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EFFECTS OF VARIOUS PLANTS ON TREATMENT EFFICIENCY OF HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLANDS BASED ON THE HYDRAULIC RETENTION TIME

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Abstract

In this study the effectiveness of *Lactuca sativa*, *Medicago sativa* and *Phragmites australis* for the treatment of domestic wastewater in horizontal subsurface flow was investigated. The removal efficiency of chemical oxygen demand (COD), total nitrogen (TKN), total phosphorus (TP), and total suspended solids (TSS) was measured. The experiment was conducted in two different retention time (5 and 7 days) in three seasons (spring, summer and fall). The removal efficiency was increased as the retention time increased. Based on the results, *M. sativa* had the highest removal efficiency of COD (90.7%), TSS (87.8%) and TKN (59%) in 7 days HRT. Meanwhile, *P. australis* removed (67%) TP during 7 days HRT from wastewater. Seasonal changes showed different effects on removal rate and L. sativa showed lower removal efficiency in compare to other two plants.

Key words: Lactuca sativa, *Medicago sativa*, *Phragmites australis*, sub-surface flow constructed wetland, wastewater treatment

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1. Introduction

To promote environmental quality, remediation techniques is one of the key factors which can be used for wastewater treatment (Fortuna et al., 2011). Phytoremediation as an environmentally friendly, low cost and effective method can be implemented in constructed wetlands (Calheiros et al., 2015; Darajeh et al., 2017; Malschi et al., 2018). For wastewater treatment, different types of constructed wetlands (CWs) have been used around the world extensively (Goswami et al., 2017; Vymazal, 2010). It should be noted that CWs is considered as an effective method for reuse and treatment of wastewater while producing less greenhouse gas emission (Chen et al., 2011). Wide range of wastewaters such as agricultural municipal, and industrial have been remediated using constructed wetland (Pedescoll et al., 2015; Qasaimeh et al., 2015). Besides, the major application of plants in CWs is providing suitable conditions for removal of pollutants such as nutrients and heavy metals (Goswami et al., 2917; Riggio et al., 2018; Shahid et al., 2019). As the nitrogen and phosphorus are essential elements for plants and living beings, the excess of these elements is the crucial that threatens the water quality (Amanatidou et al., 2018; Chang et al., 2006). CWs with emergent plants vegetation are more efficient rather than unplanted filters and some species such as *Phragmites australis* are more efficient in compare to the others (Zhang et al., 2010).

Wide range of aquatic plants are capable to remove organic, inorganic and heavy metals from water bodies (Malschi et al., 2015; Rezania et al., 2016a). For instance, up to 99% of COD removed with

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polyculture of ornamental flowering plants in horizontal subsurface flow CW. According to Brisson and Chazarenc (2009), the plant growth and phytoremediation performance can be influenced by some environmental factors like solar radiation, temperature, water salinity and pH. Hence, high growth rate of aquatic plants in wetlands and warm environment can increase the efficiency of phytoremediation (Rezania et al., 2016b). As described by Engloner (2004), for effective phytoremediation, water availability in plants shoot is considered as an important factor which is more crucialin dry habitats in comparison to wet habitants (a maximum water depth should be 30 to 40 cm), respectively.

Phragmites australis with a large diversity of species is the most often used emergent plant in CWs with high potential for remediation of various type of pollutants (Rezania et al, 2019). In addition, *Phragmites* with wide worldwide distribution had a considerable effect on climate change (Engloner, 2009). For better remediation performance in horizontal subsurface flow CWs, *Phragmites australis* (Common reed) is usually planted with a combination of some species such as *Phalarisarundinacea*and *Reed canarygrass* (Vymazal, 2013). *Phragmites australis* aboveground produces < 1000 g m $^{-2}$ on dry matter basis wet biomass in natural stands (Vymazal and Březinová, 2016).

As reported by Panchenko et al. (2017), *M. sativa* is one the best-known member of alfalfa family which is the effective in phytoremediation. Lettuce (*lactuca sativa)*, is an edible vegetable which is sensitive to the toxic environments and capable to remove different types of heavy metals from soil and water bodies (da Silva et al., 2015; Tang et al., 2016).

Moreover, there is not many published study in regard to using *M. sativa* and *L. sativa* for phytoremediation of organic and inorganic compounds from wastewater. Therefore, the main objective of this study is to determine the effect of nutrient removal by *Medicago sativa, Lactuca sativa,* and *Phragmites australis* in the retention time of 5 and 7 days.

2. Material and methods

2.1. Experimental setup

As shown in Fig.1, the fabrication was built with 1.15 mheight, 0.75 m width and 0.6 m depth. The fabrication was filled with a large stones with 15 to 32 mm diameter at the bottom layer and medium stones with 9.5 to 15 mm diameter in the middle and small stones at the top with 6 to 9 mm diameter. Then, mixed with the sand which resulted totally 0.4 cmporosity. The container was filled with farming soil with the depth of 30 cm and parallel grooves were considered for future plantations. Then, cultivating soil was added to create the proper environment for the growth of plants. Three reactors were named A, B and C by culturing *M. Sativa*, *L. sativa* and *P. Australis,* respectively. In addition, the wastewater flow rate was continually with a flow rate of 0.093 m3/d with 5 days HRT and with a flow rate of 0.066 m3/d in 7 days HRT. In the cultivation system, *M. Sativa* and *M. Sativa* had long roots (10 cm) with long root inside the sand while the length of *L. Sativa* roots was 6 cm. *P. australis* root was bushy that reached to the bottom of soiland *L. Sativa* roots with radius shape was inside the sand. A reactor without plant considered as control to compare with the planted reactors. The pump model was (PED ROLLO CPM 158-E) and the samples were collected from influent and effluent of each CWs. The samples was taken once a week and lasted for 20 days of each month for each season.

2.2. Characteristics of wastewater

Table 1 shows the characteristics of wastewater which used as influent in this study.

Table 1. Influent concentration of parameters in untreated wastewater

Parameters (mg/L)	***Value***
TSS	202.4
TKN	45.5
TP	17
COD	480

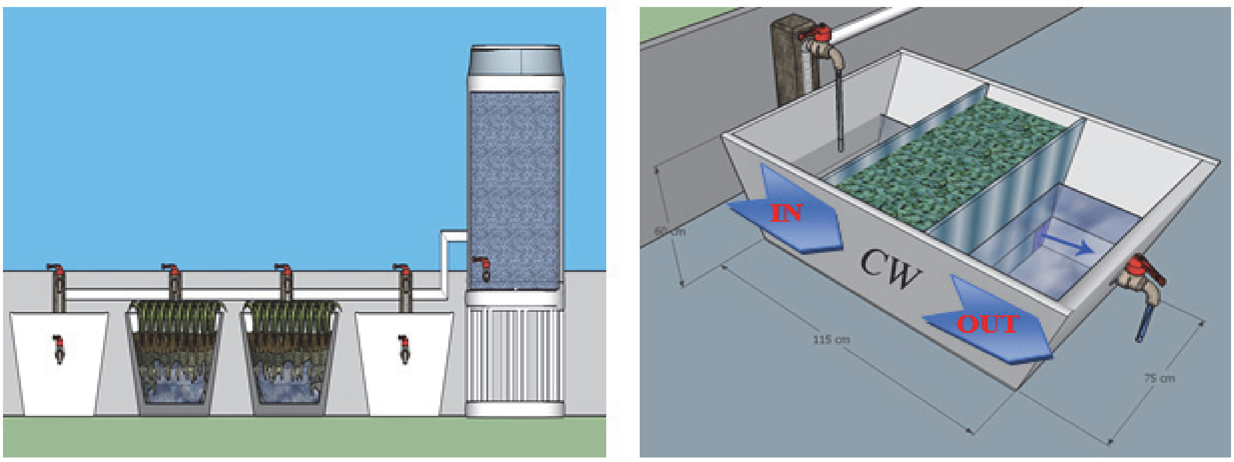


Fig. 1. Schematic of experimental design

2.3. Operational procedure

Table 2 shows the calculation of HLR based on the fabrication dimensions.

Table 2. Calculations of HLR

A (m^2)	*V (m^3)*	*Q (m^3/d)*	*HLR (m/d)*	*HRT (day)*
0.78	0.46	0.093	0.11	5
0.78	0.46	0.066	0.08	**7**

HLR and HRT shows the amount of influent contamination to wetlands which is calculated using Eqs. (1) and (2):

$$HLR = \frac{Q\left(m^3 d^{-1}\right)}{A\left(m^2\right)} \quad (1)$$

$$HRT = \frac{V\left(m^3\right)}{Q\left(m^3 d^{-1}\right)} \quad (2)$$

By considering the fabrication size, the influent rate calculated which was 0.093 m^3/d for 5 days HRT and 0.066 m^3/d for 7 days HRT.

All the parameters were investigated in accordance with APHA (2005). COD was measured by colorimetric method (5220-D) and TSS by using Method No. 2540D. TP was measured using vanado-molybdate colorimetric method by measuring the absorbance at a wavelength of 420 nm (Fiske and Subbarow, 1925). TKN was measured using APHA (2005). The removal efficiency of TKN, TP, TSS and COD in the effluent was calculated based on the difference between the influent and effluent divided by the concentration of influent (Eq. 3). The standard deviation (SD) was calculated and the results were analyzed using excel. The major equations were calculated with a correlation index of 0.97.

$$R = \frac{C_0 - C_e}{C_e} \times 100 \quad (3)$$

where: C_0 is the initial concentration, C_e is the final concentration and *R* is the removal efficiency.

3. Results and discussions

3.1. Removal efficiency of TKN, PO_4^{-3}, TSS and COD

The removal efficiency in two different HRT (5 and 7 days) using *L. sativa, M. sativa* and *P. Australis* is shown in Table 3.

Based on the results, 89.8 % COD and 87.5% TSS removed by *P. astralis*in 7 days HRT. In a study by Çakir et al., (2015), *P. astralis* removed 62.5%, 86.3% of COD and TSS from domestic wastewater with a hydraulic loading rate of 0.050 m^3 day^{-1} m^{-2}.They found that for some nutrients like Phosphorus and Ammonium–Nitrogen lower removal rate is expected using subsurface horizontal-flow constructed wetlands. Similarly, only 51.6 % TKN and 67% TP removed in 7 days retention time using *P. astralis* (Table 3).

Table 3. The removal rate of TKN, TP, TSS and COD based on 5 and 7 days retention time

Reactors	*Parameter*	*HRT (day)*	*C0*	*Ce*	$C_0 - C_e$	$R = \frac{C_0 - C_e}{C_0} \times 100$
A *M. sativa*	COD	5	480.2	53.6	426.6	88.8
		7	480.2	44.7	435.5	90.7
	TSS	5	202.4	25.8	176.6	86.9
		7	202.4	24.7	177.7	87.8
	TKN	5	45.5	22.6	22.9	50.3
		7	45.5	18.6	26.9	59
	TP	5	17	8	9	52.9
		7	17	6.3	10.7	62.9
B *L. sativa*	COD	5	480.2	55.9	424.3	88.3
		7	480.2	51.9	428.3	89
	TSS	5	202.4	27.4	175	86.4
		7	202.4	27.1	175.3	86.6
	TKN	5	45.5	24.7	20.8	45.7
		7	45.5	23.8	21.7	47.7
	TP	5	17	8	9	52.9
		7	17	7.7	9.3	54.7
C *P. australis*	COD	5	480.2	52.6	427.6	89
		7	480.2	48.8	431.4	89.8
	TSS	5	202.4	27	175.4	86.6
		7	202.4	25.3	177.1	87.5
	TKN	5	45.5	24	21.5	47.2
		7	45.5	22	23.5	51.6
	TP	5	17	6.8	10.2	60
		7	17	5.6	11.4	67

According to Rodríguez and Brisson (2015), *P. astralis* was more effective in COD removal rather than TN and TP. Meanwhile, there was not significance differences in removal of TSS in compare to the control due to abiotic process. In CW with plantation of *P. australis and C. angustifolia,* with an extended retention time and higher COD influent, the removal efficiency increased (Zhu et al., 2014). As found by Sultana et al. (2016), by using *P. australis,* 91% COD removed for treatment of secondary cheese whey. In addition, they found that the one day HRT has effect on COD removal efficiency meanwhile temperature is not significant parameter for COD removal. Similarly, the removal rate of all parameters was higher in 7 days HRT in compare to 5 days HRT.

Moreover, by using *M. sativa* 90.7% COD, 87.8% TSS, 59% TKN and 62.9% of TP removed in 7 days HRT. Meanwhile the removal rate by using *L. sativa* for COD, TSS, TKN and TP was 89%, 86.6%, 47.7% and 54.7%, respectively (Table 3).

3.2. Effect of seasonal changes on the removal efficiency of TKN- PO_4^{-3}, TSS and COD

During five years experiment, *P. Australis* was effective in removal of BOD and COD as reported by Březinová and Vymazal (2014). In another study, Carballeira et al. (2016) found the high removal of TSS using *P. australis*in horizontal subsurface flow CW in fall. As shown in Fig. 2, the highest removal of TP and TSS was in the fall season. In addition, highest COD removal occurred in spring meanwhile highest TKN removal observed in the summer season. According to Vymazal (2010), 60 to 80% of nitrogen present in wastewater is removed using wetland plants. Nutrients such as phosphorus and nitrogen are absorbed in the form of ion through root, while the nitrogen available in wastewater is converted into nitrite or nitrogen via microorganisms by oxidation and to ammonium nitrogen by deoxidation. So, it can be concluded that the absorption rate can be influenced by changes in temperature. Fig. 2 shows the removal efficiency of parameters based on the three seasons of the experiment.

In this study, TKN removal in spring, fall and summer was 47.8%, 48.7% and 65.8%, respectively. Hence, TP removal was 58%, 65% and 78% respectively. This result confirmed that TP removal in cold season was higher than warm season that confirmed the temperature was significance factor for TP removal. Similarly, temperature was significant factor for TSS removal in this type of constructed wetlands. On contrary, COD removal was higher spring in compare to summer and fall. It means that COD removal was not effective in cold seasons which was the lowest in fall season.

3.3. Investigation for the removal rate of nutrients using different plants

Fig. 3 shows the removal rate of TKN, TP, TSS and COD by *M. sativa, L. sativa, and P. australis*. Different plans showed different ability of removal. Based on the results, the highest removal of TSS and COD removal obtained using *M. Sativa* by 85.5% and 88.3 % respectively.

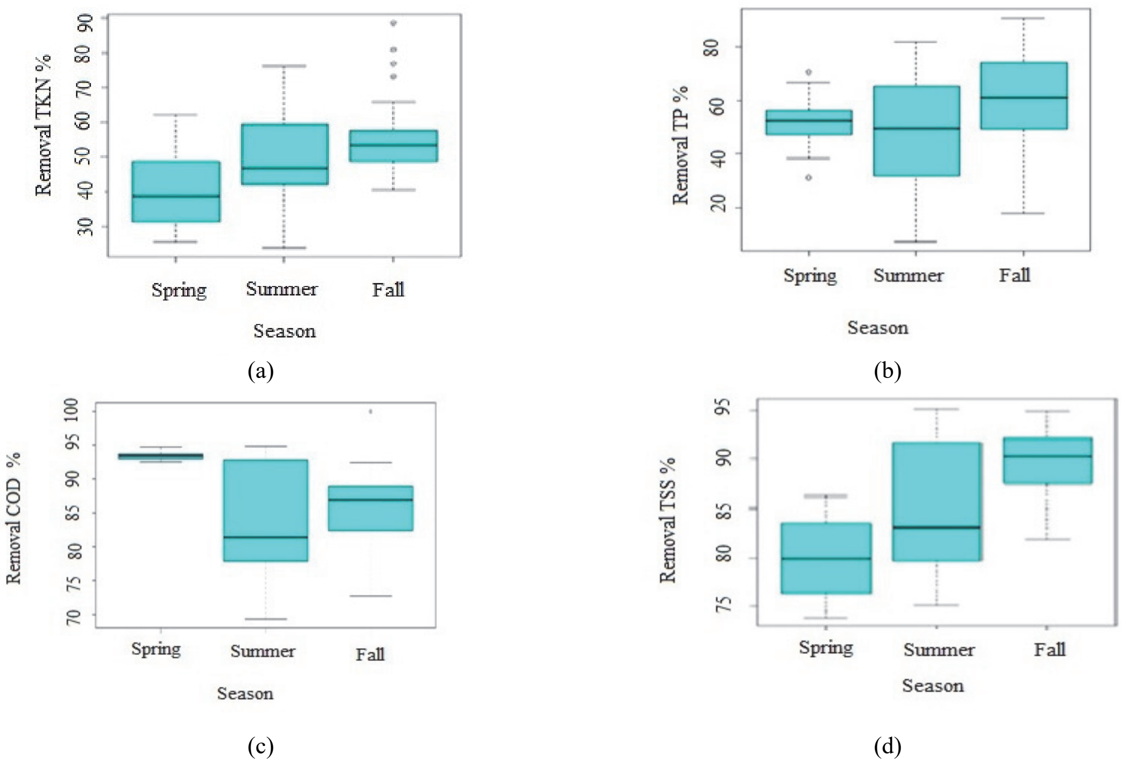
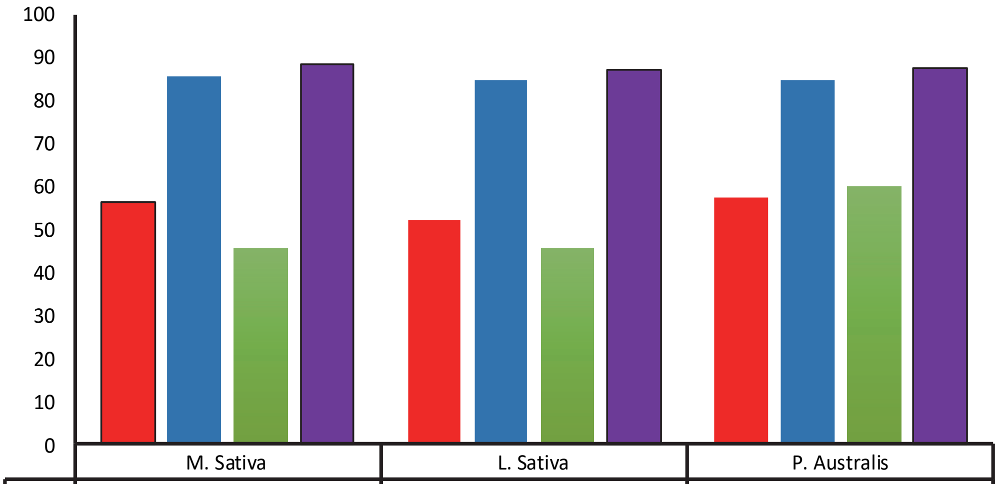


Fig. 2. The removal efficiency of (a)TKN, (b) PO_4^{-3}, (c) COD and (d) TSS based on the three seasons



	M. Sativa	L. Sativa	P. Australis
TP	56.4	52.1	57.2
TSS	85.5	84.6	84.8
TKN	45.6	45.6	60
COD	88.3	87.1	87.5

Fig. 3. Nutrient removal by *M. Sativa* (A), *L. Sativa* (B) and *P. Australis* (C)

As shown in Fig.3,the highest removal rate of TKN and TP was by *P. Australis* (60% and 57.2) respectively. Fuchs et al. (2011) found lower removal rate of TN and TP using *P. australis* at 35.6% and 31%, respectively. The reduction in removal of nitrogen was due to material grading usage in system layering. Also, it can be due to the proper design of the pilot, appropriate compatibility and the simultaneous growth of plants during the first three months of operation. Based on the results, *L. Sativa* was not effective in compare to others but this plant removed only 52.1% TP, 84.6% TSS, 45.6% TKN and 87.1% of COD.

4. Conclusions

This study compared the ability of three wetland plants (*medicago sativa, lactuca sativa, and phragmites australis*) for phytoremediation of domestic wastewater. The significant results are as follows:

- Seasonal changes had affect in the removal of parameters while the highest removal of TSS and TP was in fall which was for COD and TKN in spring and summer, respectively.
- Removal efficiency in 7 days HRT was higher than 5 days for all the parameters.
- Highest removal ofCOD, TSS and TKN obtained using *M. Sativa* while for TP the highest removal was using *P. Australis*.
- *L. Sativa* removed 52.1% TP, 84.6% TSS, 45.6% TKN and 87.1% COD but was not effective in compare to *M. Sativa* and *P. Australis*.

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