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Treatment of domestic wastewater using a lab-scale activated sludge/vertical flow subsurface constructed wetlands by using *Cyperus alternifolius*

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ABSTRACT

Activated sludge-vertical flow subsurface constructed wetland systems (VFSCW) were investigated in order to remove COD and N in sewage of Aksaray. Over a study period of 25 days, the system was able to achieve moderate total nitrogen removals with the range of removal efficiencies of 35.28% and 59.84% at organic loading rates of 940 mg TN/m^2 d. In the effluent of the system, COD and TN observed was higher than those by last of operation as roots of plant were decomposed and dissolved in the effluent of the system. Conventional wastewater treatment plant could not remove N and P in sewage in order to prevent eutrophication in receiving water bodies. CWs may be an economical option for N and P removal in the effluent of secondary treatment such as activated sludge, trickling filter of oxidation ponds because conventional nutrient removal is much costly and complex compared to natural treatment systems.

1. Introduction

Constructed wetlands (CWs) are land based wastewater treatment systems that consist of shallow ponds, beds, or trenches which contain floating or emergent rooted wetland vegetation. CWs are used in order to treat domestic wastewater from rural areas all over the world since they were firstly applied in Germany in the 1960s. The potential of CWs for the removal of contaminants occurring in urban wastewater has attracted increasing interest over the last decades, with a view to treating wastewaters from small populations to comply with environmental regulations such as the European Union Directive 91/271 and the US EPA Clean Water Act (Matamoros and Bayona, 2008). An economical and ecological method to treat wastewater by constructed wetlands has been widely used in the world during the past decades. Constructed wetlands can effectively remove suspended solids, organic pollutants and nutrients from wastewater (Vymazal, 2007; Kadlec, 2008; Peng et al., 2014). CWs provide an inexpensive and reliable method for treating a variety of wastewaters such as sewage, landfill leachate, mine leachate, urban storm-water, agricultural run-off, are very efficient for nutrient removal are comparatively simple to construct, operate, maintain and are suitable for advanced and polishing treatment if water reuse is an option (Białowiec et al., 2014). Probably more than 100,000 CWs worldwide currently treat over billion litres of water per day (Türker et al., 2014).

Estimates from the World Health Organization (WHO) and the Water Supply and Sanitation Collaborative Council indicate that <18% of rural populations have access to sanitation services in developing countries (Massoud et al., 2009). As of 2010, the amount of domestic wastewater treated in Turkey is just 76% for discharged wastewater. The discharged wastewaters have been treated by using treatment methods such as advanced biological of 37.9%, biological of 34.3, physical of 27.6%, and natural of 0.2% (TUIK, 2012).

Methods of improving the quality of water sources and dealing with domestic wastewater in rural areas have been an urgent concern for Turkey and other countries. The application of CWs has significantly expanded from traditional tertiary and secondary domestic sewage treatment to the treatment of agricultural effluents, industrial effluents, landfill leachate as well as urban and high way run off (Wu et al., 2013).

Abbreviations: ANR, assimilative nitrate reduction; AS, active sludge; ASR, active sludge reactor; C, carbon; COD, chemical oxygen demand; CWs, constructed wetlands; EPA, Environmental Protection Agency; HLR, hydraulic loading rate; HRT, hydraulic retention time; N, nitrogen; NO_3-N, nitrate-nitrogen; P, phosphorus; SRT, sludge retention time; SS, solids in suspension; SSFW, subsurface flow constructed wetland; TN, total nitrogen; VSFCW, vertical subsurface flow constructed wetlands; VSS, volatile suspended solids; WHO, World Health Organization.

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Nitrogen is one of the main causes of eutrophication in water bodies, especially for lakes and rivers. Discharging into aquatic systems is a precedence in constructed wetland treatment, after the nitrogen removal in wastewater (Ye and Li, 2009; Ding et al., 2013). Depending on the plant type and flow regime, constructed wetlands may remove about 30–80% of nitrogen from domestic wastewaters and may also be successfully utilized for nitrogen removal from secondary effluents with efficiencies above 90% (Ayaz et al., 2012).

The aim of this study is determine the treatment performance of a lab scale vertical flow constructed wetlands planted *Cyperus alternifolius* treating effluent of a model activated sludge system feeding domestic wastewater to take attention for rural domestic wastewater in Turkey and other developing countries. Our specific objective was to determine the overall performance of the CWs in removal of COD and TN from wastewaters.

2. Materials and methods

2.1. *C. alternifolius* and reactor system

C. alternifolius, better known as the umbrella plant is a very popular house plant and commonly grown as a marginal pond plant. Growing to a height of 60 cm (24 in), the bracts are symmetrically arranged in an umbrella formation and held atop elegant stems that sway with the breeze, giving a tropical touch to the garden. This lovely and versatile plant is easily grown and makes an excellent ornamental waterside or marginal plant for water gardens. In the pond the plants grow best when half submerged up to 10 cm (4 in) on the margins of the pond. Ideally the pots should not be flooded with water. Moderate fertilization levels are required, but avoid high nitrogen levels (URL, 2014). *C. alternifolius* (umbrella grass) is a perennial herb, which grows in humid areas or swampland. It grows fast with strong root system. Its productivity is high and it can form a good landscape. *Cyperus* spp. has been used successfully in small-scale gravel-bed constructed wetlands in Australia and New Zealand (Chan et al., 2008). As identified by Hocking (1985) the attributes that make *Cyperus* spp. as a potentially useful plant for constructed wetlands include: year-round growth in warm temperate regions (withstanding moderate frosts), tolerance of hyper-eutrophic conditions and salinity, ease of propagation, and apparent lack of serious weed potential (Hocking, 1985; Chan et al., 2008).

An experimental activated sludge reactor (AS) following constructed wetland (CW) system with vertical subsurface flow (VSFCW) was built at laboratory in Environmental Department of Aksaray University (Fig. 3). AS reactor received domestic wastewater collected in the sewer system of the campus. AS reactor had dimensions of 7 × 18 × 30 cm; and consisted of aeration basin of 1.5 L and sedimentation basin of 0.65 L. Aeration basin and sedimentation unit was separated by a perforated plate that allowed water transition. AS reactor was operated by using hydraulic retention time (HRT) of 9 h and sludge retention time (SRT) of 20 days with sludge wasted from aeration tank which allowed nitrification process. The composition in the reactor was created by using air pump that could provide sufficient oxygen (>2 mg/L) in the aeration basin. The effluent of AS reactor had fed to VSFCW. Latter reactor had dimension of 55 cm length × 35 cm width × 25 cm height. Gravel of 10–30 mm in diameter was filled to a depth of 5 cm followed by an upper layer of 15 cm with sand of 1–3 mm in diameter and water level from surface is 5 cm. *C. alternifolius* was selected and transplanted into the VSFCW at a density of 20 stems/m^2. Wastewater of 4 L/d with a hydraulic loading rate (HLR) of 20.78 mm/d was introduced into the VSFCW.

Table 1
Characterization of wastewater during study period.

Parameter	Values		
	n	X_{ort}	σ
pH	8	7.6	0.2
COD_{total} (mg/L)	8	612.6	233.1
Total N (mg N/L)	8	66.9	12.8
Ammonium (mg NH_4^+-N/L)	8	50.8	4.5
Nitrate (mg NO_3^--N/L)	8	1.3	1.6
Phosphate (mg PO_4^{3-}/L)	6	16.9	2.3

Domestic wastewater was given to the reactors by peristaltic pumps. Reactor and removal studies were implemented in a fixed temperature of 25 °C.

2.2. Wastewater

Domestic wastewater was taken from a sewage canal on the campus of Aksaray University, Aksaray. This wastewater was analyzed for characterization and performance evaluation of the system as influent, aeration tank effluent and VSFCW effluent.

2.3. Analyses

The measurements of solids in suspension (SS), volatile suspended solids (VSS), and chemical oxygen demand (COD) were implemented by using standard methods (APHA, 2005). Merck Spectroquant kits were used for measuring ammonium nitrogen (NH_4-N). The values of pH were measured by pH 330i/SET equipment (WTW Germany). Nitrate, phosphate, analyses (DIONEX ICS-1000) were measured by the relevant instruments. Ammonium was measured photometrically a VIS spectrophotometer (Thermo Spectronic-Aquamate, USA) by Merc-Spectroquant kits (number: 14752) and total nitrogen (TN) measurements were realized by TOC-TN (Shimadzu TOC-VCPN) analysis system.

Each experiment was replicated three times, and the mean values were used in the analyses. If the standard errors (SE) were greater than 0.01, the test was repeated to control for errors.

3. Results and discussion

3.1. Characterization of wastewater

The wastewater taken from the drainage in Campus area, which removed suspended matters in pre sedimentation tank, feed to the reactor system by water. Samples analyzed during the working period could be seen in Table 1. Wastewater could be characterized as very polluted when its characterization in Table 1 is evaluated (Metcalf and Eddy, 2003; Orhon et al., 1997).

Results are very similar to previous study performed by Işık et al. (2010) in Aksaray. The high concentration of pollutant parameters could be linked to the cultural properties such as low water consumption, industrial discharges, and personal practices (Mahmoud, 2002).

Daily water production per person could be calculated as 156 L/day (σ = 65, n = 4) in studies concerning Turkey (Orhon et al., 1997; Işık et al., 2010), while the pollutants' values were accepted as 68 g COD/per day, 8 g N/per day; and 1.3 g PO_4^{3-}-P/per day. This value of wastewater production could be related to rainfall, fewer industrial discharge, and rates of water consumption in the region.