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Full Length Article

Screening Wetland Plants for Nutrient Uptake and Bioenergy Feedstock Production

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Abstract

The constructed wetlands are considered as low cost systems for treating municipal, industrial and agricultural wastewater. However, there is limited information about the subsequent disposal of how to deal with the harvested biomass. This study was conducted to investigate the phyto-uptake potential of nitrogen and phosphorus of six perennial wetland plants and their biomass potential for bioenergy use. One square meter of aboveground part of each plant species was harvested in triplicate and weighed to determine the biomass. Subsamples were prepared to determine nitrogen (N) and phosphorus (P) contents. Results indicated that the biomass of giant reed (*Arundo donax*) was up to 5.59 kg m^{-2} and its phyto-uptake of N and P in the aboveground tissues was also the highest one followed by green reed (*Phragmites* (sp.)). Giant reed and green reed had higher calorific value (about 18 MJ kg^{-1}), which was significantly higher than umbrella plant, canna and alligator flag ($P \leq 0.05$). Therefore, giant reed and green reed could be the preferential wetland plants for nutrient phyto-uptake and bioenergy feedstock usage.

Keywords: Wetland plants; Nutrient; Phyto-uptake; Bioenergy feedstock production

Introduction

Eutrophication of surface water is becoming worse and threatening the quality of drinking water and human health safety now a days. Nitrogen and phosphorus are the main elements causing eutrophication (Zhao *et al.,* 2012a). Most municipal wastewater treatment plants (MWTP), with active sludge procedure designed to remove biochemical oxygen demand (BOD) and chemical oxygen demand (COD), cannot reduce the N and P. Moreover, NH_4^+-N and TP in effluent from the MWTP is as high as 20 and 1.0 mg L^{-1}, respectively (Grade I-B of discharge standard of pollutants for MWTP, GB 18918-2002), which are 20 and 50 times higher than Grade III of Chinese National Surface Water Quality Standards (GB 3838-2002). Low cost innovative system of high efficiency and sustainability for plant-ecosystem purification and remediation procedure to treat effluents from MWTP is needed urgently. Constructed wetlands (CWs) are found cost effective for remediation of wastewater from municipal, industrial and agricultural sources (Seo *et al.,* 2005; Liu *et al.,* 2008). Moreover, the plants of terrestrial and aquatic systems have potential usage for bioenergy production along with other economical uses such as animal feeds (Licht and Isebrands, 2005).

The development of renewable energy and reduction of greenhouse gas (GHG) emissions has now been prioritized within EU, USA, China, and many other countries of the world. Carbon dioxide (CO_2) and N_2O emissions are mainly due to the anthropogenic sources (Schlamadinger and Marland, 1996). However, N_2O has been found as around 300 times more powerful with respect to CO_2 (Del Grosso *et al.,* 2005). Carbon-neutral biomass plants have been promoted as an option to reduce GHG emissions (Bjørnstad and Skonhoft, 2002; Schneider and McCarl, 2003). Thermo chemical procedures like combustion, pyrolysis, and gasification can covert biomass into energy. Similarly methane and ethanol can be obtained by fermentation of carbohydrates (Hamelinck *et al.,* 2005). Timber, waste paper, residues of crops and bioenergy crops are the main source of lignocellulosic biomass. Perennial energy crops a major feedstock source when grown need no reseeding for a long time. Assuming that whole nitrogen waste of China could be utilized by constructed wetlands, biofuel production can account for 6.7% of national gasoline consumption (Liu *et al.,* 2012). Therefore, both environmental and economic benefits exist there (Lemus and Lal, 2005).

However, limited information is available about the subsequent disposal of harvested biomass from wetlands. The present study was conducted to investigate the phyto-

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uptake potential of nitrogen and phosphorus of six perennial wetland plants (See Table 1) and evaluate their biomass utilization potential as bioenergy feedstock.

Materials and Methods

Wetland Location

The local government has imposed a ban to drain the domestic waste water into Qingshan Lake before that it is safe as carries high quantity of nutrients. Consequently, a full-size wetland was constructed in a submerged area of the lake in Lin'an city (30°14′N, 119°42′E), of eastern China in Zhejiang province. The climate of region is subtropical monsoonal having cold moist winters and warmer dry summers. Mean annual precipitation and temperature of the area are 1628 mm and 16.4°C respectively.

Sampling and Analysis

Six wetland plants used in the experiment are given in Table 1. One square meter of aboveground part of each plant species was harvested in triplicate and weighed in September, 2010. Subsamples were kept in polyethylene bags and carried into the laboratory. The samples were then divided into stem and leaf. Subsamples were ground using a mill, passed through a 60 mesh sieve and stored after drying in an oven at 80°C to a constant weight. The determination of N content was performed using a CNS analyzer (Vario MAX CNS Macro Elemental Analyzer, Germany). Having acid digested plant tissues (HNO_3:$HClO_4$=5:1), P content was determined using an Agilent 7500a ICP–MS system (Agilent Technologies). The content of acid-detergent fibers (ADF), acid-detergent lignin (ADL), neutral-detergent fiber (NDF) were examined by a Raw Fiber Extractor (Velp Scientifica, Italy) and hemicellulose (HE) and cellulose (CL) were calculated (Zhao *et al.*, 2012b). Calorific value was determined using a bomb calorimeter (GB/T 213-2003).

Statistical Analysis

The analysis of variance (ANOVA) and Tukey's comparison of means were performed with statistical software package SPSS (version 16.0). Means of data were compared by least significant difference (LSD) test at 5% significance level.

Results

Biomass Production

The biomass production of all of the species was significantly different (Fig. 1) indicating that the six plant species can grow well in wetland environment. Aboveground dry weight of the six wetland plants ranged from a lowest level of 1.32 kg m^{-2} for canna to a highest level of 5.59 kg m^{-2} for giant reed (Fig. 1). The biomass production in the tested species was in the order: giant reed > vetiver > green reed > umbrella plant > alligator flag > canna. The stem biomass of giant reed was up to 4.93 kg m^{-2}, which was significantly greater than other plant species. However, vetiver had the greatest leaf biomass (1.57 kg m^{-2}) due to its herbal properties and lower moisture contents.

Table 1: The six tested plants in constructed wetland for purifying the effluent from the municipal wastewater treatment plants

Common name	Scientific name
Vetiver	*Vetiveria azizanioides*
Alligator flag	*Thaliade albata*
Umbrella plant	*Cyperus alternifolius*
Green reed	*Phragmites* (sp.)
Giant reed	*Arundodonax*
Canna	*Canna indica*

Phyto-uptake of Nitrogen and Phosphorus

Nitrogen (N) content and N phyto-uptake of the experimental plants has been shown in Fig. 2. N contents of six wetland plants from aboveground tissues ranked as a lowest from 11.57 mg g^{-1} for vetiver to a highest of 34.54 mg g^{-1} for canna. Canna, umbrella plant and green reed had a significantly higher N content (30 mg g^{-1}) than vetiver and alligator flag ($P \leq 0.05$). The N phyto-uptake of giant reed and green reed were 88.87 and 73.79 g m^{-2}, respectively, which were significantly greater than other plant species.

Umbrella plant, canna and green reed contained more P, 2.22 mg g^{-1}, 2.17 mg g^{-1} and 1.77 mg g^{-1}, significantly higher than found in vetiver and giant reed. However, giant reed demonstrated the greatest phyto-uptake (5.18 g m^{-2}) followed by green reed (4.76 g m^{-2}), and both of them were significantly greater than vetiver and canna (Fig. 3).

Biomass Assessment of Wetland Plants as Bioenergy Feedstocks

Fig. 4 shows that all of tested plant species have a consistent trend of neutral-detergent fiber (NDF) > acid-detergent fiber (ADF) > acid-detergent lignin (ADL). NDF contents of vetiver and giant reed were 75.52% and 74.20%, respectively, which were significantly ($P \leq 0.05$) higher than that of canna (52.01%). All of giant reed, green reed and vetiver contained more than 40% ADF, which was significantly higher than canna (30.95%). There was a consistent trend in ADL.

Hemicellulose, cellulose and calorific value in aboveground tissue of the six plant species are presented in Fig. 5. Hemicellulose contents of vetiver and umbrella plant were both about 35%, which was significantly higher than alligator flag (25.62%) and canna (21.06%). There were no significant differences in the cellulose content of six tested wetland plants ($P > 0.05$). The sum of hemicellulose and cellulose content of vetiver, umbrella plant and giant reed were all more than 60%. Calorific value of green reed, giant reed and vetiver was about 18 MJ kg^{-1}, which was significantly higher than alligator flag (8.72 MJ kg^{-1}) and canna (9.52 MJ kg^{-1}).

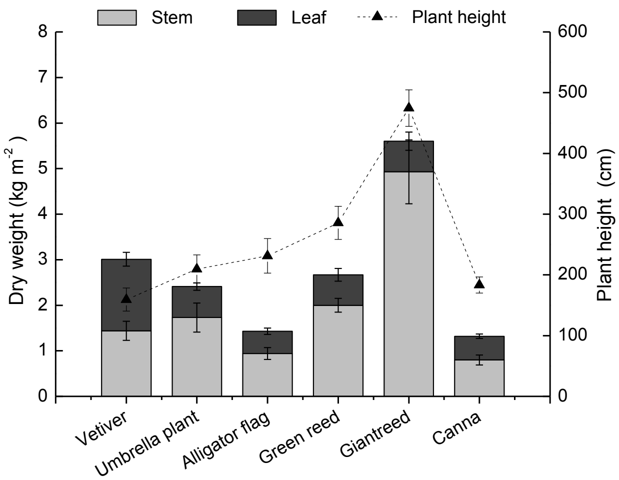

Fig. 1: Biomass allocation and plant height of the six tested plants in constructed wetland for purifying the effluent from the municipal wastewater treatment plants. Values are the means of 3 replications ± standard deviation (SD)

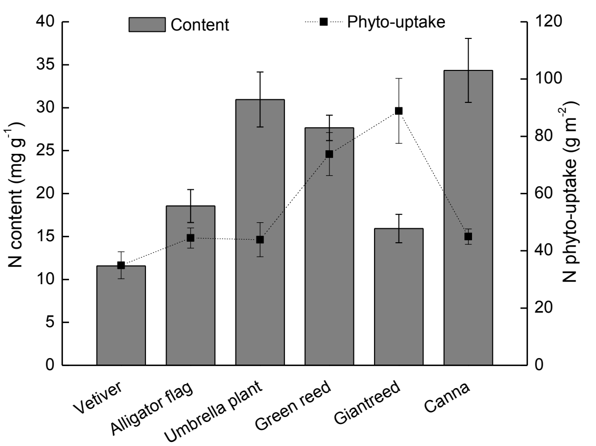

Fig. 2: Nitrogen (N) content and phyto-uptake of the six tested plants in constructed wetland for purifying the effluent from the municipal wastewater treatment plants. Values are the means of 3 replications ± SD

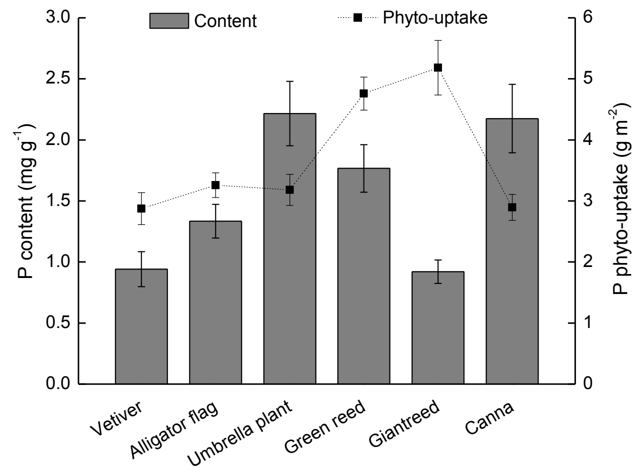

Fig. 3: Phosphorus (P) content and phyto-uptake of the six tested plants in constructed wetland for purifying the effluent from the municipal wastewater treatment plants. Values are the means of 3 replications ± SD

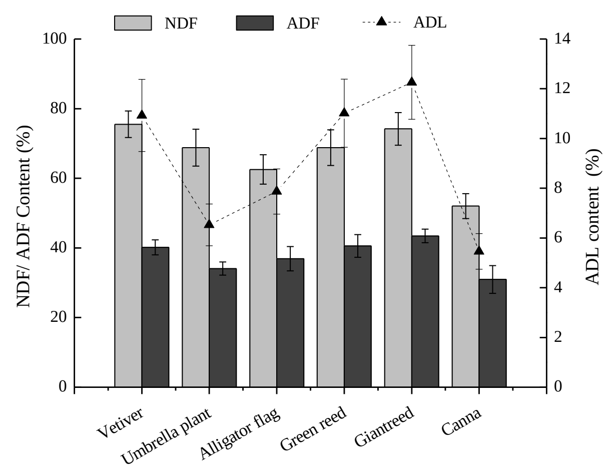

Fig. 4: Neutral-detergent fiber (NDF), acid-detergent fiber (ADF) and acid-detergent lignin (ADL) content of the six tested plants in constructed wetland for purifying the effluent from the municipal wastewater treatment plants. Values are the means of 3 replications ± SD

Discussion

The biomass variations of wetland plant species may be due to the plant species as well physiological and morphological characters of the plants (Ma *et al.,* 2010; Zhu *et al.,* 2011). In this study, the aboveground biomass of giant reed were greater than those of reported macrophyte species (0.83-2.35 kg m^{-2}) (Fan *et al.,* 2010; Tanner and Headley, 2011). The biomass of giant reed was up to 5.59 kg m^{-2}, which was significantly greater than other plant species (Fig. 1). The larger leaf area and longer duration of green leaves for phytosynthesis were the main reasons for more biomass.

Due to the more biomass, giant reed showed had the great N and P phyto-uptake, which were 88.87 g m^{-2} and 5.18 g m^{-2} (Fig. 2 and 3). The N and P phyto-uptake of green reed were near to those of giant reed. Therefore, the amount of nutrients stored by standing biomass depends upon plant growth rate and nutrient content in tissues. Screening criteria to wetland plant species should be taken into account in detail including all of the important attributes of high biomass, well developed root system, high uptake efficiency of N and P, adaptation of extreme weather, and disease- and pest- resistance. Giant reed and green reed were found effective counterpart to meet these criteria, both of which were comparable to floating hydrophytes (Zhao *et al.,* 2012a).

Perennial crops, like grasses, have particular advantages as bioenergy feedstocks. Grasses are not generally used for human food and demonstrate fast growing characters. They can produce large biomass with

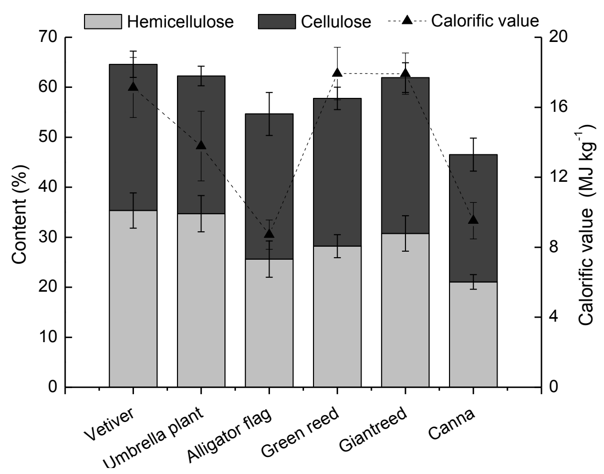

Fig. 5: Hemicellulose, cellulose and calorific value of the six tested plants in constructed wetland for purifying the effluent from the municipal wastewater treatment plants. Values are the means of 3 replications ± SD

minimum inputs. On the other hand, their annual planting/seeding is not required (Johnson *et al.,* 2007; Karp and Shield 2008). It is reported that plant biomass currently provides 13–15% of the global energy demand and at least half of the world's population relies on plant biomass as their main source of energy (Parikka, 2004). However, the development of high biomass yield plants is slow in China. Many factors may have contributed to it, but the lack of incentives and available land is probably among the major ones (Marland *et al.,* 1997). Therefore, wetland eco-system for purifying eutrophic water, is an attractive alternative for the production of biomass energy in China. Except for *Canna*, the aboveground tissues of all the tested wetland plants contained 63-75% NDF and 34-43% ADF (Fig. 4), both of which were comparable with that of the model bioenergy plant—swithgrass (*Panicum virgatum*) (Lee and Vn Doolittle, 2007). With higher hemicellulose, cellulose and calorific value, giant reed, green reed and vetiver could be preferential as bioenergy plants.

In conclusion, giant reed (*Arundo donax*) and green reed (*Phragmites* (sp.) have greater phyto-uptake of N and P. Similarly their calorific value was about 18 MJ kg^{-1}, significantly higher than umbrella plant, canna and alligator flag. Therefore, giant reed and green reed could be recommended as the most suitable wetland plants for phyto-uptake and bioenergy feedstocks in the constructed wetlands receiving wastewater.

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References

Bjørnstad, E. and A. Skonhoft, 2002. Wood fuel or carbon sink? Aspects of forestry in the climate question. *Environ. Resour. Econ.*, 23: 447–465

Del Grosso, S.J., A.R. Mosier, W.J. Parton and D.S. Ojima, 2005. DAYCENT model analysis of past and contemporary soil N_2O and net greenhouse gas flux for major crops in the USA. *Soil. Till. Res.*, 83: 9–24

Fan, X.F., X.C. Hou, H.T. Zuo, J.Y. Wu and L.S. Duan, 2010. Biomass Yield and Quality of Three Kinds of Bioenergy Grasses in Beijing of China. *Sci. Agric. Sin.*, 43: 3316–3322

Hamelinck, C.N., G. Hooijdonk and A.P.C. Faaij, 2005. Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle-and long-term. *Biomass Bioenerg*, 28: 384–410

Johnson, J.M.F., M.D. Coleman, R. Gesch, A. Jaradat, R. Mitchell, D. Reicosky and W.W. Wilhelm, 2007. Biomass-bioenergy crops in the United States: A changing paradigm. *Amer. J. Plant Sci. Biotechnol.*, 1: 1–28

Karp, A. and I. Shield, 2008. Bioenergy from plants and the sustainable yield challenge. *New Phytol.*, 179: 15–32

Lee, D.K. and J.J. Vn Doolittle, 2007. Switchgrass and soil carbon sequestration response to ammonium nitrate, manure, and harvest frequency on conservation reserve program land. *Agron. J.*, 99: 462

Lemus, R. and R. Lal, 2005. Bioenergy crops and carbon sequestration. *Crit. Rev. Plant Sci.*, 24: 1–21

Licht, L.A. and J.G. Isebrands, 2005. Linking phytoremediated pollutant removal to biomass economic opportunities. *Biomass Bioenerg*, 28: 203–218

Liu, D., Y. Ge, J. Chang, C. Peng, B. Gu, G.Y.S. Chan and X. Wu, 2008. Constructed wetlands in China: recent developments and future challenges. *Front. Ecol. Environ.*, 7: 261–268

Liu, D., X. Wu, J. Chang, B. Gu, Y. Min, Y. Ge, Y. Shi, H. Xue, C. Peng and J. Wu, 2012. Constructed wetlands as biofuel production systems. *Nat. Clim. Change*, 2: 190–194

Ma, X., F. Ma, C. Li, Y. Mi, T. Bai and H. Shu, 2010. Biomass accumulation, allocation, and water-use efficiency in 10 Malus rootstocks under two watering regimes. *Agroforest. Syst.*, 80: 283–294

Marland, G., B. Schlamadinger and P. Leiby, 1997. Forest/biomass based mitigation strategies: Does the timing of carbon reductions matter? *Crit. Rev. Env. Sci. Tec.*, 27: 213–226

Parikka, M., 2004. Global biomass fuel resources. *Biomass Bioenerg*, 27: 613–620

Schlamadinger, B. and G. Marland, 1996. The role of forest and bioenergy strategies in the global carbon cycle. *Biomass Bioenerg*, 10: 275–300

Schneider, U.A. and B.A. McCarl, 2003. Economic potential of biomass based fuels for greenhouse gas emission mitigation. *Environ. Resour. Econ.*, 24: 291–312

Seo, D.C., J.S. Cho, H.J. Lee and J.S. Heo, 2005. Phosphorus retention capacity of filter media for estimating the longevity of constructed wetland. *Water Res.*, 39: 2445–2457

Tanner, C.C. and T.R. Headley, 2011. Components of floating emergent macrophyte treatment wetlands influencing removal of stormwater pollutants. *Ecol. Eng.*, 37: 474–486

Zhao, F., S. Xi, X. Yang, W. Yang, J. Li, B. Gu and Z. He, 2012a. Purifying eutrophic river waters with integrated floating island systems. *Ecol. Eng.*, 40: 53–60

Zhao, F., W. Yang, Z. Zeng, H. Li, X. Yang, Z. He, B. Gu, M.T. Rafiq and H. Peng, 2012b. Nutrient removal efficiency and biomass production of different bioenergy plants in hypereutrophic water. *Biomass Bioenerg*, 42: 212–218

Zhu, L., Z. Li and T. Ketola, 2011. Biomass accumulations and nutrient uptake of plants cultivated on artificial floating beds in China's rural area. *Ecol. Eng.*, 37: 1460–1466

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