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THE INVESTIGATION OF ARTIFICIAL WETLAND SYSTEMS FOR THE IMPROVEMENT OF AGRICULTURAL DRAINAGE WATER

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Abstract: Harmful substances in the wastewater negatively affect the ecological balance by reducing the dissolved oxygen concentration. High phosphorus and nitrogen compounds discharged into surface water resources may cause to eutrophication, due to increased algal growth. In this study, Elodea densa (Egeria), Lemna minor (Duckweed), Micranthemum micranthemoides (Micra), Pistia (Water Lettuce), Ceratophyllum demersum (Foxtail) plants were investigated for the removal of nitrate and ammonium from rice field drainage water. Synthetic drainage water was prepared to rely on the literature and real rice field drainage water composition from the Samsun Bafra region. Artificial wetland studies were carried out as individual systems in order to understand the treatment ability of each plant and as a combined system in batch and continuous flow mode. pH, electrical conductivity, dissolved oxygen, nitrate, and ammonium values were measured periodically. Results of the individual plant wetland system represented that the wetland plant Elodea densa revealed the highest nitrate removal efficiency (77%) at the end of 1 day, followed by Pistia (76%). It was observed that the treatment efficiency increased with increasing hydraulic retention time. In the combined system, the nitrate removal efficiency was 40%, while the ammonium removal efficiency was 51% at the end of the first day. It was concluded that the wetland plants successfully reduced the ammonium and nitrate content of the drainage water and showed resistance to the drainage water with high salinity. In the wetland experiments carried out under continuous flow mode, ammonium was reduced from 0.80 mg/L to 0.10 mg/L, while nitrate was reduced from 1.90 mg/L to 1.40 mg/L, yielding approximately 90% and 30% at the end of the 16th day. Studies have in general revealed the importance of plant type as well as residence time.

Keywords: Artificial wetland, Agricultural drainage water, Residence time, Ammonium and nitrate

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1. Introduction

Artificial wetlands have been used in two ways, as subsurface and free surface area flow, for the improvement and treatment of wastewater since the 1950s (Shutes, 2001). While wetlands directly contribute to the treatment processes, they also contribute to the collection of precipitation waters, balancing the water in the system, and supporting biodiversity. Wetlands used today are accepted as an efficient treatment method for the removal of organic compounds and suspended solids. The removal efficiencies of nitrate (NO_3-N), ammonium (NH_4-N), and phosphate (PO_4^{3-}) pollutants vary depending on the type of artificial wetland system (Vymazal, 2019).

In wetlands formed by different plant species; subterranean plants grow horizontally and vertically, creating a large surface area for the uptake of nutrients ions while also providing bottom oxygenation (Brix, 2003). Surface plants provide natural filtration under photosynthesis and aerobic conditions while also contributing to the removal of many pathogenic microorganisms (Brix, 2003).

In recent years, the effect of systemic design parameters on pollutant levels has been continuously investigated. Each parameter influencing the system has advantages and disadvantages. In recent years, high-efficiency systems have been more suitable for land integration. In addition, it offers many opportunities as systems that are relatively more advantageous in terms of cost compared to other systems (Borin et al., 2007). Influences of agricultural drainage waters are on the nitrogen and phosphate cycle and salinity of receiving waters. Drainage waters arising from agricultural activities are generally directly given to the receiving environment (Borin et al., 2007). Artificial wetland systems composed of plant species with high salinity tolerance decrease the levels of drainage water parameters such as NO_3-N, NH_4-N, PO_4^{3-}, and others that negatively affect living beings and nature (Kadlec and Wallace, 2009). The influence of nitrogen and phosphorus compounds especially on surface waters is well known (Tırınk, 2021).

In this study, the potential of Elodea densa, Lemna minor, Micranthemum micranthemoides, Pistia, and Ceratophyllum demersum, in individual and combined wetland systems, in removing NO_3-N and NH_4-N under batch and continuous flow mode was investigated.

2. Materials and Methods

2.1. Drainage Water

The composition of agricultural drainage waters varies depending on the type and amount of pesticides and fertilizers used (Tanji and Kielen, 2002). Based on the literature and the analyzed drainage water obtained from Samsun Bafra, the NO_3-N and NH_4-N level of the synthetically prepared drainage water was determined as 1.90 mg NO_3-N /L, 0.80 mg NH_4-N /L, and 1.00 g/L NaCl.

2.2. Artificial Wetland Plants and Wetland Structure

Shown in Figure 1, the plants selected for use in the study were Elodea densa, Lemna minor, Micranthemum, Ceratophyllum, Pistia, and Bafra seaweed. The Bafra seaweed obtained from the Kızılırmak Delta of the Samsun region was used only in the batch studies. All other plants were obtained from the WOOF Company that supplies aquarium plants. All of the plant pictures in Figure 1 were obtained from the internet (Leslie, 2007; Lovell, 2009; Vidéki, 2009; Shaun, 2018).

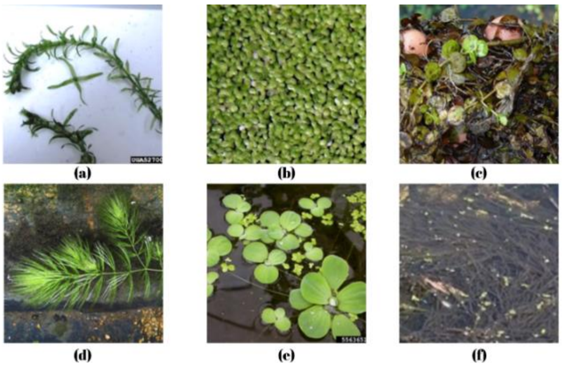

Figure 1. (a) Elodea densa, (b) Lemna minor, (c) Micranthemum, (d) Ceratophyllum, (e) Pistia, and (f) Bafra seaweed.

Submerged plants like Ceratophyllum demersum were planted into a 10-15 cm lava pea gravel layer which was initially placed into the individual or combined system tanks, while free-floating plants like Lemna minor were homogeneously distributed along the water surface of tanks.

2.3. Experimental Methods

In the individual wetland system study, each plant species was placed into a 10 L tank containing synthetic drainage water to understand their treatment potential under high salinity conditions (Figure 2). Parameters of daily samples were determined according to standard procedures.

In the combined wetland system study under batch mode conditions, the plants were taken into a common tank containing 5 L drainage water and exposed to the same hydraulic retention time. In both studies, the parameters of daily samples were determined according to standard procedures (Figure 3). In order to investigate the potential of a combined wetland system under continuous flow mode, wetland plants were placed into a 40 L tank operating with a flow rate of 12.5 ml/min and the NO_3-N and NH_4-N removal efficiencies were followed by taking samples with 2-day intervals.

After the measurement of dissolved oxygen (DO), pH, and electrical conductivity (EC), samples were passed through a 0.45μ MF-Millipore MCE membrane syringe filter and further analyzed for NO_3-N and NH_4-N.

Figure 2. Individual wetland systems.

Figure 3. Continuous flow combined wetland system.

2.4. Analytical Methods

Dissolved Oxygen: Measurements were carried out with a HACH-HQ430d flexi device containing a Luminescent/optical dissolved oxygen electrode.

pH and Electrical Conductivity (EC): Thermo Scientific-Orion Star A215 with a DuraProbe 4-cell conductivity sensor and a ROSS Ultra Triode epoxy-body pH/ATC electrode was used for pH and EC measurements.

Nitrate (NO_3-N): Spectrophotometric measurements were done by selecting 353 N, NO_3-N MR PP 400 nm from the recorded programs in the HACH Lange DR6000 device. HACH Method 8171 is based on the cadmium reduction method.

Nitrite (NO_2): Spectrophotometric measurements were carried out by selecting 373 M, NO_2 HR PP 585 nm from the registered programs in the HACH Lange DR6000 device. HACH Method 8153 is based on the ferrous sulfate method.

Ammonium (NH_4-N): Spectrophotometric measurements were done by selecting 380 N, NH_4-N Ness 425 nm from the recorded programs in the HACH Lange DR6000 device. HACH Method 8038 is based on the Nessler method.

3. Results

3.1. Batch System Operation

3.1.1. Individual wetland system

The variation in NO_3-N and NH_4-N concentrations with respect to different hydraulic retention times for each wetland plant is given in detail in Figure 4. Results generally showed that treatment efficiencies increased over time for all plants but at different levels. NO_3-N removal efficiencies for a residence time of one day were determined to be 72%, 38%, 22%, 38%, 77%, and 22% for Lemna minor, Micranthemum, Pistia, Bafra seaweed, Elodea densa, Ceratophyllum demersum plants respectively. When the residence time was increased to five days, these values increased to approximately 94%, 94%, 88%, 72%, 94%, and 78%, respectively. NH_4-N removal efficiencies at the end of the first day were found to be 59%, 64%, 77%, 63%, 69%, and 64% for Lemna minor, Micranthemum, Pistia, Bafra seaweed, Elodea densa, Ceratophyllum demersum plants, respectively. These values increased on the fifth day and reached values of approximately 81%, 85%, 88%, 77%, 85%, and 85%, respectively. The highest NO_3-N removal efficiencies obtained for a retention time of one day were for Lemna minor and Elodea densa. Regarding NH_4-N removal efficiencies, all plants revealed efficiencies above 60% except for Lemna minor. The highest NO_3-N removal efficiencies obtained for a retention time of five days were for Lemna minor, Micranthemum, and Elodea densa, reaching values as high as 94%. NH_4-N removals by all plants were more than 80%.

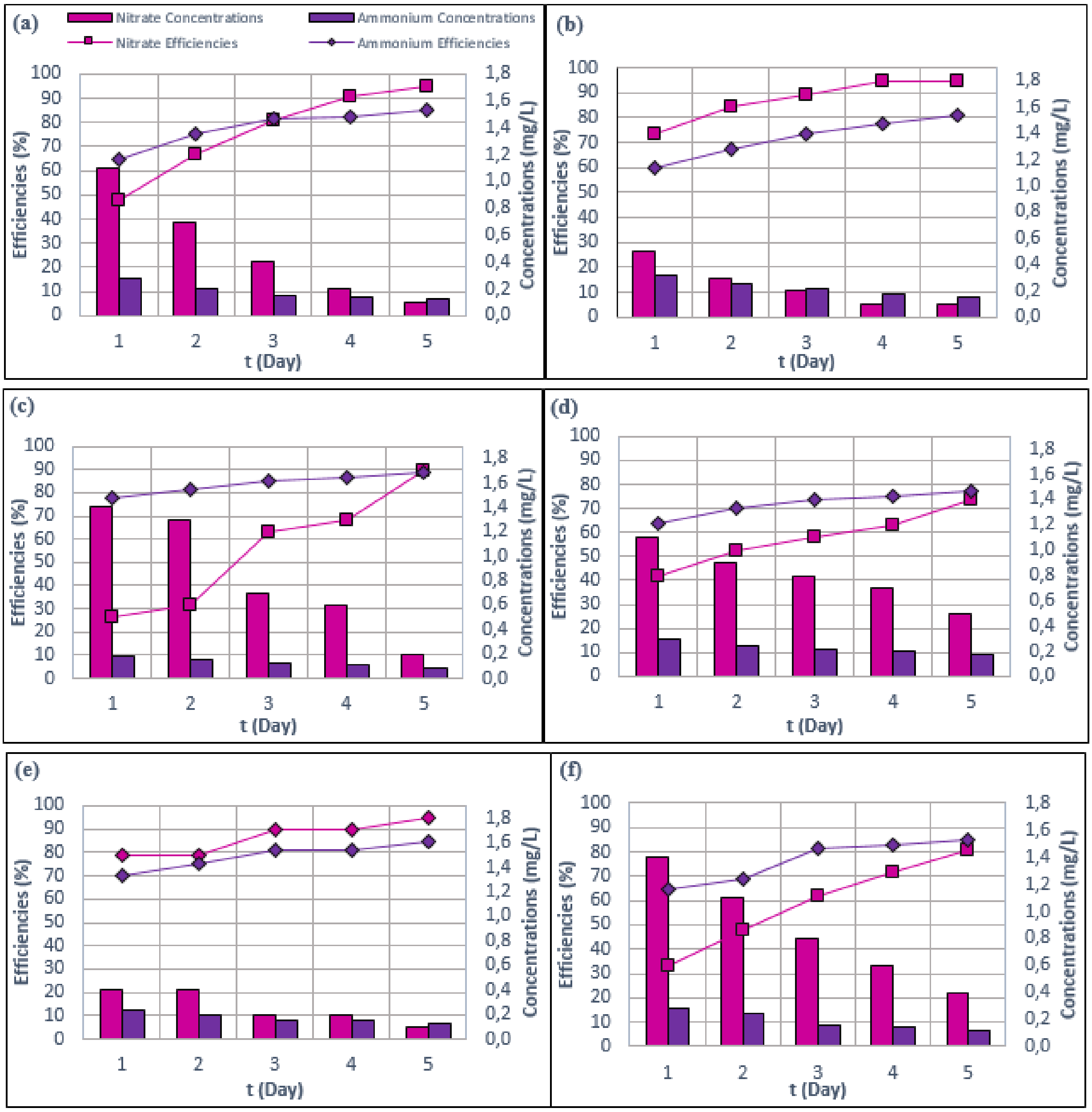

Figure 4. NO3-N and NH4-N levels and removal efficiencies of plant for individual wetland system (a) Micranthemum, (b) Lemna minor, (c) Pistia, (d) Bafra seaweed, (e) Elodea densa, (f) Ceratophyllum.

Regarding the changes in pH values, an increase in pH from 7.20 to 8.94 in 4 days was observed for all plants. Most of the time, the increase of underwater plants, phytoplankton, and algae in the pool water in the spring causes the pH value to increase too much (Ölmez and Saraç, 2009). According to the EC measurements, an increase was observed for all plants in individual wetland systems.

DO levels were found to remain approximately at the same level, except for Elodea densa and Ceratophyllum demersum, which revealed slightly higher DO values when compared with the systems of other plants.

3.1.2. Combined wetland system

As natural systems rely on the effort of various species, plants were combined, and NO_3-N and NH_4-N removal efficiencies were daily monitored as done in the individual wetland system. As can be seen from Figure 5, the NO_3-N removal efficiency achieved at the end of the first day was about 40%, while the NH_4-N removal efficiency approached 51%. These values increased to about 70% and 95% at the end of the 5th day.

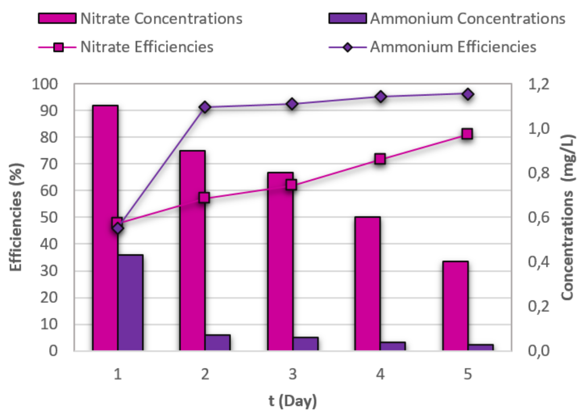

Figure 5. NO_3-N and NH_4-N treatment efficiencies in the common plant system.

3.2. Continuous Flow System Operation

After the evaluation of plant responses and performances in individual and combined wetland systems, the influence of drainage water supply mode was investigated. The combined wetland system was operated under continuous flow mode with the same drainage water at a rate of 12.5 mL/min. A retention time of approximately two days was selected since higher retention times increase the dimensions and thus the investment costs of wetlands. The continuous flow was provided with the help of a laboratory pump. As can be seen from Figure 6, the results of the continuous flow mode were different from the batch mode. Removal efficiencies of both parameters increased with time but remained lower than the efficiencies of batch mode. The NH_4-N removal efficiency increased from about 51% to 88% after 14 days, while the NO_3-N concentration remained high (1.40 mg NO_3-N/L), reaching a removal efficiency of only 26%. The NH_4-N concentration observed after fourteen days was approximately 0.10 mg NH_4-N/L. Results of the continuous flow mode revealed a significant NH_4-N removal, while the ability of plants to remove NO_3-N was very limited. Plants presented better performances in the batch mode.

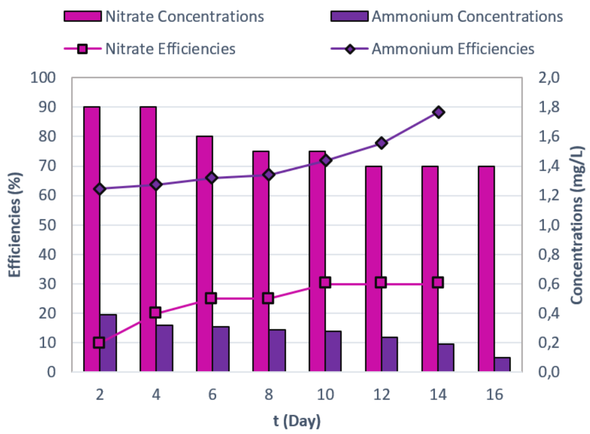

Figure 6. Contaminant removal efficiencies in a continuous flow artificial wetland tank.

Regarding the pH, EC and DO levels of the combined wetland systems under continuous flow mode, it can be stated that the EC values were presenting a decreasing trend while pH remained rather at the same level with minor fluctuations. Surprisingly, the DO values in the system tend to decrease within the system.

4. Discussion

The investigation of treatment methods based on natural ecosystem services, rather than high chemical and technology use is receiving attention. Scientific improvement of natural systems, e.g., wetlands, by supporting its components and/or process combinations during the design stage enables higher efficiencies. Research on the incorporation of advanced treatment systems into environmental systems is increasing. Investments for constructed wetland systems rather focus on pollutant removal from urban and sewage wastewater; however, do not provide sufficient information about plant species and plant treatment yields under salt stress.

Lemna minor, Micranthemum, Pistia, Elodea densa, and Ceratophyllum demersum plants were frequently reported for their ability to reduce nitrogen compounds present in wastewater. Selvarani et al. (2015) mentioned NH_4-N, NO_2, and NO_3-N removal efficiencies up to 98% from different types of wastewaters with Lemna minor. According to the research of Bialowiec et al. (2019) on the Elodea densa plant, a total nitrogen removal efficiency of 52.9% and phosphate removal efficiency of 15.9% were reported. In addition, it was stated that the Elodea densa plant increased the O_2 level in the water with increasing period depending on time (Bialowiec et al., 2019). In a study by Victor et al. (2016) with the Pistia plant, NH_4-N removal from wastewater was determined to be about 58% at the end of the first day, while Gaballah et al. (2019) reported efficiency of about 83%. NO_3-N removal efficiency of 62% was presented for the

Ceratophyllum demersum plant for a retention time of six days (Foroughi et al., 2013). In a detailed study by Teles et al. (2017), the effect of NO_3-N load on the ability of Lemna minor to remove nitrogen compounds was investigated and the decrease in the treatment efficiency of the plant was related to high NO_3-N input.

In the study carried out, the investigation of these plant species for nutrient removal from drainage water with very high salt enabled the evaluation of plants tolerance and future use. Results demonstrated that these plants, other than salt tolerant plant species, have a potential to provide high NH_4-N and regular NO_3-N removal efficiency. The current study also represented the capability of Bafra seaweed, a local plant species, in removing nutrients from water. The effect of water quality (salinity) on the efficiency of wetland systems under different operating conditions (batch and continuous flow mode) was additionally observed. Limitations in the growth rate of evaluated plant species were recorded with respect to salt water exposure over time. Continuous high load of water pollutants are reported to result in decreased plant survivorship causing to disappearance of plants (Wu et al., 2015). Observations, additionally, showed that the number of plants distributed throughout the tank has an influence on removal efficiency. Thus, reduced plant numbers presented lower removal efficiencies. Similarly, in a study carried out by Liu et al. (2017), the lower nitrogen removal efficiency by Lemna minor was attributed to the salinity of water. Results of the continuous flow combined wetland system similarly emphasizes the effect of continuous salt load on the plants, revealing quite low NO_3-N removals when compared with the results of the batch combined wetland system. Wu et al. (2015) stated that the feeding mode (such as batch, intermittent and continuous) may influence the oxidation-reduction conditions, transfer and diffusion rates in wetland systems.

5. Conclusion

Lemna minor, Micranthemum, Pistia, Bafra seaweed, Elodea densa, Ceratophyllum demersum, and Bafra seawood, a local species, were investigated for NO_3-N and NH_4-N removal from agricultural drainage water, with individual and combined plant wetland systems operated under batch and continuous flow mode. The individual plant wetland system aimed to understand each plants potential for salt tolerance and nitrogen removal. NO_3-N concentrations were reduced to 0.10 mg/L NO_3-N (73% efficiency) by Lemna minor, Micranthemum and Elodea densa plants with a retention time of 5 days. The local seaweed plant from Bafra revealed a removal efficiency of 73%. The Pistia plant presented the highest NH_4-N reduction to 0.10 mg NH_4-N/L (88%). The individual wetland system showed that plants having the capacity to remove more NO_3-N provided less NH_4-N removal, while those with a capacity to remove NH_4-N revealed less NO_3-N reduction. NO_3-N and NH_4-N concentration determined for the combined wetland system in batch mode reduced to 0.40 mg/L NO_3-N (78%) and 0.05 mg/L NH_4-N (97%) at the end of the 5th day. Regarding the continuous flow mode system an increase in removal efficiencies was observed with time. However, continuous load of salty drainage water into the system resulted in especially a reduction in NO_3-N removal efficiency when the 5-day NO_3-N and NH_4-N removal efficiencies were compared with that of batch mode.

In general, it can be concluded that the selection of wetland plant species, residence time and flow rate with respect to contaminant plays a crucial role in wetland performance. Higher residence times yielded higher treatment efficiencies. While salinity did not appear to influence some plants, it had negative effects on others (e.g. Lemna minor), resulting in lower overall. In particular, feeding the salty drainage water continuously into the system caused a decrease in plant number over time. Pistia and Elodea densa plants, seem to have a higher tolerance to salinity, yielding more effective NH_4-N reduction. Overall, plants revealed higher NH_4-N treatment efficiencies in the continuous flow wetland system.

Author Contributions

Concept: İ.G. (50%) and E.B.Ö. (50%), Design: İ.G. (50%) and E.B.Ö. (50%), Supervision: İ.G. (50%) and E.B.Ö. (50%), Data collection and/or processing: İ.G. (100%), Data analysis and/or interpretation: İ.G. (100%), Literature search: İ.G. (50%) and E.B.Ö. (50%), Writing: İ.G. (50%) and E.B.Ö. (50%), Critical review: İ.G. (50%) and E.B.Ö. (50%). Submission and revision. All authors reviewed and approved final version of the manuscript.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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