

Floating Bed Plant Diversity and Combination Affect the Purification Efficiency of Domestic Wastewater Postprint

Authors: Liao Jianxiong, Zeng Danjuan, Yao Yuefeng, Pu Gaozhong, Mo Ling, Zhang Denan

Date: 2018-06-25T00:00:00+00:00

Abstract

Ecological floating bed systems are currently a focal point of research and application in the field of comprehensive water environment management. To investigate the effects of plant diversity and assemblage on domestic wastewater purification, this study constructed five diversity levels and two assemblage patterns using *Arundo donax* as the constructive and dominant species, and comparatively analyzed their plant growth, system productivity, and N, P, COD removal rates. The results showed that with increasing diversity, the individual biomass and relative growth rate (RGR) of wetland plants such as *Arundo donax* exhibited a decreasing trend, while the survival and growth of mesophytes were promoted. System productivity showed a decreasing trend with increasing diversity, whereas N, P, COD removal rates significantly increased with diversity. At the same diversity level, mesophyte-dominated assemblages, although exhibiting lower system productivity compared to wetland plant-dominated assemblages, demonstrated higher N, P, COD removal rates. Under the same diversity and assemblage conditions, P removal rate was the highest, followed by N removal rate, with COD removal rate being the lowest. With increasing establishment time of the ecological floating bed system, N, P, COD removal rates exhibited a trend of rapid initial increase followed by gradual decrease. These results indicate that plant diversity and assemblage in ecological floating bed systems affect the purification efficiency of domestic wastewater, and that microbial removal processes may be more important than direct plant uptake and adsorption.

Full Text

Plant Diversity and Composition of Ecological Floating Bed Affect Domestic Sewage Purification

LIAO Jianxiong, ZENG Danjuan, YAO Yuefeng, PU Gaozhong, MO Ling, ZHANG Denan

(Guangxi Key Laboratory of Plant Conservation and Restoration Ecology in Karst Terrain, Guangxi Institute of Botany, Guangxi Zhuang Autonomous Region and Chinese Academy of Sciences, Guilin 541006, Guangxi, China)

Abstract

Ecological floating bed systems have become a research and application hotspot in the comprehensive management of polluted aquatic environments. To investigate how plant diversity and composition affect domestic sewage purification, this study established five species richness levels and two compositional arrangements using *Arundo donax* as the dominant and constructive species, and measured plant growth, system productivity, and nitrogen (N), phosphorus (P), and chemical oxygen demand (COD) removal rates. The results indicated that the individual biomass and relative growth rate (RGR) of wetland plants such as *A. donax* decreased with increasing species richness, while the survival and growth of mesophytes were promoted. System productivity declined with higher species richness, but N, P, and COD removal rates increased significantly. At the same species richness level, compositions with more mesophytes exhibited lower system productivity than those dominated by wetland plants, yet achieved higher N, P, and COD removal rates. Under identical species richness and composition conditions, P removal was highest, followed by N removal, with COD removal being lowest. Moreover, removal rates showed a pattern of rapid initial increase followed by gradual decline over time. These findings demonstrate that plant diversity and composition in ecological floating bed systems significantly affect domestic sewage purification. While pollutants can be removed through direct plant absorption and adsorption, microbial processes may play a more important role.

Keywords: ecological floating bed, *Arundo donax*, N, P, COD

Introduction

Rapid urban expansion and economic development have led to increasing volumes of domestic sewage, which not only exacerbates water quality deterioration in rivers and lakes and contaminates groundwater, but also seriously threatens the living environment of urban and rural residents and the sustainable development of the economy and society. Consequently, effective domestic sewage purification has become a scientific issue of widespread concern (Schindler, 2012; Finlay et al, 2013). Compared with traditional physicochemical methods and constructed wetlands, ecological floating bed technology offers lower investment,

easier operation, and can create aquatic landscapes while providing certain economic benefits, making it a current research and application hotspot in comprehensive water environment management (Zhang et al, 2007). Plants are the key component of ecological floating beds, possessing different biological characteristics and purification mechanisms and preferences. Therefore, plant selection and combination are paramount in ecological floating bed technology. Numerous studies have found that multi-species plant combinations generally purify water more effectively than single species (Li et al, 2010; Hu et al, 2016), and that higher plant diversity yields stronger purification effects (Zhu et al, 2010; Liang et al, 2011; Zhang et al, 2011; Chang et al, 2014). However, these studies have primarily focused on constructed wetlands and mainly targeted nitrogen (N) removal. In most cases, phosphorus (P) is the primary factor causing water eutrophication (Xie, 2003; Finlay et al, 2013; Yan et al, 2016), while organic pollutants readily cause black and odorous water (Yu and Huang, 2010). Moreover, when studying the effects of plant diversity and composition on water purification, ecological floating beds are not only easier to operate than constructed wetlands but can also be applied to water bodies of various depths (Liao et al, 2018). Therefore, using ecological floating beds to investigate the removal effects of plant diversity and composition on N, P, and organic pollutants in domestic sewage holds greater theoretical and practical significance.

In studies of the relationship between plant diversity and ecosystem function, many researchers have confounded species composition effects with species richness effects (Huston, 1997). Therefore, controlling plant diversity while establishing different species compositions at the same diversity level represents a more reasonable approach. Additionally, our previous research found that *Arundo donax* not only adapts to various polluted water bodies but also exhibits high N and P removal rates (Liao et al, 2017). However, the effects of neighboring plants on *A. donax* have rarely been reported (Curt et al, 2017). Consequently, this study designed five diversity levels for ecological floating beds with *A. donax* as the constructive species, with two compositional arrangements established at three of these diversity levels. The objective was to analyze the effects of plant diversity and composition on plant growth, system productivity, and removal rates of N, P, and COD from domestic sewage, thereby providing theoretical guidance for improving ecological floating bed technology for comprehensive domestic sewage treatment.

Materials and Methods

The experiment was conducted in a rain shelter greenhouse at the Guangxi Institute of Botany. During the experimental period (September 10 to October 29, 2014, totaling 49 days), the average day/night temperature inside the greenhouse was 30.0/21.2 °C, with relative humidity at 77.3%. Before the experiment, five wetland plant species (*Arundo donax*, *Iris wilsonii*, *Ruellia brittoniana*, *Alocasia macrorrhiza*, *Scirpus triangulatus*) and four mesophyte species (*Boehmeria nivea*, *Pteris cretica* var. *nervosa*, *Phytolacca acinosa*, *Helianthus annuus*) were

selected as experimental species. *Arundo donax* was obtained as tissue culture seedlings, *Ruellia brittoniana* as cuttings, and *Helianthus annuus* as seeded plants, while the others were wild seedlings or produced through division. When most seedlings reached approximately 20 cm in height, their roots were washed and pre-cultured in tap water for one week.

Eighteen 300 L plastic tanks (mouth dimensions: 86 cm \times 65 cm; bottom dimensions: 70 cm \times 50 cm; depth: 62 cm) were purchased and buried approximately 50 cm in soil to minimize water temperature fluctuations from air temperature. Domestic sewage from a sewage channel in Yanshan District, Guilin City (with N, P, and COD concentrations of 39.89, 4.24, and 413.37 mg \cdot L⁻¹, respectively) was added to each tank to ground level (approximately 270 L), and tap water was added every other day to compensate for evaporation (measured through a dangling float). The ecological floating bed simulation was improved based on our patent (Liao et al, 2018). Pre-cultured plants of relatively uniform size were selected, and their stem bases were wrapped with 100 cm \times 7 cm \times 2 cm high-density PU foam strips and fixed in 17 cm \times 15.3 cm (diameter \times height) two-color PP flowerpots, which were then placed in planting holes on PS extruded boards floating on the tank water. The extruded boards were square with 60 cm sides and 3 cm thickness, with nine uniformly distributed planting holes of 16 cm diameter. Thus, each tank could accommodate nine plants. Except for the control tanks, which contained extruded boards and foam-wrapped flowerpots without any plants, the remaining tanks were planted with 1, 3, 5, 7, or 9 species using *A. donax* as the constructive species (Table 1). At species richness levels of 3, 5, and 7, two compositional arrangements were established: wetland plant-dominated and mesophyte-dominated combinations. When multiple species were planted, each species other than *A. donax* was represented by a single individual, and multiple *A. donax* individuals were spaced as far apart as possible. Each diversity level and composition was replicated twice, with the two replicate tanks placed adjacent to each other.

1.2 Sampling and Measurement

After establishing the ecological floating bed system, water samples were collected weekly for seven weeks. Sampling was conducted uniformly at approximately 9:00 AM, using medical syringes to extract approximately 50 mL of water from 12 cm below the water surface at each of the four tank corners, which were then mixed. Nitrogen and phosphorus concentrations were measured using alkaline potassium persulfate digestion UV spectrophotometry (HJ 636-2012) and ammonium molybdate spectrophotometry (GB 11893-89), respectively. COD was measured using Hach reagents and a DR1010 COD analyzer (USA). After each water sample measurement, N, P, and COD removal rates for each tank were calculated according to $(C_0 - C_1)/C_0 \times 100$ (Liao et al, 2017), where C_0 represents the initial concentration of domestic sewage, and C_0 and C_1 represent the concentrations in the plant-free control tank and planted tanks, respectively.

Before transferring pre-cultured plants to the tanks, their initial fresh weight was measured, and initial dry weight (DW0) was estimated based on the dry-to-fresh ratio of spare plants. After 49 days, each plant was washed, placed in an envelope, fixed at 105 °C for 20 minutes, and then dried at 80 °C for at least 24 hours before weighing to obtain dry weight (DW). The relative growth rate (RGR, $\text{mg} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$) of each plant was calculated as $(\ln \text{DW} - \ln \text{DW0})/49 \times 1000$, while productivity per tank ($\text{mg} \cdot \text{d}^{-1}$) was calculated as $(\text{total harvested biomass} - \text{total initial biomass})/49 \times 1000$ (Garnier et al, 2004).

1.3 Statistical Methods

All data processing and analysis were performed using SPSS 20.0 software (SPSS Inc., Chicago, USA). Since individual plant biomass and RGR at harvest were related to DW0, and system productivity and N, P, COD removal rates were related to the system's initial total biomass, one-way ANCOVA was used to analyze the effects of plant diversity and composition on individual plant biomass and RGR, with DW0 as the covariate. Two-way ANCOVA was used to analyze the effects of plant diversity, composition, and sampling time on system N, P, and COD removal rates, with the system's initial total biomass as the covariate. When main effects were significant, subsequent multiple comparisons were conducted using the LSD method. When interactions were significant, differences among sampling times at the same diversity level were compared using one-way ANCOVA. Paired-sample t-tests were used to compare N, P, and COD removal rates under the same diversity and composition conditions.

Results

The individual biomass and RGR of the four mesophyte species all increased with plant diversity, with significant increases observed for *Phytolacca acinosa* and *Helianthus annuus* in both biomass and RGR, and for *Boehmeria nivea* in RGR (Table 2). The five wetland plant species showed different responses in individual biomass and RGR to plant diversity: *Arundo donax* and *Alocasia macrorrhiza* decreased with increasing diversity, while *Iris wilsonii* increased, though none of these trends were statistically significant (Table 2, Figure 1 [Figure 1: see original paper]).

According to the experimental design, at species richness levels of 3, 5, and 7, there were two compositional arrangements (wetland-dominated and mesophyte-dominated). *Arundo donax* was included in all three diversity levels and both compositions, while *Alocasia macrorrhiza*, *Scirpus triangulatus*, *Boehmeria nivea*, and *Pteris cretica* var. *nervosa* were included in the richness level 7 compositions (Table 1). However, at the same diversity level, different compositions had no significant effects on the individual biomass and RGR of these five plants. Overall, wetland-dominated compositions increased the individual biomass and RGR of these plants (Table 2, Figure 1).

2.2 System Productivity

System productivity showed a significant decreasing trend with increasing plant diversity (Figure 2 [Figure 2: see original paper]). At the same diversity level, although differences in system productivity between compositions were not significant, wetland plant-dominated compositions generally exhibited higher productivity than mesophyte-dominated compositions.

2.3 N, P, and COD Removal Rates

Plant diversity and composition had significant effects on domestic sewage N, P, and COD removal rates (Table 3). N, P, and COD removal rates increased significantly with plant diversity. At the same diversity level, mesophyte-dominated compositions showed significantly higher N removal rates than wetland-dominated compositions. Although differences in COD and P removal rates between compositions at the same diversity level were not significant, mesophyte-dominated compositions generally achieved higher removal rates than wetland-dominated compositions.

Treatment time also significantly affected N, P, and COD removal rates (Figure 3 [Figure 3: see original paper]). Removal rates showed a pattern of rapid initial increase followed by gradual decline over time. The maximum removal rates for the highest diversity level (9 species) occurred in week 4, while maximum values for other diversity levels and compositions appeared in week 3. Under the same diversity and composition conditions, P removal rates were highest, followed by N removal rates, with COD removal rates being lowest (Figure 3). For wetland-dominated compositions, P removal rates were significantly higher than N removal rates, while N and COD removal rates did not differ significantly. Conversely, for mesophyte-dominated compositions, P and N removal rates did not differ significantly, but N removal rates were significantly higher than COD removal rates.

Discussion

3.1 Effects of Plant Diversity and Composition on Plant Growth in Ecological Floating Beds

In plant communities, plant diversity exerts both conservation and resource competition effects on individual species, with their relative importance depending on species characteristics and composition. This study found that different species compositions at the same plant diversity level had no significant effects on individual plant biomass and RGR. However, with increasing diversity, the RGR of *Helianthus annuus*, *Phytolacca acinosa*, and *Boehmeria nivea* increased significantly. These three species are all mesophytes that would struggle to survive when applied individually in ecological floating bed systems. Through combination with wetland plants, however, they grew well. During this process, root oxygen release from wetland plants (Zhang and Chen, 2005) and their root

exudates (Lambers et al, 2015) likely promoted the survival and growth of these mesophytes.

Under natural conditions, our primary study species *Arundo donax* typically occurs as a monodominant community, indicating strong interspecific competitive ability but weak intraspecific competition. However, when species diversity was artificially increased in its community, its interspecific competitive advantage did not manifest; instead, its individual biomass and RGR decreased with increasing diversity. We propose two possible reasons: (1) *A. donax* growth in the first year is primarily vertical and relatively slow, resulting in weak competitive advantage against neighboring plants (Curt et al, 2017); and (2) neighboring species may conversely exert inhibitory effects on *A. donax* (Curt et al, 2017). Therefore, *A. donax* should be planted as a monoculture during the initial stage of ecological restoration.

3.2 Effects of Plant Diversity and Composition on System Productivity and N, P, COD Removal Rates

Most studies have found significant positive correlations between plant diversity and productivity (Loreau and Hector, 2001). However, this study found the opposite result. We believe that, in addition to the relatively short experimental period, species-specific or sampling effects represent important reasons. This study used fast-growing *A. donax* as the constructive and dominant species (i.e., *A. donax* was present in all species combinations). As diversity increased, the number of *A. donax* individuals decreased, leading to declining community productivity. At the same plant diversity level, wetland plant-dominated compositions showed higher productivity than mesophyte-dominated compositions, clearly because wetland plants are better adapted to aquatic environments than mesophytes.

Some studies have found that wetland N removal rates increase significantly with plant diversity (Ge et al, 2015). By increasing plant diversity in ecological floating bed systems, this study similarly found that tank N, P, and COD removal rates increased significantly. The removal of N, P, and COD is related not only to direct plant absorption and adsorption but also closely associated with plants' modification of the microenvironment (Li et al, 2010; Cai et al, 2011; Liao et al, 2017). The latter can affect N removal through two mechanisms: First, plants influence neighboring plants' N uptake through root exudates (e.g., carboxylates, O_2), as Novak and Chan (2002) found that neighboring plants can affect P-hyperaccumulating plants' enrichment function. Second, plants affect microbial proliferation and diversity in the rhizosphere through root growth and exudate secretion, and the metabolic activities of these microorganisms contribute more substantially to N removal (Yuan et al, 2004; Ge et al, 2015). This study found that N, P, and COD removal rates showed opposite trends to productivity changes with increasing plant diversity, suggesting that microbial processes may be more important than direct plant effects.

At the same diversity level, mesophyte-dominated compositions achieved higher N, P, and COD removal rates than wetland plant-dominated compositions, with N removal rates reaching statistical significance. Cai et al (2011) suggested that combining mesophytes with wetland plants facilitates the formation of aerobic-anoxic-anaerobic microenvironments near roots, promoting the coexistence of aerobic and anaerobic microorganisms and enhancing water purification. Specifically regarding N removal, wetland plants create aerobic conditions in the rhizosphere that can lead to substantial nitrate accumulation (Zhang et al, 2007; Finlay et al, 2013). Adding mesophytes to the configuration creates local anoxic conditions favorable for denitrifying bacteria survival and reproduction, thereby significantly promoting denitrification.

Natural domestic sewage possesses certain self-purification capacity (Zhang et al, 2007; Schlesinger, 2009; Schindler, 2012). Therefore, this study calculated COD, N, and P removal rates using plant-free sewage as a control to highlight plants' direct and indirect purification effects. The results showed that N, P, and COD removal rates exhibited a pattern of rapid initial increase followed by gradual decline as the ecological floating bed system establishment time increased. Similar patterns were observed in hydroponic experiments by Wang et al (2013) and Liao et al (2017). We propose that after brief acclimation, plant growth accelerates while promoting microbial attachment and proliferation, causing rapid initial increases in N removal rates. However, as time progresses, plant growth slows and microbial populations gradually reach saturation, causing N removal rates to decline. Therefore, Liao et al (2017) suggested that timely harvesting of aboveground parts or whole plants is necessary and essential for more effective water purification. Additionally, Reich et al (2012) proposed that as establishment time increases, interspecific complementarity becomes more complete, causing the saturation point of the diversity-ecosystem function curve to be delayed at higher diversity levels. This study found that peak removal of N occurred one week later at the highest plant diversity level (9 species) than at other diversity levels, indicating that complementarity effects also contribute to diversity-enhanced N removal.

3.3 Comparison of N, P, and COD Removal Rates

Yan et al (2016) suggested that pre-industrial freshwater P concentrations were very low, so most wetland plants developed stronger P uptake capacity than N under long-term selective pressure. In other words, wetland plants generally remove P from water faster than N. This study indeed found that P removal rates were higher than N removal rates. However, we propose that in addition to plant absorption, the oxygen microenvironment or microbial processes represent important reasons for higher P removal rates. Compared with P, N removal is more strongly affected by the oxygen microenvironment because denitrification (the primary N removal pathway) must occur under anaerobic conditions. Consequently, if surface water is oxygen-rich, nitrate pollution can easily occur (Zhang et al, 2007; Finlay et al, 2013). This study also found that when meso-

phytes dominated (creating persistent anaerobic microenvironments), P and N removal rates did not differ significantly, but when wetland plants dominated (primarily aerobic microenvironments), P removal rates were significantly higher than N removal rates. Compared with N, organic matter removal depends more on microbial decomposition (Yuan et al, 2004; Li et al, 2010), and plant root exudates also increase organic matter content in water. If these organic compounds are not decomposed into CO₂ or methane that escapes the water, COD removal rates are generally lower than N removal rates (Du et al, 2010). Based on this, our study found the same trend, indicating that organic pollutants in this domestic sewage were primarily persistent, difficult-to-degrade compounds.

Conclusion

Altering plant diversity and composition in ecological floating bed systems with *Arundo donax* as the constructive and dominant species significantly affected plant growth, system productivity, and N, P, and COD removal. With increasing diversity, wetland plants showed declining individual biomass and RGR, while mesophyte survival and growth were promoted. Productivity decreased with increasing diversity, likely due to species-specific or sampling effects. Concurrently, N, P, and COD removal rates increased significantly with diversity, suggesting that microbial processes are more important than direct plant absorption and adsorption. Similarly, at the same diversity level, mesophyte-dominated compositions achieved higher N, P, and COD removal rates than wetland plant-dominated compositions despite lower system productivity. Under identical diversity and composition conditions, P removal rates were highest, followed by N removal rates, with COD removal rates being lowest. As ecological floating bed system establishment time increased, N removal rates exhibited a pattern of rapid initial increase followed by gradual decline.

References

- CAI PY, LIU AQ, HOU XL, 2011. Study on effects of seven hydrophytes on nitrogen and phosphorus removal from domestic sewage [J]. Chin J Environ Eng, 5 (5): 1067-1070.
- CHANG J, FAN X, SUN HY, et al, 2014. Plant species richness enhances nitrous oxide emissions in microcosms of constructed wetlands [J]. Ecol Eng, 64: 108-115.
- CURT MD, MAURI PV, SANZ M, et al, 2017. The ability of the *Arundo donax* crop to compete with weeds in central Spain over two growing cycles [J]. Ind Crop Prod, 108 (2017): 86-94.
- DU XL, XU ZX, WANG S, 2010. Enhanced removal of organic matter and ammonia nitrogen in a one-stage vertical flow constructed wetland system [J]. Environ Prog Sustain, 29 (1): 60-67.

- FINLAY JC, SMALL GE, STERNER RW, 2013. Human influences on nitrogen removal in lakes [J]. *Science* 342: 247-250.
- GARNIER E, CORTEZ J, BILLÈS G, et al, 2004. Plant functional markers capture ecosystem properties during secondary succession [J]. *Ecology*, 85 (9): 2630-2637.
- GE Y, HAN WJ, HUANG CC, et al, 2015. Positive effects of plant diversity on nitrogen removal in microcosms of constructed wetlands with high ammonium loading [J]. *Ecol Eng*, 82: 108-115.
- HU ZF, CHEN AM, QIU Z, et al, 2016. The effects of plant species and plant diversity on nitrogen removal in simulated vertical sub-surface flow constructed wetlands [J]. *Environ Poll Contr*, 38 (3): 45-49.
- HUSTON MA, 1997. Hidden treatments in ecological experiments: Re-evaluating the ecosystem function of biodiversity [J]. *Oecologia*, 110: 449-460.
- LAMBERS H, HAYES PE, LALIBERTÉ E, et al, 2015. Leaf manganese accumulation and phosphorus-acquisition efficiency [J]. *Trends Plant Sci*, 20 (2): 83-90.
- LI SS, TIAN K, LIU YG, et al, 2010. Compare the purification effects of sewage by the wetland plant community composition and spatial patterns [J]. *Ecol Environ Sci*, 19 (8): 1951-1955.
- LIANG MQ, ZHANG CF, PENG CL, et al, 2011. Plant growth, community structure, and nutrient removal in monoculture and mixed constructed wetlands [J]. *Ecol Eng*, 37: 309-316.
- LIAO JX, ZHANG DN, MALLIK A, et al, 2017. Growth and nutrient removal of three macrophytes in response to concentrations and ratios of N and P [J]. *Int J Phytoremediat*, 19 (7): 651-657.
- LIAO JX, HUANG YQ, ZHANG DN, et al, 2018. An ecological floating bed without requiring to joint in the water [P]. Utility model patent, number: ZL201720167872.6.
- LOREAU M, HECTOR A, 2001. Partitioning selection and complementarity in biodiversity experiments [J]. *Nature*, 412: 72-76.
- NOVAK JM, CHAN ASK. 2002. Development of P hyperaccumulator plant strategies to remediate soils with excess P concentrations [J]. *Crit Rev Plant Sci*, 21 (5): 493-509.
- REICH PB, TILMAN D, ISBELL F, et al, 2012. Impacts of biodiversity loss escalate through time as redundancy fades [J]. *Science*, 336: 589-592.
- SCHINDLER DW, 2012. The dilemma of controlling cultural eutrophication of lakes [J]. *Proc Roy Soc B-Biol Sci* 279: 4322-4333.
- SCHLESINGER WH, 2009. On the fate of anthropogenic nitrogen [J]. *Proc Natl Acad Sci USA*, 106: 203-208.

WANG M, TANG JC, WANG F, 2013. Remediation effect of common aquatic plants on the combined water pollution of eutrophication and heavy metals [J]. J Water Resour Water Eng, 24 (2): 50-56.

XIE LQ, XIE P, LI SX, et al, 2003. The low TN:TP ratio, a cause or a result of *Microcystis* blooms [J]? Water Res, 37: 2073-2080.

YAN Z, HAN W, PEÑUELAS J, et al, 2016. Phosphorus accumulates faster than nitrogen globally in freshwater ecosystems under anthropogenic impacts [J]. Ecol Lett, 19: 1237-1246.

YU YB, HUANG Y, 2010. Review of reason and mechanism of black and stink in urban rivers [J]. Environ Sci Technol, 23 (S2): 111-114.

YUAN DH, REN QJ, GAO SX, et al, 2004, Purification efficiency of several wetland macrophytes on COD and nitrogen removal from domestic sewage [J]. Chin J Appl Ecol, 15 (12): 2337-2341.

ZHANG CB, LIU WL, WANG J, et al, 2011. Effects of monocot and dicot types and species richness in mesocosm constructed wetlands on removal of pollutants from wastewater [J]. Bioresour Technol, 102 (22): 10260-10265.

ZHANG TP, CHEN WL, 2005. Advances in removal efficiency of nitrogen and phosphorus in constructed wetland ecosystem [J]. Ecol Environ, 14 (4): 580-584.

ZHANG ZY, FENG ML, YANG LZ, 2007. Nitrogen and phosphorus removal and N₂O emission from domestic sewage in floating-bed plant systems [J]. Acta Ecol Sin, 27 (10): 4333-4341.

ZHU SX, GE HL, GE Y, et al, 2010. Effects of plant diversity on biomass production and substrate nitrogen in a subsurface vertical flow constructed wetland [J]. Ecol Eng, 36 (10): 1307-1311.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv – Machine translation. Verify with original.