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EFFECT OF ELECTRICAL CONDUCTIVITY (EC) ON GROWTH PERFORMANCE OF DUCKWEED AT DUMPSITE LEACHATE

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Abstract: Two batch experiments were conducted during the months of June-July (summer) and September-October (fall) to determine the effect of Electrical Conductivity (EC) on nutrient and COD removal & uptake efficiency and growth of duckweed (*Lemna minor*) at leachate with various EC levels (500-3,000 µS cm^{-1}) under the natural climatic conditions of Islamabad, Pakistan. Maximum removal rates (mg m^{-2} day^{-1}) of TKN (175.6±0.7), NH4-N (124±0.4), TP (92.4± 0.1), o-PO_4^{3-}-P (31.8 ± 1.2) and COD (3,660±9.1) were observed at 1,000 µS cm^{-1} EC of leachate during summer while; during the fall season, these removal rates were 182.9 ± 0.7, 117.3 ± 0.3, 91.1 ± 0.04, 76.9 ± 1.8 and 3,295 ± 6.1 mg m^{-2} day^{-1} respectively. The maximum growth rate of duckweed was 5.70±0.2 g m^{-2} day^{-1} during summer and 3.21±0.08 g m^{-2} day^{-1} during fall at 1,000 µS cm^{-1} EC of leachate. Out of the total removed, about 79.77% & 68.83% of N and 75.75% & 53.02% of P was absorbed by duckweed during summer and fall seasons respectively at 1,000 µS cm-1 EC. Seasonal variations during June to September have less significant effect on duckweed growth and its nutrient & COD removal efficiency from leachate. Results of the study show that duckweed can be used as potential aquatic macrophyte for duckweed based leachate treatment under natural climatic conditions.
Keywords: Leachate, Duckweed, Lemna minor, Nutrient, Electrical Conductivity.

INTRODUCTION

Leachate is the high strength wastewater. At open waste dumping sites it is produced by biochemical reactions within the waste stream, due to interstitial water content of the waste mass and percolation of rainwater through solid waste layers [1, 2]. Various physico-chemical and bio-chemical processes in solid waste transfer variety of pollutants from waste streams into percolating rain water [3]. A typical leachate contains four major groups of pollutants; dissolved organic matter, xenobiotic organic compounds, heavy metals and inorganic macro compounds [4].

Quantity and composition of leachate depends on quantity and composition of waste material, age of landfill site, availability of moisture and oxygen and hydrology of waste landfill site

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[5]. Nutrients content of a typical leachate may be as high as 13,000 mgL-1 of organic nitrogen up to 400-3000 mgL-1 of ammonia-nitrogen and 3000 mg L-1 of phosphate [6, 7].

Unattended leachate from municipal waste landfills/dumpsites may pose serious impacts on human health and surrounding eco systems including surface & ground water and soil [8]. Recently, it has become major concern worldwide to impose more stringent environmental requirements related to leachate management and treatment [2].

Currently many physical, chemical, biological and combination of two or more leachate treatment methods are used in the world [9]. Phytoremediation is the use of green plants to remove, detoxify or immobilize the pollutants in environmental media (soil, water or sediments) [10].

Use of aquatic plants such as duckweed, water hyacinth, water lettuce in wastewater treatment has received greater attraction during few years back [11-13]. Production of aquatic plants on wastewater has two fold benefits: treatment of wastewater and, as an alternate technology, converting wastewater nutrients into potentially useful forms [14].

Duckweed is a small floating macrophyte belonging to family Lemnaceae of monocotyledonous plants. Duckweed has 37 species belonging to 4 genera: i) Lemna, ii) Spirodela, iii) Wolffia and, iv) Wolffiella [15]. Composition of duckweed is highly variable and depends on composition of water on which duckweed is grown. Protein content constitutes the major part of duckweed biomass of most of duckweed species [16]. Similar to other photosynthetic terrestrial and aquatic plants, nitrogen, phosphorus and potassium (NPK) are the main nutrient required for duckweed growth [17].

Duckweed is amongst the promising aquatic plants having ability to absorb large amounts of nutrients and trace metals from eutrophicated wastewater and has high growth rates. Wastewater treatment by duckweed is owed to its high nutrients and minerals accumulation capacities into biomass and high growth rates under diverse environmental conditions [18, 19].

Cheng et al. reported that duckweed can grow well at wastewaters with high nitrogen and phosphorus levels (240 mg NH4-N/L and 31.0 mg PO_4-P/L). The highest nutrient uptake rate achieved was 0.995 mg N/L-h, and 0.129 mg P/L-h, and duckweed growth rate was 1.33 g dry biomass/m2-h [14]. Bergmann et al., 2000a concluded that *Lemna gibba* and *Lemna minor* species of duckweed are best for the treatment of high strength swine effluent with high biomass production and nutrient removal rates [20].

Duckweed grows well between temperature ranges of 6 to 33° C and can survive below freezing temperatures for many days. Optimum range of pH for duckweed growth is 6.5-7.5 however; it can grow well in pH range of 5-9. According to the management requirements, water depth of 2 meters should be maintained while using duckweed for water treatment purpose [14]. Electrical conductivity has significant effect on biomass production and growth of duckweed by effecting various biochemical and physiological processes in the plant. A study reports that growth rates and water purification efficiency of aquatic plants has inverse relationship with the dissolved salts in growth media [21].

This study has been designed to investigate the effect of Electrical Conductivity on growth and nutrient & COD removal efficiency of duckweed while grown on leachate under natural climatic conditions. So far very small amount of work have been conducted on EC and its effects on duckweed. Results of the study may be useful in designing the duckweed based leachate treatment system under natural conditions.

MATERIALS AND METHODS

Leachate used in this research was prepared by the processing of decomposed solid waste collected from various residential, commercial and industrial areas of Islamabad and Rawalpindi, Pakistan. About 100 to 120 kg well decomposed solid waste was collected from each residential, commercial and industrial dump sites. Waste was collected from pre-determined lowest points at each dump site at soil depths of 0.5 m to 1.5 m [22]. Collected samples were mixed in large plastic water storage tank having an internal diameter of about 1.5m and height of about 1.8 m. A sieve (pore size 1mm) was fixed at an internal height of 10 cm of the plastic container. Through shaking was applied to well mix the waste and achieve a homogenized sample. The homogenized waste was soaked with leaching solution (distilled water) and maintained for 30 days after which, the leachate was collected from bottom outlet in container.

Remaining solid waste was again mixed thoroughly and soaked with distilled water. Afterwards, the leachate was collected three times at an interval of ten days each. Leachate collected from various runs was mixed to form single homogenized sample to be used for this research.

Duckweed (*L. minor*) used in this research was collected from wastewater pond in Islamabad. Prior to grow on leachate, duckweed was repeatedly washed with excess water to remove bacteria, algae and other unwanted compounds [23].

Experimental Setup

Using 30% leachate, six (06) solutions were prepared with EC levels of 500, 1000, 1500, 2000, 2500 and 3000 µS/cm each. Desired EC values in leachate were achieved by adding common salt, NaCl to original leachate to increase EC level and diluting the original leachate with distilled water to decrease the EC.

Two batch experiments were conducted during summer (June-July) and fall (September-October) seasons. At each EC level, duckweed was grown in transparent plastic containers of 300 ml capacity. 250 ml of initial volume of leachate was used in each container at leachate depth of 9.5 cm. Surface area of each container was 25.8cm^2. For each test during summer and fall seasons, 24 containers were used. Out of these, 18 containers had duckweed cultures with each EC level from 500-3,000 µS/cm in triplicates. Six control containers having leachate without duckweed were also placed at corresponding EC levels. Values of controls were subtracted from experimental values.

Duckweed containers were placed within a porous iron rack having three compartments to place the duckweed containers. Rack with duckweed containers was placed in open environment at Institute of Environmental Sciences and Engineering (IESE), National University of Science and Technology, Islamabad under natural climatic conditions. Each experiment was lasted for 25 days.

Seasonal data related to ambient air temperature and day lengths during both experiments was retrieved from website of Pakistan Metrological Department whereas; the solar radiation data during the experimental period was obtained from the web site of LEO Corporation, Pakistan.

Average ambient air temperature, solar radiations and day lengths during summer season was 38.3 ^{0}C, 3.8-4.9 kWh m^{-2} day^{-1} and 13.40 hours, respectively and during fall season it was 26-30 ^{0}C, 4.2- 4.5 kWh m^{-2} day^{-1} and 12.10 hours, respectively.

During both tests, samples from the leachate and control containers were analyzed for TKN, NH4+-N, TP, o-PO4-3-P and COD at the start and end of experimental period. The dry weight of duckweed was measured after drying the plants at 70 0C until constant weight. Dry biomass of duckweed was analyzed for TKN and TP contents before and after the experiment. Statistical analyses during both experiments were performed using Statistix-8.1 software and MS excel.

RESULTS AND DISCUSSIONS

Duckweed was grown at six different EC levels (500, 1000, 1500, 2000, 2500 and 3000 µS cm-1) of leachate. The initial nutrients concentration (TKN, NH_4-N, TP and o-PO_4^{3-}-P) and COD of leachate is presented in Table 1.

Table 1. Initial nutrients concentrations and COD of leachate (mean± SD) used as medium for growth of *L. minor*

Experiment Season	Nutrients concentration (mg dm^{-3})				COD (mg dm^{-3})
	TKN	**NH_4-N**	**TP**	**o-PO_4^{3-}-P**	
Summer	49.76±0.24	32.55±0.24	76.00±0.17	15.00±0.12	1693±3.53
Fall	56.05±0.30	29.04±0.16	43.17±0.24	16.97±0.17	1624±2.57

TKN = Total kjeldahl nitrogen, NH_4-N = Ammonium nitrogen, TP = Total phosphorus, o-PO_4^{3-}-P = Orthophosphate, COD = Chemical oxygen demand

Duckweed efficiently removed the nutrients from leachate and showed healthy growth during both the summer and fall seasons. During both seasons, after 25 days of retention time of duckweed on leachate, maximum removal of nutrients and COD and duckweed growth was observed at 1,000 µS cm^{-1} EC of the leachate (Table 2.).

Table 2 shows that with an increase or decrease in EC from 1,000 µS cm^{-1}, growth rate and nutrient & COD removal efficiency is decreased. Table also shows that reduction in growth rates and removal efficiency of duckweed is more significant at higher EC levels (>1,500 µS cm^{-1}).

Maximum removal rates (mg m^{-2} day^{-1}) of TKN (175.6±0.7), NH4-N (124±0.4), TP (92.4± 0.1), o-PO_4^{3-}-P (31. 8 ± 1.2) and COD (3,660±9.1) were observed with 1,000 µS cm^{-1} EC of leachate during summer while; during the fall season, the removal rates were 182.9 ± 0.7, 117.3 ± 0.3, 91.1 ± 0.04, 76.9 ± 1.8 and 3,295 ± 6.1 mg m^{-2} day-1 for TKN, NH_4-N, TP, o-PO_4^{3-}-P and COD respectively.

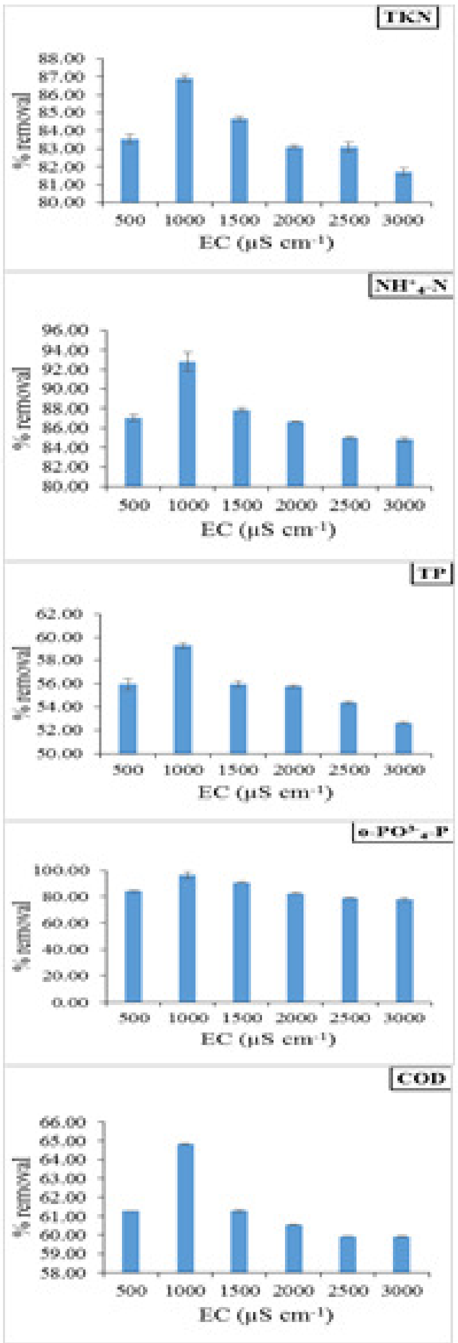
Overall growth rates of duckweed were higher during the summer as compared to fall seasons. The maximum growth rate of duckweed was 5.70±0.2 g m^{-2} day^{-1} during summer and 3.21±0.08 g m^{-2} day^{-1} during fall at 1,000 µS cm^{-1} EC of leachate (Table 2.).

It is evident from table 2 that seasonal variations from June to September have little effect on nutrient removal rates of duckweed except for the ortho-phosphate which is significantly increased during fall seasons (31. 8 ± 1.2 to 76.9 ± 1.8 mg m^{-2} day^{-1}) however; the COD removal was greater during summer (3,660±9.1 mg m^{-2} day-1) as compared to fall (3,295 ± 6.1 mg m^{-2} day^{-1}).

Table 2. Nutrients and COD removal and growth rates (mean ± SD) of duckweed (*L. minor*) at various EC levels of leachate

Experiment	EC µS/cm	Nutrients removal rate (mg m^{-2} day^{-1})				COD (mg m^{-2} day^{-1})[a]	Growth rate (g m^{-2} day^{-1})
		TKN	NH_4-N	TP	o-PO_4^{3-}-P		
Summer Experiment	500	166.43±1.07	118.80±0.37	89.76±0.21	30.91±0.42	3459±7.21	3.63±0.11
	1000	175.64±0.72	124.01±0.39	92.35±0.07	31.83±1.25	3660±9.07	5.70±0.16
	1500	168.45±0.34	122.22±0.51	90.32±1.18	31.17±0.88	3459±9.37	4.63±0.13
	2000	164.22±1.09	118.40±0.31	86.44±0.24	30.29±0.30	3417±8.89	3.53±0.11
	2500	154.77±1.02	115.61±0.51	86.09±0.41	29.18±1.92	3383±7.37	3.47±0.10
	3000	152.71±0.55	112.61±0.47	84.27±0.45	28.49±0.83	3382±7.37	3.22±0.12
Fall Experiment	500	179.16±1.13	114.54±0.35	84.71±0.28	63.19±0.16	3195±5.86	3.07±0.08
	1000	182.89±0.75	117.31±0.32	91.12±0.04	76.86±1.77	3295±6.08	3.21±0.08
	1500	180.99±0.36	114.83±0.50	88.47±1.15	75.52±0.24	3230±5.77	3.17±0.18
	2000	176.46±1.18	11.63±0.30	84.21±0.23	72.35±0.94	3147±4.62	2.94±0.10
	2500	172.86±0.62	109.90±0.45	82.68±0.47	56.84±0.43	3139±4.73	2.90±0.07
	3000	164.24±1.06	107.54±0.55	76.30±0.38	52.59±0.60	3103±5.57	2.87±0.12

At Electrical Conductivity of 1,000 µS cm^{-}1, maximum removal percentages of TKN, NH_4-N, TP, o-Po^{3-}_4-P and COD was 86.9 %, 92.8%, 59.3%, 96.51 % and 64.83 % during summer whereas; the removal percentages of these nutrients and COD during fall season were: 84.83%, 86.42%, 55.89%, 82.59 % and 60.86 % respectively (Fig.1& 2). It is clear from the figures 1 & 2 that removal percentage of nutrients and COD was less affected by seasonal variations from June to September.



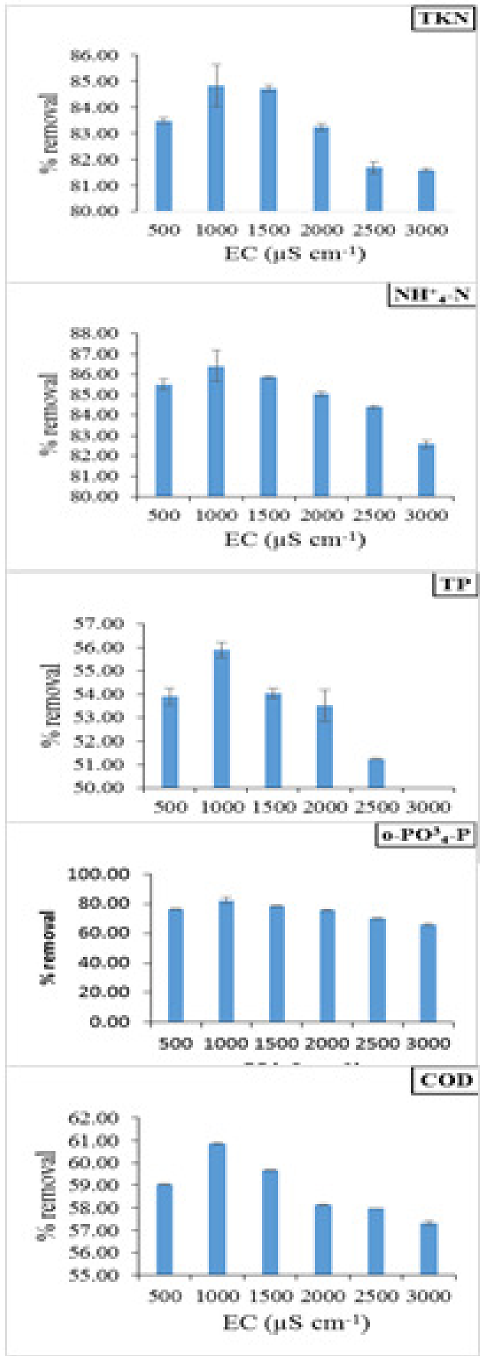


Figure 1 Percent removal of total kjeldahl nitrogen (TKN), ammonium-N (NH_4-N), total phosphorus, ortho-phosphate-P (o-PO_4^{3-}-P) and chemical oxygen demand (COD) at various EC levels of leachate by growing *Lemna minor* during summer

Figure 2 Percent removal of total kjeldahl nitrogen (TKN), ammonium-N (NH_4-N), total phosphorus, ortho-phosphate-P (o-PO_4^{3-}-P) and chemical oxygen demand (COD) at various EC levels of leachate by growing *Lemna minor* during fall

Table 3 shows the mass balance of nitrogen and phosphorous removed from the leachate and uptake by the duckweed into its biomass. Table shows that duckweed effectively absorbed the nitrogen and phosphorous into its biomass at all EC levels however the maximum absorption was observed at EC of 1,000 µS cm^{-1}. Out of the total removed, about 79.77% & 68.83% and 75.75% & 53.02% N and P respectively was absorbed by duckweed during summer and fall seasons at 1000 µS cm-1 EC of the leachate.

Table 3. Mass balance of total N and P removal and uptake (mean ± SD) by Lemna minor at various EC levels of leachate during summer and fall seasons.

Experiment	EC (µS cm^{-1})	Total nutrients removed from media				Nutrients uptake by duckweed			
		mg/L		%		mg/L		% of total removed	
		N	P	N	P	N	P	N	P
Summer Experiment	500	41.57±0.1	22.79±0.24	83.53±0.26	55.97±0.47	31.17±0.07	14.75±0.50	74.98±0.05	64.71±1.6
	1000	43.24±0.2	24.13±0.01	86.89±0.18	59.27±0.25	34.49±0.52	16.61±0.42	79.77±1.05	68.83±1.8
	1500	42.12±0.2	22.80±0.05	84.66±0.13	55.99±0.27	32.47±1.09	14.83±0.22	77.08±2.39	65.08±1.1
	2000	41.35±0.2	22.72±0.07	83.10±0.08	55.79±0.10	30.68±0.16	14.59±0.05	74.19±0.06	64.21±0.1
	2500	41.34±0.1	22.14±0.10	83.09±0.24	54.38±0.11	30.52±0.89	14.09±0.35	73.83±2.32	63.63±1.3
	3000	40.66±0.1	21.42±0.07	81.72±0.22	52.62±0.07	28.57±0.56	13.02±0.46	70.25±1.44	60.76±2.0
Fall Experiment	500	46.79±0.2	23.27±0.04	83.49±0.11	53.90±0.38	33.65±0.54	11.50±0.30	71.92±1.44	49.40±1.4
	1000	47.54±0.2	24.13±0.01	84.83±0.80	55.89±0.33	36.02±1.81	12.79±0.60	75.75±3.50	53.02±2.5
	1500	47.48±0.2	23.33±0.04	84.72±0.12	54.05±0.22	34.53±0.72	11.55±0.61	72.74±1.80	49.50±2.6
	2000	46.65±0.3	23.10±0.19	83.24±0.14	53.51±0.68	33.54±0.95	11.20±0.70	71.90±2.38	48.50±3.2
	2500	45.79±0.1	22.13±0.11	81.70±0.23	51.26±0.04	32.67±1.49	10.51±0.87	71.35±3.34	47.52±4.2
	3000	45.74±0.4	21.51±0.09	81.60±0.06	49.84±0.12	31.89±1.73	10.10±0.34	69.73±4.02	46.96±1.4

Little scientific information is available related to the effects of salinity on duckweed growth and its nutrient and COD removal ability. However, some studies reveal that duckweed is the salt sensitive plants and EC of the medium directly and indirectly effects the growth and physiology of duckweed [24].

High salinity imposes osmotic stress which may cause damage to duckweed cells by the production of inducing reactive oxygen species or by disrupting detoxification mechanisms in the plant [25]. Specific toxic effects of certain pollutants in leachate may also significantly affect the growth and nutrient removal efficiency of duckweed. A study found that duckweed can tolerate wide range of salinity an EC ranging from 1,000-1200 µS cm-^{1} is optimum for duckweed growth when at saline wastewaters [26].

Conclusions

Results of this study show that during both seasons duckweed (*Lemna minor*) performed well at an EC range of leachate from 500-1,500 µS cm^{-1} under natural climatic conditions whereas; the maximum growth and nutrient and COD removal efficiency of duckweed was observed at EC 1,000 µS cm^{-1}.

At this EC (1,000 µS cm^{-1}), duckweed showed the maximum removal rates (mg m^{-2} day^{-1}) of TKN (175.6±0.7), NH4-N (124±0.4), TP (92.4± 0.1), o-PO_4^{3-}-P (31. 8 ± 1.2) and COD (3,660±9.1) during summer while; during the fall season, the removal rates were 182.9 ± 0.7, 117.3 ± 0.3, 91.1 ± 0.04, 76.9 ± 1.8 and 3,295 ± 6.1 mg m^{-2} day-1 for TKN, NH_4-N, TP, o-PO_4^{3-}-P and COD respectively.

At these rates, duckweed removed about 86.9 %, 92.8%, 59.3%, 96.51 % and 64.83 % of TKN, NH_4-N, TP, o-$Po^{3-}{}_4$-P and COD respectively during the summer and 84.83%, 86.42%, 55.89%, 82.59 % and 60.86 % respectively during the fall seasons.

Out of the total removed N and P, about 79.77% & 68.83% and 75.75% & 53.02% respectively was taken up by duckweed during summer and fall seasons at the EC of 1,000 µS cm^{-1}.

The maximum growth rate of duckweed (5.70±0.2 g m^{-2} day^{-1}) was observed during summer and 3.21±0.08 g m^{-2} day^{-1} during fall at 1,000 µS cm^{-1} EC of leachate.

Seasonal variations from June to September have little effect on nutrient and COD removal rates and growth of duckweed on leachate.

Overall, the results of study show that *Lemna minor* growth and its nutrients removal efficiency is greatly influenced by presence of salts in growth media and an EC of 1,000 µS cm^{-1} can be considered as optimum for duckweed based leachate treatment system under the natural climatic conditions of Islamabad, Pakistan.

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