Desalination and Water Treatment
www.deswater.com

38 (2012) 371–377
January

doi: 10/5004/dwt.2012.3592

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Seasonal biomass changes at a newly constructed wetland in agricultural area

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Received 14 October 2011; Accepted 24 December 2011

ABSTRACT

The objective of this study was to present and evaluate the rate of biomass growth due to temperature changes and to identify the type of vegetation that best adapts to temperature changes in a surface flow constructed wetland (CW). The operation of the CW started in 2009 treating stream agricultural runoff from a watershed area of 221 ha which are mainly wet paddy fields. The CW is composed of seven connected cells which include a sedimentation zone, deep and shallow marshes. Five typical wetland plant species such as *Acorus calamus*, *Oenanthe javanica*, *Phragmites australis*, *Phragmites japonica,* and *Typha orientalis* were planted surrounding the CW. The water quality and plant biomass were monitored from April to December 2009. The mean inflow DO and pH concentration were 6.9 ± 2.0 mg/l and 7.0 ± 0.5, respectively during the whole season. The water and air temperature at the CW were not significantly different (T_a = $0.86T_{aw}$; n = 15; r = 0.91; p <0.0001). Based on the results, the optimum temperature for the growth of vegetation was at 3400°C accumulated daily air temperature. The highest biomass rate was achieved during the summer season. Among the plants in the CW, the highest biomass rate (3.26 kg/m^2) was exhibited by *Typha orientalis*. Relative growth rate (RGR) showed similar trend for each plant and the RGR values were highest between April and May. Findings indicated that flooding restricted the growth of most plants. In this newly CW, *Typha orientalis* and *Phragmites australis* were found to be the most suitable plants in the CW.

Keywords: Agricultural; Biomass; Constructed wetland; Relative growth rate; Seasonal trend; Temperature

1. Introduction

Korea's total agricultural area expands at 19,680 km^2 corresponding to almost 20% of Korea's total land area [1], which shows that the country's land is intensively cultivated mostly by wet paddy fields. During one rice cropping, the standard nitrogen (N) and phosphorus (P) content in the chemical fertilizers are limited to 11.0 g/N-m^2 and 4.8 g/P-m^2, but the Rural Research Institute have reported an excess of 4.9 g/N-m^2 and 3.0 g/P-m^2 usage in fertilizer application [2]. The weather in Korea is Asian Monsoon, which means most rainfall is concentrated during the summer months between June and August. The timing of fertilizer application to crops usually coincides with the summer season, so most of the runoff from these areas, after being used by the rice plants is usually washed-off to the nearby streams following rain storms. In agricultural areas, surface runoff

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during storms escalates the release of sediments, nutrients and other pollutants which causes eutrophication. In the United States, agriculture is the leading contributor to water quality impairments, degrading 60% of the impaired river miles and half of the impaired lake acreage surveyed by states, territories, and tribes [3]. Surveys showed in other research that 54% of lakes in Asia are eutrophic; in Europe, 53%; in North America, 48%; in South America, 41%; and in Africa, 28% [4].

In Korea, the identification and monitoring of nonpoint source (NPS) pollution still represent a great challenge. In fact, this issue has not been properly addressed and according to the Ministry of Environment (MOE), the contribution of NPS loadings to the major four rivers is predicted to increase up to 65–70% in 2015 if there will be no appropriate measures to be undertaken [5]. The total maximum daily load (TMDL) and NPS control programs are legislated by the MOE in the 'Act Of Water Quality and Aqua-Ecosystem Conservation' to improve the water quality in rivers and lakes from the target pollutants such as biochemical oxygen demand (BOD), total nitrogen (TN) and total phosphorus (TP) [6]. The MOE recommended the use of constructed wetland (CW) to control NPS in agricultural areas. The CW can operate under a wide range of hydraulic loads, have internal water storage capabilities, and can remove or transform a number of contaminants, including oxygen-demanding substances, suspended solids, and nutrient [7]. Furthermore, as natural systems CWs are low cost systems, easily operated and maintained, their performance depends on seasonal changes and vegetative cycles [8]. According to Vymazal [9], CWs are ecological engineered systems designed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters.

Macrophytes (plants) are assumed to be the main biological component of CWs. They not only assimilate pollutants directly into their tissues, but also act as catalysts for purification reactions by increasing the environmental diversity in the rhizosphere, promoting a variety of chemical and biochemical reactions that enhance purification [10]. Reed and Brown [11] found that the most common plants used for water treatment were reeds (*Phragmites spp*.), cattails (*Typha spp*.) and bulrush (*Scirpus spp*.). These plants alter dissolved oxygen (DO) concentrations and temperature of sediment and water, shade out algae and provide organic carbon. In a discussion on vegetation's role in CWs, Hammer [12] states vegetation principally creates additional oxic environments for microbial populations through increasing the substrate surface area in the water column and oxygenating the sediments around root hairs. He additionally states that plants facilitate sedimentation by obstructing flow. Regionally abundant plant species are adapted to the local climatic and edaphic conditions. Their performance under the environmental conditions imposed by wastewater was unknown [13]. During an initial succession period of rapid plant growth, direct pollutant immobilization in wetland plants may be important. The objective of this paper was to present and evaluate the rate of biomass growth due to temperature change, and to identify the type of vegetation that best adapts temperature changes in the CW.

2. Materials and methods

2.1. Site description

The CW is located at N36°28′11.48″, E127°5′14.63″ in Kongju City, Chungnam Province, Korea. It serves a population of 127,391 inhabitants in [14]. The CW was built in 2008 by the MOE and the operation started in January 2009. The CW has a total area of 24,461 m^2 treating a watershed area of 221 ha which is mainly agricultural lands (99% wet paddy fields and 1% dry paddy field). The influent to the CW comes from the agricultural stream flow in the tributaries of Geum River. It was also designed to treat stormwater runoff during period of rain storms. Main pollutant source sediment which is adsorbed agrichemicals and fertilizer and by product of crop. It effect during harrowing a field, rice planting and wet season.

2.2. Constructed wetland design

Fig. 1 shows the composition of the CW, sampling points and water flow path. Based on the figure, the CW is composed of seven cells. The main treatment mechanism is sedimentation of particulates using different water depths and treatment by wetland plants. Listed in Table 1 are the dominant plant species in the CW. The wetland plants were selected on the basis of their characteristics such as fast growing, capability of contaminant removal

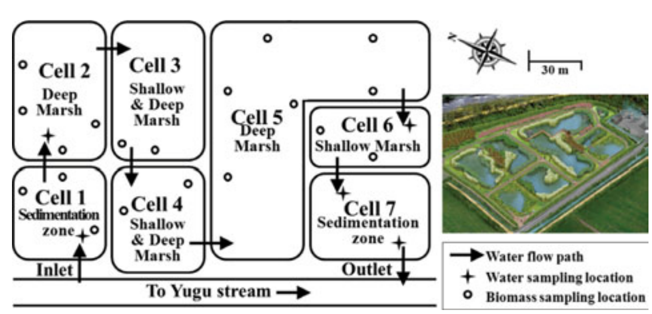

Fig. 1. Schematic of constructed wetland.

Table 1
Dominant plant species in the constructed wetland

Scientific name	Code	Common name	No. of plants	Cultivated cell
Acorus calamus	AC	Sweet flag	19,000	2 and 5
Oenanthe javanica	OJ	Water dropwort	7800	1
Phragmites australis	PA	Common reed	17,300	2, 3, 4, 5 and 6
Phragmites japonica	PJ	Reed	17,500	2, 3, 4 and 5
Typha orientalis	TO	Cattail	19,700	3, 4, 5 and 6

and high tolerance towards toxicities. *Oenanthe javanica* (OJ) is very common in Korea which grows in rivers, lakes, ponds, wetlands, etc. It can also grow well during winter. OJ was planted in cell 1 (sedimentation zone) like natural wetland. Majority of the cells in the CW were planted with *Typha orientalis* (TO) and *Acorus calamus* (AC).

2.3. Monitoring methods

2.3.1. Water quality monitoring

Water quality monitoring was conducted during April to December 2009. Physico-chemical water parameters, such as dissolved oxygen (DO), pH, electrical conductivity (EC), turbidity and temperature were measured in the field using portable meters. Samples were analyzed for water quality parameters including total suspended solids (TSS), BOD, chemical oxygen demand (COD), TN, total Kjeldahl nitrogen (TKN), ammonium (NH_4–N), nitrate (NO_3–N), TP and phosphate (PO_4–P). Analyses were performed in accordance with ASTM standard methods for the examination of water and wastewater.

2.3.2. Plant biomass monitoring

Plant biomass measurements (height, weight, count, etc.) including measurements of the total planted area were carried out during the macrophytes life cycle between May and September 2009. The five plant species listed in Table 1 were selected for monitoring. A total of 19 plant biomass samples were collected from cells 1 to 6. The plant count and average plant height for each square frame (30 × 30 cm^2) were measured and sample plant representation was cut at the ground level. The collected plants were oven-dried until constant weight was achieved. The relative growth rate of plants (RGR) was calculated according to the equation proposed by Hunt [15]:

$$RGR = (\ln W_2 - \ln W_1) / (T_2 - T_1) \quad (1)$$

where W_1 and W_2 are the initial and final dry weight in grams; T_1 and T_2 are the beginning and end of sampling period in days.

3. Results and discussions

3.1. Climate in the monitoring site

The plants showed growth at the onset of spring but after summer, the growth slowed and most plants started to die. As observed, plants growth was consistent with climate. Most rainfall occurs during summer when the temperature is high. Table 2 provides the climate characteristics in Kongju city for the year 2009. The total annual precipitation was 1101 mm of which more than half was concentrated in the months of June to August. The mean monthly rainfall ranged from 1.0 to 11.1 mm. The mean seasonal temperatures were 12.3°C in spring, 24.0°C in summer, 14.1°C in fall and −0.3°C in winter. The air temperature ranges from 5.9 to 29.4°C during spring until summer, and between −5.0 to 20.4°C during fall and winter.

3.2. Inflow water quality

The seasonal changes of temperature, DO and pH are presented in Fig. 2. The inflow water temperature (T_w) was higher than the daily average air temperature (T_a) during spring to fall since the CW has lots of open water spaces, hence the values of T_a and T_w were not significantly

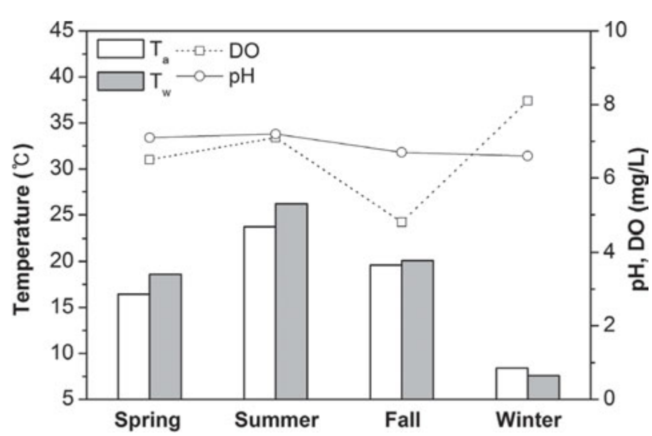

Fig. 2. Seasonal trend of inflow temperature, DO and pH.

Table 2
Climate characteristics in monitoring site during 2009

Parameter		Spring (Mar.–May.)	Summer (Jun.–Aug.)	Fall (Sep.–Nov.)	Winter (Dec.–Feb.)
Rainfall (mm)	Total	240	688	119	64
	Min	0.0	0.0	0.0	0.0
	Max	67.5	98.5	25.0	19.0
	Mean ± SD	2.7 ± 9.4	11.1 ± 22.4	8.5 ± 7.0	1.0 ± 3.3
$Temp._{Min}$ (°C)	Min	−5.7	11.7	−6.3	−15.3
	Max	15.7	25.5	20.2	7.1
	Mean ± SD	5.9 ± 6.0	19.5 ± 2.8	9.3 ± 6.8	−5.0 ± 4.7
$Temp._{Mean}$ (°C)	Min	0.5	18.1	−0.2	−8.2
	Max	22.0	28.4	25	12.3
	Mean ± SD	12.3 ± 6.3	24.0 ± 2.2	14.1 ± 6.8	−0.3 ± 4.4
$Temp._{Max}$ (°C)	Min	4.2	20.2	2.5	−5.4
	Max	30.6	34.7	32.2	17.1
	Mean ± SD	19.3 ± 7.4	29.4 ± 3.0	20.4 ± 7.7	5.2 ± 4.9

different ($p > 0.05$). The water temperature was measured on the water surface. In the first operation year of the CW, plants were still not adapted to the new surroundings. The mean DO concentration was 6.9 ± 2.0 mg/l during the whole season. The CW reached the highest DO value of 8.1 mg/l in winter season. This parameter presented an inverse variation with temperature and can be explained by the combined effects of lower solubility of DO and greater BOD in the wetland system at higher temperatures [16]. On the other hand, pH was close to 7.0 ± 0.5 units. The pH is a fundamental factor for water quality, exerting a great influence over the aquatic system [8]. In addition, pH drives many chemical reactions in living organisms. During the end of life cycle of the plants (summer to fall), the pH decreased from 7.2 to 6.7.

Fig. 3 shows the seasonal inflow water quality characteristics. The highest concentrations were measured during the spring season except for TSS, which appeared to peak in fall. Since most rainfall occurred during summer (total rainfall 688 mm), the runoff usually contained many pollutants and particulate matter during summer. Because of this, the mass concentration of all parameters was high during the summer season.

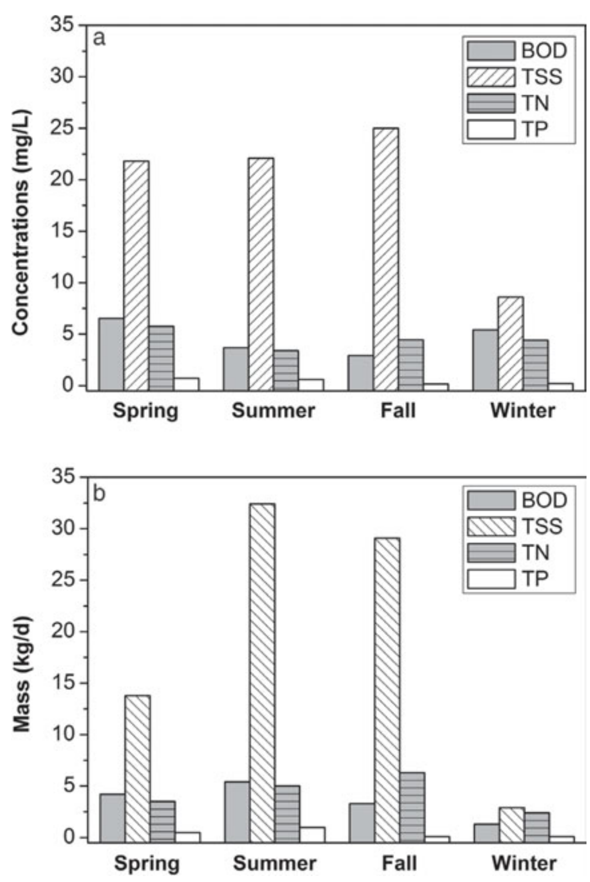

Fig. 3. Characteristics of inflow water quality, (a) average concentrations and (b) mass.

3.3. Plant biomass and temperature

3.3.1. Wetland water and air temperature

Fig. 4 shows the relationship between the average wetland water and average daily air temperature.

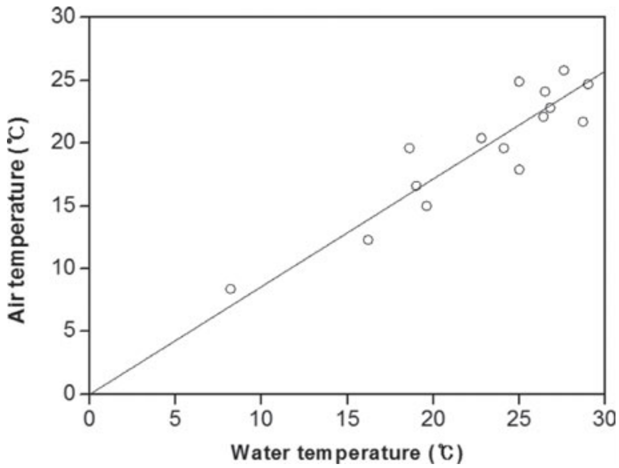

Fig. 4. Relationship between water and average daily air temperatures.

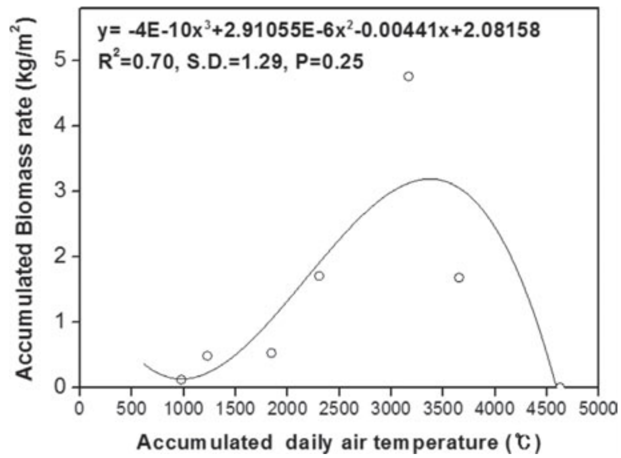

Fig. 5. Accumulated total biomass and daily air temperature.

Seasonal fluctuations of the wetland water temperature could influence the processes of microbial transformation [17]. In this study, temperature cycles for water and air demonstrated comparable distribution with the correlation coefficient, r of 0.91 ($T_a = 0.86T_{aw}$; $n = 15$). Also, the water and air temperature were not significantly different ($p < 0.0001$). While biological activity is oftentimes higher in warm waters, microbial abundance is still very high even under the ice of winter. Generally, wetland exit water temperatures are approximately equal to the mean daily air temperature during unfrozen seasons, for condition of moderate humidity and air temperature [7].

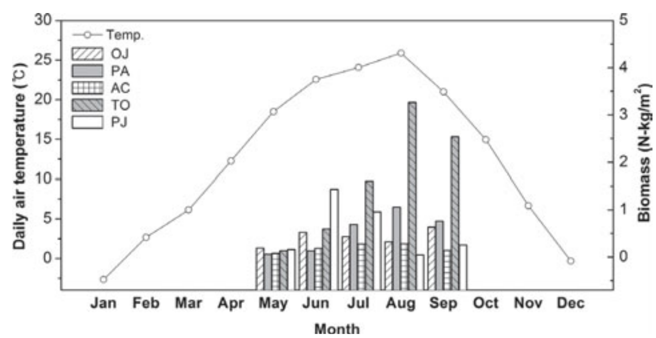

Fig. 6. Monthly trend of each plant species and air temperature.

3.3.2. Plant biomass and air temperature

Fig. 5 shows the accumulated total biomass and daily air temperature during January to December 2009. The maximum accumulated total biomass was attained at accumulated daily air temperature of 3400°C. Biomass rate declined gradually as plant reaches the optimum temperature. The optimum temperature for the growth of vegetation in the CW happened on 5th September. Vegetation cover at the CW started to expand from May 2009. The biomass coverage was 122.6 m^2 in May and continuously increased until September (489.4 m^2). Fig. 6 shows the monthly biomass changes of the five dominant plants during its first growing season along with the daily air temperature in the CW. The average monthly air temperature ranges from –2.7 to 25.9°C from January to August. The highest biomass rate is different for each plant. The greatest biomass rate for PJ was 1.43 kg/m^2 in June, while during July to August rainy season, this plant were sunk and decreased. It was observed that after summer, PJ could not grow well. The highest biomass rate for PA, AC and TO all occurred in August with 1.05 kg/m^2, 0.28 kg/m^2 and 3.26 kg/m^2, respectively. In September, OJ biomass was highest with 0.63 kg/m^2, which proved that OJ could still grow after summer. However, OJ and PJ were sensitive to changes in water level. Photosynthesis cycle and nutrient uptake plays a major role in the growth of plants in the CW. Since five plants are perennial plants, they grow during spring, become dormant during winter, and grow back during spring of the next growing season. Therefore, it is very important to evaluate the performance of the treatment system in response to seasonal changes such as heavy rainfall and dry periods. The increase of plant productivity is mainly due to the increase in availability of water, light and nutrients. According to Engloner [18], the high mean temperatures in spring and summer generally led to higher and earlier increases of biomass in the CW. Since summer is the season where most rainfall occurs, many nutrients are being transported back into the CW.

3.3.3. Relative growth rate

Aside from visual observations on plant growth, the RGR can be employed to confirm the health of plants [19]. All plants have similar trend of RGR as can be seen in Fig. 7. The highest growth rate of OJ, PA, AC, TO and PJ were 0.14 g/g-d, 0.04 g/g-d, 0.06 g/g-d, 0.09 g/g-d and 0.21 g/g-d, respectively. It was observed that the fastest growth of plants occurred at the beginning of the vegetation period followed by a gradual decrease of RGR one month subsequent to the monitoring. The RGR of OJ, AC and PJ were rapidly decreased by 76% for OJ, 57% for AC and 85% for PJ from June to July. Five storm events in July 2009 generated over 30 mm/d rainfall (twice over 90 mm/d). Because of the heavy rain events, floods happened. The average inflow to the CW in summer was 2.5 times greater than in spring. The increased in water level in the CW have caused the shorter plant species such as OJ and AC (average height are 55 cm and 71 cm, respectively) to sink and submerge, also PJ (average height is 72 cm during summer; similar to AC's height). Many wetland plants prefer water depths of less than 40 cm and most also prefer intermittent rather than continues flooding. Relatively stable water levels, rather than seasonal and rain-driven hydrologic regimes, may place stress on wetland vegetation [7]. The duration and depth of flooding affect plant physiology because of soil oxygen concentration, soil pH, dissolved and chelated macro and micronutrients, and toxic chemical concentrations. On the other hand, TO and PA live mildly and can survive until September. During the last biomass monitoring on October 28, 2009, we observed that all plants already died. Therefore, the RGR could not be calculated. Other studies reported that the RGR of shoots was highest in April to May [20] and growth was faster in potentially taller than shorter shoots [21]. In this newly CW, TO and PA seemed to be the most suitable vegetation in the CW.

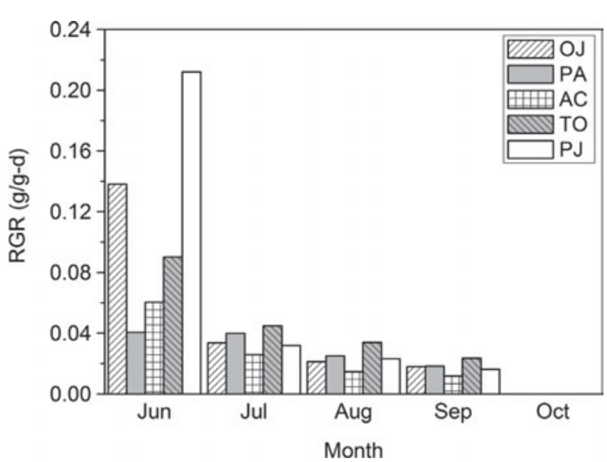

Fig. 7. Relative growth rate (RGR) of five plant species.

4. Conclusions

This research focused on the effect of seasonal changes of growth of vegetation which was important in determining the life cycle as well as the most suitable type of vegetation to be used in the CW. Based on the accumulated total biomass and daily air temperature, the optimum temperature for the growth of vegetation was achieved at 3400°C that happened in early September. The increased in biomass rate occurred during the summer season. The highest biomass rate in CW was 3.26 kg/m^2 for *Typha orientalis*. The relative growth rate of the plants in the CW showed similar trend and the RGR values were higher from April to May. Flooding affected the species OJ, AC and PJ which restricted their growth during the summer season. In this newly CW, TO and PA seemed to be the most suitable vegetation in the CW. Furthermore, long term monitoring on the water quality and vegetation should be conducted for maintenance and future improvements.

Acknowledgements

The funding for this research was financially supported by Eco-Innovation Project: Non-point source pollution control research group under the grant of the Ministry of Environment (#413-111-004) in Korea. The authors were grateful for their support.

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