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REMOVAL EFFICIENCIES OF NUTRIENTS FROM WASTEWATER TREATED WITH DUCKWEED *(Lemna minor* L.)

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REMOVAL EFFICIENCIES OF NUTRIENTS FROM WASTEWATER TREATED WITH DUCKWEED *(Lemna minor* L.*)*

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SUMMARY

In this study, the nutrient removal from wastewater treated with duckweed (*Lemna minor)* was assessed using a laboratory scale pilot system consisting of two ponds. *Lemna minor* was grown by feeding synthetic wastewater at loading rates of 4000 mg/m^2/d COD, 3520 mg/m^2/d BOD_5, 740 mg/m^2/d NH_3-N and 73 mg/m^2/d PO_4-P. The hydraulic retention times (HRTs) were 3 and 6 days for pond 1 and pond 2, respectively. Water samples from the influent and effluent of the system were analyzed for COD, BOD_5, NH_3-N and PO_4-P and the removal efficiencies were found to be 88.1 %, 88.8 %, 85.4 % and 37.5 % for HRT of 3 days, but 92.2 %, 94.7 %; 75.3 % and 50.0 % for HRT of 6 days. These results show that duckweed is quite successful in removing nutrients from wastewater.

KEYWORDS:
Duckweed, *Lemna minor*, wastewater treatment, nutrient removal.

INTRODUCTION

The use of aquatic macrophytes, such as water hyacinth, duckweed and water lettuce, in wastewater treatment has attracted global attention in recent years. These plants can be applied on the surface of stabilization ponds and may contribute to nutrient recovery from wastewater. Duckweed species have shown characteristics that make duckweed-based systems very attractive not only for wastewater treatment, but also for nutrient recovery [1]. The reason for this is the rapid multiplication and the high protein content of its biomass.

Duckweed is the name for floating aquatic plants belonging to the family *Lemnaceae.* This family consists of 5 genera (*Wolffia*, *Lemna*, *Landoltia*, *Spirodela* and *Wolffiella*) and about 40 species. Duckweed grows on more quiescent or slow-current waters, even on relatively polluted, saline and eutrophic water bodies. Duckweed can accumulate considerable amounts of nutrients and control algae compared to most mechanical and chemical systems. These plants can be removed by simple and low-cost harvesting technologies. Because of their high protein content, the harvested duckweed may be used as valuable fish or animal feed [2]. It provides a practical, environmentally friendly and financially attractive option for small communities requiring a minimal power operation process for sewage treatment.

In this study, the nutrient removal by *L. minor* grown in a laboratory pilot system by feeding synthetic wastewater was investigated. Removal efficiencies of COD, BOD_5, NH_3-N and PO_4-P were studied for 3 and 6 day hydraulic retention times (HRTs). The experimental results showed that removal efficiencies did not differ significantly for both ponds. It is concluded that 3-day HRT, rather than 6-day HRT, provides enough retention time for effective removal of COD, BOD_5, NH_3-N and PO_4-P by *L. minor* in our laboratory pilot system.

MATERIALS AND METHODS

Culture medium

The solution for high growth rates of duckweed consists of (mg/L), K_2HPO_4 (4000), $NaHCO_3$ (15000), $CaCl_2.2H_2O$ (4410), $MgCl_2$ (5700), $FeCl_3$ (96), $Na_2EDTA.2H_2O$ (300), $MnCl_2$ (264), $MgSO_4.7H_2O$ (14700), H_3BO_3 (186), $Na_2MoO_4.2H_2O$ (7.26), $ZnCl_2$ (3.27), $CoCl_2$ (0.78), $CuCl_2$ (0.009), and pH is 7.5-8 [3]. This stock solution was diluted and used as medium to cultivate *L. minor* for nutrient removal experiments. NH_4Cl and glucose were added to this solution to obtain a synthetic wastewater similar to domestic wastewater. The influent characteristics of this synthetic wastewater and operational conditions of the continuous flow system are summarized in Table 1.

Plant material

The plants used for experiments were collected from Silifke region near Mersin (Turkey). They were washed vigorously with tap water to remove debris, and acclimatized for 1 month under experimental conditions before starting the experiments.

TABLE 1 - Operation conditions of the continuous flow system.

Parameters	Operational Conditions
Flow Rate, Q (mL/min)	1
COD ($mg/m^2/day$)	4000
BOD_5 ($mg/m^2/day$)	3520
NH_3-N ($mg/m^2/day$)	740
PO_4-P ($mg/m^2/day$)	73
Water temp. (^0C)	20-27

Pilot System

This system consisted of two small ponds sitting in a big pond as shown in Fig. 1. All the experiments were carried out in these two small ponds. The big pond, however, filled with water, was used to keep the medium temperature constant for optimal plant growth. The two small ponds had volumes of 4.4 and 8.8 L, resulting in 3 and 6-days HRT at a flow rate of 1 ml/min. Each pond was segmented into eight 10x10 cm sections, connected to each other. Plants were grown in the small ponds under sufficient light provided by using fluorescence lamps (TCL 18 W/54) over a 16-h photoperiod. The light intensity at plant level was 2150 lux. Temperature was maintained at 20-27 ^{0}C. Hydraulic retention times (HRT) for the ponds were chosen to be 3 and 6 days to compare the wastewater treatment effectiveness of *L. minor* in different HRTs. The synthetic wastewater was introduced into the system continuously using a peristaltic pump. Water samples were collected from each pond periodically. Concentrations of dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), phosphate (PO_4-P) and pH were measured in both the influent and effluent of the system. All parameters were analyzed according to Eaton et al. (1995) [3].

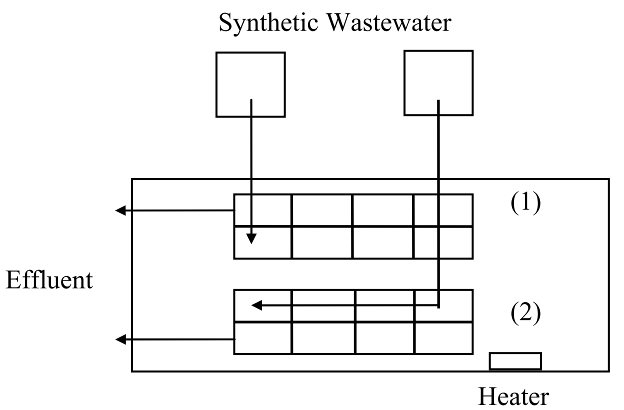

FIGURE 1 - Scheme of the experimental system.

RESULTS AND DISCUSSION

The nutrient removal capacity of *L. minor* was estimated under continuous flow conditions. Figure 2 shows the NH_3-N and PO_4-P removal of both ponds depending on the HRTs of 3 and 6 days and maximum efficiencies of 85.4% and 75.3% for NH_3-N, 37.5 and 50.0% for PO_4-P were achieved at HRTs of 3 and 6 days, respectively. The maximum nitrogen and phosphorus removal rates were determined to be 108 $mg/m^2/d$ (HRT: 3 d) and 34 $mg/m^2/d$ (HRT: 6 d), respectively. The maximum biomass production rate was 29 g dry weight/m^2 for HRT of 6 days. Fujita et al. [4] reported nitrogen and phosphorus removal rates of duckweed *Wolffia arrhiza* to be 126 $mg/m^2/d$ and 38 $mg/m^2/d$. Reddy and DeBusk [5] determined the nutrient removal rates of various aquatic plants, including water hyacinth (*Eichhornia crassipes*) (1278 mg-N/m^2/d, 243 mg-P/m^2/d), water lettuce (*Pistia stratiotes*) (985 $mg/m^2/d$, 218 mg-P/m^2/d) and giant duckweed (*Spirodela polyrhiza*) (151 mg-N/m^2/d, 34 mg-P/m^2/d). Compared with these values, the nitrogen removal capability of *L. minor* can be said to be weaker than that of other weeds or duckweeds, however, the phosphorus removal capability of it is equal to other duckweed species, but lower than that of other weeds.

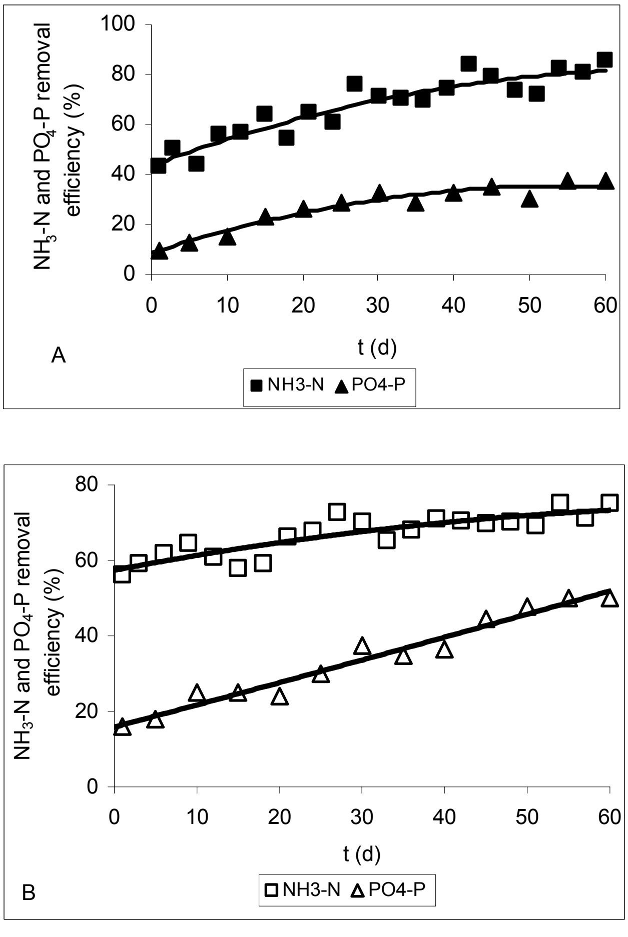

FIGURE 2 - Effect of HRT on NH_3-N and PO_4-P removal efficiency (A: HRT 3 days, B: HRT 6 days).

COD and BOD_5 concentrations of effluents were measured periodically and removal efficiencies were found to be similar for both ponds. COD and BOD_5 loading rates were 4000 mg/m^2/d and 3520 mg/m^2/d, respectively, and reduced to 495 mg/m^2/d and 394 mg/m^2/d in the 3-days HRT pond, and to 330 mg COD/m^2/d and 183 mg BOD_5/m^2/d in the 6-days pond (Figure 3). COD and BOD_5 removal were slightly dependent on HRT and maximum efficiencies of 92.2% for COD and 94.7% for BOD_5 were achieved at an HRT of 6 days. Alaerts et al. [6] found COD and BOD_5 reduction rates of 90-97% and 95-99% in a duckweed lagoon at an HRT of 20 days. But already 80-90% removal of BOD_5 and 90% nutrient uptake by the duckweed plants took place in the first three compartments of the lagoon within 7.3 days of actual retention time.

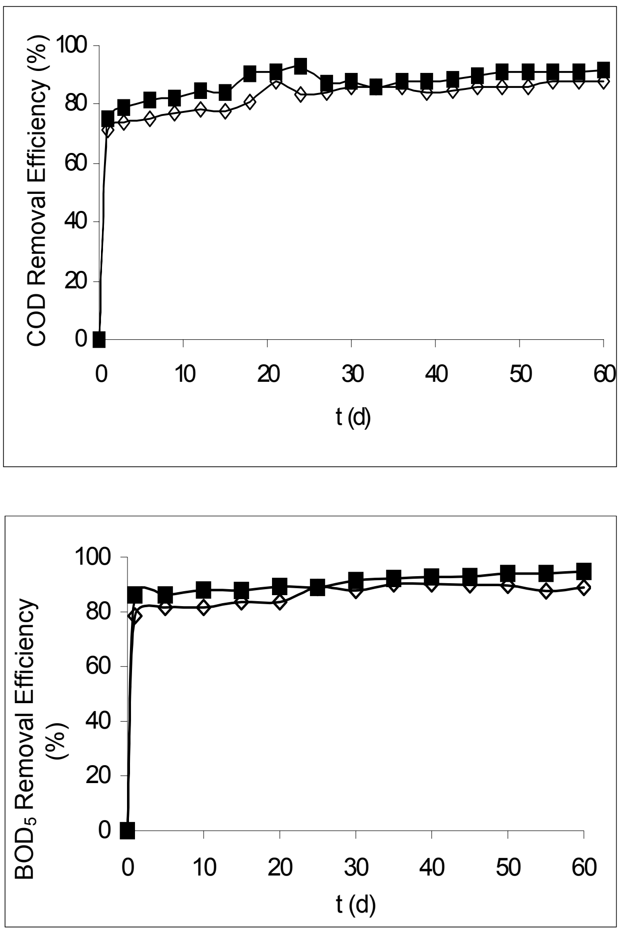

FIGURE 3 - Effect of HRT on COD and BOD_5 removal efficiency (HRT 3 days (◇) and 6 days (■)).

In order to determine the COD removal efficiency of duckweed along the system, COD was analyzed along the small sections of the ponds. These sampling points along the ponds are shown in Fig. 4 and percent COD removal in Fig. 5. COD concentrations decreased from section 1 to the effluent zone and the removal occurred mainly in the first sections of the ponds. These results indicate that stepwise loading of wastewater in field experiments would increase treatment efficiency and the desired effluent COD concentration will be reached within a shorter time.

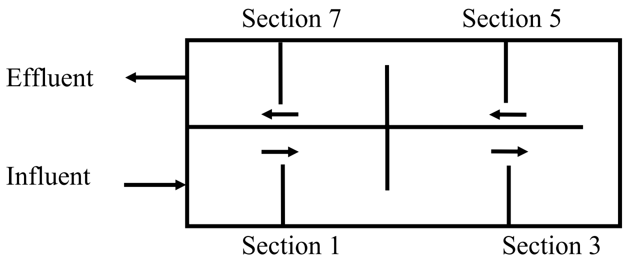

FIGURE 4 - Sampling points of ponds for the COD measurements.

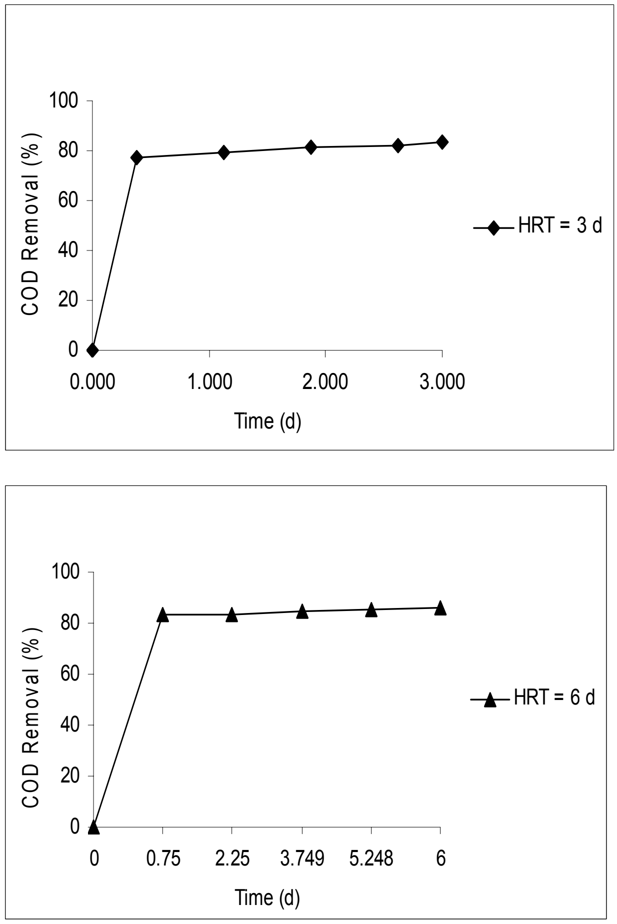

FIGURE 5 - COD removal efficiencies (%) along the ponds.

DO contents of water at the influent were 7 ± 0.959 mg/L. At the effluents of the ponds, DO values were reduced to 6.05 and 6.14 mg/L respectively. However, DO in the duckweed ponds were gradually increasing along the pond's length and measured to be 3.0-4.5 mg/L. DO transfer is influenced by the reactor depth, time of day, and the degree of wind-induced turbulence of the water surface [7]. Because of the re-aeration through the surface and partly obstruction by duckweed mats, DO values in duckweed lagoons were reported to be fairly constant and high (2.0-

4.0 mg/L) [8, 9]. DO increase along the pond's length is most likely due to the decreasing activity of heterotrophic bacteria oxidizing organic substrates with oxygen [6]. The pH of the influent water was 7.44 ± 0.55, but was reduced to 6.34 ± 0.43 and 6.32 ± 0.44, respectively, at the effluents. However, when the growth of plants decreased, the pH values increased at the effluents, possibly due to growth and photosynthetic activity of algae.

HRT and pond's depth are the factors affecting both treatment efficiencies, but also dry matter and protein contents of the plants. The experiments evidenced that the treatment efficiency of the system increases slightly with increasing HRT and pond's depth.

The growth of the plants in the ponds was observed daily. The plants were healthy, displayed light green color and the amount of young fronds was high. However, in the last sections of the ponds the plant sizes were big, the roots long and the colors of fronds pale. The amount of nutrients in the wastewater decreased in the last section of ponds but, this adversely affected the duckweed plants' growth and, therefore, caused algal growth.

CONCLUSION

The use of macrophytes in wastewater treatment is very effective, especially in developing countries. These systems are relatively low in costs compared to conventional methods, and can be used for the treatment of industrial wastewaters (e.g. food industry) without mechanical or chemical equipment.

In large ponds or lagoons duckweed needs to be protected from the wind, water birds (ducks, coots and gallinules) and aquatic mammals. To maximize its yields the duckweed should be harvested daily. Compared to the traditional lagoons, these systems are free of mosquitoes and do not emit bad odors. Furthermore, these plants create a dense and green cover on the water surface, and can even be used for recreational purposes.

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