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RESEARCH REVIEW

Study of bioremediation of water environment using constructed wetland for ecological engineering and bioenergy generation from biomass recycling

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ABSTRACT

Environmental water ecosystems are facing serious hypoxia challenges because of high nutrient loadings from point and non-point sources. Therefore, the use of Vertical sub-surface flow constructed wetlands (VSSFCWs) for mitigating environmental water pollution through enhanced nitrification and denitrification processes. They offer a promising nutrient removal mechanism while also providing an ideal environment for the growth of perennial grasses. VSSFCWs not only play a role in providing safe sanitation, they produce biomass that can be harvested and used to produce fodder and biofuel in this complex global world. Biochar offers best habitation for microorganisms to decompose organic matter. The potential of constructed wetland biomass for bioenergy production through carbon sequestration had been observed. Planted with common reed macrophytes to promote biodiversity, the 0.251 m2 constructed wetland has been treating 0.03 cubic meter per day (CMD) of farm wastewater. The overall aboveground biomass was 1277 kg and total carbon content 471 kg at the peak of aboveground accumulation for the system emergent macrophyte. Incinerating of 80% biomass harvested of experimental area in an incineration plant could produce 2446 kWh for one month.

1. Introduction

Wetlands are ecosystems that provide abundant services and materials that have economic value, not only to the adjacent local population but also to regional communities (Dubbe et al., 1988; Fan et al., 2009; and Zygas, 2010), providing valuable services such as water quality improvement, flood mitigation, erosion control and recreational enrichment (Cook and Beyea, 2000; Gran, 1984; and Hey, 2002).

Recently, the potentials of bioenergy production from wetland biomass were getting attention (Fan et al., 2009 and Zygas, 2010). Through definitions, constructed wetlands were designed to imitate the physic-chemical processes to reproduce similar effluent quality to natural wetlands provide. Wetlands (constructed or natural) have the potentiality in providing recreational services as well as wildlife restoration, considering their effluent quality (Fan et al., 2009 and Zygas, 2010).

Nomenclature and Abbreviation	
VSSFCW	Vertical sub-surface flow constructed wetlands
CMD	Cubic meter per day
BTU	British thermal unit
TP	Total phosphorus
TN	Total nitrogen
COD	Chemical oxygen demand

This study analyzes the economic efficiency of a Vertical sub-surface flow constructed wetlands (VSSFCWs) for both nutrient removal and biomass harvest for bioenergy production (Fan et al., 2009; Kadlec and Knight, 1995; Kadlec and Wallace, 2009; and Kadlec et al., 2007). Extensive improper waste water treatment has led to nutrient-based water quality issues, the effects of which can be seen not only in river water bodies, but also as far as the nearby Lake Chivero, Zimbabwe. One method of mitigating such pollution at low cost and energy use that has been gaining recent attention is the constructed wetland (Fan et al., 2009; Zygas, 2010; and Kadlec, 2007), a series of one or more planted with aquatic vegetation that is engineered for the purpose of improving water quality would be a solution (Kadlec and Knight, 1995; Kadlec and Wallace, 2008; and Reddy and Smith, 1987). This primes to the hypothesis of this study: Through the cultivation of wetland vegetation in a constructed wetland benefits can be realized in the form of water quality treatment as well as monetary revenue from the sale of biomass to ethanol processing facilities.

Study main objective centered on to suitably find a less demanding crop, grows quickly and/or on land not currently used for conventional row crops, produces a large yield, can be processed efficiently and is sustainable (Mitsch and Gosselink, 2000 and Thullen et al., 2000). Subtropical warm weather in Zimbabwe, like Thailand, is particularly beneficial to the growth of emergent macrophyte. Both aboveground and belowground portion could serve as carbon sink by primary production (Cronk and Fennessy, 2001 and Scholz, 2006).

While previous studies focused on the harvesting of emergent aquatic vegetation from natural wetlands or the efficiency of constructed wetlands when treating sewage treatment effluent (Mart et al., 2007; Sheng and Azevedo, 2005; and Waier, 2006), this study offers a unique analysis of the use of a constructed wetland with biochar as a substrate for the treatment of point source nitrate-nitrogen and phosphorus loadings (Reddy and DeLaune, 2008). This study will simultaneously provide a controlled environment for the growth of microorganisms for DNA extraction and harvest of emergent macrophytes as a biofuel feedstock.

2. Site description and methodology

2.1 Site description

Maejo University in Chiang Mai has a tropical climate with geographical location Latitude: 18 51' 08" and Longitude: 99 02' 43". When compared with winter, the summers have much more rainfall (Climate graph, 2018 and Boyd, 1970). The average annual temperature in Chiang Mai is 25.6 °C. In a year, the average rainfall is 1184 mm. The driest month is February, with 6 mm of rainfall. In September, the precipitation reaches its peak, with an average of 241 mm. The warmest month of the year is May, with an average temperature of 28.5 °C. At 20.8 °C on average, January is the coldest month of the year. (Boyd, 1970).

2.2 Configuration and operation of the constructed wetland

Two systems of 4 cylinders of, Vertical sub-surface flow constructed wetlands (VSSFCWs), each connected in series constituting biochar and sand and common reed was used as shown in figure 1. The total area of the wetland is 0.251 m^2 with flow rate of 0.03 m^3/day in up-flow and downflow manner from animal wastes.

Figure 1: Planted constructed wetland showing 2 systems with 4 cylinders each

The 4*2 sequential cylinders and flow regime of the constructed wetland are depicted as shown below with average height of 0.8m. The set up has been made and established at Maejo University in Chiang Mai, Thailand to test the removal efficiency of nutrients and define nitrification and denitrification through a unique fluid mechanics as shown in figure 2.

2.3 Biomass production model

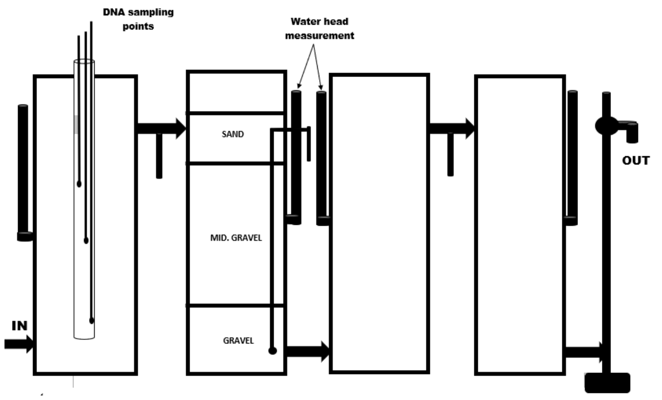

Figure 2: The system`s hydraulics design elevation

The five state variables used to illustrate plant growth are the biomass per square meter of shoots, inflorescence, roots, old rhizomes and new rhizomes Pratt et al.,1984; Schuyt and Brander, 2004; and Zhanget al., 2009). For bioenergy generation, the biomass could be harvested, grounded, tested and return to the anaerobic tank for decomposition and enhancing methane production from the reed plant. Some biomass will be wasted depending on the concentration of transferred N and P evaluated.

2.4 Nutrient removal model

For the nutrient removal model, time steps of 0.5, 1, and 2 days were compared to determine whether a one-day time step would suffice for the model simulation adlec and Wallace, 2009 and Kadlec and Wallace, 2009). The negligible differences in the outflow NO_3-N concentration between the three different time steps suggest that a time step of one day is sufficiently small to provide accurate results for the nutrient removal model (Gran, 1984; Hey, 2002; and Hargreaves, 1985). The nutrient removal model used in this analysis assumes first order denitrification kinetics under perfectly mixed conditions.

The overall water mass balance for a wetland is

$$q - Qo + Qc - Qb - Qgw + Qsm + (P \times A) - (ETc \times A) = \frac{dV}{dt}$$

The daily mass balance used in the wetland nutrient removal simulation then becomes:

$$q - Qo + (P \times A) - (ETc \times A) = \frac{dV}{dt}$$

2.5 Analysis of biomass fundamental properties

Plant samples were washed, and oven dried at 60 °C for 96 h and weighted. All samples were ground in a laboratory fine grinder and the fraction passing a 40-mesh screen was used for further analysis (Zygas, 2010 and Calheiros, 2009). Carbon content for each macrophyte species was analyzed by Perkin Elmer CHNS 2400 elemental analyzer (Zygas, 2010 and Kadlec, 2007). Ash content was analyzed by heating with 600 °C according to ASTM D 1102-50T using a muffle furnace. Carbon and ash contents for each macrophyte species were analyzed from the equal mixture of oven dried biomass samples collected each time at each plot in each compartment (Zygas, 2010 and Mitsch and Gosselink, 2000). To evaluate the reproducibility of the results, all experiments were measured in triplicate samples. Some were collected and transferred to the intake closed anaerobic tank for methane generation.

2.6 Water quality sampling and analysis

Monthly sampling was conducted from periodically for the influent and effluent of the constructed wetland. The samples were analyzed for TN and TP, COD and other nutrients.

3. Result and discussions (Paper review and current research)

3.1 Correlation between macrophyte growth and influent nutrient removal

Since the nitrogen and phosphorous are necessary nutrients for the growth of emergent macrophytes, the adequate nutrient supply has to be ensured for biomass production. The correlation between macrophyte growth and influent nutrient removal was examined in this study. Monthly sampling and analysis for total nitrogen (TN) and total phosphorus (TP) were conducted for overall system removals from the effluents (Fan et al., 2009).

Averaged total nitrogen (TN) values in the system influent and effluent were 27.9 and 8.7 mg/l. Averaged total phosphorous (TP) values in the system influent and effluent were 3.2 and 1.5 mg/l (Kadlec et al., 2007). The above information demonstrated that the constructed wetland satisfactorily performed its original mission for nutrient removals (Fan et al., 2009).

Mass removals for total nitrogen and total phosphorus were estimated by summation of multiplying nutrient concentration differences with flow rate (0.03 CMD).

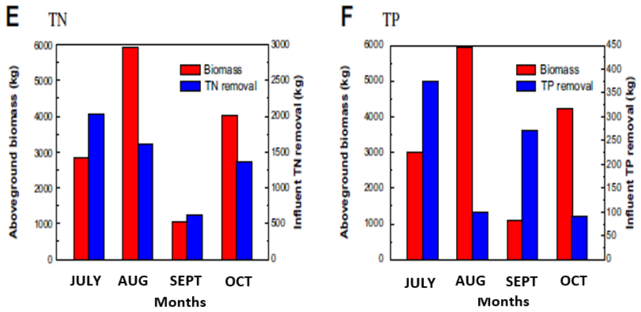

Figure 1: TN (E) and TP (F) removals (to the right x-axis) from the influent in the VSSFCW (Kadlec et al., 2007).

3.2 Assessment of bioenergy production potentials from a review paper

Then it is assumed that from 16737 kg-based biomass and 252 GJ of high heating values 202 GJ of heat contents would be delivered to an incineration plant from the constructed wetland (Thullen et al., 2000 and Calheiros, 2009).

Assumed the combustion behavior of wetland biomass is equivalent to urban trash, and energy output of the incineration plant is proportional to combustible input. After linear interpolation from Chun-Han, 2010 data interpretation, it could be deducted that 11 846 kWh per month could be generated at the month of harvesting.

For the current research biomass will be recycled back into the same system for methane gas generation and a comparison will be made thereafter. The above concept will be applied in future with some modification that suits the current research for bioenergy generation through recycling manner. The implementation of the research would be of paramount important and fundamental to Zimbabwe for the same reason and more.

Table 2: Available standard Canadian biomass production waste and residue

Product	Quantity *10^6 metric tons	Energy 10^{12} B.T.U	*10^6 G Joules
Animal wastes	27.5	574.9	606.6
Crops residue	16.9	234	246.9
Forest residue	45.5	758.3	800
Total	89.9	1567.2	1653.5

4. Conclusion

Although emergent macrophytes play an indispensable role of construction wetlands, the plant litters from unbridled growth may cause problems for the long-term operation of wetlands in subtropical climate. Biomass-to-energy was also shown as a viable alternative for wetland plantation management. The incorporation of other benefits that wetlands provide into the analysis may make constructed wetlands for biomass production a possibility in the future. Apart from nitrogen removal, wetlands provide environmental benefits in the form of habitat restoration, flood protection, as well as the treatment of other water-borne pollutants. More research on bioenergy generation could be further studied and its application would be fundamental.

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