep water (0.30 to 1.20 m). E. quadrangulata and J. effusus grow in shallower water (0.15 to 0.30 m), while S. cyperinus grows in the shallowest water (0.05 to 0.30 m).

All five species were tested with 20 replicates each. A control without plants tested the differences in DO due to O₂ diffusion down aerenchymal tissue and atmospheric diffusion. Dead plants and cut-off plants covered with paraffin to seal aerenchymal tissue were also tested to determine if O₂ presence was due to diffusion or plant enzymes.

Laboratory Procedure

To detect oxygen, we used an indigo carmine dye technique developed by Armstrong¹⁵ for detecting ROL in some bog plant species. We deoxygenated deionized water with nitrogen gas. One-liter bottles were filled with 500 mL of deoxygenated water. Hydrogen sulfide (H₂S) saturated water (5 mL) was added to the deoxygenated solution to reduce the solution Eh below ~250 mV. Five milliliters of 0.28% (weight/volume) indigo carmine dye was added to the deoxygenated solution.

The test plants' roots were carefully cleaned to remove sediment and decaying plant matter and placed in the reduced solution. Mineral oil was added to the surface to prevent O₂ from diffusing into the solution. At 6, 12, and 24 hours (h), samples were removed for spectrophotometric analysis to measure the percentage of light transmitted through the samples. Readings at 6, 12, and 24 h in conjunction with the plants' dry mass were used to determine differences in O₂ diffusion into solution. To reduce variation due to plant size, we developed a weighted index by dividing the spectrophotometer reading by the plants' total mass (% transmittance/total plant biomass = ROL index).

RESULTS

Transmittance taken during the experiment ranged from 80% to 7%. Controls had readings greater than 70% and only a small percentage of the dye had been oxidized, but complete dye oxidation with H₂O₂ permitted 7% light transmittance.

Figure 1a is a box plot showing relationships between species after 12 h. There is clearly a difference between controls and samples with plants. S. cyperinus, although statistically different from the control, did not diffuse as much O₂ into the sediments as other species tested.

Much of the variability in Figure 1a was removed by using mass as a scaling factor. Figure 1b shows relationships when transmittance readings are divided by the individual's total dry weight. Variation in S. cyperinus values was substantially greater than in other species.

Differences in transmittance for each plant and controls demonstrates an input of O₂ by the plants (Table 1). Experiments with cut and waxed plants had significantly higher readings than those for live, intact plants. However, waxed plant treatments did have more O₂ present than controls. This is likely due to some O₂ storage in the roots and subsequent diffusion into solution. Dead plants tested were able to transmit a significant amount of O₂ into solution but were not as efficient as live plants. For example, the mean value for dead J. effusus plants at six hours was 53.5; live J. effusus had a mean reading of 30.5
for the same time. Sample size for dead plants was small, and a definitive statement that dead plants have less ROL was not possible.

Since preliminary tests revealed these data are not normally distributed, we used the nonparametric Kruskal-Wallis One-Way Analysis to rank each observation. The test statistic for readings at 6 h was 49.68 at a significance of 4.22\(^{-10}\) \((p = 0.05)\). The high test statistic and small significance level indicate that the 6-h readings differ significantly among species. The values for 12 and 24 h were significant as well (Table 2). \(T.\) \textit{latifolia} transferred more \(O_2\) to solution than any other species at all times. Pairwise analysis for unequal sample sizes revealed that \(J.\) \textit{effusus} and \(S.\) \textit{americanum} were more efficient than \(S.\) \textit{cyperinus} at 6 h. \(S.\) \textit{americanum} transferred more \(O_2\) than \(S.\) \textit{cyperinus} at 12 and 24 h.

The Kruskal-Wallis analysis for species differences corrected for differences in biomass and showed significant species differences (Table 2). \(T.\) \textit{latifolia} transferred the most \(O_2\) at all three sampling times. \(J.\) \textit{effusus} was better at transferring \(O_2\) than \(S.\) \textit{cyperinus} at 6 and 24 h.

### DISCUSSION

The role of dissolved oxygen in wetlands used for treating mining-related effluent is important in improving water quality. Oxygen is required for the removal of dissolved metals, to support aerobic microorganisms, and to reduce BODs. Results of this experiment indicate that \(O_2\) concentration in the soil-water matrix can vary with plant species. By planting and managing for specific plants to maximize \(O_2\) concentration, toxic metals can be oxidized more quickly and efficiently.

Our ROL experiments have shown the following trends on a per unit biomass basis:

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\text{\(T.\) \textit{latifolia} > \(J.\) \textit{effusus} > \(S.\) \textit{americanum} > \(E.\) \textit{quadragulata} > \(S.\) \textit{cyperinus}\)}
\]

However, individual growth characteristics, such as stand density, need to be considered when comparing ROL performance as a management tool.

\(J.\) \textit{effusus} performed better in terms of ROL than \(S.\) \textit{cyperinus} per unit biomass. Because both species grow in shallow water, planting \(J.\) \textit{effusus} instead of \(S.\) \textit{cyperinus} will result in greater \(O_2\) contribution to the substrate. \(T.\)
latifolia and *S. americanum* both grow in deep water. *T. latifolia* consistently contributed more O\textsubscript{2}, but *S. americanum* grows in much denser stands. Oxygen transfer per unit of substrate must be investigated before recommending which to plant. Because *E. quadrangulata* did not transfer O\textsubscript{2} as well as *J. effusus, S. americanum,* or *T. latifolia,* it might be advantageous to minimize the area of depth where *E. quadrangulata* grows (0.15–0.60 m).

Oxygen transport varied significantly in the emergent wetland macrophytes evaluated, suggesting that plant species can influence the amount of O\textsubscript{2} in the sediments. The importance of O\textsubscript{2} in the water column and sediments and the poor understanding of plant-oxygen transport mechanisms warrant further research into oxygen transfer per unit area and effects of oxygen transport on BOD\textsubscript{5} and metal oxidation. This study points toward the continued research into constructed wetlands and their potential contribution in the remediation of contaminated water.

REFERENCES


