Tropical Agricultural Research Vol. 21(4): 353 - 360 (2010)

Effect of Submerged and Floating Plants on Dissolved Oxygen Dynamics and Nitrogen Removal in Constructed Wetlands

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ABSTRACT. *Dissolved oxygen (DO) concentration affects the treatment processes in constructed wetlands. This study examined the dissolved oxygen dynamics and total nitrogen removal in constructed wetlands with submerged and floating plants. Four constructed wetland units each with the surface area of 3 x 1 m^2 were constructed at University of Peradeniya. Two of those with the depths of 0.3 m (A) and 0.6 m (B) were planted separately with Hydrilla verticillata (submerged) and Lemna minor (floating), respectively. Other two (C and D) were constructed with two sections of 0.3 and 0.6 m depths and planted with H. verticillata and L. minor, respectively in each section. Secondary effluent from student hostel was fed with hydraulic retention time of 6 days. DO was measured at different depths of water, 0.0, 0.1, 0.2, 0.4 and 0.5 m from the water surface and along the longitudinal axis of the wetland at 6 hours interval. The total nitrogen was measured for water samples at inlet and outlets. The average dissolved oxygen concentrations of A and B were 17.7 and 0.4 mg L^{-1} respectively. Oxic condition was maintained in the submerged plant units. Anoxic condition resulted throughout the day in floating plant system. DO varied significantly with depths in oxic condition. DO dynamics in these wetlands can be explained by photosynthesis, respiration, deaeration and reaeration processes. The highest total nitrogen removal was achieved in unit D where combined anoxic and oxic conditions were maintained together H. verticillata and L. minor could effectively be used to maintain required dissolved oxygen in constructed wetlands for nitrate removal.*

INTRODUCTION

Dissolved oxygen (DO) in water is essential for the biochemical processes which determine the fate of nitrogen and organic pollutants of wastewater in constructed wetlands (CWs) (Mowjood and Kasubuchi, 1998). Oxidative and reductive conditions can affect the transformation process of organic and inorganic substances in a submerged system. Oxygen can be transferred to wetlands with the influent water, from the atmosphere and via plant tissues into the water column (Mowjood and Kasubuchi, 2002; Tanner *et al.*, 2002; Imfeld *et al.*, 2009).

Submerged plants have been studied for different purposes such as uptake of pollutants (Ozimek *et al.*, 1993; Kanabkaew and Puetpaiboon, 2004), competition between different submerged plant species (James *et al.*, 1999), integration with microbes (Chang *et al.*, 2006)

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and enhancing microbial activities (Karjalainen *et al.*, 2001). Floating plants also have been studied in treating domestic wastewater (Ran *et al.*, 2004), municipal wastewater (Greenway and Woolley, 1999; Dalu and Ndamba, 2003) as well as industrial wastewater (Miretzky *et al.*, 2004). Brix (1994) and Reed *et al.* (1995) have studied the effect of roots of emergent plants on providing oxygen to substrate and bacteria. Another study has been reported by Sasikala *et al.* (2009) on root oxygen release by emergent plants in vertical flow CWs.

However, the studies on effect of combine system of submerged and floating plants on pollutant removal in CWs are still not adequately reported. Therefore, this study aims to investigate the DO dynamics in CWs with *H. verticillata (submerged)* and *L. minor (floating).* The specific objectives were to examine the effect of depth, distance from the inlet and time of the day on DO concentration and nitrogen removal in CW systems in combination with plants.

MATERIALS AND METHODS

Wetland units

A pilot scale study was carried out at University of Peradeniya, Sri Lanka (7°15'N 80°35'E) to treat secondary treated wastewater (Effluent from a treatment system of septic tank followed by an emergent plant constructed wetland). Four CW units, A, B, C and D were constructed each with the surface area of 3 x 1 m^2 as shown in Fig. 1. The units A and B were constructed with depths 0.3 and 0.6 m, respectively. The unit C was constructed with two sections, shallow (0.3 m) water column followed by a deep (0.6 m) water column. These sections were connected with a pipe. The unit D was similar to the unit C, but deeper water column was followed by shallow water column. Sand was filled up to 0.1 m depth at the bottom of each wetland unit.

Planting

The units A and B were planted with *H. verticillata* and *L. minor* with the initial plant density of 100 plants m^{-2} and 8% surface coverage, respectively. The first and second sections of the unit C was planted with *H. verticillata* and *L. minor,* respectively while the unit D was planted in other way around. The system was fed with tap water for a week to assure the initial plant establishment and to avoid the shock by the wastewater to the plants. Subsequently, secondary treated wastewater was fed to the units at a rate of 3 mLs^{-1} so that the hydraulic retention time of 6 days was achieved.

Dissolved Oxygen measurement

Dissolved oxygen (DO) was measured when the plants reached the maximum growth (*i.e*. when *H. verticillata* reached the highest plant density and *L. minor* grown to provide 100% coverage). Dissolved oxygen was measured by a DO meter (SATO SHOUJI INC, *DO-5509*) in six hours intervals (06.00 h, 12.00 h and 18.00 h) during the day at water surface and the depths of 0.2, 0.4 and 0.5 m from the water surface. This was repeated along the CW units at 0.5 m interval from the inlet. Similarly, DO were measured at the water surface and the depths 0.1 m and 0.2 m shallow water column with *H. verticillata* from the free water surface.

Influent and effluent water samples were collected at weekly intervals and measured the total nitrogen (TN) concentration was measured using standard methods (APHA, 1980). Removal efficiency of TN was calculated using the Equation 1.

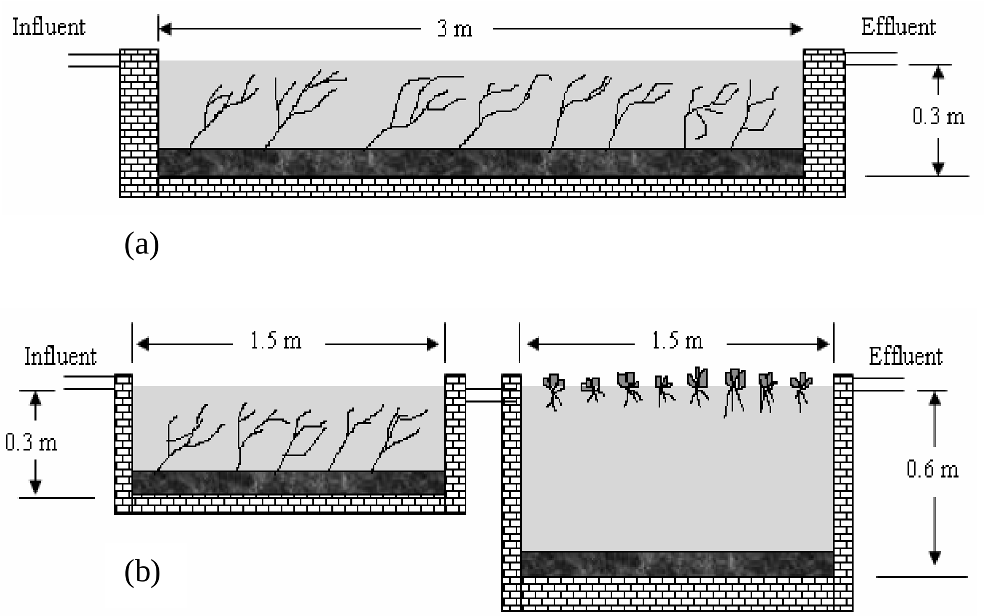

Fig. 1. Schematic diagram of (a) wetland unit A (0.3 m deep; *H. verticillata*) and B (0.6 m deep: *L. minor*) (b) wetland unit C (0.3 and 0.6 m deep) and D (0.6 and 0.3 m deep)

$$\eta = \frac{(C_{in} - C_{eff})}{C_{in}} X100 \qquad [1]$$

η = % removal efficiency

C_{in} = influent concentration (mg L^{-1})

C_{eff} = effluent concentration (mg L^{-1})

RESULTS AND DISCUSSION

Effect of plant type on DO concentration

Figure 2 shows the plant growth variation in unit A and B with time. Sections in C and D with *H. verticillata* and *L. minor* also showed a similar variation in plant growth. *H. verticillata* has reached its maximum growth by 30 days and died due to adverse environmental conditions. However, it has grown again and reached its maximum growth within 30 days. The *L. minor* took about 75 days to provide a dense mat with 100 % coverage.

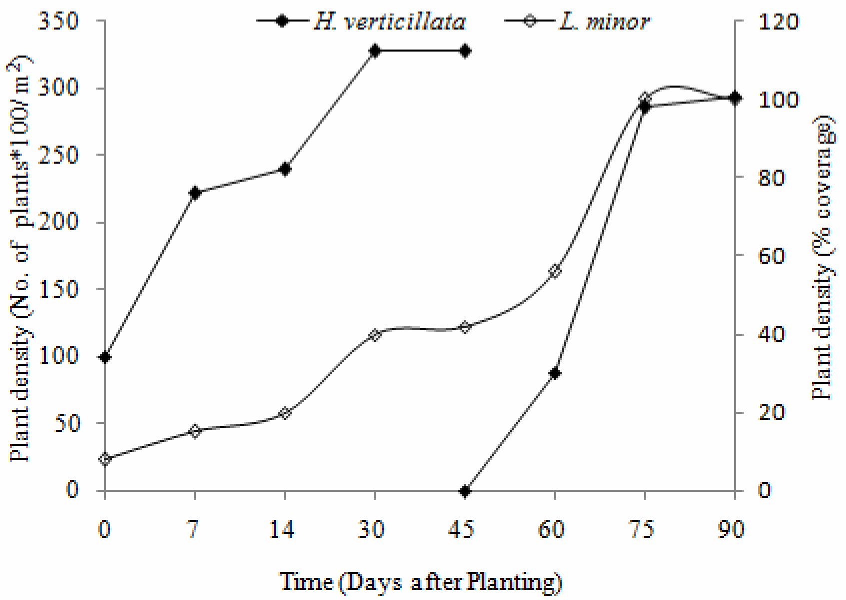

Fig. 2. Plant growth variation with time

Dissolved oxygen concentrations were compared among the CW units. The DO variation in units A and B are shown in Table 1. Figure 3 illustrates the DO variation in units A and B at 0.2 m depth with time. The highest DO concentration was resulted at noon at all depths while the lowest has been resulted before dawn in unit A with *H. verticillata*. A similar result has been reported by Mowjood and Kasubuchi (2002) in ponded water of the paddy field. They also observed the super saturation of DO around 12h. The maximum DO was 20 mg L^{-1} at noon and the lowest was 1.4 mg L^{-1} in the early morning at the depth of 0.1 m below the water surface in the unit A. In contrast, DO was very low in units with *L. minor*. The DO varied from 0.2 to 1.1 mg L^{-1} throughout the day in all depths in the unit B.

Table 1. The DO in units A and B at different depths in different times of the day

Time (h)	Wetland A		Wetland B	
	Depth (m)	DO (mg L^{-1})	Depth (m)	DO (mg L^{-1})
	0.0	1.9	0.0	0.6
0600	0.1	1.4	0.2	0.5
	0.2	1.2	0.4	0.2
			0.5	0.2
	0.0	19.7	0.0	1.1
1200	0.1	20.0	0.2	0.4
	0.2	17.7	0.4	0.3
			0.5	0.2
	0.0	8.4	0.0	0.5
1800	0.1	13.5	0.2	0.3
	0.2	7.5	0.4	0.3
			0.5	0.3

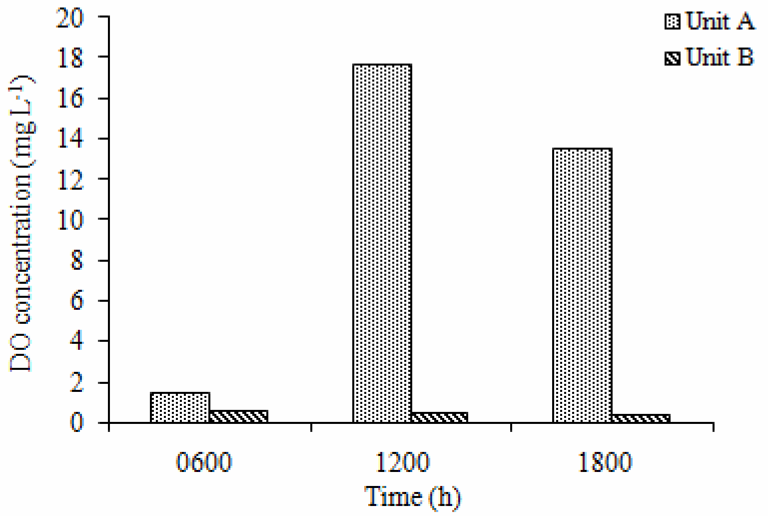

Fig. 3. The variation of DO concentration at 0.2 m depth in units A and B

Due to the submerged nature, oxygen, produced by photosynthesis by *H. verticillata* in the day time increased the DO concentration in the unit A. Oxygen source is not available in the unit B due to the floating nature of *L. minor*. Shading by the abandoned floating plants and shelter the water column from atmospheric oxygen diffusion caused the lower level of DO in the unit B. Nahlik and Mitsch (2006) also observed the same results in similar wetlands studies.

The low DO concentration in early morning may be due to the oxygen consumption by plants (dark respiration) and other organisms present in water.

Effect of depth on DO concentration

Dissolved oxygen concentration varied with depths and not with the distance from the inlet to the outlet in all the wetland units. This shows that the DO in submerged units is more influenced by one dimensional (vertical) transfer. The DO concentration in the unit A at 0.1 m depth is higher than the water surface between noon and the evening. The saturated DO concentration at 25 ^{o}C is 8.2 mg L^{-1} (Whipple and Whipple, 1911). Since the water in the unit A contains DO more than the saturated level, the oxygen transferred from the water to the atmosphere in order to reach equilibrium is referred as deaearation (Lewis and Whitman, 1924). In contrast, in unit B, the DO concentration at the surface is higher than the sub surface. This may be due to reaeration, the transfer of oxygen from atmosphere into water since DO is lower than the saturated level.

Nitrogen removal from wastewater

Nitrogen removal capacity of each unit was also different as a result of variation in DO concentrations in CWs. Total nitrogen (dissolved inorganic nitrogen, particulate organic nitrogen and dissolved organic nitrogen) is an important indicator of nutrient loading to a water course and the removal is affected by the DO concentration. Table 2 shows the TN concentration in effluent and removal efficiencies for 70 mg L^{-1} influent concentration. Accordingly, higher TN removal has resulted from the units A, C and D compared to unit B. Anoxic and oxic order in unit D resulted 75% of nitrogen removal.

Table 2. Total nitrogen removal efficiencies imparted by wetland units

Wetland unit	Effluent concentration (mg L^{-1})	Removal efficiency (%)
A	28	60
B	49	30
C	26	63
D	19	75

CONCLUSIONS

The DO concentration was varied significantly with the type of plant, depth from the water surface and the time of the day. CW units with submerged plant showed a greater oxygen level than units with floating plant units. DO concentration ranged from 1.2 to 20 mg L^{-1} in submerged wetlands while it was from 0.2 to 1.1 mg L^{-1} in floating plants system. Thus, floating plants creates an anoxic condition in submerged water bodies. Higher DO was observed during noon in submerged plant wetlands at all depths. However, DO did not vary with distance from the inlet to the outlet. Deaeration process occurred in the unit A due to supersaturated level of DO. Lack of solar radiation and photosynthesis and low reaeration caused low level of DO in the unit B. Therefore, oxic and anoxic conditions can be obtained using submerged and floating plants in constructed wetlands.

The highest nitrogen removal was achieved from the combined system of anoxic and oxic conditions that is *L. minor* plants followed by *H. verticillata* system (unit D). The lowest removal efficiency was shown in the unit B where only the anoxic conditions prevailed. The integration of submerged and floating plants are important not only as cost effective methods of maintaining DO as required but also as it plays an important role in removing pollutants by plant uptake.

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