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Assessment of the Efficiency of Duckweed (*Lemna gibba)* in Wastewater Treatment

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ABSTRACT

In the present study the efficiency of duckweed (*Lemna gibba* L.) as an alternative cost effective natural biological tool in wastewater treatment in general and eliminating concentrations of both nutrients and soluble salts was examined in an outdoor aquatic systems. Duckweed plants were inoculated into primary treated sewage water systems (from the collector tank) for aquatic treatment over eight days retention time period under local outdoor natural conditions. Samples were taken below duckweed cover after every two days to assess the plant's efficiency in purifying sewage water from different pollutants and to examine its effect on both phytoplankton and total and fecal coliform bacteria. Total suspended solids, biochemical oxygen demand, chemical oxygen demand, nitrate, ammonia, ortho-phosphate, Cu, Pb, Zn and Cd decreased by: 96.3%, 90.6%, 89.0%, 100%, 82.0%, 64.4%, 100%, 100%, 93.6% and 66.7%, respectively. Phytoplankton standing crop decreased by 94.8%. Total and fecal coliform bacteria decreased by 99.8%. Dry and wet weights and protein content of *Lemna gibba* increased with increasing treatment period.

Key Words: *Lemna gibba*; Wastewater; Drains; Egypt

INTRODUCTION

The Lemnaceae family consists of four genera (*Lemna, Spirodela, Wolffia* & *Wolffiella*) and 37 species have been identified so far. Compared to most other plants, duckweed has low fiber content (about 5%), since it does not require structural tissue to support leaves and stems. Of these, applications of *Lemna gibba* L (duckweed) in wastewater treatment was found to be very effective in the removal of nutrients, soluble salts, organic matter, heavy metals and in eliminating suspended solids, algal abundance and total and fecal coliform densities.

Duckweed is a floating aquatic macrophyte belonging to the botanical family Lemnaceae, which can be found world-wide on the surface of nutrient rich fresh and brackish waters (Zimmo, 2003). The nutrients taken up by duckweed are assimilated into plant protein. Under ideal growth conditions more than 40% protein content on dry weight basis may be achieved (Skillikorn *et al.*, 1993). Outdoor experiments to evaluate the performance of the duckweed as a purifier of domestic wastewater in shallow mini-ponds (20 & 30 cm deep) showed that quality of resultant secondary effluents met irrigation reuse criteria (Oron, 1994). Wastewater ammonia was converted into a protein rich biomass, which could be used for animal feed or as soil fertilizer. The economic benefit of the biomass by-product reduced wastewater expenditures to approx. US$ 0.05 per treated m^3 of wastewater, which was in the range of conventional treatment in oxidation ponds.

Hammouda and Abdel Hameed (1994) conducted an experiment on the effect of duckweed (used to treat wastewater) on algae at a wastewater station at Beni-Suef and reported that the efficiency of this species for out-competing algae was higher in mixed systems of Nile and wastewater than in separate systems. The percentage of algal reduction increased from 86 to 90%. The data further revealed that the most predominant algal species belonged to the Bacillariophyta. *Lemna gibba* treatment of the wastewater induced a reduction in the total species number of phytoplankton populations to only 5 species of diatoms with the order of dominance as follows: *Synedra ulna* > *Navicula cryptocephala* > *Nitzschia acicularis* > *Melosira granulatus* > *Cyclotella glomerata*. Laboratory experiments were carried out by Korner and Vermaat (1998) in shallow (3.3 cm), 11-batch systems to assess the contributions of duckweed to nitrogen and phosphorus removal in domestic wastewater. They showed that depending on the initial concentrations, the duckweed covered systems removed 120 - 590 mg N m^2 day^{-1} (73 - 97% of the initial Kjeldahl-nitrogen) and 14 - 74 mg phosphorus m^2/day (63 - 99% of the initial total phosphorus) in three days. Also duckweed was directly responsible for 30 - 47% of the total nitrogen loss by the uptake of ammonium. Zayed (1998) found that under experimental conditions, duckweed proved to be a good accumulator of Cd, Se, and Cu, a moderate accumulator of Cr, and a poor accumulator of Ni and Pb. The toxicity effect of each trace element on plant growth was in the order: Cu > Se > Pb > Cd > Ni > Cr. The previous author concluded that duckweed shows promise for the removal of Cd, Se and Cu from contaminated wastewater since it accumulates high concentrations of these elements. Further, the growth rates and harvest potential make duckweed a good species for phytoremediation.

Steen *et al*. (2000) compared fecal coliform (FC) decay in a series of five shallow algal ponds to FC decay in an integrated system of algal and duckweed ponds. In algal ponds, light attenuation by algal matter became rate limiting for FC decay. In the integrated system, the algal concentration in the algal ponds was reduced by the intermediary duckweed ponds. This was shown to increase the FC decay in the algal ponds of the integrated system considerably, compared to the FC decay in the algal ponds alone. Falabi *et al.* (2002) carried out a study to determine the ability of duckweed ponds used to treat domestic wastewater to remove *Giardia* and *Cryptosporidium*. The influent and effluent of a pond covered with duckweed with a six days retention time was tested for *Giardia* cysts, *Cryptosporidium* oocysts, fecal coliforms and coliphage. Results showed that these structures were reduced by 98 and 89%, respectively total coliforms by 61%, fecal coliforms by 62% and coliphage by 40%.

The present study was concerned with identifying solution for decreasing soluble salt concentrations in sewage water and effluent, where the tertiary treatment system (El-Katameya city southeast of Cairo, Egypt) was not designed for eliminating soluble salts. Thus, if salinity increased over the acceptable levels the use of effluent in irrigation purposes might pose a risk.

MATERIALS AND METHODS

Preparation steps. Primary treated sewage water were transferred to the laboratory from the tertiary sewage water treatment plant after the preliminary sieving step to get rid of large suspended solids. The transferred water was immediately collected into two opaque tanks (as replicates) to prevent light entering except at the top (Parr *et al*., 2002), each tank with dimensions of 50 cm long, 35 cm wide and 25 cm deep and was filled with 25 L primary treated sewage water. Duckweed (*Lemna gibba* L.) plants were collected from Ganabiet-Tersa drain (Fig. 1). The stocks were cleaned by tap water then washed by distilled water inocula of *Lemna* plants were transferred to the water systems for aquatic treatment. The experiment was kept under outdoor local environmental conditions for eight days retention time.

Water sampling. Subsurface (under duckweed mat) water samples for physico-chemical, biological and bacteriological parameters were collected in polyethylene bottles from all sides of each tank and then mixed. This procedure carried out every 2 days. Samples volume taken every two days for each of phytoplankton count and chlorophyll a determination was 100 mL.

Parameters measured. Physico-chemical analyses (Table I) were carried out according to standard methods for examination of water and wastewater (APHA, 1992). Field parameters (pH, conductivity & dissolved oxygen) were measured *in situ* using the multi-probe system (model Hydralab-Surveyor) and rechecked in laboratory using bench-top equipment to ensure data accuracy for biological parameters including total coliform count and fecal coliform count, phytoplankton identification and counting and chlorophyll a determination.

Fig. 1. Effluent sampling location

Determination of duckweed growth rate. This was determined for fresh and dry weights. Samples of 20 cm^2 area of *Lemna* plants were harvested periodically at the designated time periods (every 2 days) and filtered using filter papers then fresh weights were determined. These samples were then dried at 60^{o}C for 48 h to a constant weight and then dry weights were calculated.

Protien content. Duckweed organic nitrogen content was estimated at the beginning of the experiment and after 8 days retention time by using Micro-Kjeldahl method, then the obtained values were multiplied by 6.25 to obtain protein content values.

RESULTS AND DISCUSSION

Duckweed plant was inoculated into a primary treated sewage water systems for aquatic treatment over 8 day's retention time period to assess the plant's efficiency in improving physico-chemical, bacteriological and biological characteristics of sewage water. The primary treated sewage water used in the experiment was taken from the collector tank of the tertiary sewage water treatment plant.

Pysico-chemical parameter. Data recorded in Table I showed that, values of pH were always alkaline and ranged between 7.25 as a minimum value recorded at zero days and 7.51 as maximum value obtained after six days treatment period. A 7.5 pH was found to be the most ideal for the successful establishment of a duckweed system and optimum pond performance (Dalu & Ndamba, 2002). Hicks (1932) found that duckweed grew well at pH 6 - 7.5 with outer limits of 4 and 8. Other studies have found that duckweed growth declines as the pH becomes more alkaline (Hillman, 1976; McLay, 1976). The dissolved oxygen values increased as temperatures values decreased, revealing

Table I. Effect of aquatic treatment with *Lemna gibba* on physico-chemical characteristics of primary treated sewage water

Parameters	Retention time (days)				
	Zero days	**After 2 d.**	**After 4 d.**	**After 6 d.**	**After 8 d.**
Temperature (oC)	29.4	23.4	22.5	20.6	24.2
pH	7.25	7.46	7.49	7.51	7.39
D.O (mg O2/L)	0.46	0.77	0.96	1.25	0.58
TSS (mg/l)	379.0	28.0	20.0	16.0	14.0
E.C (umhos/cm)	905.0	852.0	878.0	899.0	995.0
TDS (mg/L)	579.0	545.0	559.0	578.0	637.0
CO3 (mg/L)	0.0	0.0	0.0	0.0	0.0
HCO3 (mg/L)	268.6	265.9	244.5	239.4	308.7
T.alkalinity (mg/L)	268.6	265.9	244.5	239.4	308.7
BOD (mg O2/L)	320.0	-	-	-	30.0
COD (mg O2/L)	800.0	159.0	130.0	111.0	88.0
Phosphorus (mg/L)	4.91	4.68	4.13	3.35	2.56
O.phosphate (mg/L)	1.5	1.49	1.45	1.423	0.534
Phosphate(mg/L)	11.0	10.5	9.25	8.12	6.20
Ammonia (mg/L)	10.0	6.5	4.7	2.2	2.0
Nitrate(mg/L)	8.32	1.8	0.5	0.0	0.0
Calcium (mg/L)	120.0	78.0	80.0	80.0	120.0
Magnesium (mg/L)	124.8	72.0	75.0	76.8	115.2
Sodium (mg/L)	69.7	68.85	70.6	73.95	76.5
Chloride (mg/L)	197.82	156.9	159.3	161.6	181.1
Sulfate (mg/L)	150.33	109.9	102.6	97.3	128.6

that the more cooler the water the more dissolved oxygen it can hold (Cole, 1983).

Korner *et al*. (2003) reported that sewage temperature is one of the crucial design parameters of duckweed ponds. In the present experiment temperature ranged between 20.6°C and 29.4°C (Table I), which was within temperature tolerance limit for duckweed growth as mentioned by Culley *et al.* (1981) who found that the upper temperature tolerance limit for duckweed growth was around 34°C. On the other hand the plants showed a slight decrease in growth below 10°C. It was also proved that duckweed survived in outdoor wastewater treatment tanks at below freezing temperatures and resumed growth when the temperature rose above freezing (Classen *et al*., 2000). Duckweed cold tolerance allows it to be used for year–round wastewater treatment in areas where tropical macrophytes, such as water hyacinths, can only grow in summer (Cheng *et al.*, 2002).

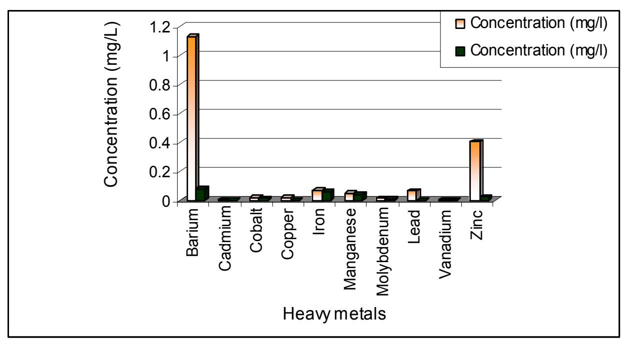
As evident from Table I, total suspended solids (TSS) values decreased by increasing treatment periods, reaching minimum concentration of 14 mg L^{-1} after 8 days (reduced by 96.3%), which corroborates the findings of Pandey (2001) regarding discharged duckweed treatment system in Halisahar. Likewise, Dalu and Ndamba (2002) carried out a three year investigation into the potential use of duckweed based wastewater stabilization ponds for wastewater treatment at two small urban areas in Zimbabwe, when influent and effluent levels were compared at Gutu obtaining up to 90% reduction in TSS.

Data in Table I revealed that both electrical conductivity (EC) and total dissolved solids (TDS) recorded their minimum values of 852 µmhos cm^{-1} and 545 mg L^{-1}, respectively after two days treatment (EC & TDS reduced by 5.8% & 5.9%, respectively) and then values increased gradually to the end of the experiment reaching their maximum values of 995 µmhos cm^{-1} and 637 mg L^{-1}, respectively after 8 days. Fig. 2 showed that calcium (Ca), magnesium (Mg), sodium (Na) and chloride (Cl) reached their minimum concentrations of 78, 72, 68.85 and 156.9 mg L^{-1}, respectively after two days, with a reduction percentage of 35%, 42%, 1.2% and 20.7%, respectively and then their values returned to increase gradually till the end of the experiment. On the other side sulfate concentrations showed a continuous gradual removal by increasing retention time, where its values decreased from 150.33 mg L^{-1} at zero days until reaching 97.3 mg L^{-1} after six days

Table II. Effect of sewage water enrichment mixture on *Lemna gibba* growth and protein content

Parameters	Zero days	After 2 days	After 4 days	After 6 days	After 8 days
Lemna wet wt. (gms)	2.762	3.963	4.432	4.958	5.387
Lemna dry wt. (gms)	0.117	0.152	0.164	0.171	0.187
Protein content (g/Kg)	311.4	-	-	-	331.25

Fig. 2. Removal of heavy metals by *Lemna gibba* aquatic system



(reduced by 35.3%), then it increased to reach 128.6 mg L^{-1} after 8 days. Dalu and Ndamba (2002) reported that electrical conductivity gives an indication of the mineral ion content of the water, but it does not give an indication to which ions might be present. High levels of conductivity indicated that there was a wide range of mineral ions in the wastewater, which represents a problem during water treatment. Electrical conductivity is particularly sensitive to variations in total dissolved solids. In this experiment electrical conductivity was positively correlated with TDS, Ca, Mg, Na and Cl values.

Biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphorus (P), *ortho*-phosphate, phosphate, ammonia (NH_3^+) and nitrate (NO_3^-) showed a gradual removal by prolonged treatment periods (Table I). Data revealed that duckweed mat effectively reduced BOD by 90.6% (reduced from 320 mg O_2 L^{-1} at zero days reaching 30 mg O_2 L^{-1} after 8 days treatment), COD by 89% (reduced from 800 mg O_2 L^{-1} to 88 mg O_2 L^{-1}), phosphorus by 48% (reduced from 4.91 mg L^{-1} to 2.56 mg L^{-1}), ortho-phosphate by 64.4% (reduced from 1.5 mg L^{-1} to 0.534 mg L^{-1}), phosphate by 43.6% (reduced from 11.0 mg L^{-1} to 6.2 mg L^{-1}), ammonia by 80% (reduced from 10.0 mg L^{-1} to 2.0 mg L^{-1}). On the other side the present treatment conditions were capable of depleting the water body of any detectable nitrates (NO_3) after 6 days treatment period. In concurrence with the present findings, Oron *et al*. (1988) mentioned that the duckweed contribution for the removal of organic material is due to their ability to direct use of simple organic compounds. Korner *et al*. (1998) mentioned that duckweed significantly enhanced COD removal in shallow batch systems. Pandey (2001) reported that COD removal was in the range of 70% - 80% in the discharged duckweed treatment system at Halisahar. Zimmo *et al*. (2005) found that BOD removal efficiency was higher in duckweed based ponds than in algae based ponds. Pandey (2001) reported that in Delhi the duckweed ponds were operated at different flow rates giving hydraulic retention time from 5.4 to 22 days, a 30 - 50% reduction in phosphate, 56 - 80% reduction in ammoniacal nitrogen and 66 - 80% reduction in BOD.

Nitrogen uptake rates of fat duckweed vary between 45 and 1670 mg N m^2 d^{-1} (Culley *et al*., 1981; Zirschky & Reed, 1988), while the direct contribution of duckweed to P removal can vary between 9 and 61% (Reddy & Smith, 1987; Alaerts *et al*., 1996; Korner & Vermaat, 1998; Vermaat & Hanif, 1998). Nitrogen and P removal by duckweed uptake were mainly realized by newly grown tissue, not by increasing the tissue N or P content (Korner & Vermaat, 1998). Pandey (2001) reported that nitrogen removal was in the range of 50% - 75% and this range for phosphate was 17% - 35% in the discharged duckweed treatment system at Halisahar. Total alkalinity showed a continuous gradual removal by increasing retention time (Table I). Values decreased from 268.6 mg L^{-1} at zero days until reaching 239.4 mg L^{-1} after six days (reduced by 10.9%), then it increased to reach 308.7 mg L^{-1} after 8 days. The increase in total alkalinity recorded on the 8th day of the experiment might be attributed to increased decomposition of organic matter, which in turn produced excess CO_2 in the water resulting in an increase of alkalinity concentration (Peavy *et al*., 1986).

Removal of heavy metals by duckweed aquatic treatment system. The removal of heavy metals from primary treated sewage water is illustrated in Fig. 2. All detected heavy metals were progressively reduced after 8 days treatment period. Duckweed aquatic treatment system performed 100% copper and lead removal after 8 days treatment; on the other side it efficiently reduced the content of zinc by 93.6%, barium by 93% and cadmium by 66.7%. *Lemna* treatment reduced other heavy metals to minute amounts; cobalt reduced by 15.8%, iron reduced by 11.8%, manganese reduced by 10.6%, molybdenum reduced by 25% and vanadium reduced by 16.7%. Ferrara *et al*. (1985) indicated the reliability of wastewater treatment by some aquatic plants including duckweed in adsorption of the heavy metals cadmium and zirconium. Viet *et al*. (1988) reported that duckweed plants proved to be an excellent bio-accumulator of various heavy metals, which allowed it to treat a variety of wastewaters including industrial and highly polluted wastes. Hammouda *et al*. (1995) evaluated the efficiency of duckweed aquatic treatment in heavy metals removal in various water systems data obtained suggested a maximum reliability of systems with mixtures containing high ratios of wastewater. Despite higher levels of some minerals in duckweed, Mibagwu and Adeniji (1988) anticipated no toxicity problems when it was incorporated into animal feeds.

Bacteriological parameters. Data on efficiency of duckweed aquatic system in eliminating bacteria revealed that total and fecal coliform counts decreased gradually with increasing treatment period reaching minimum values of 147 x 10^3 and 96 x 10^3 CFU 100 mL^{-1}, respectively after 8 days with a reduction of 99.8% for both bacterial types (Fig. 3). The present results are in agreement with those of Pandey (2001) who reported that bacteriological analysis in influent and treated effluent at Delhi duckweed pond indicated removal of fecal coliform in the range of 99.27% and 99.78% at hyrdraulic retention time of 6.4 to 14.2 days. Ran *et al*. (2004) also carried out a pilot study on constructed wetlands using duckweed for treatment of domestic primary effluent to be used for reuse purposes. Results indicated that the system efficiently reduced fecal coliform by approximately 95% under average hydraulic residence time of about 4.26 days. On the other side our results disagreed with Dewedar and Bahgat (1995) who found that fecal coliform in sacs suspended under the duckweed green film did not decline during the period of the experiment.

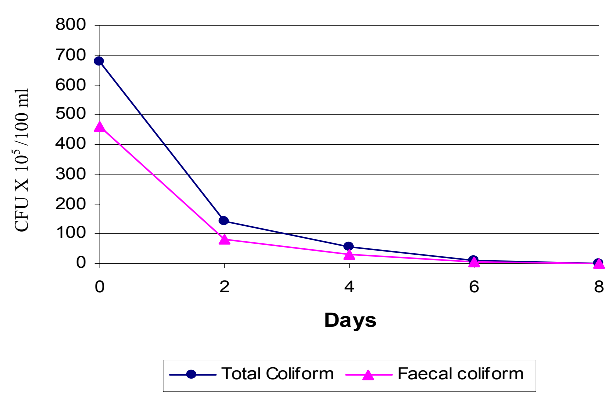
Effect of sewage water enrichment mixture on duckweed growth and protein content. Duckweed fresh and dry weights increased with corresponding increase in treatment time (Table II). These results were in

Table III Effect of aquatic treatment with *Lemna gibba* on phytoplankton population (individuals x 10 ^{3}/L)

Species	Zero days	After 2 days	After 4 days	After 6 days	After 8 days
		Cyanophyceae			
Aphanothece clathrata	10.0	0.0	0.0	0.0	0.0
Microcystis aeruginosa	15.0	7.5	5.0	5.0	5.0
Oscillatoria amphigranulata	30.0	0.0	0.0	0.0	0.0
Phormidium dictyothallum	130.0	25.0	0.0	0.0	0.0
Phormidium molle	350.0	142.5	17.5	15.0	15.0
Phormidium molle var. tenuis	100.0	30.0	12.5	12.5	10.0
Phormidium sp.	25.0	20.0	10.0	7.5	3.5
Spirulina laxissima	290.0	50.0	15.0	15.0	15.0
Spirulina meneghiniana	200.0	20.0	0.0	0.0	0.0
Spirulina major	225.0	25.0	12.5	10.0	10.0
Spirulina platensis	10.0	0.0	0.0	0.0	0.0
		Chlorophyceae			
Chlamydomonas globosa	10.0	7.5	2.5	1.25	0.0
Chlamydomonas snowii	25.0	12.5	7.5	5.0	5.0
Chlorococcum texanum	10.0	5.0	0.0	0.0	0.0
Oocystis solitaria	55.0	0.0	0.0	0.0	0.0
		Bacillariophyceae			
Cyclotella meneghiniana	10.0	10.0	5.0	3.5	3.5
Gomphonema parvulum	5.0	5.0	0.0	0.0	1.25
Synedra ulna	10.0	2.5	0.0	0.0	0.0
		Euglenophyceae			
Lepocinclis salina	7.5	2.5	0.0	0.0	0.0
Phacus acuminatus	10.0	10.0	5.0	5.0	0.0
		Cryptophyceae			
Cryptomonas ovata	10.0	5.0	0.0	0.0	0.0
Total individuals	1337.5	380.0	92.5	79.75	68.25
Number of species	21	17	10	10	9
Richness	2.8	2.7	2.0	2.06	1.9
Diversity index	2.3	2.19	2.16	2.12	1.98
Eveness	0.64	0.65	0.79	0.78	0.76
		Chlorophyll a & Trophic State Index			
Chlorophyll a (mg/L)	35.254	8.761	8.097	7.23	6.912
Trophic State Index	65.5	52.0	51.1	50.0	49.2

accordance with Hammouda *et al*. (1995) who found that wastewater supported higher growth rates for duckweed with increasing treatment periods but the differences were insignificant. Table II further showed that duckweed protein content increased from 311.4 g kg^{-1} at zero days to reach 331.25 g kg^{-1} after 8 days retention time. In this context Tripathi and Misra (1990) reported that duckweed grown in domestic wastewater indicated higher nutritional values than those grown in natural water. The crude protein content of duckweed tissue removed from solutions containing 50 and 100% sewage effluent was almost three times higher than that of plants grown in pond water (Sutton & Ornes, 1975). Haustein *et al*. (1990) mentioned that duckweed may be a useful substitute for soybean and some fish meal in poultry feed especially in countries where some of these commodities are imported. Furthermore Hillman and Culley (1978) and SkilliKorn *et al*. (1993) opined that protein content is also an important characteristic for which duckweed species have been fed to cattle, poultry, fish and ducks feed.. Rusoff *et al*. (1980) found that the spectrum of amino acids in duckweed plants, especially with regards to lysine (7.5% of total protein) and methionine (2.6% of total protein) is much better as compared with other plants. Hammouda *et al*. (1995) found that protein content in duckweed increased upon enrichment with wastewater and reached a maximum of 47.1% in mixture of Nile water to wastewater ratio of 1:3, with a maximum increase in all amino acids, lysine content was markedly increased by 105%. Pandey (2001) reported that duckweed had high nutrient value in the dried biomass; 20 - 31% protein, 0.5 - 2.2% fat, 0.008 - 0.01% vitamin C and 0.003 - 0.007% iron who recommended its use as a food supplement for fish, poultry and cattle. It was also noticed that fish

Fig. 3. Values of total and fecal coliform bacteria at zero days and after 2, 4, 6 and 8 days of treatment



growth was better in a pond in which duckweed was given as a feed.

Response of phytoplankton population to duckweed aquatic treatment. Duckweed was effective in reducing phytoplankton population, which was 71.6, 93.06, 94.0 and 94.8% after 2, 4, 6 and 8 days treatment period, respectively (Table III). Duckweed aquatic treatment system induced a reduction in the population of nine phytoplankton species after 8 days treatment period. The persisted species were: *Microcystis aeruginosa, Phormidium molle, P. molle var. tenuis, Spirulina laxissima, S. major, Chlamydomonas snowii, Cyclotella meneghiniana and Gomphonema parvulum*. According to Palmer (1969) all the algal species that persisted to the end of the experiment are considered to be tolerant to organic pollution and can be employed as pollution indices. In this regard the suppression of algae was described by Viet *et al*. (1988) as a major achievement of *Lemna* wastewater in North Dakota. *Lemna* mat effectively reduced sunlight transmission, thereby reducing photosynthesis by algae. In addition to the inhibition of sunlight, *Lemna* fiercely competed for food materials and eliminated various algae rapidly. Hammouda *et al.* (1995) found that duckweed was capable of efficient quantitative and qualitative algal reduction, they mentioned that the presence of *Lemna* plants at the water surface restricts the penetration of sunlight, controls and reduces algal growth and consequently reduces the odor problem. Pandey (2001) mentioned that duckweed rhizosphere complex may secrete organic substances, which suppress and kill algae cells. Diversity index and richness values decreased with increasing treatment period indicating the success of duckweed aquatic system in reducing algal diversity and number of species, whereas evenness values increased with increasing treatment time indicating that the distribution of the species in the community structure became more or less equilibrated.

Duckweed aquatic treatment system caused a continuous gradual decrease in chlorophyll-a concentration with prolonged treatment periods. Chlorophyll-a content was reduced by 75, 77, 79.5 and 80.4% after 2, 4, 6 and 8 days treatment period respectively (Table III). It was found that chlorophyll a concentrations were positively correlated with phytoplankton standing crop during the period of the experiment; this was in conformity with Lai and Lam (1997) who mentioned that chlorophyll a is usually used as an estimate of phytoplankton abundance. Also Labib (1997) stated that chlorophyll a is a function of phytoplankton standing crop. Values of trophic state index decreased gradually by increasing treatment time, shifting the trophic status of the system from eutrophication towards mesotrophication.

In conclusion duckweed can be used as fodder and in fish farms due to its high protein content and nutritional value especially if it is grown on wastewaters free of industrial inputs. Duckweed could be employed in reducing soluble salt concentrations in irrigation water, where the only alternative to demineralize water is the reverse osmosis technology, which is very expensive to construct and operate.

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