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The influence of plant roots on the clogging process and the extractive capacity of nutrients/pollutants in horizontal subsurface flow constructed wetlands

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ABSTRACT

The root system of plants grown in horizontal subsurface flow constructed wetlands (HSSF CWs), although it favors the removal of nutrients/pollutants from the wastewater under treatment, can contribute to the clogging of these systems. The objective of this work was therefore to evaluate the influence of Vetiver and Tifton 85 grass roots on the process of clogging and extraction of nutrients/pollutants in HSSF CWs. The drainable porosity in the medium was quantified before planting and after 250 days of cultivating the above-mentioned grass, having obtained the volume, productivity and nutrient extraction of the roots and shoots of these plants. There was a reduction in the porosity of the medium in the HSSF CWs due to the development of roots of the Vetiver and Tifton 85 grasses in the medium, however these roots occupied only 3.07 and 4.11% of the total pore space, respectively, and therefore are not factors of great influence in clogging process. HSSF CWs cultivated with Vetiver grass presented higher extractions of K and P by the roots, especially when the medium saturating solution presented greater availability of nutrients. On the other hand, higher extraction capacity of nutrients/pollutants was presented by the Tifton 85 shoots.

1. Introduction

The clogging process in horizontal subsurface flow constructed wetlands (HSSF CWs) can result from a number of factors, including: accumulation of suspended solids from the wastewater under treatment, biofilm formation by microorganisms, deposition of plant wastes generated by plants cultivated in these systems, wear of the filter material (substrate) and chemical precipitation of some chemical elements. This phenomenon can reduce the hydraulic conductivity in the porous medium, causing problems such as surface runoff, dead zones and short circuits, as well as reducing the hydraulic retention time in the system, compromising wastewater treatment efficiency (Kadlec and Wallace, 2009; Hua et al., 2014).

The cultivation of plants in the HSSF CWs, with consequent development of roots and rhizomes in the porous medium, can contribute to faster clogging of these systems. Authors such as Knowles et al. (2010), Pedescoll et al. (2011), Paoli and von Sperling (2013) and Miranda et al. (2017) stated that in planted units, mainly in those where cutting of the plant shoots is not frequently performed, plant senescence with the consequent fall of leaves and death of the root system can cause premature system clogging. On the other hand, authors including Brasil and Matos (2008), Fu et al. (2013), Matos et al. (2015) and Carballeira et al. (2017) stated that swelling as a result of root growth in the porous medium favors flow through the HSSF CWs bed, and also provide aerobic regions near the root zone, favoring the degradation of organic material in these systems.

According to Hua et al. (2014), the roots of plants grown in the HSSF CWs occupy less than 5% of the total bed porosity, having little impact on the hydraulic conductivity in the system. According to these authors, in the initial clogging stage the plant roots are most responsible for the obstruction of pores in the medium, however during the more advanced stages of the clogging process, root growth contributes to the opening of new porous spaces in the substrate. After death and degradation of roots and rhizomes there is an increase in the volume of voids, and consequently the hydraulic conductivity in the porous medium increases.

In addition to influencing the hydraulic conditions of the medium, plant cultivation in HSSF CWs provides the following benefits: absorption of nutrients/pollutants, formation of aerobic environments near the root system which favors the growth of heterotrophic and

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Table 1
Nutrient concentrations for the different electrical conductivity values (EC) in the porous medium saturating solutions.

EC	N	P	K	Ca	Mg	S	Fe	B	Cu	Mn	Mo	Zn
($dS\ m^{-1}$)	($mg\ L^{-1}$)							($\mu g\ L^{-1}$)				
0.2	11.5	0.8	6.5	10.4	3.1	4.1	0.3	32	1	45	1	6
0.5	38.3	3.8	24.3	25.9	7.8	10.4	0.8	81	3	113	2	15
1.0	82.8	8.9	53.9	51.8	15.6	20.7	1.6	162	6	227	3	29
1.5	127.4	13.9	83.6	77.8	23.3	31.1	2.4	243	10	340	5	44
2.0	172.0	19.0	113.2	103.7	31.1	41.5	3.2	324	13	454	6	58

autotrophic bacteria, supply of carbon to the microorganisms from root exudates, and increase the specific surface area of the porous medium which facilitates fixation of the bacterial biofilm (Białowiec et al., 2014).

The capacity of nutrient/pollutant extraction by plants via removal of their shoots and root system is still not well known, lacking further studies on the subject. According to Vymazal and Březinová (2016), the heavy metals content in tissues of the root system is substantially greater than that present in the plant shoots, which is due to the fact that the roots are responsible for absorption of these elements and they are not very mobile in the plant. Gao et al. (2014) studied the nutrient removal capacity by *Iris sibirica* cultivated in vertical flow constructed wetlands (VF CWs) and verified that accumulation of nitrogen and phosphorus in the plant roots was higher than in the shoots. According to the same authors, the higher the concentration of nutrients in the effluent being treated, greater is extraction by the plants until reaching a maximum point, which is characteristic of each crop.

Despite the higher levels of nutrients and metals in the root tissue of plants cultivated in CWs, their lower productivity in terms of dry mass in relation to the shoots may result in a small removal of these chemical elements, therefore evaluation of the nutrient/pollutant removal capacity should be performed based on the content present in plant tissue and its respective dry matter yield (Vymazal, 2016), as well as the frequency of harvesting the plant tissue. However, in most studies only the nutrient/pollutant contents in the root system and shoots were evaluated, and no information was presented regarding its removal capacity.

Considering the importance of the plant root system in the processes of clogging and nutrient/pollutant extraction in HSSF CWs, this work sought to evaluate the influence of plant roots in the process of clogging the porous medium of the HSSF CWs and to evaluate the nutrient/pollutant extraction capacity of Vetiver and Tifton 85 grass when grown in these treatment systems subjected to different nutrient availability in the medium saturating solution.

2. Material and methods

The experiment was conducted in the Hydraulics, Irrigation and Drainage Experimental Area of the Department of Agricultural Engineering, Federal University of Viçosa, Viçosa – MG, Brazil. The geographical coordinates of the site correspond to 20°46′08″ S latitude and 42°51′44″ W longitude, with an average elevation of 674 m.

The experiment was performed from March 5 to November 17, 2016, using Vetiver grass (*Chrysopogon zizanioides*) and Tifton 85 grass (*Cynodon* spp.) grown in HSSF CWs prototypes constructed of masonry, with rectangular shape and average dimensions of 0.92 m × 0.73 m × 0.35 m (width, length and height), totaling a surface area of 0.68 m^2. Drainage of these systems consisted of 32 mm PVC pipes, perforated and located opposite the entrance of the porous medium saturating solution, maintaining a saturation height of 0.25 m (useful height). The prototypes were filled with a 0.30 m layer of pea gravel (D_{60} = 9.1 mm and coefficient of uniformity – D_{60}/D_{10} = 3.1), and the Vetiver and Tifton 85 grasses were transplanted at a density of 12 propagules per m^2. The hydraulic retention time (HRT) in the system was 3.3 days and the mean hydraulic conductivity of 7,97 m d^{-1} (Brasil and Matos, 2008).

The experiment was conducted in a completely randomized design (CRD), with five treatments (salinity levels of the porous medium saturating solution) for each cultivated plant species.

The salinity levels of the nutrient solution saturating the porous medium were monitored via the electrical conductivity values of 0.2, 0.5, 1.0, 1.5 and 2.0 dS m^{-1}, where preparation of the porous medium saturating solutions was performed separately for each pre-determined electrical conductivity value (EC), which was measured using a benchtop conductivity meter, Hach model Sension 7. The pH of the solution was maintained between 5.5 and 6.5 using hydrochloric acid or sodium hydroxide solutions of 0.1 mol L^{-1}. The nutrient solution used as reference in this work was that of Hoagland and Arnon (1950), where the nutrient concentrations for the different EC values in the porous medium saturating solutions are shown in Table 1.

2.1. Evaluation of clogging as a result of the roots

Evaluation of influence of the plant root system in the clogging process of the HSSF CWs was performed by quantifying the drainable porosity of the porous medium (Hua et al., 2014; Dittrich and Klincsik, 2015; Carballeira et al., 2017), before and after cultivation of the Vetiver and Tifton 85 grasses. The methodology is not usually used in horizontal flow units, in reasons of the dimensions used, but provide the direct results of porosity of the systems and do not present the problems reported in the quantification of hydraulic conductivity, as described by Matos et al. (2017) and other authors.

Initially, the height of the substrate (0.30 m) and the volume of water required to saturate completely the layer of pea gravel were measured, thus obtaining the initial pore volume. After the 250 day cultivation period of the plants in the prototypes, the same substrate height and the volume of water needed to saturate it were measured again, including the presence of the roots to determine the final pore volume. Then the roots were removed from the substrate and volume quantified. The volume determination was performed by placing the roots in a graduated cylinder containing water, where the volume difference resulting from introduction of the roots was considered equivalent to the effective volume of the roots.

From the initial and final pore volume, substrate height and surface area of each prototype, the initial and final drainage porosity of each system was calculated, as well as the reduction in pore volume as a result of root growth. This was compared to the effective root volume of the plants.

2.2. Nutrient/pollutant extraction by the plants

The nutrient/pollutant extractions by roots and shoots of the Vetiver and Tifton 85 grasses were obtained from the root and shoots biomass productivity and the nutrient content present in this tissue. The plant shoots were cut every 30 days, with the first cut conducted on April 16 and the last on November 16, totaling 7 cuts.

The laboratory analyses were performed at the Laboratory of Soils and Solid Residues of the Department of Agricultural Engineering,