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Root features related to plant growth and nutrient removal of 35 wetland plants

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ABSTRACT

Morphological, structural, and eco-physiological features of roots, nutrient removal, and correlation between the indices were comparatively studied for 35 emergent wetland plants in small-scale wetlands for further investigation into the hypothesis of two types of wetland plant roots (Chen et al., 2004). Significant differences in root morphological, structural, and eco-physiological features were found among the 35 species. They were divided into two types: fibrous-root plants and thick-root plants. The fibrous-root plants had most or all roots of diameter (D) ≤ 1 mm. Roots of $D > 1$ mm also had many fine and long lateral roots of $D \leq 1$ mm. The roots of these plants were long and had a thin epidermis and a low degree of lignification. The roots of the thick-root plants were almost all thicker than 1 mm, and generally had no further fine lateral roots. The roots were short, smooth, and fleshy, and had a thick epidermis. Root porosity of the fibrous-root plants was higher than that of the thick-root plants ($p = 0.001$). The aerenchyma of the fibrous-root plants was composed of large cavities which were formed from many small cavities, and distributed radially between the exodermis and vascular tissues. The aerenchyma of the thick-root plants had a large number of small cavities which were distributed in the mediopellis. The fibrous-root plants had a significantly larger root biomass of $D \leq 1$ mm, of 1 mm $< D <$ 3 mm, above-ground biomass, total biomass, and longer root system, but shorter root longevity than those of the thick-root plants ($p = 0.003$, 0.018, 0.020, 0.032, 0.042, 0.001). The fibrous-root plants also had significantly higher radial oxygen loss (ROL), root activity, photosynthetic rate, transpiration rate, and removal rates of total nitrogen and total phosphorus than the thick-root plants ($p = 0.001$, 0.008, 0.010, 0.004, 0.020, 0.002). The results indicate that significantly different root morphological and structural features existed among different wetland plants, and these features had a close relationship to nutrient removal capacity.

1. Introduction

As the major component of a constructed wetland, wetland plants play an important role in nutrient removal (Kivaisi, 2001; Matheson et al., 2002; Yang et al., 2007). Research has indicated that several processes in constructed wetland nutrient removal, such as nutrient absorption and settlement of suspended substances, are strongly linked to the functional characteristics of wetland plants, especially in regards to the important functions of the roots (Tanner, 2001; Kadlec et al.,

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2005; Stein and Hook, 2005). However, investigation is still incomplete about the function of wetland plant roots in constructed wetland nutrient removal (Stottmeister et al., 2003; Gutknecht et al., 2006). The rhizoplane and rhizosphere of wetland plant roots are the most important areas, where the plants, microorganisms, substrates of the wetland and wastewater contact directly, and physicochemical and biological processes take place (Stottmeister et al., 2003; Greenway, 2007; Weber et al., 2008). As an important component of a constructed wetland, plant roots create favorable habitats for microorganism attachment, growth, and decomposition activities (Sinha et al., 2007; Muench et al., 2007). This function of the roots may have a close relationship to root morphology, structure, growth, and distribution. Previous studies indicated that constructed wetland nutrient removal correlated with plant root numbers, and root surface area (Kyambadde et al., 2004; Cheng et al., 2009). Different wetland plants exhibited great differences in radial oxygen loss (ROL), the phenomenon of wetland plant roots releasing oxygen through the aerenchyma to the rhizosphere (Armstrong, 1979), which correlated with morphological and structural features of the roots (Pezeshki, 2001; Colmer, 2003; Stottmeister et al., 2003), with inundation adaptation or tolerance (Armstrong, 1967; Jackson and Armstrong, 1999), and with nutrient removal (Sorrell and Brix, 2003; Sasikala et al., 2009). However, results were generally only based on a few species, and could not reveal the mechanisms of the correlations. At present, it is widely understood that microorganisms play a key role in nutrient removal from constructed wetlands (Greenway, 2007; Muench et al., 2007; Weber et al., 2008). Root systems in constructed wetlands are closely correlated with the growth and decomposition activities of the microorganisms. It is difficult to understand the roles of microorganisms in constructed wetland nutrient removal, and difficult to reveal the nutrient removal mechanisms in constructed wetlands without an extensive understanding of the growth, distribution, and function of plant roots. However, the relationship between root characteristics (morphological and structural features, growth and distribution, and eco-physiological characteristics) and microorganism characteristics, and nutrient removal is still unclear, and the roles that plant roots and root zone play in the constructed wetland are still regarded as a"black box" (Stottmeister et al., 2003; Thullen et al., 2005).

In their study of the morphological differences of wetland plant roots, Chen et al. (2004) distinguished two types of wetland plants: rhizomatic-root plants, and fibrous-root plants. Rhizomatic-root plants had rhizomes or a root system composed of thicker roots, and fibrous-root plants had a root system mostly composed of thinner roots ($D \leq 3$ mm). They hypothesized that there were significant differences between the two types of wetland plants in root morphological and structural features, root growth and distribution characteristics, root amount and biomass, ROL, and nutrient removal. Primary results indicated that fibrous-root species had more roots and a larger root biomass, larger root surface area, faster root growth, more ROL, and higher nutrient removal rates, while having shorter root longevity, when compared with rhizomatic-root plants (Chen et al., 2007; Cheng et al., 2009). However, the current literature on plant comparison (including the above results) has been basically limited to a few wetland species. Comparisons based on a few species may result in inconsistent results (Qiu et al., 2011). Greater research on more plant species is necessary in order to confirm the hypothesis. The aim of the present study was to investigate the supposition by comparatively studying the morphological, structural, and eco-physiological features of roots, root growth and biomass, and nutrient removal rates based on a greater selection of wetland plants.

2. Materials and methods

2.1. Wetlands and the plants used in the experiment

Thirty-five plant species or varieties were used in the present study (Table 1). They were planted in small-scale wetlands which were constructed in circular plastic pails ($23 \times 19 \times 23$ cm, $D_1 \times D_2 \times H$). The plants were fixed with round cystosepiments, a diameter of which was about the same as the upper inner diameter of the wetlands. All the seedlings (tillers or clones) used in the study were well established, with the age and size being almost identical (about 3 weeks old, 20 cm height, and 10 g weight). One seedling was planted in each wetland. Each species-specific wetland had five replicas. All the wetlands were arranged randomly at a distance of 30 cm from each other in a climate chamber. The average air temperature during daylight hours (7: 00–19: 00) and during the evening was 28.0 ± 1.0 °C and 18.0 ± 1.0 °C, respectively. Relative humidity was 80% ± 5%, and the illumination intensity was 20 K lx during daylight hours. The plants were cultured with tap water in the 1st week, with an influent of 50% nutrient solution and 50% tap water during the 2nd week, and with nutrient solution thereafter. Every wetland was provided with 5 L of the influent, which was exchanged every 5 d, with an average hydraulic loading of 0.03 $m^3 m^{-2} d^{-1}$. The nutrient solution was prepared according to Wießner et al. (2005). The average concentration (mg L^{-1}) was 326.0 of chemical oxygen demand (COD_{cr}), 61.6 of total nitrogen (TN), and 5.0 of total phosphorus (TP).

2.2. Root length and longevity

For longevity measurement, two roots from the new growth of each plant were marked and observed every 3 days, and the average survival period of the marked roots of five plants was considered as longevity of the species. The longest root length of each plant was measured every 10 days, and the average of the five plants was considered as the root length of the species.

2.3. Root porosity

Root porosity was measured using a modified buoyancy-based method (Visser and Bögemann, 2003). The installation was made according to the density accessories of Sartorius YDK01. A glass beaker was filled with water at room temperature (25 °C), and a hang sieve was immersed into the water. About 2 g of plant roots were sampled from each wetland during the 10th week. The samples were washed to remove any debris, wiped of surface water, and cut into pieces of 2–2.5 cm in length before being weighed on a salver to an accuracy level of