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Relationships between plant photosynthesis, radial oxygen loss and nutrient removal in constructed wetland microcosms

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ABSTRACT

The objective of this study was to investigate the relationships between root radial oxygen loss (ROL), photosynthesis, and nutrient removal, based on the hypothesis that ROL is primarily an active process which is affected positively by photosynthesis, and is correlated positively with nutrient removal. Four common wetland plants were studied in small-scale monoculture wetlands. Higher ROL coincided with faster growth among the four monocultures. Significant correlation between ROL and photosynthetic rate existed in *Cyperus flabelliformis* wetland ($P < 0.01$). Both ROL and photosynthesis represented close correlations with nutrient removal rates in all four monocultures. Significant differences in ROL, photosynthetic rate, removal rates of NH_4^+, and soluble reactive phosphorus (SRP) were found among the four species. ROL and photosynthetic rates showed single-peak daily and seasonal patterns, with maximum daily values around noon, and with maximum yearly values in summer or autumn for the four monocultures. The results suggest that the ROL of wetland plants is related to active physiological processes. Both ROL and photosynthetic rate are indices which can be used to identify wetland plants with a higher nutrient removal capacity.

1. Introduction

Wetland substrates are generally anoxic, but wetland plant root systems require oxygen for respiration, and the physiological and biochemical activities in the wetland substrate require a large amount of oxygen (Fennessy et al., 1994; Armstrong and Armstrong, 2001). Previous studies have shown that plant roots can release oxygen into their surroundings and are therefore a major oxygen source for the wetland matrix (Boon and Sorrell, 1991; Soda et al., 2007). The phenomenon that wetland plant roots release oxygen through the aerenchyma to the rhizosphere is termed radial oxygen loss (ROL) (Armstrong, 1978). ROL is one of the most important functional characteristics of wetland plants. As wetland plant roots release oxygen into the media, aerobic and anoxic areas co-occur around the rhizosphere where aerobic, anaerobic and facultative anaerobic microorganisms can co-exist (Brix, 1997). These interactions of microorganisms and plant roots could improve nutrient removal efficiency. Under high oxygen concentration, some biochemical processes such as nitrification (Reddy et al., 1989), iron and manganese oxidation and deposition (Kirk et al., 1993; Wang and Peverly, 1999), heterotrophic

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microbial respiration (Darrah, 1991) and mineralization (McLatchey and Reddy, 1998) might occur in wetlands. Previous research indicates that ROL varies with plant species and is correlated with morphological characteristics of roots, such as aerenchyma, porosity, age, length, and diameter (Visser et al., 2000; Li et al., 2011). ROL is also affected by environmental factors such as light conditions and the oxidation-reduction potential of the substrate (Wieβner et al., 2002; Dickoppa et al., 2011). However, less is understood about ROL and physiological and growth attributes such as photosynthesis and nutrient removal, especially in field conditions (Bezbaruah and Zhang, 2005; Pi et al., 2009).

Photosynthesis is one of the most important plant growth indices, but it is understudied in wetland plants (Chen et al., 2005; Pennington and Walters, 2006). Some research indicates that a positive correlation exists between nutrient removal and wetland plant growth (Cheng et al., 2009), implying a correlation between plant photosynthesis and nutrient removal. Conversely, other research suggests that wetland plants contribute little towards nutrient removal (Tanner, 2001; Münch et al., 2005), so it is unclear whether photosynthesis can affect nutrient removal in constructed wetlands. Photosynthesis produces oxygen, so can it generally be asked whether photosynthesis by wetland plants, which produces oxygen, correlates with the ROL of wetland plants. Some research suggests that photosynthesis is the source of oxygen released by plant roots (Caffrey and Kemp, 1991; Connell et al., 1999). Wetland plants can transfer part of the oxygen produced through photosynthesis within the aerenchyma to the roots, and release it into the wetland substrate (Brix and Schierup, 1990; Tanaka et al., 2007). However, it is unclear whether the process of ROL is active or passive, and how closely ROL and photosynthesis are correlated. We hypothesized that ROL is primarily an active process which is positively affected by photosynthesis, and is positively correlated with nutrient removal. The objective of this study was to investigate our hypothesis by comparatively studying relationships among ROL, photosynthesis and nutrient removal.

2. Materials and methods

2.1. Construction of the wetland

The experiment was conducted in the Biological Garden of South China Normal University, Guangzhou, China (23°8′23″ N, 113°20′58″ E). Guangzhou has a subtropical climate, with an annual average air temperature of 21–22 °C. The average air temperatures of the coldest month (January) and the hottest month (July) were 12–14 and 28–29 °C, respectively. The annual precipitation was about 1700–1900 mm, with the wet season occurring from April to September, and the dry season from October to March. Twenty wetland microcosms were constructed in rectangular plastic tanks (56 × 46 × 38 cm, length × width × depth). The tanks were filled with granite gravel (1–2 cm diameter) as a growth medium. Two plastic tubes of 4 cm diameter were inserted vertically into each wetland for water sampling: the first was to the mid-depth of the gravel and the second to the bottom. Four common wetland plant species, *Acorus calamus* Linn., *Cyperus flabelliformis* Rottb., *Phragmites australis* Trin. ex Steud., and *Vetiveria zizanioides* (Linn.) Nash were used in the study. One plantlet (about 20 cm in height) was planted in a wetland microcosm. Each species-specific wetland had five replications. They were randomly arranged among the twenty microcosms. The wastewater used as influent to each wetland microcosm, came from a dormitory, and flowed into a large depositing pool before use. The average concentration (average for 20 months, mg L^{-1}) was 45 ± 19 of 5 d biochemical oxygen demand (BOD_5), 130 ± 52 of chemical oxygen demand (COD), 45 ± 14 of total nitrogen (TN), 3.0 ± 1.2 of soluble reactive phosphorus (SRP), 27 ± 10 of NH_4^+, and 0.9 ± 0.3 of NO_3^-.

2.2. Root radial oxygen loss

The ROL of wetland plants was measured using the modified method of Armstrong (1964, 1967). The instruments used in the experiment included a polarograph, a cylindrical platinum electrode, an Ag/AgCl electrode, and a list-style recorder. Roots of similar size and length (about 1 mm in diameter and 10 cm in length) from each wetland were nondestructively measured at the point 0.5 cm from root tip. Measurement of the electric current was started as soon as a balanced voltage was set. The ROL was calculated using the formula: $ROL = nFA/i$, where ROL is the external O_2 flow rate (ng cm^{-2} min^{-1}); i is the electric current shown by the polarograph (μA); n is the number of electrons for deoxygenating one molecular oxygen, set at 4; F is Faraday's constant 96,500; A is the surface area of the root within the cylindrical platinum electrode (cm^2). The ROL was measured on sunny days during July (summer), October (autumn), and January (winter).

2.3. Photosynthetic rate

The photosynthetic rate was measured for 3 to 5 sunny days during April (spring), July, October and January, using a LI-6400 portable photosynthesis measurement system (LI-COR, USA). Five leaves were measured in each wetland and each leaf was measured three times to obtain the average photosynthetic rate. The plants were measured once every 2 h from 7:00 to 17:00.

2.4. Root activity

Root activity was determined monthly using the modified method of Yang et al. (2004). Plant roots of 1–2 g, with a diameter of less than 3 cm, were sampled from each wetland during July (summer), October (autumn), and January (winter).