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Evaluation of the effects of drainage and different rest periods as techniques for unclogging the porous medium in horizontal subsurface flow constructed wetlands

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ABSTRACT

The development of easy-to-perform techniques for unclogging of horizontal subsurface flow constructed wetlands (HSSF-CW) is essential to make them operationally simpler and increase their useful life. The objective of this work was to evaluate the drainable porosity, the extension of the bed presenting surface runoff and the characterization and quantification of the constituent solids clogging the porous medium of the HSSF-CW, after they were drained and submitted to different rest periods. Three systems were evaluated measuring 1.0 m wide and 4.0 m long, with 0.25 m working depth; one was cultivated with Vetiver grass (*Chrysopogon zizanioides*), the other with Tifton 85 (*Cynodon* spp.) and a control, in which no plant species were cultivated, where all were used for the treatment of municipal wastewater and presented conditions of partially clogged porous medium. After drainage of the system, the drainable porosity of the porous medium increased exponentially with the rest time during which they remained unsaturated, where the control and the HSSF-CW cultivated with Tifton 85 grass tended to stabilize. There was an increase in porosity of 18, 19 and 39% in relative to the initial porosity for the control HSSF-CW and those cultivated with the Tifton 85 and Vetiver grasses, respectively. Surface runoff in the HSSF-CW bed stopped completely between the 7th and 13th days after draining. However, no change was observed in the volatile solids content in the clogging material of the porous medium due to drainage of the HSSF-CWs.

1. Introduction

The clogging process observed in horizontal subsurface flow constructed wetlands (HSSF-CW) is due to numerous factors, which may include: accumulation of suspended solids from the wastewater under treatment, formation of a biofilm resulting from microbial growth adhered to the substrate (filter medium), deposition of residues from plants grown in these systems, wear of the filter material and precipitation of some chemical elements. This phenomenon can reduce the hydraulic conductivity in the porous medium, resulting in problems such as surface runoff, dead zones and short circuits, and reduce the hydraulic retention time in the system, compromising the wastewater treatment efficiency (Kadlec and Wallace, 2009; Knowles et al., 2011; Hua et al., 2014b; Aiello et al., 2016; Matos et al., 2017).

Remediation of clogging of the HSSF-CW porous medium can be carried out by employing *ex situ* or *in situ* methods. The former is characterized as being more invasive to the system, requiring substitution of the substrate, which is an important portion of the inherent costs of utilizing the CWs. According to Kadlec and Wallace (2009), substrate substitution can cost between 10 and 19% of the initial construction cost of the units, in addition to the financial resources required for final disposal of the material removed. In relation to *in situ* unclogging, the main advantage is the possibility of preserving part of the biofilm formed or providing conditions for the microbiota to recover in a short period of time (Guofen et al., 2010), which is important for maintaining the treatment efficiency of the system. Of these methods, highlighted are aeration, backwashing, the addition of nutrients and chemical substances, application of earthworms and leaving the system at rest (Hua et al., 2010; Nivala et al., 2012; Du et al., 2016; Miranda et al., 2016).

Considering the simple operation and maintenance of HSSF-CW, unclogging techniques that are easy-to-perform and interfere as little as possible with the operational conditions of these systems should be prioritized. Authors such as Knowles et al. (2011), Nivala et al. (2012)

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and Hua et al. (2014a) recommended leaving the system at rest in an unsaturated condition as a natural technique for unclogging of the constructed wetlands, due to the low cost and the fact that no high level of technical knowledge is required. Leaving the system at rest in unsaturated conditions is an extremely beneficial technique for reversing clogging of the HSSF-CW porous medium, because it favors degradation of the organic matter retained in the pores. The objective of this technique is to drain the system, which allows for aeration of the porous medium with consequent increase in aerobic degradation rates of the organic solids (Nivala et al., 2012; Hua et al., 2014b; Carballeira et al., 2017). Batchelor and Loots (1997) verified a reduction in the extent of surface runoff after the HSSF-CW were subjected to a resting period under unsaturated conditions for two weeks. According to these authors, the degradation of organic material accumulated on the surface allowed for infiltration of wastewater in the HSSF-CW bed.

According to Hua et al. (2014a), Carballeira et al. (2017), Hua et al. (2017, 2018), information on the resting period required for unclogging of vertical flow constructed wetlands (VF-CW) can be well defined. However in HSSF-CW the rest time should be determined for each type of wastewater due to the particularities of each system, as depth, type of substrate, cultivated plant species, and the great influence of environmental factors. Thus, HSSF-CW operated in cold and humid conditions require a longer rest period than those located in hot and dry climates (Knowles et al., 2011). In addition, Hua et al. (2014b) emphasized that the ideal rest period in cultivated HSSF-CW must provide positive effects of pore space recovery with conditions conducive to plant survival.

Based on the above, there is a great need for more information regarding the drainage and resting of HSSF-CW as a technique for unclogging the porous medium. Thus, the aim of this study was to evaluate the drainable porosity, the extension of the bed with surface runoff and alteration of the volatile solids content in the HSSF-CW porous medium being drained and undergoing different periods of unsaturated rest.

2. Materials and methods

Evaluation of the effect of bed drainage as a technique for unclogging the porous medium was carried out in three HSSF-CW, one cultivated with Vetiver grass (*Chrysopogon zizanioides*), another with Tifton 85 grass (*Cynodon* spp.) and one control which contained no plant species, all used in the treatment of municipal wastewater and under conditions of partial clogging, presenting drainable porosity, respectively, of 18.0, 23.6 and 18.8% in the systems. The systems are located in the Experimental Area of Urban Waste Treatment of the Department of Agricultural Engineering, Federal University of Vicosa, Brazil. The geographical coordinates of the site correspond to latitude 20°46′20″ S and longitude 42°52′19″ W, with an average elevation of 677 m. Climatic conditions were monitored by means of an automatic meteorological station, installed near the experimental units evaluated.

The HSSF-CW, in operation since August 2014, were constructed with the following dimensions: 4.0 m long, 1.0 m wide and 0.3 m deep, with a level bottom. The support medium consisted of a 0.25 m layer of gneiss gravel (D_{60} = 9.1 mm and uniformity coefficient - D_{60}/D_{10} = 3.1), in which seedlings of the Vetiver and Tifton 85 grasses were transplanted with planting density of 12 propagules per m^2. The systems were fed with a mean flow rate of 0.22 $m^3\ d^{-1}$, resulting in an organic loading rate of approximately 100 $kg\ ha^{-1}\ d^{-1}$ of BOD or 160 $g\ m^{-2}\ d^{-1}$ of BOD of the cross sectional area, and hydraulic retention time (HRT) of 1.8 days. This HRT is close to that used by other authors (Costa et al., 2013; Miranda et al., 2016; Matos et al., 2017) to obtain high efficiencies in pollutants removal.

2.1. Evaluation of the surface runoff extension and drainable porosity of the HSSF-CW

The evaluation of unclogging of the HSSF-CW was carried out by monitoring the variations in drainable porosity of the bed (Hua et al., 2014a; Dittrich and Klincsik, 2015; Carballeira et al., 2017) and the extension of surface runoff in these systems (Miranda et al., 2016), which characterizes the wastewater flow on the HSSF-CW surface due to the porous medium clogging. The systems were initially evaluated on January 3, 2017 (start date of monitoring), being totally drained and submitted to rest periods in unsaturated conditions for 7, 13, 24 and 40 days, which were counted from the interruption of the municipal wastewater feed.

To determine the drainable porosity of each HSSF-CW, the 0.25 m deep gravel layer was totally saturated with water free of solids. Then the HSSF-CW was drained at a slow flow (less than 1.4 $L\ min^{-1}$, for about 4 h) in order to avoid washout of solids, quantifying the volume of water filling the porous medium for further calculation of the drainable porosity. After 4 h, the drained flow reduced significantly, but did not ceased, therefore the quantification of the total drained volume was performed after 12 h of draining the system, and was carried out at night to avoid considerable evapotranspiration losses in the HSSF-CW.

The drainable porosity was calculated by dividing the volume of water drained by the total volume occupied by gravel in the bed, multiplying the result by 100 to obtain a percentage. This variable was determined at the beginning of system monitoring (Day 0) and after the aforementioned days of rest. For example, after 7 days without feed flow and under unsaturated conditions, the HSSF-CW was saturated with water and the drainable porosity and the surface runoff extension evaluations were performed. It was then drained again to leave the bed at rest for another six days (13th day of rest), and so on. Monitoring of the surface runoff extension in the HSSF-CW was performed after the bed saturation and before the measurement of drainable porosity. For this, the gravel constituting the bed of the HSSF-CW was saturated to a height of 0.2 m (system operational level) by applying clean water, under a flow rate of 0.22 $m^3\ d^{-1}$, until the effluent flow equaled the influent flow. After stabilization of the system, the surface runoff distance was measured, using measuring tapes installed along the edges of the HSSF-CW.

2.2. Characterization of solids clogging the porous media of the HSSF-CW

Sample collection for characterization of the porous medium was carried out after the first drainage of all water present in the HSSF-CW. Sampling was performed by inserting a 0.10 m diameter PVC tube measuring 0.10 m in height in the bed, so that all material contained inside was removed by hand. Extraction of the substrate and accumulated solids was carried out in each third of the beds. After the solids separation from the gravel, the substrate was returned to the sampling site to reduce interferences in the hydrodynamics of the system. Samples were taken for analysis at the Laboratory of Soils and Solid Wastes of the Department of Agricultural Engineering, Federal University of Vicosa, where the substrate was washed using 1.0 L of water for each sample. Subsequently, the suspensions generated from the washing of each sample were placed in 2 L beakers and dried on a hot plate at 60 °C, and drying of the solids was completed in a forced air oven at 65 °C for 24 h (Miranda et al., 2016). After these procedures, the following analyses were carried out on the dry organic material: total solids content by the gravimetric method, volatile solids (VS) and fixed (FS) solids obtained after calcination in a muffle furnace at 550 °C for 2 h (Matos, 2015). At the end of the experiment, the same characterization procedures of the substrate and accumulated solids were performed, as described previously.