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Effect of reversal of the flow direction on hydrodynamic characteristics and plants cultivated in constructed wetland systems

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ABSTRACT. The objective of the present study was to evaluate the effect of reversal of the flow direction, when used the surface flow as an operating criteria, on hydrodynamic characteristics and plants grown in horizontal subsurface-flow constructed wetland systems (HSF-CWs). For this purpose, six HSF-CWs were used: two non-cultivated (HSF-CWs 1 and 4), two cultivated with Tifton 85 grass (*Cynodon* spp.) (HSF-CWs 2 and 5) and two cultivated with Alternanthera (*Alternanthera philoxeroides*) (HSF-CWs 3 and 6). It was made a reversal in the flow direction of the HSF-CWs 1, 2 and 3. The reversal of the wastewater flow direction was performed when the superficial flow of the wastewater applied (*SF*) reached 50% of the length of the HSF-CWs. There was a single reversal for each system, on different dates. Reversing the flow direction promoted distinction on the dry matter yield of Tifton 85 grass. This was not observed in HSF-CWs cultivated with Alternanthera. The reversal of the wastewater flow direction promoted, in principle, the extinction of the *SF* advance in the HSF-CWs, but did not prevent its return. Waiting for the *SF* to reach 50% of the length was not the best criterion for reversing the flow direction.

Keywords: clogging, wastewater treatment.

Efeito da inversão no sentido do escoamento nas características hidrodinâmicas e nas plantas cultivadas em sistemas alagados construídos

RESUMO. Neste trabalho, objetivou-se avaliar o efeito da inversão no sentido do escoamento, quando utilizado o escoamento superficial como critério operacional, nas características hidrodinâmicas e nas plantas cultivadas em sistemas alagados construídos de escoamento horizontal subsuperficial (SACs-EHSS), submetidos à inversão no sentido do escoamento. Para isso, foram utilizados seis SACs-EHSS: dois não cultivados (SACs-EHSS 1 e 4), dois cultivados com capim-tifton 85 (*Cynodon* spp.) (SACs-EHSS 2 e 5) e dois cultivados com alternantera (*Alternanthera philoxeroides*) (SACs-EHSS 3 e 6). Os SACs-EHSS 1, 2 e 3 foram submetidos à inversão no sentido do escoamento da água residuária, realizada quando se observou que o escoamento superficial da água residuária em tratamento (*ES*) alcançou 50% do comprimento do SAC-EHSS. Fez-se uma única inversão em cada sistema, em datas distintas. A inversão no sentido do escoamento promoveu distinção na produtividade do tifton 85. Não foi possível observar essa mesma distinção para a alternantera. A inversão no sentido do escoamento da água residuária promoveu, a princípio, a extinção do *ES* nos SACs-EHSS, embora não tenha evitado seu reaparecimento. Considera-se que a espera pelo avanço do ES até 50% do comprimento não foi a melhor escolha como critério de operacional.

Palavras-chave: colmatação, tratamento de águas residuárias.

Introduction

Horizontal subsurface flow constructed wetland systems (HSF-CWs), used in the treatment of wastewater, have advantages such as reduced cost and simplicity of operation, low mechanization demand, low maintenance requirement and good rates of efficiency (Fia, Matos, Fia, Borges, & Teixeira, 2012; Prata, Matos, Cecon, Lo Monaco, & Pimenta, 2013; Zhang et al., 2014).

One of the main problems related to these systems, and that became evident in the last two decades, is the increase in clogging of the porous medium (Knowles, Dotro, Nivala, & García, 2011). This phenomenon is characterized by clogging of the pores with a resultant reduction in porosity, mainly in front of the system. The consequences include modifications to the hydrodynamic conditions of the porous medium, such as reduced hydraulic retention time, surface runoff and resulting decrease in the treatment efficiency of the system (Knowles et al., 2011; Nivala, Knowles, Dotro, García, & Wallace, 2012).

In addition to identifying and characterizing the clogging, many studies have been conducted with a focus on management of clogging in constructed wetland systems (CWs) (Nivala et al., 2012). However, while the concept of clogging is simple, the process involves many factors that are not yet fully understood (Kadlec & Wallace, 2008; Knowles et al., 2011).

In order to propose appropriate operational techniques, there is a need for greater understanding of the dynamics of the pore clogging process and how this blockage can be slowed or even eliminated. The proposition of operational techniques that enable clogging control is essential for greater spread in the use of CWs for wastewater treatment.

With the reversal of the wastewater flow direction, the front end of the HSF-CWs with the high pore clogging index, could receive wastewater that has gone through a purification process. This would stimulate microorganisms to degrade clogged materials, since this partially treated wastewater has a high concentration of available nutrients. In addition to microorganisms, plants that contribute with the mineralization of organic material and large removal of inorganic material would also support the unclogging process. It is known that plants grown in HSF-CWs are capable of incorporating air by their leaves, transferring it to the rhizomes and roots via aerenchyma, resulting in aerobic sites near the roots, which facilitate the degradation of organic material (Matos, Freitas, Brasil, & Borges, 2010; Zhang et al., 2014).

In order to identify and monitor the clogging and unclogging processes by reversing the flow direction, it was sought to select variables related to the two phenomena, which were simple to determine. For this purpose, the option selected was the superficial flow (*SF*) of wastewater, generally associated with clogging of CWs (Nivala & Rousseau, 2009; Knowles et al., 2011; Butterworth et al., 2013), and productivity of plants usually sensitive to environmental changes.

Thus, the objective of this study was to evaluate the effect of reversing the flow direction of horizontal subsurface-flow constructed wetland systems (HSF-CWs), on the hydrodynamic characteristics of the system and dry matter yield of two plant species. In addition to using the monitoring of the *SF* as a criterion to estimate the time and percentage of clogging and the decision to reverse the flow direction in these systems.

Material and methods

The experiment was conducted at the Federal University of Viçosa (UFV), Viçosa, Minas Gerais State, Brazil (20°45'S, 42°45'W and 650 m of altitude). According to Köppen-Geiger climate classification, the local climate is Cwa, mesothermal humid, with rainy summers and dry winters (Vianello & Alves, 2012).

The experimental structure consisted of six HSF-CWs, maintained in a greenhouse, used to treat swine wastewater (SWW). These systems had been in operation for approximately 1 year, when the data collection began for the present study.

The HSF-CWs were made of fiberglass boxes, on a pilot scale, with the dimensions of 0.6 m x 0.5 m x 2.0 m in height, width and length, respectively, located on the ground level. Gravel was used as the support medium (D_{60} = 9.1 mm, uniformity coefficient - UC D_{60}/D_{10} = 3.1 and initial void volume of 0.398 m^3 m^{-3}), with which the HSF-CWs were filled up to a height of 0.55 m and the water level maintained 0.05 m below the surface of the support material.

At the outlet of each experimental unit, a drainage system was installed, consisting of a PVC pipe measuring 32 mm in diameter. In order to allow the reversal of the flow direction, in the three experimental units, a second input and a second output were installed (HSF-CWs 1, 2 and 3) (Figure 1).

The plant species cultivated were Tifton 85 grass (*Cynodon* spp.) (HSF-CWs 2 and HSF-CWs 5) and Alternanthera (*Alternanthera philoxeroides*) (HSF-CWs 3 and HSF-CWs 6). In the HSF-CWs 1 and 4, no plants were cultivated.

At the inlet of each HSF-CW, a 20 L reservoir was installed, equipped with a PVC tap at its bottom, which fed the system with SWW. Every day, the 20 L reservoir was filled to its maximum capacity and then the SWW was applied to the HSF-CWs. The SWW was homogenized before each application in order to ensure that the solid contents present were applied uniformly to the systems. The application was intermittent, superficial and lasted, on average, 2h.

The ranges of values, for the principal variables in the SWW affluent, to the HSF-CWs throughout the experiment period are listed in Table 1. The operational characteristics of the HSF-CWs, established based on the characteristics of the SWW, are presented in Table 2.

To monitor the weather conditions in the greenhouse, a thermo-hygrometer was installed to determine the maximum and minimum daily temperatures, as well as the relative humidity. Values of temperatures and relative humidity were collected in the morning at 9h00 am. The maximum and minimum temperatures and humidity of the air outside the greenhouse were obtained from an automatic weather station, located at the Irrigation and Drainage Experimental Area, at the campus of UFV, Viçosa, Minas Gerais State. Table 3 shows the maximum, minimum and mean values obtained for temperature and relative humidity of the air inside and outside the greenhouse.

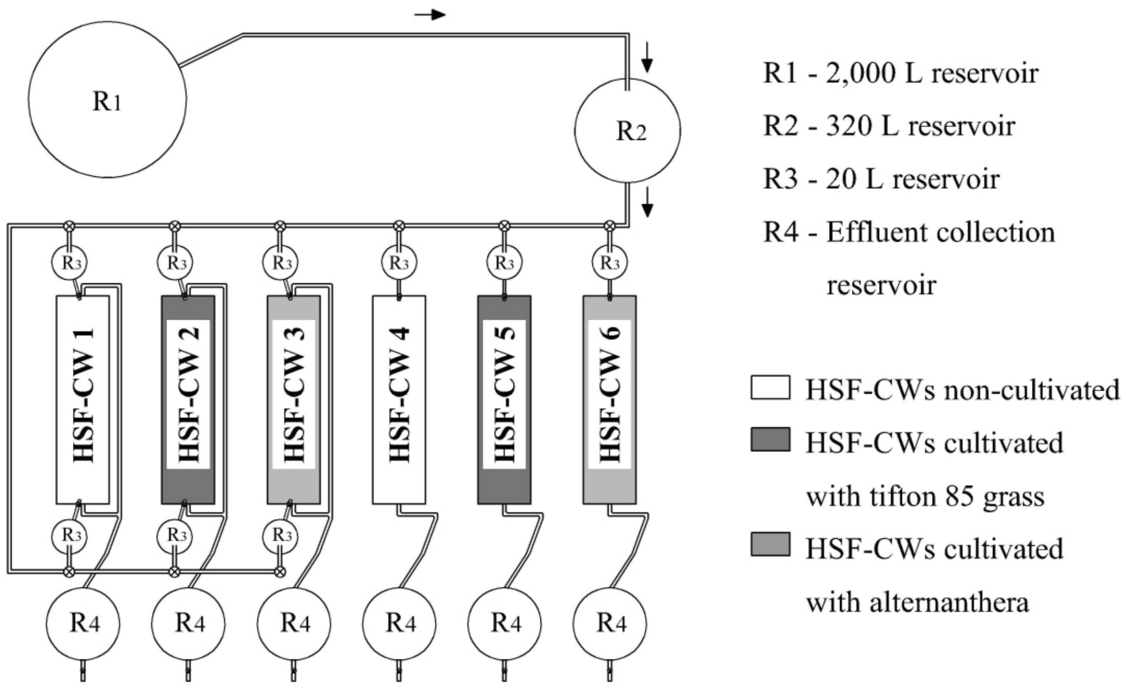

Figure 1. Schematic representation of the experimental structure, where: HSF-CWs 1, 2 and 3 were adapted to enable the reversal of the flow direction; and HSF-CW 4, 5 and 6 were not adapted to enable the reversal of the flow direction.

Table 1. Mean values and standard deviation of the main variables of the SWW affluent to the HSF-CWs.

pH	EC ($dS\ m^{-1}$)	COD	BOD	TS	TVS	TSS	TN	P	K	Na
			----------------	----------------	----------------	($mg\ L^{-1}$)	----------------	----------------		
7.46 ± 0.30	5.741 ± 2.768	5.529 ± 4.392	2.220 ± 1.548	4.363 ± 2.684	2.419 ± 1.504	2.111 ± 2.032	675 ± 411	127 ± 97	350 ± 258	84 ± 56

Table 2. Operational characteristics of the HSF-CWs.

Q ($m^3\ d^{-1}$)	Q* ($m^3\ h^{-1}$)	HRT (h)	OLR ($g\ m^{-2}\ d^{-1}$ de BOD)
0.020	0.010	19.9	44.4 ± 31.0

Q – affluent flow, *Q** - affluent flow considering the application time of 2 h, *HRT* – hydraulic retention time, *OLR* – organic loading rate, established based on the surface area.

Table 3. Maximum, minimum and mean values of temperature and relative humidity inside and outside the greenhouse.

	$T_{air\ internal}$	$T_{air\ external}$	$U_{air\ internal}$	$U_{air\ external}$
	---------------- °C	----------------	---------------- %	----------------
Maximum	49.6	36.7	99	100
Minimum	7.2	5.2	20	25
Mean	26.6	20.4	61.9	78.4

T_{water} – water temperature in the HSF-CWs; $T_{air\ internal}$ – air temperature inside the greenhouse; $T_{air\ external}$ – air temperature outside the greenhouse; $U_{air\ internal}$ – relative humidity inside the greenhouse; $U_{air\ external}$ – relative humidity outside the greenhouse.

Throughout the experimental period, plant cuttings were performed on average every 65 days. Eight cuttings were performed between Jul/2012 and Sep/2013. The HSF-CW was divided into three thirds, numbered 1 to 3 from inlet to outlet, respectively. All material from each third was collected, gathered in paper bags and dried in an air circulation oven at 65°C until constant weight, and then quantified the dry matter yield.

Tifton 85 plants were cut at approximately 6 cm above the substrate level, and Alternanthera plants cut at 6 cm from the roots. In both cultivated species, one criterion imposed was the cutting out of all non-rooted branches.

Monitoring of the *SF* was performed by measuring twice a week with the aid of tape measures installed along the edges of the systems. Measurements were taken from 10 to 15 min. after the application of SWW. Data were taken between Jun/2012 and Oct/2013.

The reversal in the flow direction of the wastewater was performed when the *SF* of the applied wastewater reached 50% of the HSF-CW length, i.e. 1 m, and remaining for at least four successive measurements. Therefore, the flow direction of the wastewater in the systems was reversed at different times for each treatment.

During the experimental period, there was a single reversal in the flow direction in each system, where the first to have its flow reversed was HSF-CW 2, cultivated with Tifton 85, in Jul/2012, the second was the non-cultivated HSF-CW 1, in Nov/2012, and finally the HSF-CW, cultivated with Alternanthera, in Sep/2013.

After reversing the flow direction, the distribution of the treatments was made as follows: HSF-CW control, which had no reversal in the flow direction - HSF-CW 4ni, HSF-CW5ni and HSF-CW 6ni; and the HSF-CWs which the flow direction was reversed - HSF-CW 1i, HSF-CW 2i and HSF-CW 3i.

Data were analyzed through descriptive statistics based on the physical, chemical and biological phenomena observed, in addition to the information provided by the data collected and analyzed during the experimental period.

Results and discussion

During the experimental period, there were problems with pest infestation in both plant species, which may have been favored by the growth in the greenhouse. According to Picanço and Marquini (1999), the optimal conditions for development and reproduction of some pests are inside protected environments. However, despite the problems with pests, it was considered that the cultivated species showed good adaptability to the culture medium during the experimental period.

The results of the quantification of dry matter yield for the species cultivated over time are illustrated in Figure 2. The presentation of the results was discriminated for HSF-CWs 2 and 5 cultivated with Tifton 85 due to the reversal of the flow direction. After the flow reversal, each system was subjected to different treatments (with and without reversal), called HSF-CW 2i and HSF-CW 5ni.

In the HSF-CWs 3 and 6, cultivated with Alternanthera, this discrimination was not made because the dry matter yield data referred to the period without reversal of the flow direction, therefore, these systems constitute repetitions and data were presented as mean values. No dry matter yield values were obtained for Alternanthera in the last cutting, which is due to the attack of pests that significantly affected the plants.

The HSF-CWs 2, 3 and 6 showed an increasing trend in the dry matter yield over the operational period of the systems, and this trend is less obvious in the HSF-CW 5. In relation to the HSF-CWs 3 and 6, this may be related to the fact that Alternanthera is an aquatic species, better adapted to the conditions of flooding to which it was exposed. This same trend was observed by Matos, Freitas, and Lo Monaco (2009), and indicates that the accumulation of organic material in the porous medium makes the conditions most suitable for the growth of Alternanthera.

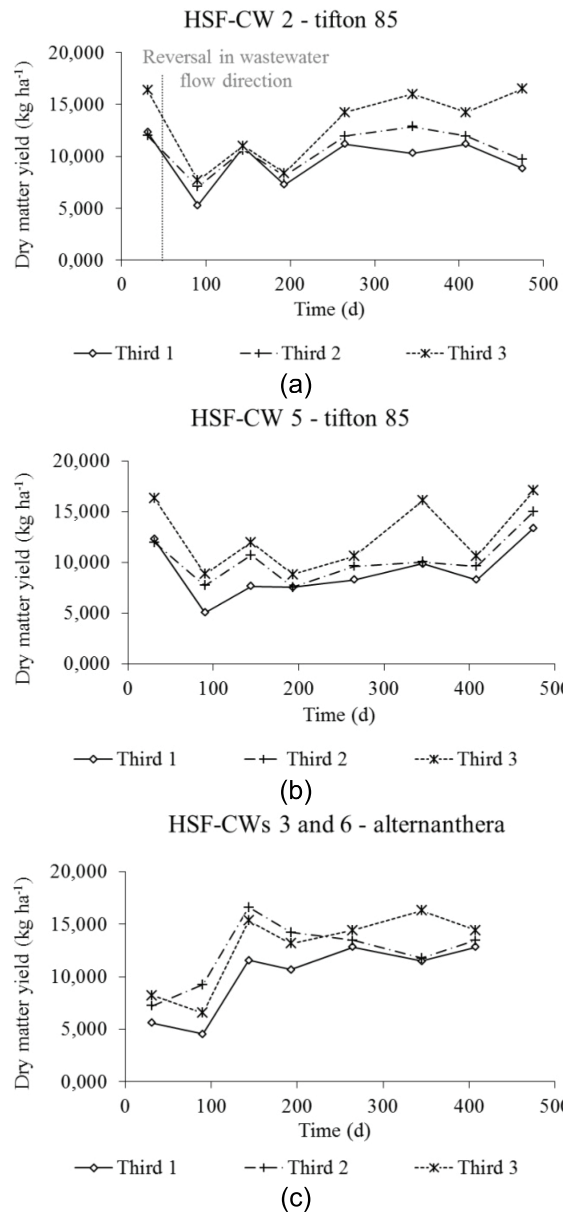

Figure 2. Variation in dry matter yield (kg ha^{-1}) for: (a) HSF-CW 2, with reversal of the flow direction after the second cutting of the plants and (b) HSF-CW 5, without reversal of the flow direction, both cultivated with Tifton 85; and (c) HSF-CW 3 and 6, cultivated with Alternanthera.

In the case of HSF-CWs 2i and 5ni, cultivated with Tifton 85, the increase in the dry matter yield of shoot was more pronounced in the first system, i.e., in which the flow direction of wastewater was reversed. It is noticed that in the HSF-CW 2i, the dry matter yield was slightly higher in all thirds of the systems, resulting in a correspondingly higher total average. Furthermore, when analyzing the results shown in Figure 2, it appears that the reversal was especially beneficial for the last third of the HSF-CW 2i.

It was expected that, with the reversal in the flow direction, the SWW would reach the first third of the system more ‘treated’, i.e., with nutrients available from the degradation of organic matter in the previous thirds. This would stimulate the microorganisms to degrade the clogged material and provide greater availability of nutrients to plants; therefore, the plants would develop more and better in the first third of the HSF-CWs, in the case of reversal of the flow direction. Thus, microorganisms and vegetation together would act as agents for unclogging the porous medium.

By analyzing the average dry matter yield obtained for Tifton 85, it was showed that there were increases of 6.3, 2.3 and 3.8% in the thirds 1, 2 and 3, respectively, in the HSF-CW 2i when compared with HSF-CW 5ni, in which there was no reversal in the flow direction. Therefore, although the average dry matter yield of the first third did not exceed that of the other thirds of the HSF-CW 2i, the third 1 showed the largest increase in response to the reversal of the flow direction.

Another fact demonstrating the benefits of the flow reversal for plants was the greater difficulty of the field regrowth in the HSF-CW 5ni in relation to HSF-CW2i, especially for the thirds 1 and 2. This occurred little after 2 years of operation of the systems. It is believed that this difference in regrowth capacity is related to the redox behavior (*Eh*) of the porous medium, since the HSF-CW 2i, also cultivated with Tifton 85, did not present the same problem of regrowth. In the HSF-CWs, the *Eh* varies along the length and depth of the system, increasing from the input to output, and decreasing from the surface to the bottom (Kadlec & Wallace, 2008; Matos et al., 2010; Prata et al., 2013). Thus, it is believed that reversing the flow direction resulted in increased *Eh* in the first two thirds of the HSF-CW 2i, by virtue of SWW being applied to the third 3 (new affluent application position). Therefore, the organic matter is more degraded and nutrients are more available in the thirds 2 and 1, providing an opportunity for the recovery of the vegetation in these areas, contrary to what occurred in the HSF-CW5ni. Furthermore, reversing the flow direction may have favored the diffusion of oxygen in the upper layer of the bed to eliminate the *SF* in the thirds 1 and 2, which will be discussed later, favoring increased *Eh* near the roots and therefore the development of vegetation in the HSF-CW 2i.

The results of the *SF* monitoring in the HSF-CW over time are shown in Figure 3.

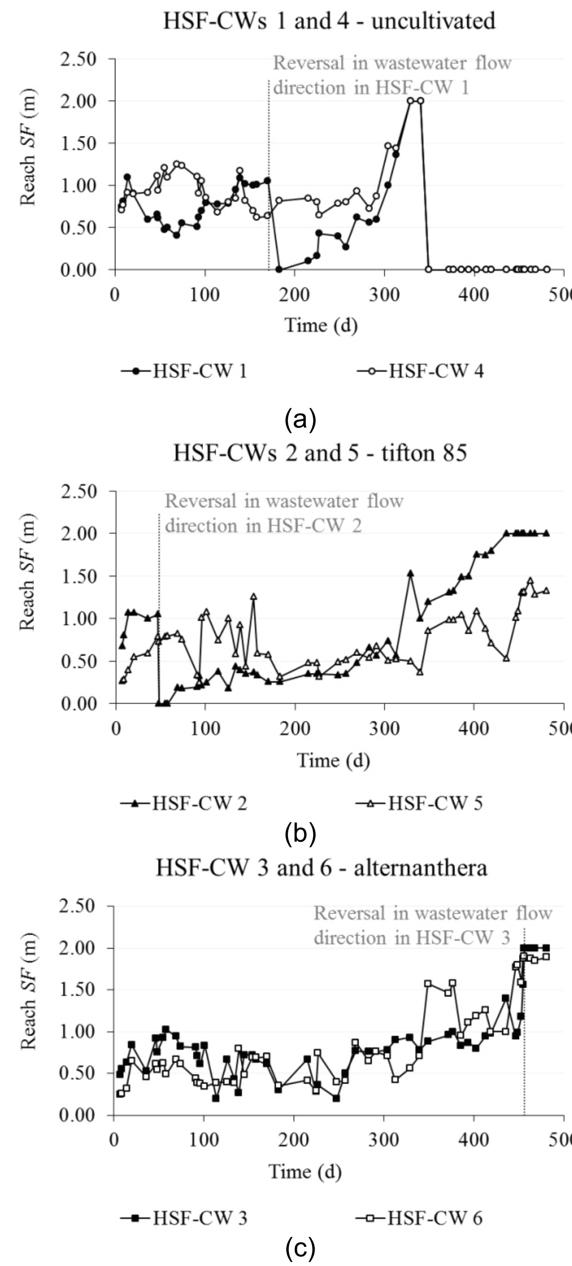

Figure 3. Variation in the *SF* before and after the reversal of the flow direction in: (a) HSF-CWs 1 and 4, non-cultivated; (b) HSF-CWs 2 and 5, cultivated with Tifton 85; and (c) HSF-CWs 3 and 6, cultivated with Alternanthera.

Figure 3 shows that the reversal in the flow direction promoted, in principle, the elimination of the *SF* in the HSF-CWs, with the exception of HSF-CW 3i. However, the rate of the *SF* advance in the reversed systems was greater than in the non-reversed systems. Shortly thereafter, the *SF* advance in the reversed systems reached the same values of the non-reversed systems.

The HSF-CWs 1i and 4ni presented 200 cm of *SF* during the same period (Figure 3a), and the *SF* of the HSF-CW 2i exceeded that of the HSF-CW

5ni, which did not reach 200 cm at the end of the experimental period. The HSF-CWs 1i and 4Ni were deactivated after observing that they were completely flooded.

Based on this information, it is believed that the systems studied were larger lengthwise. In other words, if the criterion of *SF* was based on smaller ranges, for instance, between 10-20%, the positive effects of the flow reversal may have potentially been more enduring, since the HSF-CWs would be in a less evolved state of clogging, which could be reversed or mitigated with the technique of reversal of the wastewater flow direction.

If the systems were longer, there would be time for the wastewater to be treated subsequently in the remedied zone and the process of unclogging may have been more efficient. It was also observed in Figure 3a that the behaviors of *SF* in the HSF-CWs 1 and 4, before reversing the flow direction, were opposite to each other for a certain operational period of the systems. A possible explanation for this occurrence is the position of the HSF-CW 1, which was closer to the door of the greenhouse, which remained open during the daily monitoring, about one and a half hours. This may have led to a greater exposure of the system to wind, in comparison with the HSF-CW4, thus drying solids on the surface layer, and generating cracks, which may have facilitated higher infiltration of wastewater through the porous medium, which led to a reduction in *SF*.

From the behavior observed for the HSF-CW 1, it was noticed that due to the use of a greenhouse, the positive effects that the environmental conditions have on the clogging, were eliminated or significantly reduced, especially on the surface of the HSF-CWs. This includes the effect of the direct sunlight and wind on the systems. The direct sunlight and wind could enhance the dehydration of the solid layer deposited on the surface of the bed, promoting cracks that would aid in increasing the infiltration rate of the SWW that could also eliminate or lessen the presence of the *SF*. Moreover, wind also results in the 'lever arm' effect, as mentioned by Knowles et al. (2011), since it provides oscillations of the plant stems, which causes ruptures in the sludge layer on the surface of the system, with subsequent generation of channels through which the water can return to the subsurface of the bed. The rainfall, in turn, causes greater displacement of the accumulated surface solids to the substrate profile, promoting a decrease in surface sealing, in both cultivated and non-cultivated systems.

In the HSF-CW 3i, cultivated with Alternanthera, after the reversal of the flow direction, the *SF* did not decrease, varying from 156 to 200 cm, the opposite of what occurred in the other reversed systems. The later reversal in this system was probably the main cause of this behavior.

The delay to reverse the wastewater flow direction in the HSF-CW 3i caused a considerable clogging, especially in the first third. This may have caused clogging of the drainage system piping, which after the reversal of the flow direction became connected to the first third. After the reversal of the flow direction, it was observed that the flow rate of the effluent was reduced, which may have contributed to mask the potential positive effects of reversing the flow direction in this CW.

Cooper, Griffin, and Cooper (2005) observed that many of the 126 HSF-CWs considered in their study presented blockage in the effluent collection system, since there was formation of biofilm and solid deposit in the holes of the pipes used.

Another fact to consider in relation to the results obtained is the chronological order of the reversals in the flow direction of the CWs. Because the reversal criterion was based on the *SF*, the factor of greatest influence in this case was the accumulation of material on the bed, which promoted reduction of the infiltration rate, directly linked to the *SF*. The thickness of the layer of solids accumulated on the surface of the bed was higher in planted systems than in unplanted systems, since besides the contribution of the SWW, there was the contribution of plants. According to Knowles et al. (2011), leaves and stems contribute to the obstruction of the surface, reducing the water infiltration rate in the medium.

The configuration of the wastewater entering the system is therefore an important factor. In the case where the influent is applied superficially, as in the present study, the infiltration of wastewater into the porous medium is greatly impaired due to the accumulation of dead (plant remains) or living (plant roots) organic matter, which enhances the runoff. According to Knowles et al. (2011), the application of wastewater to the subsurface maximizes the use of the cross-sectional area of the HSF-CWs, reducing the preferential accumulation of solids on the bed surface. The studies of Chazarenc, Maltais-Landry, Troesch, Comeau, and Brisson (2007) and Knowles, Griffin, and Davies (2010) showed that, in both configurations of subsurface and surface inlet of the influent, there may occur the formation of SF due to the clogging. However, Chazarenc et al. (2007) noticed that in the configuration of the subsurface inlet, the appearance of *SF* is apparently subsequent in relation to the surface inlet.

In the present study, the first HSF-CW to have its flow direction changed was the one cultivated with Tifton 85. The HSF-CWs cultivated with this plant species were the systems that presented the greatest sludge accumulation on the surface, where the material accumulated comprises a mixture of solid plant debris, present in the full extent of the systems, with the exception of the last third of the HSF-CW 5. The sludge layer presented thicknesses of about 30 and 35 mm in the third 3 of the HSF-CW 2i and third 1 of the HSF-CW 5ni, respectively.

The unplanted system was the second to have its flow direction reversed, and presented a thin sludge layer on the surface. Because its surface was unprotected, this thin layer of sludge was frequently dry and brittle, which is a positive aspect. By contrast, it was noticed that because the surface level of the unplanted HSF-CWs was higher than that of the planted HSF-CWs, the sealing of the pore spaces between the aggregates on the surface of the system was favored.

The third to be reversed was the HSF-CW, cultivated with Alternanthera, which presented an intermediate sludge layer with considerable presence of plant debris. This layer was primarily concentrated in the first half of the system. It presented a thickness of approximately 20 mm in the first third of the HSF-CWs 3i and 6ni, and of 10 mm in third 3 of the HSF-CW 3i.

When comparing the support medium surfaces of the unplanted HSF-CWs with those cultivated with Alternanthera, the latter was quite irregular in relation to the former. Apparently, the pattern of growth of the plant promoted some disturbance of gravels on the surface and this may have favored the maintenance of higher SWW infiltration rates in the HSF-CWs, delaying the *SF* advance, which indicated the moment for the reversal of the flow direction. The same observation was reported by Brasil and Matos (2008) in the HSF-CWs planted with cattail (*Typha* sp.) for the treatment of domestic sewage effluent from primary treatment.

Another relevant factor observed was the intertwining of stolons of alternanthera, which promoted a uniform distribution of the vegetation and this certainly represents a physical barrier to the displacement of water, preventing greater accumulation of solids on the bed surface. Thus, the use of Alternanthera and other plants with similar development should be prioritized in the initial region of the HSF-CWs in order to promote this physical barrier, since it is a positive factor allied with the prevention of clogging. Furthermore, this species is characterized as a plant with good adaptability to reducing environments, such as those present in front of the HSF-CWs.

The presence of *SF* in the CWs is often reported in the literature as one of the main symptoms of clogging. Nivala and Rousseau (2009) reported the presence of puddles measuring 7 x 10 m in width and length, respectively, in a HSF-CW of 33.5 x 20 x 0.6 m (length, width and depth, respectively) used for treating domestic wastewater with 7 years of operating time, in Minnesota, USA. The authors reported that the first signs of *SF* came four years after starting its operation. Pedescoll et al. (2009) also reported the presence of small pools of wastewater near the inlet of the HSF-CWs with approximately 6 years of operation, registering a *SF* advance of 60% of the length of one of the HSF-CWs.

Cooper et al. (2005) visited, in the UK, 126 CWs used for tertiary treatment of domestic sewage, from November 2002 to June 2004, in order to identify the factors affecting the longevity of these systems. According to the authors, one of the major problems was the deposition of sludge on the surface of the bed. Observations of deposits of sludge and plant debris were reported in all systems visited. The authors reported that it was common to find layers accumulated on the surface with thicknesses exceeding 150 mm at the inlet and 40 mm at the outlet, and attributed the emergence of puddles and *SF* on the surface of the CWs to these deposits of organic material.

At last, the reversal of the flow direction in the HSF-CWs promoted changes in the behavior of the systems. However, these changes could have been more significant and sustained if the criterion established to determine the moment to promote the reversal of the wastewater flow direction in the systems was not after waiting for the *SF* advance to reach 50% of the HSF-CW length. The very late reversal in the wastewater flow direction allowed the HSF-CWs to remain clogged, making it difficult to reverse the degree of clogging of the systems. Furthermore, it is understood that because the *SF* is a superficial phenomenon, directly associated with the capacity of the wastewater to infiltrate the porous medium and not with the capacity of the subsurface flow to pass through the porous medium, its use as a criterion to determine the time to change the flow direction may not be the most appropriate.

Conclusion

The reversal in wastewater flow direction resulted in changes in the dry matter yield of Tifton 85 grass. It was not possible to observe changes in the dry matter yield of Alternanthera, due to the late reversal of the flow direction and the attack of pests on the plants cultivated.

Waiting for the *SF* advance to reach 50% of the length of the HSF-CWs was not the best criterion for defining the wastewater flow reversal time. This variable does not reflect the state of clogging of the HSF-CWs throughout its profile, but reflects only the degree of surface clogging.

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References

Brasil, M. S., & Matos, A. T. (2008). Avaliação de aspectos hidráulicos e hidrológicos de sistemas alagados construídos de fluxo subsuperficial. *Engenharia Sanitária e Ambiental, 13*(3), 323-328.

Butterworth, E., Dotro, G., Jones, M., Richards, A., Onunkwo, P., Narroway, Y., & Jefferson, B. (2013). Effect of artificial aeration on tertiary nitrification in a full-scale subsurface horizontal flow constructed wetland. *Ecological Engineering, 54*, 236-244.

Chazarenc, F., Maltais-Landry, G., Troesch, S., Comeau, Y., & Brisson, J. Effect of loading rate on performance of constructed wetlands treating an anaerobic supernatant. (2007). *Water Science and Technology, 56*(3), 23-29.

Cooper, D., Griffin, P., & Cooper, P. (2005). Factors affecting the longevity of sub-surface horizontal flow systems operating as tertiary treatment for sewage effluent. *Water Science and Technology, 51*(9), 127-135.

Fia, F. R. L., Matos, A. T., Fia, R., Borges, A. C., & Teixeira, D. L. (2012). Remoção de matéria orgânica e determinação de parâmetros cinéticos em sistemas alagados construídos em escala laboratorial. *Acta Scientiarum. Technology, 34*(2), 149-156.

Kadlec, R. H., & Wallace, S. (2008). *Treatment wetlands*. (2nd ed.). Florida: CRC press.

Knowles, P. R., Griffin, P., & Davies, P. A. (2010). Complementary methods to investigate the development of clogging within a horizontal sub-surface flow tertiary treatment wetland. *Water Research, 44*(1), 320-330.

Knowles, P., Dotro, G., Nivala, J., & García, J. (2011). Clogging in subsurface-flow treatment wetlands: occurrence and contributing factors. *Ecological Engineering, 37*, 99-112.

Matos, A. T., Freitas, W. S., & Lo Monaco, P. A. V. (2009). Capacidade extratora de diferentes espécies vegetais cultivadas em sistemas alagados utilizados no tratamento de águas residuárias da suinocultura. *Revista Ambiente e Água, 4*(2), 31-45.

Matos, A. T., Freitas, W. S., Brasil, M. S., & Borges, A. C. (2010). Influência da espécie vegetal cultivada nas condições redox de sistemas alagados construídos. *Engenharia Agrícola, 30*(3), 518-526.

Nivala, J., & Rousseau, D. P. L. (2009). Reversing clogging in subsurface-flow constructed wetlands by hydrogen peroxide treatment: two case studies. *Water Science and Technology, 59*(10), 2037-2046.

Nivala, J., Knowles, P., Dotro, G., García, J., & Wallace, S. (2012). Clogging in subsurface-flow treatment wetlands: measurement, modeling and management. *Water Research, 46*(6), 1625-1640.

Pedescoll, A., Uggetti, E., Llorens, E., Granés, F., García, D., & García, J. (2009). Practical method based on saturated hydraulic conductivity used to assess clogging in subsurface flow constructed wetlands. *Ecological Engineering, 35*, 1216-1224.

Picanço, M. C., & Marquine, F. (1999). Manejo integrado de pragas de hortaliças em ambiente protegido. *Informe Agropecuário, 20*, 126-133.

Prata, R. C. C., Matos, A. T., Cecon, P. R., Lo Monaco, P. A. V., & Pimenta, L. A. (2013). Tratamento de esgoto sanitário em sistemas alagados construídos cultivados com lírio-amarelo. *Engenharia Agricola, 33*(6), 1144-1155.

Vianello, R. L, & Alves, A. R. (2012). *Meteorologia básica e aplicações*. (2a ed.). Viçosa, MG: Ed. UFV.

Zhang, D. Q., Jinadasa, K. B. S. N., Gersberg, R. M., Liu, Y., Ng, W. J., & Tan, S. K. (2014). Application of constructed wetlands for wastewater treatment in developing countries – A review of recent developments (2000–2013). *Journal of Environmental Management, 141*, 116-131.

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