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EMERGING HARMONY AND BIODYNAMIC INTERACTIONS

Vertical phytoremediation of wastewater using *Vetiveria zizanioides* L.

Amir Parnian[1] · James Nicholas Furze[2,3,4]

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Abstract

In many areas, wastewater feeds water bodies, which leads to it being non-usable for agricultural and other uses. Phytoremediation is a scientific approach which cleans contaminated waters, demanding large areas for application. Vertical agriculture is a new method to compact plant cultures. This study investigates vertical wastewater phytoremediation (VWP). Twenty vetiver grasses were planted in a hydroponic vertical agriculture system. Wastewater flowed into the system in four different flow rates, 60, 80, 100, and 160 l day^{-1} and water purity was assessed in order to measure the remediation ability of the VWP. Results showed a reduction in biochemical oxygen demand (BOD5 and NO_3^- concentrations and an increase of electrical conductivity (EC) and dissolved oxygen (DO) in the outlet. Maximum and minimum (BOD5) reduction percentage (78.47% and 67.36%) and NO_3^- removal percentage (90.53% and 36.41%) occurred in flow rates 60 and 160 l day^{-1}, respectively. With the increase of wastewater flow rate, phytoremediation performance decreased, but the performance of VWP with vetiver grass was efficient enough to enable wastewater remediation. Scaling up VWP with Vetiver and related competitive plant species holds promise for wastewater remediation for both human and ecosystem services.

Keywords Wastewater · Phytoremediation · Vertical agricultural · Vetiver · VWP · Water reuse

Introduction

Physical, chemical, and biological characteristics define water quality. Water quality must be obtained such that it has appropriate properties for ecosystem or human demands, giving it a purity qualification (WHO 2017). Providing clean water is an important priory for human societies and development (Dharminder et al. 2019).

Local water bodies are the main receivers of wastewater, which causes water pollution (Egun 2010). Water contamination makes economic development increasingly vulnerable and fragile (Lu et al. 2017). Water treatment is a process, which improves the quality of water for specific uses. The notable parameters in water and wastewater treatment are pH, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), and organic material (OM), especially biological/biochemical oxygen demand (BOD), nutrients, and heavy metal content (Cheremisinoff 2002).

Phytoremediation is the use of plants to remediate contaminated environments (Parnian et al. 2016). Wastewater phytoremediation refers to techniques that use plants for wastewater remediation. Moreover, remediation of contamination by plants is completed by different mechanisms/paths, that of the root system and the foliar surface (Demirezen et al. 2007; Sawidis et al. 2001). A plant's active surface area in phytoremediation is the parts of the plant body that have direct contact with the contamination and also have a major role in the remediation of the contaminants (Dhir 2013). Active parts

Responsible Editor: Elena Maestri

✉ Amir Parnian
amir.parnian86@gmail.com

James Nicholas Furze
jamesfurze@hotmail.com; james.n.furze@gmail.com

1 National Salinity Research Center (NSRC), Agricultural Research Education and Extension Organization (AREEO), Yazd, Iran

2 Royal Geographical Society (with the Institute of British Geographers), 1 Kensington Gore, London SW7 2AR, UK

3 Laboratory of Biotechnology and Valorization of Natural Resources, Faculty of Sciences of Agadir, Department of Biology, Ibn Zohr University, 8106, 80000 Agadir, BP, Morocco

4 Control and Systems Engineering Department, University of Technology, Alsinaah Street, P.O. Box: 19006, Baghdad Postal Code: 10066, Iraq

of plants for aquatic medium remediation could be plant shoots (Thomas et al. 2016; Upadhyay et al. 2014) or roots (Mathew et al. 2016; Rane et al. 2015). The high active surface area of plants is the key to promote remediation performance by providing more places for uptake, absorption, and microorganism's activities (Pivetz 2001; Kodituwakku and Yatawara 2020).

All available plant-based wastewater treatments demand a widespread area to work in comparison with other biological wastewater treatment systems. In such methods, wastewater passing through the plant's living habitat is remediated by uptake and biological processes such as de-nitrification (Pepper et al. 2019). Plants are chosen with high growth rates and high root biomass; hence, grass species can be useful in these treatments (Oyuela Leguizamo et al. 2017). Vertical agricultures are systems that grow plants in vertically stacked layers. Those systems mostly use hydroponic techniques for plant production and can provide growing systems with rapid productivity, which are highly efficient in terms of area (Al-Chalabi 2015; Epting 2016).

Vetiver is a C4 grass, that can grow under many other near thermal conditions. It has a long and huge root system, which reaches 2–3 m in the first year, vertically and in nature under appropriate conditions (Darajeh et al. 2019; Kumar and Nikhil 2016). Moreover, vetiver grass is tolerant of high acidity and alkalinity, salinity, Na, Al, and heavy metal toxicities (Banerjee et al. 2019; Chusreeaeom and Roongtanakiat 2020; Darajeh et al. 2019; Liu et al. 2016). The Vetiver System (VS) is a new phyto-technology based on the use of vetiver grass (*Vetiveria zizanioides* L.) for numerous environmental protection applications. The vetiver grass is an effective plant for water and wastewater treatment (Badejo et al. 2017; Mathew et al. 2016; Panja et al. 2020; Seroja et al. 2018).

The premise of vertical wastewater phytoremediation (VWP) mixes vertical agriculture and wastewater phytoremediation. Thus, VWP efficient wastewater treatment systems are in the category of ecological wastewater treatments. VWP with vetiver grass is purported to be more area efficient than normal aquatic systems in specially constructed wetlands. There are many limitations for phytoremediation (Banjoko and Eslamian 2016), in the context of VWP; these include the following: (1) The inlet water temperature affects the plant rhizosphere within the system, consequently the water within the system, nutrient absorption, and rhizospheric microbiota activity are affected; (2) the environment temperature affects plant growth; (3) light quantity/wavelength and light period has an effect on plant growth leading to the VWP system being subject to seasonal effects as well as having different outcomes in day and night periods; (4) the VWP requires water flow to sustain its operation, an irrigation source must be constantly maintained; (5) the VWP may be affected by plant diseases and pests; (6) additional factors which affect plant growth, interactive rhizospheric processes also affect VWP performance. The objective of the present study was to determine the efficiency of wastewater phytoremediation by the vertical agriculture method vertical wastewater phytoremediation (VWP) using vetiver grass (*V. zizanioides* L.).

Materials and methods

The study was conducted in laboratories of the College of Agriculture, Shahid Chamran University (SCU), Ahvaz, Iran. After adaptation (Parnian et al. 2016), 20 normal V. zizanioides plants were cultivated in a vertical plastic tube of 20 cm diameter and 150 cm height. Mature plants were then cultivated horizontally parallel to each other on opposite sides of the tube with each plant at 90° horizontal angles with one above.

Reserved wastewater flowed into the VWP system and out of it. Row wastewater stored in a reservoir tank, dropped into the tube using a simple nozzle, and moved down through the plant's roots. A small pump and valve were used for the control of wastewater flow into the tube (Fig. 1). The inlet wastewater flow rates were 60, 80, 100, and 160 l day^{-1}; the length of each treatment was 24 h. The outlet water (system drainage) flowed into a simple plastic basin from which both inlet wastewater and drainage were sampled to examine characteristics. The water samples were stored in a temporary cooling box between 4 and 5 °C and immediately transferred to the laboratory for examination. Water characteristics pH, EC, DO, BOD_5, and NO_3^- were measured in inlet wastewater and drainage samples according to standard methods for the examination of water and wastewater of the American Public Health Association (APHA 2005) to verify the system performance. Water chemical oxygen demand (COD) was not specifically measured, as it was considered a function of organic processes that are performed by the plant's rhizosphere microbiota. BOD_5 was measured to reflect dissolved/decayable organic materials, in inlet wastewater and drainage. A schematic view of the system is shown below:

BOD_5 and NO_3^- removal were calculated by the following equation (Khellaf and Zerdaoui 2009) as quality control for the VWP performance:

$$R(\%) = \left[\frac{(C_0 - C_t)}{C_0}\right] \times 100 \quad (1)$$

where R is removal performance, C_0 and C_t represent the residual concentration of a contaminant at time = zero and at time = t, respectively.

To ensure consistency and reproducibility, 10 replicates were carried out. Identification of significant differences was

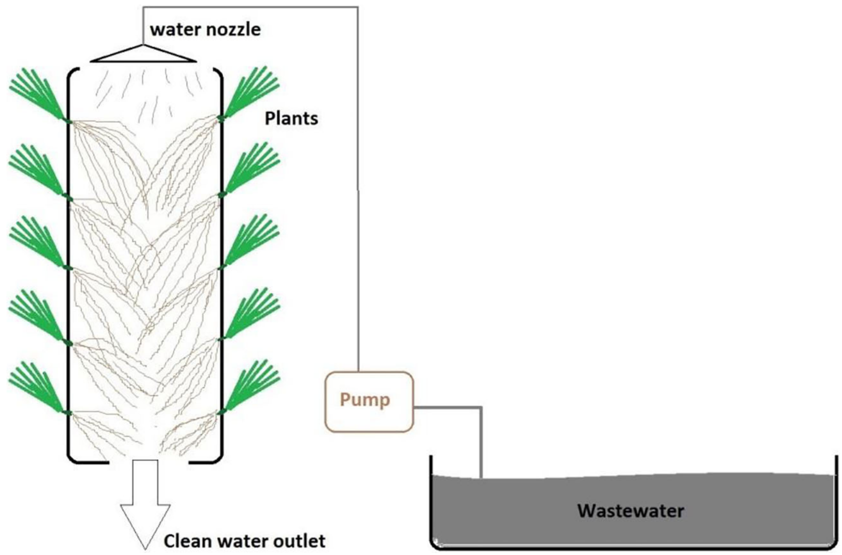

Fig. 1 Vertical wastewater phytoremediation (VWP)

performed using one-way ANOVA. Microsoft Excel 2010 and SPSS Version 16 performed the statistical analyses.

Results and discussion

The plants successfully adapted and grew well in the vertical hydroponic system, and continued in good growth after the treatment of the system with wastewater. The effect of VWP with vetiver grass and wastewater is shown in Table 1.

In Table 1, the data illustrates that vetiver plants reduced BOD_5 and NO_3^- and increased EC and DO of the wastewater. The increased EC resulted from evapotranspiration of the system; DO increase occurred by both aeration of water during the passage and in root oxygen leakage effects. Plant roots in the vessel mostly acted like a trickling filter, similar to the role of gravels or filling media. In trickling filters, the VWP process BOD_5 and NO_3^- removal of the outlet were reduced as a consequence of consumption. Rhizosphere microbiota activity and also plant absorption of NO_3^- were effective; additionally, DO and EC were seen to rise (Ali et al. 2017). Furthermore, similar outcomes are expected in constructed wetlands (Badejo et al. 2017; Zhang et al. 2014). In trickling filters, constructed wetlands and VWP water evaporation occurs which increases EC. Moreover, in plant-based systems, transpiration is an additional factor which concentrates the treated water. DO due to aeration resulted during water flow and also as a consequence of reduced BOD_5 (Ali et al. 2017; Badejo et al. 2017; Zhang et al. 2014). In this experiment after measuring the outlet waters in the collecting basin, the volume was 4–5 l less than expected. Reduction in the volume was due to evaporation and the plant's water uptake.

Plant growth and development demand water and essential elements. Plant's nutrient uptake requires a transpiration flow, which is driven by water uptake. Roots perform the main nutrient absorption role in hydroponic systems through the mass flow mechanism (Kirkham 2014; Marschner and Marschner 2012). In the VWP, vetiver grass nutrient uptake simultaneously occurs with water uptake, and consequently, EC rises in the outlet water (Table 1).

In Table 1, the inlet and outlet EC range were between 700 and 3000 μS m^{-1}, which constrained irrigation uses to a slight to moderate degree. The wastewater was rated a very satisfactory class (1500–5000 μS m^{-1}) and is usable for all classes of livestock and poultry use. However, the Food and Agricultural Organisation suggests that "it may cause temporary diarrhoea

Table 1 Effect of VWP with vetiver grass on wastewater

Inlet					Outlet			
Input wastewater flow (l day^{-1})	60	80	100	160	60	80	100	160
EC (μS m^{-1})	1845 ± 18	1845 ± 22	1848 ± 15	1846 ± 16	1954 ± 20	1941 ± 21	1888 ± 18	1885 ± 25
BOD_5 (mg l^{-1})	14.4 ± 0.2	12.8 ± 0.1	13.9 ± 0.5	14.4 ± 0.2	3.1 ± 0.3	3.8 ± 0.1	4.2 ± 0.2	4.7 ± 0.1
DO (mg l^{-1})	1.7 ± 0.1	1.9 ± 0.2	1.7 ± 0.2	1.6 ± 0.1	7.8 ± 0.3	7.7 ± 0.1	6.8 ± 0.2	6.1 ± 0.2
NO_3^- (m gl^{-1})	41.2 ± 1.5	40.8 ± 2.3	42.5 ± 1.2	43.4 ± 1.6	3.9 ± 0.4	12.2 ± 0.4	18.8 ± 0.7	27.6 ± 1.1

The different parameters measured are expressed as average ± standard deviation, n = 10

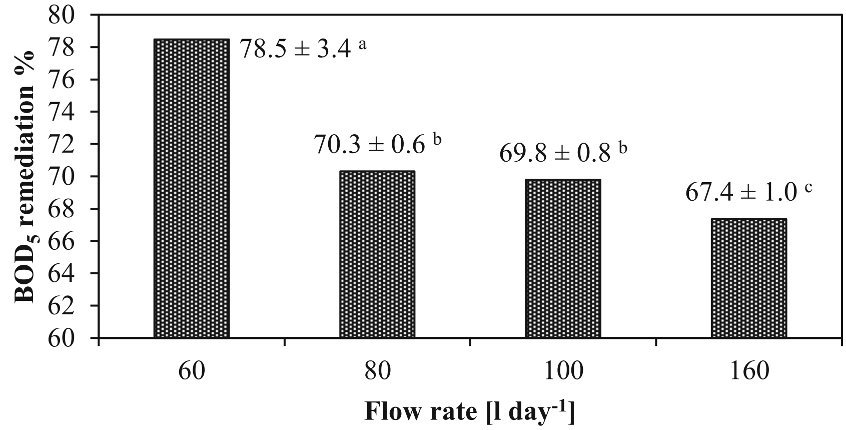

Fig. 2 Reduction of BOD_5 by vertical wastewater phytoremediation

in livestock not accustomed to such water; watery droppings in poultry" (Ayers and Westcott 1985). The upper limit of nitrate and nitrite ions recommended for livestock, and drinking water is 100 mg l^{-1}, which both inlet and outlet measurements were within. FAO guidelines of nitrate in inlet water are more stringent, at 30 mg l^{-1}, restricting irrigation uses. In the outlet flow, the water quality was improved to the slight to moderate range (5–30 mg l^{-1}) with the exception of the flow rate of 60 l day^{-1}, which achieved 5 mg l^{-1}, which is suitable for any irrigation use (Ayers and Westcot 1985). In Table 1, the allowable concentration of DO for inlets was considered less than the minimum quality for warm-water biota (5.0–6.0 mg l^{-1}) and for cold-water biota (6.5–9.5 mg l^{-1}). Conversely, DO concentrations of outlets were qualified for aquatic life purposes. Generally, water with a maximum of 30 mg l^{-1} BOD_5 concentration can be disposed in water bodies; hence, both inlet and outlet were appropriately balanced (Alabaster and Lloyd 1982).

The performance of the system in the remediation of BOD_5 and NO_3^- is shown in Figs. 2 and 3. The best remediation results occurred in the flow rate of 60 l day^{-1}.

In Fig. 2, BOD_5 is biochemical oxygen demand. The flow rates shown with different letters were significantly different ($p < 0.05$) in their BOD_5 remediation. The different parameters measured are expressed as average ± standard deviation, $n = 10$.

Trickling filters achieve 85–90% BOD_5 removal efficiency (Ali et al. 2017; Davis 2020); furthermore, constructed wetlands achieve more than 60% BOD_5 removal (Jin et al. 2002; Merlin et al. 2002; Vymazal 1999). In relation to Fig. 2, VWP BOD_5 removal efficiency is lower than the trickling filters case and higher than in constructed wetlands.

In Fig. 3. the reduction of nitrate removal as the flow rate increases is clearly seen. Each flow rate was consistently significantly different ($p < 0.05$) from the others. The different parameters measured are expressed as average ± standard deviation, $n = 10$.

In both Figs. 2 and 3, results showed a lapse between BOD_5 and NO_3^- reduction in flow rates 100 and 160 l day^{-1}. In agreement with previous studies, in phytoremediation, organic matter is mostly removed by microbial flora of the rhizosphere, but for NO_3^-, both plant uptake and microbial processes are

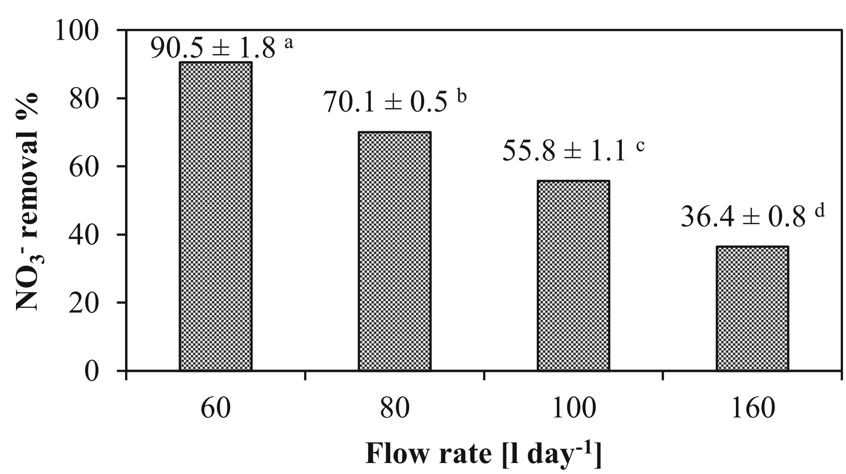

Fig. 3 Reduction of NO_3^- by vertical wastewater phytoremediation

involved (Pivetz 2001). The observed delay could be due to different active processes in the reduction of BOD_5 and NO_3^- in the system.

Considering differences in Figs. 2 and 3, it is apparent that the BOD_5 data showed a gentle reduction through NO_3^- data at the same flow rates dropped sharply and had no consistent trend. Upon closer inspection, the gap in reduction is more obvious; the reduction of BOD_5 and NO_3^- remediation performance in flow rates 60 and 160 l day^{-1} was 11% and 54%, respectively. The dependency of BOD_5 remediation performance of the inlet flow rate of wastewater is less than NO_3^-, in the VWP with vetiver grass. It is apparent that there is a limit to the mass able to be taken up in effect, organic molecules greater than the limit may not be absorbed by the plant roots, and conversely NO_3^- uptake occurs by mature root systems (Marschner and Marschner 2012).

In this experiment due to a short term of growth (1 full day for each experimental period), plant growth did not show any apparent difference. A small amount of NO_3^- changes in the system was not solely accounted for by the plant component. Overall, this method like other phytoremediation systems may be used in locations that have no serious limiting conditions for plant growth (Banjoko and Eslamian 2016; Furze et al. 2017; Parvizi et al. 2016). Moreover, due to good remediation performance and higher area efficiency than other plant-based systems, the current system would complement local urban wastewater treatment to enable simultaneous water reuse and green space, especially pertinent in arid and semi-arid environments (Hasanzadeh et al. 2020; Parnian et al. 2020) and their rehabilitation.

Conclusions

The developed vertical agricultural system enhances the area efficiency of the wastewater phytoremediation system. Thus, in the current study by using vetiver grass in the vertical agriculture system, with the aim of wastewater phytoremediation, a new method named as vertical wastewater phytoremediation (VWP) was created. The performance of the system was good, and effectively reduced BOD_5 and NO_3^- concentrations and increased EC and DO of the outlet flow. Additionally, the best performance of BOD_5 reduction (78.47%) and NO_3^- reduction (90.53%) occurred in flow rates of 60 l day^{-1}; minimum performance for both was observed in 160 l day^{-1}. In fact, BOD_5 (about 11%) remediation performance dependency of the inlet flow rates of wastewater is less than NO_3^- (about 54%), in the VWP with vetiver grass. Finally, it is concluded that in the novel method of wastewater remediation, VWP was efficient and appropriate in the current study. Field trials are required to confirm the potential application and suppression of water pollution in coastal and marshland water bodies.

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Authors' contributions Amir Parnian performed the experimentation; Amir Parnian and James N. Furze performed the analysis and wrote the manuscript.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Competing interests The authors declare they have no competing interests.

Ethics approval and consent to participate N/A.

Consent for publication Authors give full consent for data contained herein to be published; no external data sources were used.

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