Mesquite wood chips (*Prosopis*) as filter media in a biofilter system for municipal wastewater treatment

D. B. Sosa-Hernández, J. M. Vigueras-Cortés and M. A. Garzón-Zúñiga

ABSTRACT

The biofiltration system over organic bed (BFOB) uses organic filter material (OFM) to treat municipal wastewater (MWW). This study evaluated the performance of a BFOB system employing mesquite wood chips (*Prosopis*) as OFM. It also evaluated the effect of hydraulic loading rates (HLRs) in order to achieve the operational parameters required to remove organic matter, suspended material, and pathogens, thus meeting Mexican and US regulations for reuse in irrigation. Two biofilters (BFs) connected in series were installed; the first one aerated (0.62 m^3air $m^{-2}h^{-1}$) and the second one unaerated. The source of MWW was a treatment plant located in Durango, Mexico. For 200 days, three HLRs (0.54, 1.07, and 1.34 $m^3m^{-2}d^{-1}$) were tested. The maximum HLR at which the system showed a high removal efficiency of pollutants and met regulatory standards for reuse in irrigation was 1.07 $m^3m^{-2}d^{-1}$, achieving removal efficiencies of biochemical oxygen demand (BOD_5) 92%, chemical oxygen demand (COD) 78%, total suspended solids (TSS) 95%, and four log units of fecal coliforms. Electrical conductivity in the effluent ensures that it would not cause soil salinity. Therefore, mesquite wood chips can be considered an innovative material suitable as OFM for BFs treating wastewaters.

Key words | decentralized system, organic filter media, wastewater treatment in arid areas

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INTRODUCTION

Lack of or inadequate wastewater (WW) treatment causes problems in terms of public health and environmental pollution because of the excessive presence of organic matter and pathogens when effluent reaches the receiving water bodies. This represents a serious problem in developing countries, particularly in rural communities. The treatment of such effluents should be a priority. However, the need for trained personnel and the high costs of operating and maintaining conventional wastewater treatment plants (WWTP) have limited their application. Moreover, natural WWTPs such as wetlands and other decentralized solutions are becoming a relevant alternative to conventional systems in small communities due to their efficiency, low establishment costs, and low operation and management requirements (Adrados *et al.* 2014). Since the 1990s, a process of biofiltration over organic bed (BFOB) has been developed as a decentralized technological alternative. The system requires little technical support, is a clean, inexpensive, and easily adaptable technology (Garzón-Zúñiga & Buelna 2011) that efficiently removes pollutants.

The BFOB is a process based on the ability of certain organic filter materials (OFMs) to act as a natural organic resin capable of retaining different pollutants that are biodegraded to CO_2, H_2O, and N_2 (Garzón-Zúñiga *et al.* 2005). The WW feeding the BFOB passes through the OFM and is simultaneously treated by four mechanisms: (1) slow and passive filtration; (2) absorption, adsorption and ion exchange; (3) biodegradation; and (4) disinfection (Buelna *et al.* 2011). In the BFOB, the suspended solids are retained by filtration. The pores and micropores of the organic material enhance the adsorption process of ions, particularly important for the removal of phosphorus, nitrogen, and some complex organic compounds and toxins, but its capacity is limited. The OFM enhances the growth of a biofilm, which is responsible for the successful removal of contaminants from WW (Areerachakul 2014). Biodegradation is the principal removal mechanism for organic matter and the microorganisms also take up nutrients for biological assimilation. However, it is very difficult to measure the biomass content in BFOB, but the specific surface area (SSA) of the OFM is used as an indirect estimation because it represents the available surface for

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the colonization of a biofilm. So, a material with a high SSA such as peat (200 m^2g) can successfully treat large organic loads. Lastly, the disinfection is due to a reduction of fecal coliforms (FC) by a predation mechanism (Garzón-Zúñiga *et al.* 2008).

In the application of different OFMs for WW treatment, Garzón-Zúñiga & Buelna (2011) report that wood barks and chips of pine, tropical tree wood chips, and natural fibers have been successfully achieving high removal efficiencies of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), and FC. Riahi *et al.* (2009) used date-palm fibers for tertiary domestic WW treatment; Vigueras-Cortés *et al.* (2013) used agave fiber to treat municipal wastewater (MWW). However, the BFOB process is applied at full scale in only a few countries, including the USA, Canada, and more recently Mexico. A more important reason for this is that very few OFM have been assessed and considered appropriate for biofiltration and this has limited its application in many regions, including arid and semiarid zones. So, to find new and appropriate OFM with a wide distribution for biofiltration is a key parameter for BFOB installation at full scale.

Another key parameter is that OFM must be resistant to biodegradation. In relation to this, there are only very few reports about the life span of organic materials. Talbot *et al.* (1996) report that peat in biofilters (BFs) has a life span of at least five years and Garzón-Zúñiga & Buelna (2011) report that dwarf poinciana (*Caesalpinia pulcherrima*) and jacaranda (*Jacaranda mimosifolia*) have a life span of at least three years. Regarding this, Garzón-Zúñiga *et al.* (2005) mention that the resistance of the OFM depends on its chemical structure and hardness. Hard woods are more resistant than soft woods. Therefore, it is important to evaluate new resistant organic materials with a wide distribution. Finally, a third key parameter in the performance of BFOB is the hydraulic load rate (HLR). Most authors dealing with BFOB report high removal efficiencies of pollutants from MWW – $BOD_5 \leq 96\%$; $COD \leq 84\%$; $TSS \leq 72\%$; $FC \leq 99.99\%$ (4 log units) – at laboratory scale (Lens *et al.* 1994, Corley *et al.* 2006) and at full scale (Talbot *et al.* 1996; Garzón-Zúñiga & Buelna 2011) by applying $HLR \leq 0.3$ $m^3m^{-2}d^{-1}$. So, it would be important to assess the possibility of applying a higher HLR in order to optimize the process. Taking into account this information, *Prosopis* was chosen for evaluation because this genus includes 44 species of arid and semiarid zones (Burkart 1976). Its distribution includes Asia, Africa, and America and in the latter it occurs from Argentina to the southern United States (Carrillo-Parra *et al.* 2011). Moreover, *Prosopis* is not a threatened genus and it is characterized by its hard wood (Galera 2000) which would allow a good life span.

Therefore, the purpose of this study was to evaluate the performance of a BF system packing with mesquite wood chips (*Prosopis*) as OFM and the effect of the hydraulic loading rate to obtain the operational parameters required for the removal of organic matter, suspended material and pathogens, meeting the requirements of Mexican (NOM-003-SEMARNAT-1997) (DOF 1998) and United States (US EPA 2004) regulations for reuse in irrigation.

MATERIALS AND METHODS

OFM

The mesquite wood chips were obtained from the pruning of bushes in the municipality of Durango, Mexico. The mesquite wood was debarked and sundried. It was subsequently shredded and screened on a 12.7 mm mesh aperture. The OFM characteristics are listed in Table 1.

Experimental procedure

The system consisted of two polyvinyl chloride BFs measuring 2.0 m height and 0.185 m internal diameter. The columns were filled up to 1.80 m with the OFM, leaving an empty space of 10 cm at the bottom and at the top of each BF to promote the free discharge of the effluent. Both BFs contained an internal structure of four acrylic plate separations with 6 mm holes to avoid compaction of the OFM (Figure 1). The BFs contained an average weight of 15 kg of organic material.

BFs were connected in series. The first BF was aerated (ABF), with an aeration rate of 0.62 $m^3m^{-2}h^{-1}$ and the second BF was unaerated (UBF). The air was supplied at the bottom of the ABF. The airflow was monitored daily with a flowmeter. The pressure drop in the ABF was measured with a manometer as the displacement of a water column in mm. The UBF was installed in order to

Table 1 | Characteristics of OFM

Parameters	Value
Bulk density	281 kgm^{-3}
Particle size	Length: 4.5 ± 0.6 cm Width: 1.5 ± 0.5 cm
Porosity	84%

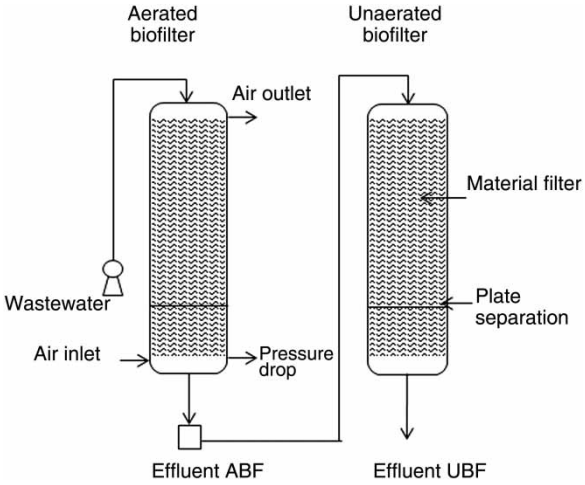

Figure 1 | Set-up of BFs system packed with mesquite wood chips.

assess if a polishing treatment system was necessary to achieve the limits established in Mexican and United States regulations.

The ABF was fed with MWW from the East Durango City WWTP after primary treatment. A characterization is shown in Table 2. MWW was sampled every week between 12:00 and 14:00 h in 40 L receptacles, stored in a tank of 400 L, and isolated from the ambient temperature. Under these conditions, parameters such as BOD_5 and COD diminished by less than 10% during the storage period.

According to the classification by Metcalf & Eddy (1991), BOD_5, COD, TSS, and FC parameters correspond to a MWW of medium composition. The effluent of the ABF fed the UBF, in order to assess whether it improves the quality of the final effluent of the BFOB system. Both the MWW and the influent to the UBF were fed with a peristaltic pump, applying flows of 5, 10, 15, 20, and 25 mL min^{-1}. The first flow was applied for the conditioning stage and corresponded to a HLR of 0.27 $m^3m^{-2}d^{-1}$. During this stage, microorganisms grew on the OFM. The period was monitored according to the BOD_5 effluent concentration and it was established that when it reached $\leq$30 mg L^{-1}, the system would be considered ready to evaluate the effect of three different HLRs (0.54, 1.07, 1.34 $m^3m^{-2}d^{-1}$). The HLRs were selected because many authors report a good performance when applying a HLR $\leq$ 0.3 $m^3m^{-2}d^{-1}$, but this study aimed to assess the possibility of using higher values to optimize the process. However, the loads were chosen taking into account the reports of a few authors that had applied a HLR as high as 1.34 $m^3m^{-2}d^{-1}$ (Buelna & Bélanger 1990; Vigueras *et al.* 2013). The influent and effluent of each BF was analyzed weekly to determine the removal efficiency in the ABF and the UBF. The duration of each experimental stage depended on the BOD_5 removal efficiency and ended when the effluent concentration of $\leq$30 mg L^{-1} (maximum permissible limit of Mexican and US norms for reuse) remained stable.

Table 2 | Raw WW composition

Parameters	Average concentration ± S.D.	No. of samples
BOD_5 (mg L^{-1})	269 ± 42	31
COD (mg L^{-1})	680 ± 32	32
FC (MPN 100 mL^{-1})	$7.52\times10^6 \pm 1.82\times10^6$	32
TSS (mg L^{-1})	200 ± 70	22
pH (units)	7.23 ± 0.60	32
EC (μS cm^{-1})	784 ± 30	22

S.D. = standard deviation, MPN = most probable number.

Analytical methods

The laboratory techniques used throughout the experimental process were based on APHA, AWWA, WEF (1998), BOD_5 according to the 5-day BOD test Method 5210 (B), COD to the Closed Reflux Colorimetric Method 5220 (C), TSS to the Dry Weight Method 2540 (D), and FC to the Multiple Tube Test Method 9230 (B). The pH and EC were measured electrometrically.

RESULTS AND DISCUSSION

Start-up of experimental units

During the start-up (HLR: 0.27 $m^3m^{-2}d^{-1}$) the effluent BOD_5 concentration of both BFs was higher than the influent, and 60 days later it started to decrease (Figure 2). This behavior can be explained by the fact that during the filtration of WW, some wood-organic compounds were dissolved (extracted) thus increasing the biological and chemical oxygen demand. This matched with reports by Garzón-Zúñiga *et al.* (2008) and Lens *et al.* (1994), who mentioned that the increase is due to the wash of fulvic acids from the OFM. Once the BOD_5 concentration in the effluent began to decrease, it took only 18 days (day 77 of operation) to reach the limit permitted by Mexican standards which is 30 mg L^{-1}. At the end of this stage, a removal efficiency of 90% was obtained, which was lower than that obtained by Garzón-Zúñiga *et al.* (2008), who

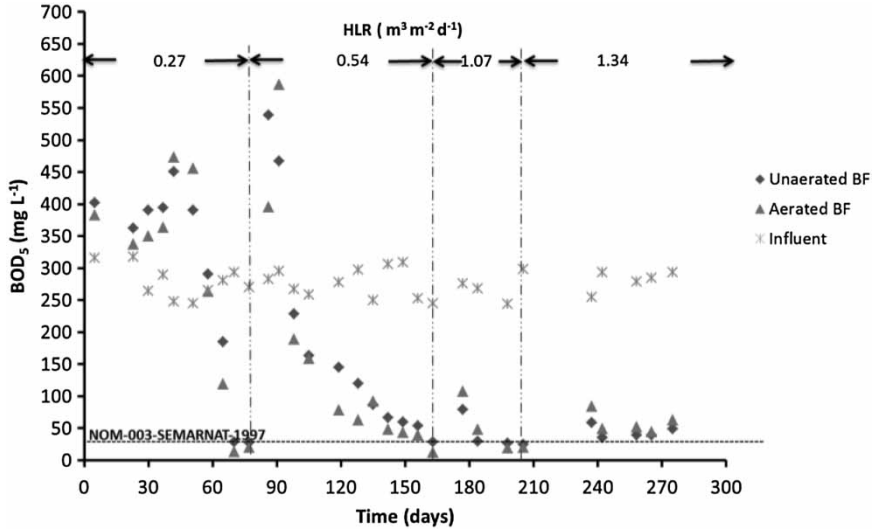

Figure 2 | Removal efficiency of biochemical oxygen demand in a system packed with mesquite wood chips.

applied a HLR of 0.3 $m^3m^{-2}d^{-1}$ with a lower concentration in the MWW than in this study. At this point of the experimentation, it was considered that the biofilm has been developed and allows passing to the next HLR. The behavior of COD (Figure 3) was similar to that of the BOD_5, the concentration increased by 443% and then it began to decrease, achieving at the end of this stage (day 77) a decrease of 134% above influent concentration. Finally, during the start-up period, the effluent showed low pH values of between 4.5 and 5.6. This was probably caused by the presence of fulvic acids that were extracted by the washing of the OFM during this stage (Garzón-Zúñiga *et al.* 2005). It lasted about 3 months, the period coinciding with that reported by Garzón-Zúñiga *et al.* (2008) when subtropical wood chips were used as OFM.

Evaluation of the biofiltration system

BOD_5 removal

The behavior of BOD_5 at different HLRs is shown in Figure 2. At the beginning of stage 1 (HLR: 0.54 $m^3m^{-2}d^{-1}$), on day 82, there was an increase in concentration because the HLR increased twice, and so the organic load also increased, affecting the organic matter removal efficiency, but it began to decrease immediately and 81 days later

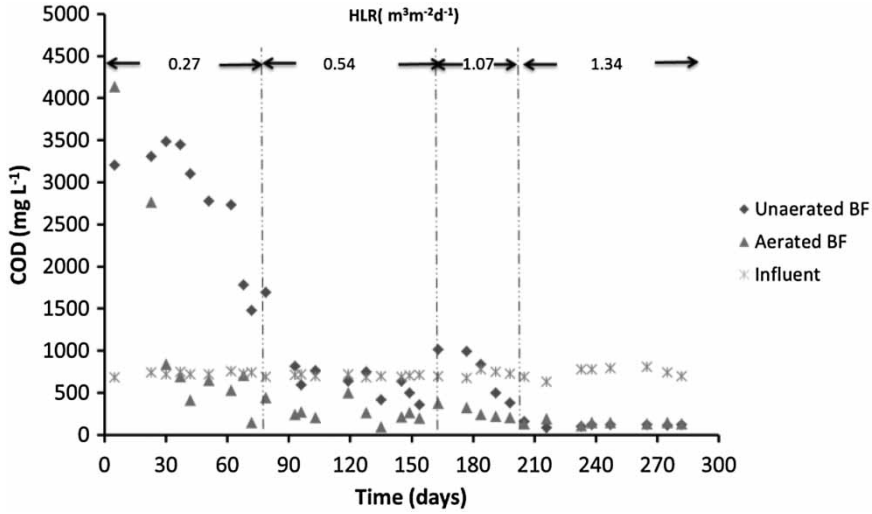

Figure 3 | Removal efficiency of chemical oxygen demand in a system of BFs packed with mesquite wood chips.

(day 163) it again reached the permissible limit, with a removal efficiency of 91%. It can be assumed that during this time, the microorganism population continued to grow and the system could improve its performance.

At the beginning of stage 2 (HLR: 1.07 $m^3m^{-2}d^{-1}$), an increase was observed when the HLR increased which was a lot lower compared with previous stages, showing after the first week a removal efficiency of 89.5% and a tendency to decrease. It only took 30 days to reach a removal efficiency of 92% corresponding to a residual value of 24 mg BOD_5 L^{-1}, similar to that obtained by Abou-Elela *et al.* (2015). The removal efficiency and quality of the effluent were equal to those obtained by Vigueras-Cortés *et al.* (2013), who used agave fiber as OFM and a lower HLR (0.80 $m^3m^{-2}d^{-1}$).

In stage 3 (HLR: 1.34 $m^3m^{-2}d^{-1}$), when the HLR increased, the concentration in the effluent did not increase by the same proportion, reaching a stable system in a shorter time. However, after 87 days (day 277) the effluent continued to show a concentration of >30 mg L^{-1} and did not reach the allowable limit, although the removal efficiency was 83%. These results indicate that the maximum HLR supporting the system to comply with regulations is 1.07 $m^3m^{-2}d^{-1}$.

It is important to note that the ABF was able to remove almost all the BOD_5 required to reach the limit allowed by the regulations at HLR $\leq$ 1.07 $m^3m^{-2}d^{-1}$, but the concentration was close to the limit. So, in this case, the UBF improved the final effluent quality by obtaining a BOD_5 value lower than the limit of 30 mg/L, which represents security for the system.

COD removal

During stage 1, the ABF effluent presented a removal efficiency of 54% and the efficiency in the UBF was −41%. This can be explained by the fact that the extraction of chemical soluble compounds was faster in the ABF than in the UBF due to the oxidation of the OFM, and so the COD in the effluent was seen faster in the ABF than in the UBF (Figure 3, start-up period). Therefore, when the effluent passed through the UBF, which continued to extract soluble compounds, the COD increased. In the ABF, the washing of soluble compounds lasted 90 days, while in the UBF it lasted 145 days. In stage 2 (HLR: 1.07 $m^3m^{-2}d^{-1}$) with the HLR increase, there was an increase in the effluent concentration above the MWW, mainly in the UBF, which can be explained by the fact that when the HLR increased, the hydraulic equilibrium changed and some compounds could be released in both BFs. However, those from the UBF were non-oxidized compounds, because there was no oxygen, so the COD at the exit of the UBF increased. But the COD was slowly decreasing in both BFs and at the end of this stage, the removal efficiency increased to 78%. This is similar to what Vigueras-Cortés *et al.* (2013) obtained; they achieved a removal efficiency of 80% with a HLR of 0.80 $m^3m^{-2}d^{-1}$. In stage 3 (HLR: 1.34 $m^3m^{-2}d^{-1}$) the system was stable and the COD concentration did not increase, indicating that the extraction of soluble compounds from wood chips was finished; an average removal of 83% was obtained, similar to the findings of Garzón-Zúñiga *et al.* (2008) who used a HLR of 0.30 $m^3m^{-2}d^{-1}$ and tropical woods as OFM. According to the system behavior, the UBF increased the final COD concentration rather than decreasing it. Therefore, the combination with the UBF was not advantageous for COD removal.

TSS removal

Regarding TSS (Figure 4), it was observed that during all stages both BFs showed high removal efficiencies with concentrations below the limit of Mexican and US standards (30 mg L^{-1}), except for a period between day 112 and day 142, when there was a problem with the hydraulic trap at the outlet of the system and very fine particles of degraded OFM were swept. From day 147 onwards, the concentration of TSS in the effluent again reached <30 mg L^{-1}, achieving a removal efficiency of 95%. This result is equal to what Garzón-Zúñiga & Buelna (2011) obtained, who dealt with a lower influent concentration, but without the aid of mechanical aeration. In stage 3, the removal efficiency was 97%, which is higher than what Vigueras-Cortés *et al.* (2013) obtained and similar to what Buelna & Bélanger (1990) reported.

The combination of BFs in the treatment train improved TSS removal, as the UBF slightly decreased the concentration obtained in the ABF. However, the effluent of the ABF met the required standards (30 mg L^{-1}) so, for the TSS, the UBF was not necessary either.

FC removal

From the start-up and during the first 60 days of operation, the BFs showed a minimal decrease in FC (less than one log unit), but from day 63 its removal began to increase exponentially achieving, at the end of this stage, a removal efficiency equivalent to two log units (Figure 5), which did not comply with the regulations. At the beginning of stage

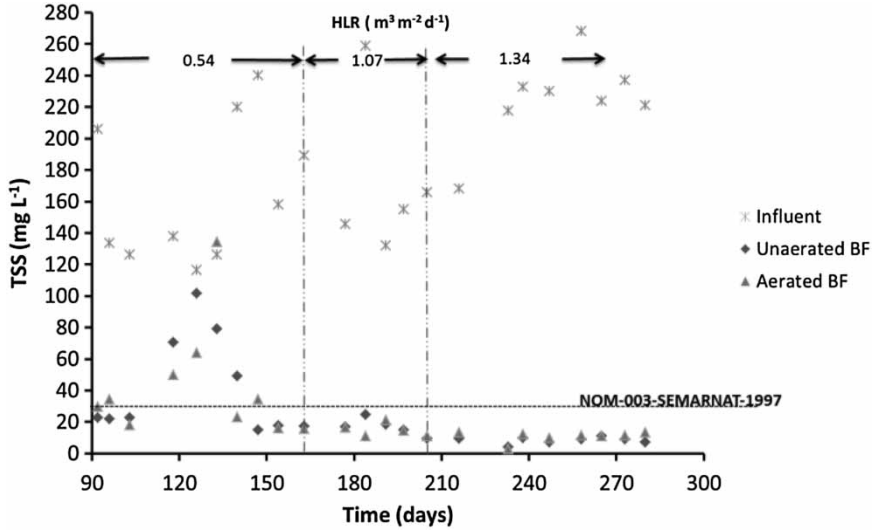

Figure 4 | Removal efficiency of total suspended solids in a system of BFs packed with mesquite wood chips.

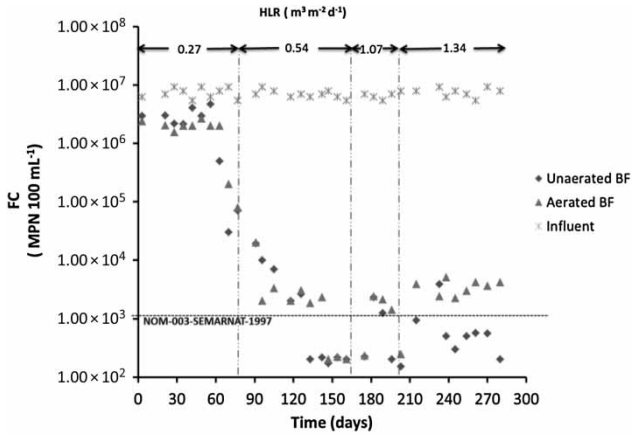

Figure 5 | Removal efficiency of fecal coliforms in a system of BFs packed with mesquite wood chips.

1 (HLR: 0.54 $m^3m^{-2}d^{-1}$), it was observed that the concentration did not show any increase compared with the start-up stage. It continued to decrease until day 130, when it reached the allowable limit (1,000 MPN 100 mL^{-1}). The FC removal at the end of this stage was four log units. This result agrees that of Vigueras-Cortés *et al.* (2013), who cited a HLR of 0.27 $m^3m^{-2}d^{-1}$, and that of Garzón-Zúñiga *et al.* (2008), who cited a HLR of 0.30 $m^3m^{-2}d^{-1}$. The result reinforces the suggestion of these authors that the initial removal (first 60 days) was caused by physical filtration processes and from day 60 to 120, when it increased noticeably, it was caused by a process of predation realized by testing amoebae living in BFs which are known to degrade lignin, cellulose, and free-living bacteria.

When the HLR changed (1.07 $m^3m^{-2}d^{-1}$), an increase in the concentration of the effluent of one-log unit was observed in both BFs, but 37 days later (day 200 of operation) the FC concentration decreased again to values of <1,000 MPN 100 mL^{-1}. At the end of this stage, a removal of four log units was achieved. In stage 3, when the HLR increased again, an increase in the concentration took place, but after 48 days (day 238) the combined system of BFs again achieved a removal efficiency of four log units, equal to what Garzón-Zúñiga & Buelna (2011) had reported, who used wood chips of tabachin (*Caesalpinia pulcherrima*) and jacaranda (*Jacaranda mimosifolia*) as OFM but at lower HLRs.

When applying the first two HLRs, the FC removal was performed almost exclusively on the ABF, so the UBF no longer increased the removal efficiency. However, when the third HLR was applied, the treatment train was efficient, because in the ABF a high removal percentage was achieved but not enough to reach the limit established by the regulations, so the UBF complemented the treatment, achieving a greater removal rate and decreasing the concentration of the final effluent below 1,000 MPN 100 mL^{-1}.

pH and EC

The pH at the start-up stage, as has been mentioned, was 4.5 to 5.6, possibly due to the presence of fulvic acids extracted from the washing of the OFM (Garzón-Zúñiga *et al.* 2005). During 120 days of operation, the pH rose to a value of 7.37 ± 0.32, which is an appropriate value for the formation and stability of a biofilm. The pH remained stable until the end of the experiment (Figure 6(a)). This behavior was

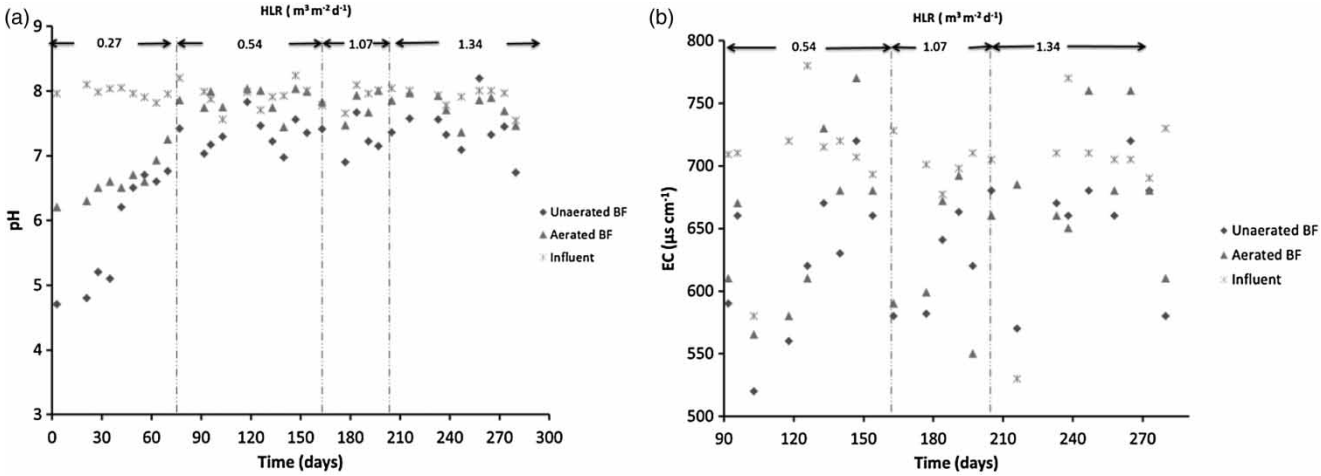

Figure 6 | Behavior of pH (a) and EC (b) in the system of BFs packed with mesquite wood chips.

similar to the stabilization period reported by Garzón-Zúñiga *et al.* (2008). Regarding the EC (Figure 6(b)), at the beginning of stage 1 a significant removal efficiency was observed in the BFs, a tendency to decrease such removal and to equalize the influent concentration. This behavior could be explained by adsorption of the dissolved salts present in the WW into the OFM, until saturation. During stage 2, a similar behavior was observed when the HLR was increased and the concentration balance changed and some removal occurred, again with a tendency to decrease until it reached an average concentration of $637 \pm 38\ \mu S\ cm^{-1}$, with a removal efficiency of 18%. Finally, in stage 3, a more uniform behavior was observed, resulting in an average concentration of $653 \pm 51\ \mu S\ cm^{-1}$ and a removal efficiency of 16%. As the HLR increased, the removal efficiency of the EC decreased, because of the saturation of the OFM.

At every stage the effluent met the criteria for agricultural reuse, without risk of soil salinization, which occurs at values $>3{,}000\ \mu S\ cm^{-1}$ (FAO 1992).

Pressure drop

Maximum offset values in the columns were between 2 and 5 mm throughout the experimentation, because of: (1) the particle size of the OFM that gave high porosity to the filtration bed (84%), which is an excellent porosity for OFM (Torres *et al.* 2003), allowing plenty of space for fluid circulation; and (2) the four column separations which prevented compaction of packing material. These two factors reduced clogging problems and enabled pressure drop values close to zero. This result agrees with that reported by Vigueras-Cortés *et al.* (2013), who noted that a column with four separations is more efficient in terms of hydraulic load loss than those containing 8 to 12.

Effect of HLR on removal efficiency

For all the HLRs tested, the pollutant removal efficiencies met the Mexican and US regulations for reuse in irrigation only in the ABF, except for the highest HLR tested (1.34 $m^3m^{-2}d^{-1}$), which did not comply with BOD_5 and FC concentration. Therefore, in this case, the combination of ABF and UBF was necessary to obtain an effluent that met Mexican and US standards. According to the results presented for the BFs at laboratory scale, the best efficiency was obtained by applying a HLR of 1.07 $m^3m^{-2}d^{-1}$ (Table 3).

Table 3 | Removal efficiency and average concentration of pollutants

	BOD_5		COD		TSS		FC	
Stage/HLR (No./$m^3m^{-2}d^{-1}$)	%	mg L^{-1}	%	mg L^{-1}	%	mg L^{-1}	log units	MPN 100 mL^{-1}
1/0.54	91	28	−41	991	90	17	4	220
2/1.07	92	24	78	158	95	10	4	130
3/1.34	83	48	83	123	97	7	4	490
Mexican and US regulations*		30				30	4	1,000

MPN = most probable number; * NOM-003-SEMARNAT-1997 and US EPA (2004).

Table 4 | Comparison of removal efficiency of pollutants with different OFMs

OFM	HLR ($m^3m^2d^{-1}$)	BOD_5		COD		TSS		FC	
		%	mg L^{-1}	%	mg L^{-1}	%	mg L^{-1}	Log units	MPN 100 mL^{-1}
Caesalpinia pulcherrima & *Jacaranda mimosifolia**	0.078[1]	97	7	71	130	95	5	4	8,800
Agave fiber**	0.80[2]	92	22	80	128	92	16	3	7,560
Peat**	1.30[3]	96	3	87	22	98	2	3	2,000
Mesquite**	1.07[4]	92	24	78	158	95	10	4	130
Endemic tropical wood chips and natural fibers**	0.30[5]	98.5	2.5	84	88	–	–	4	69

*Full scale.
**Laboratory scale.
References: [1]Garzón-Zúñiga & Buelna (2011), [2]Vigueras-Cortés *et al.* (2013), [3]Buelna & Bélanger (1990), [4]this research, [5]Garzón-Zúñiga *et al.* (2008).

Comparison with other OFMs

In Table 4, the pollutant removal efficiencies obtained with different OFMs are shown, including those in this study. It can be seen that high removals were obtained for each of the materials, but mesquite reached these efficiencies at a higher HLR than all the others, except for peat (Buelna & Bélanger 1990). However, with this OFM (peat) and HLR ($1.30\ m^3m^{-2}d^{-1}$) the maximal limit for FC demanded by the regulations was not achieved.

CONCLUSIONS

BFs packed with mesquite wood chips (*Prosopis*) can remove pollutants from WW with high efficiency and meet the regulatory standards of Mexico and the USA for irrigation of green areas when operated with HLRs $\leq 1.07\ m^3m^{-2}d^{-1}$. Mesquite wood chips are therefore considered a good material to be used as OFM support for biofilm growth in the treatment of WW in BFs over organic beds.

The treatment train (aerated BF + unaerated BF) was not necessary for the removal of organic matter and TSS, because with the first aerated BF alone, it was possible to achieve the discharge limit concentrations <30 mg L^{-1} established by Mexican and US regulations. However, for the removal of FC, the combination of aerated + unaerated BFs was necessary to reach this limit ($\leq$ 1,000 MPN 100 mL^{-1}) when the HLR was $>1.07\ m^3m^{-2}d^{-1}$.

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