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Application rates and filtering materials for biofilters in house sewage

Tasa de aplicación y materiales filtrantes para la operación de los biofiltros con aguas residuales

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ABSTRACT

Application rates and organic filtering materials for the removal of nitrogen and phosphorus in biofilters in primary house sewage are determined. An assay was prepared with 27 biofilters in an experimental area of the Universidade Federal de Viçosa, Viçosa MG Brazil. Nitrogen and phosphorus concentrations were determined monthly during 153 days of the experiment which followed the sub-subparcel scheme. Whereas parcels consisted of application rates of home sewage (0.5; 1.0; 1.5 $m^3\,m^2\,d^{-1}$), the subparcels comprised types of organic matter (composted urban organic wastes, sugarcane bagasse and sawdust) and the sub-subparcels were the evaluation periods (August, September, October, November and December 2009), in totally randomized blocks, with three repetitions. Results showed that the filtering organic matters sugarcane bagasse and sawdust were more adequate for N and P removal in home sewage. However, composted urban organic wastes raised their rates in the effluents collected by the biofilters. There was no significant effect of application rates of house sewage on N and P removal of the effluent by biofilters filled with composted urban organic wastes, sugarcane bagasse and sawdust. Biofilter effluents have high N and P quantities for fertilization-irrigation of non-raw consumed cultures.

Key words: sustainability; water re-use; treatment; earthworm.

RESUMEN

Este estudio tuvo como objetivo determinar la tasa de aplicación y material orgánico para la eliminación de nitrógeno y fósforo en los biofiltros operando con las aguas residuales domésticas. Con este fin, un sistema experimental montado consta de 27 biofiltros en el área experimental de la Universidad Federal de Viçosa-MG. Las concentraciones de nitrógeno y fósforo se determinaron mensualmente durante um período de 153 días. El experimento fue creado en el esquema de parcelas subsubdivididas, donde las tasas de aplicación de aguas residuales en las parcelas (0,5, 1,0 y 1,5 $m^2\,m^3\,d^{-1}$), las subparcelas los tipos de material orgánico (residuo compostado, bagazo de caña de azúcar y aserrín) y en periodos de evaluación las subsubparcelas (agosto, septiembre, octubre, noviembre y diciembre de 2009), en un diseño de bloques al azar con tres repeticiones. Los resultados indicaron que los materiales orgánicos de filtro de bagazo de caña y aserrín fueron más adecuados para la eliminación de nitrógeno y fósforo en las aguas residuales, mientras que el residuo compostado se incrementó en contenido de estos elementos en los efluentes recogidos en los biofiltros. No hubo un efecto significativo de las tasas de aplicación de las aguas residuales domésticas en el traslado de nitrógeno y fósforo de las aguas residuales por biofiltros llenos de compost de residuo, bagazo de caña de azúcar y aserrín. El efluente de biofiltros tiene contribuciones apreciables de fertirrigación N y P para los cultivos que no se consumen crudos.

Palabras clave: *sustentabilidad, reutilización del agua, tratamiento, lombrices.*

Introduction

Current urbanization model has produced enormous quantities of house sewage and sanitary sewage systems have proved to be so inadequate that they are the main cause of diseases and environmental pollution (Zhao *et al.*, 2010).

According to the 2008 Brazilian Research for Basic Health, 44.8% of Brazilian municipalities lack house sewage collection networks, among

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which only 28.5% have sewage treatment systems (IBGE, 2010).

The launching of crude house sewage in the water bodies by sanitation firms changes the water characteristics at the launching site and makes it unfit for human use or even for agricultural and cattle-raising activities (von Sperling, 2011).

The use of biofilters with several industrial and agro-industrial wastes (Moon *et al.*, 2010; Xing *et al.*, 2011; Fernández-Gómez *et al.*, 2012) in the treatment of primary house wastes makes use of solar radiation as tertiary treatment. Since the biofilter's filtering layers retain most suspended solids and reduce turbidity, they favor the penetration of ultra-violet radiation (UVA and UVB) within the liquid medium. Solar radiation wavelengths rupture the cytoplasm membrane of the pathogenic microorganism and trigger its non-activation (Sanches-Roman *et al.*, 2007). Further, with regard to the re-use of water by the drop irrigation system, the technology provides risk decrease in the emissaries' physical obstruction (Batista *et al*., 2010).

House sewage treatment by biofilters is a clean and low cost technology, easily performed and with high efficiency in the removal of different physical and chemical pollutants (Kim & Sorial, 2007; Jeong *et al*., 2008; Jun & Wenfeng, 2009; Fu *et al*., 2011; Wang *et al.*, 2011).

Batista *et al.* (2012) used biofilters filled with composted urban organic wastes, sugarcane bagasse and sawdust supplied with primary house sewage at the rates of 0.5; 1.0; and 1.5 m^3 m^{-2} d^{-1}. The above authors removed electrical conductivity up to 59 and 53% respectively during the period by biofilters with sawdust at the application rates of 1.0 and 1.5 m^3 m^{-2} d^{-1}.

In another experiment, Batista *et al.* (2011) removed 60, 80 and 66% of chemical oxygen demand (COD) and 65, 71 and 80% of the biochemical oxygen demand (BOD) by biofilters filled with composted urban organic wastes, sugarcane bagasse and sawdust at the rates of 1.0 and 1.5 m^3 m^{-2} d^{-1} with primary house sewage.

Current assay defines the application rate and type of organic material for the removal of total N and P in biofilters with primary house sewage.

Materials and Methods

Current assay was performed at the Pilot Unit of Waste Water Treatment and Irrigation Agriculture (UTAR) of the Universidade Federal de Viçosa (UFV) in Viçosa MG Brazil, at 20º45'14" S and 42º52'53" W and mean height 650 m.

UTAT is supplied by a discharge of 2 L s^{-1} of raw house sewage from the housing complex Bosque Acamari in Viçosa, where 600 people live. Effluent applied to the biofilters surface passed through a preliminary system comprising a sand box and a primary treatment with a 14-h hydraulic retention time septic tank.

The experiment comprised 27 cement modules 1.0 m wide, 2.0 m long and 1.2 m high, with 2.4 m^3 and surface area 2.0 m^2. Three types of filtering organic materials (sugarcane bagasse with 6 - 10 mm granulometry; sawdust with 2.0 - 5.0 mm granulometry; composted urban organic waste 2.0 - 5.0 granulometry) were assayed in the modules. Three application rates of primary house sewage (0.5; 1.0; 1.5 m^3 m^{-2} d^{-1}) were performed. Table 1 shows the characteristics of the organic wastes used in biofilter filling.

The 27 biofilters for the treatment of primary house sewage were filled with four layers of different filtrating media, namely, two were filled with organic matter and two with inorganic matter (Figure 1). The first layer, 0.20 m thick, comprised organic matter with the earthworm species *Eisenia phoetida*, as suggested by Xing *et al.* (2011), at a mean population level of 600 earthworms per cubic

Table 1. Characteristics of organic wastes used in biofilter filling.

Wastes in biofilters filling	Humidity (%)	HRT (Minutes)	Porosity (%)	pH	Temperature (ºC)
Composted urban organic waste	39.3	12	74	3.9	27.7
Sugarcane bagasse	31.1	8	62	5.0	26.4
Sawdust	43.7	10	64	8.4	27.0

HRT – hydraulic retention time.

(a) (b)

Figure 1. Experimental apparatus with 27 cement biofilters (a); detail of the biofilters (b).

meter, at the first biofilters level so that infiltration would be avoided, and treated with accumulated slug. The second layer, 0.40 m thick, was filled only with organic material. The third and fourth layers were composed of 0 and 1 pebbles at a thickness of 0.40 m for drainage in the biofilters and continuous aeration of the system. A drainage system composed of 32 mm-diameter PVC tubes was placed at the bottom of each module for the collection of the treated effluent.

During the construction of the biofilters, the organic materials were gradually conditioned in the apparatus, at a 0.2 m layer thickness, compressed at 0.167 kgf cm^{-2} (16.35 kN m^{-2}), pressure exerted by a man, 50 kgf weight, up to the height of 0.60 m.

The modules, surrounded by shade nets to deter the earthworms' predators, were supplied with primary house waste from a septic tank with a 14-h retention time. Three cv motor pumps, three 2.5 m^3 reservoirs and 50 mm diameter PVC tubes perforated throughout their length and forming small segments of windowed tubes for a homogeneous application on the surface area of each biofilters were employed.

Samples of the affluent and biofilters effluent were collected to evaluate the effluent quality from simple samples obtained at four fixed periods of the day (8, 11, 14 and 17 h), once in 30 days, during 153 days. Concentrations of total Nitrogen (N) were obtained by Kjeldhal method and phosphorus (P) concentrations were calculated by spectrophotometry, following *Standard Methods for the Examination of Water and Wastewater* (Rice *et al.*, 2012). All analyses were undertaken at the Water Quality Laboratory of the UFV.

Assay was based on a sub-subdivided parcels scheme, with parcels comprising application rates of house sewage (0.5; 1.0; 1.5 m^3 m^2 d^{-1}); subparcels comprising types of organic material (composted urban organic waste, sugarcane bagasse and sawdust); sub-subparcels comprising evaluation periods (August, September, October, November and December 2009), within a totally randomized design, with three repetitions.

Data underwent analysis of variance and mean test. The former involved test F at 1 - 5% level of probability and the latter employed Tukey's test at 5% probability. Computer program SAEG 9.1 was employed for statistical analyses (Ribeiro Júnior & Melo, 2008).

Results and Discussion

The CONAMA resolution n. 357/2005 does not establish maximum limits for total N in the discharge of treated effluents in receiving water bodies (BRASIL, 2005). The resolution deals with maximum rate of ammonia nitrogen at 20 mg L^{-1}, due to its toxicity for fish. However, von Sperling (2011) states that eutrophication risks of receiving water bodies is associated with the raise of N and P rates owing to the discharge of solid and liquid wastes and surface flow from urban and rural areas to surface water sources. Figure 1 shows that during August and September 2009 greater mean N concentrations were launched in the effluents of the biofilters when compared to those in the affluents. This was due to N release N in the filtering organic wastes when the biofilters with house wastes were activated.

With regard to the application rate of house sewage at 0.5 m^3 m^{-2} d^{-1}, excess of N in composted urban organic waste, sugarcane bagasse and sawdust occurred after 30 days (September 2009), whereas

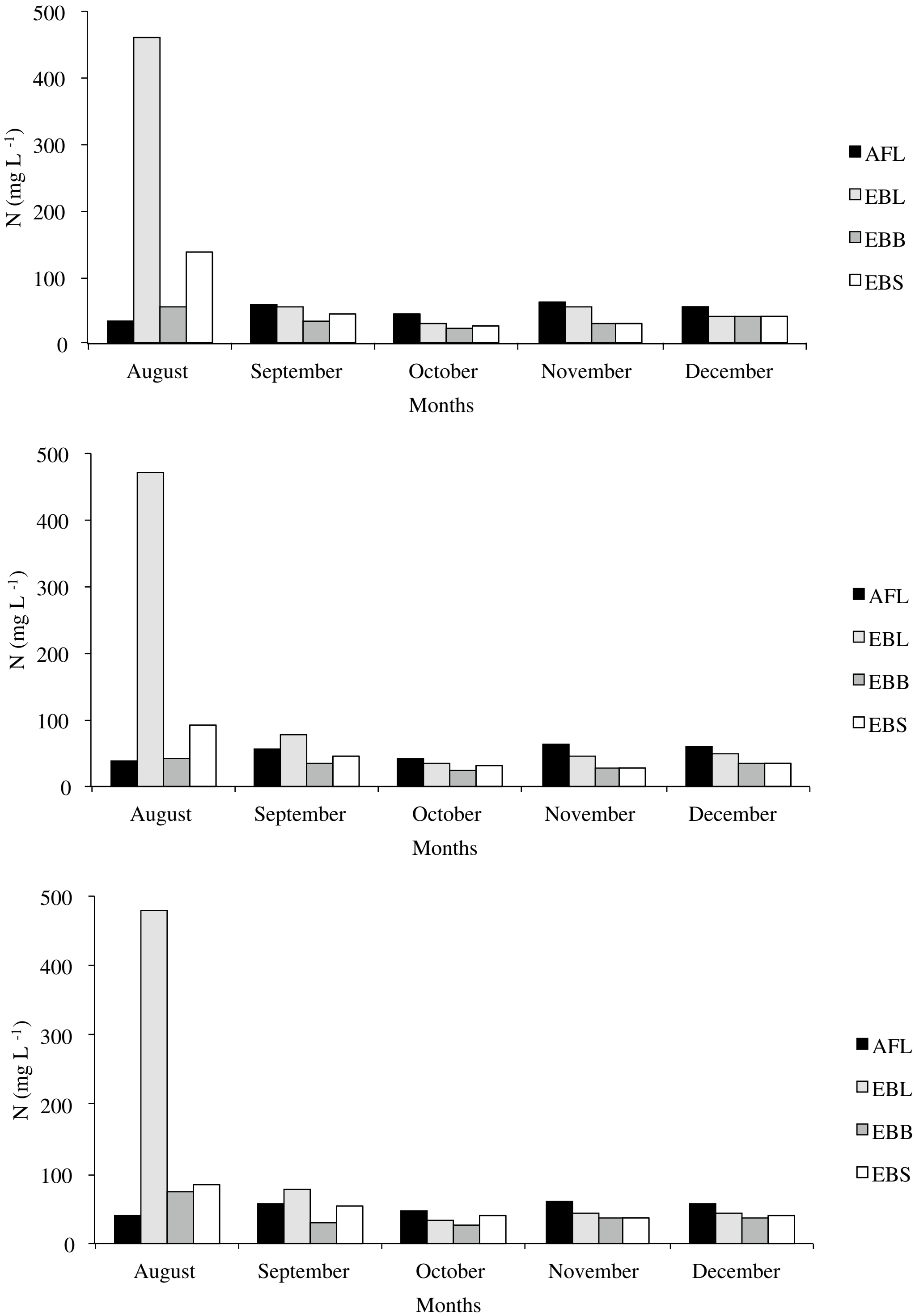

Figure 2. Rates of total N in samples of house sewage collected upstream and downstream the biological filter prototypes with application rates 0.5 (a), 1.0 (b) and 1.5 (c) $m^3\ m^{-2}\ d^{-1}$ (AFL – house sewage without any treatment; EBL – house sewage collected downstream the biological filter with composted urban organic wastes; EBB – house sewage collected downstream the biological filter with sugarcane bagasse; EBS – house sewage collected downstream the biological filter with sawdust).

N excess was removed from organic wastes after 60 days using biofilters (October 2009), with application rates of house sewage at 1.0 and 1.5 m^3 m^{-2} d^{-1}. Above results may be attributed to the development of microorganisms in the wastes when the rate of house sewage at 0.5 m^3 m^{-2} d^{-1} was applied and which helped in N removal.

It should be noted that after 153 days of bio-filtering (December 2009), mean N concentrations in the effluents decreased when compared to those of the affluents. When the house sewage rate of 0.5 m^3 m^{-2} d^{-1} was applied, mean N concentrations in the effluents of biofilters filled with composted urban organic wastes, sugarcane bagasse and sawdust were 43, 40 and 41 mg L^{-1}, or rather, lower than mean N rate of 55 mg L^{-1} with mean removals of 22, 27 and 25%, after 153 days. It has been verified that for the application rate of house sewage of 1.0 m^3 m^{-2} d^{-1}, the effluents of biofilters with composted urban organic wastes, sugarcane bagasse and sawdust had mean N concentrations of 49, 35 and 36 mg L^{-1}, with mean N removals of 17, 41 and 39%, respectively, after 153 days. Mean N concentration in the affluent reached 59 mg L^{-1} after 153 days of bio-filtering. In biofilters with composted urban organic wastes, sugarcane bagasse and sawdust at an application rate of house sewage of 1.5 m^3 m^{-2} d^{-1} the mean N concentrations were 45, 38 and 40 mg L^{-1}, respectively, with mean N removal of 22, 34 and 30%. In fact, mean concentration in the affluent was 58 mg L^{-1} after 153 days of bio-filtering.

According to von Sperling (2011), the effluents treated with all types of biofilters may eutrophyze the receiving water bodies since the eutrophic level may be reached at P concentrations ranging between 0.025 and 0.10 mg L^{-1}. Figure 3 shows that in August and November 2009 there were higher mean P concentrations only in the biofilters with composted urban organic wastes, when compared to the affluents. This was due to P release in the above-mentioned organic waste.

Mean P concentrations in the effluents after 153 days of bio-filtering (December 2009) decreased when compared to affluents, with the exception of biofilters with composted urban organic wastes. When the house sewage rate 0.5 m^3 m^{-2} d^{-1} was applied, P concentrations in the effluents of biofilters filled with composted urban organic wastes, sugarcane bagasse and sawdust were 7.9; 4.4; and 4.2 mg L^{-1}, respectively. The above amounted to mean removal of 0, 40 and 44%, since mean P concentration in the affluent reached 7.4 mg L^{-1}, after 153 days of bio-filtering. It was verified that in the case of an application rate of house sewage at 1.0 m^3 m^{-2} d^{-1}, P concentrations in biofilters effluents with composted urban organic wastes, sugarcane bagasse and sawdust were respectively 7.0; 2.7; and 2.4 mg L^{-1}. Mean removals reached 9, 65 and 69%, with mean P concentration of 7.70 mg L^{-1} in the affluent after 153 days. P concentration rates in the house sewage application rate of 1.5 m^3 m^{-2} d^{-1} were 7.6; 5.3; and 5.7 mg L^{-1} in the biofilter effluents with composted urban organic wastes, sugarcane bagasse and sawdust. Mean P removal rates were 3, 32 and 27%, respectively and mean P concentration in the affluent reached 7.8 mg L^{-1}.

Table 2 details the analysis of variance of total N and P removal rates from the effluents collected in the biofilters, with different filtrating modes, at three application rates of treated house sewage, within the sub-subdivided parcel scheme. The interactivity application rate of house sewage (TA) x type of filtrating material (TF) and application period (PA) in the N and P removal variables was not significant at 5% probability.

The interactivity TA x TF x PA for N and P removal variables was considered significant to analyze the performance of the biofilters. Detailing of the interactivity TA x TF x PA for the variables of N and P removals was undertaken for results of the analyses of variance.

Table 2. Details of the analyses of variance from variables N and P in the sub-subdivided parcel scheme.

Variation source	Degree of freedom	Means	
		N	P
TA	2	4702ns	8453ns
Waste (a)	6	1511	3489
TF	2	7.73x105**	2.87x105**
TA x TF	4	1234ns	3200ns
Waste (b)	12	1232	2694
PA	4	1.28x106**	1.07x105**
TA x PA	8	6790**	4454ns
TF x PA	8	6.08x105**	7.74x104**
TA x TF x PA	16	1876ns	4104ns
Waste (c)	72	1216	3069

**, * and ns F were significant at 1 and 5% probability and not significant at 5% probability, respectively.

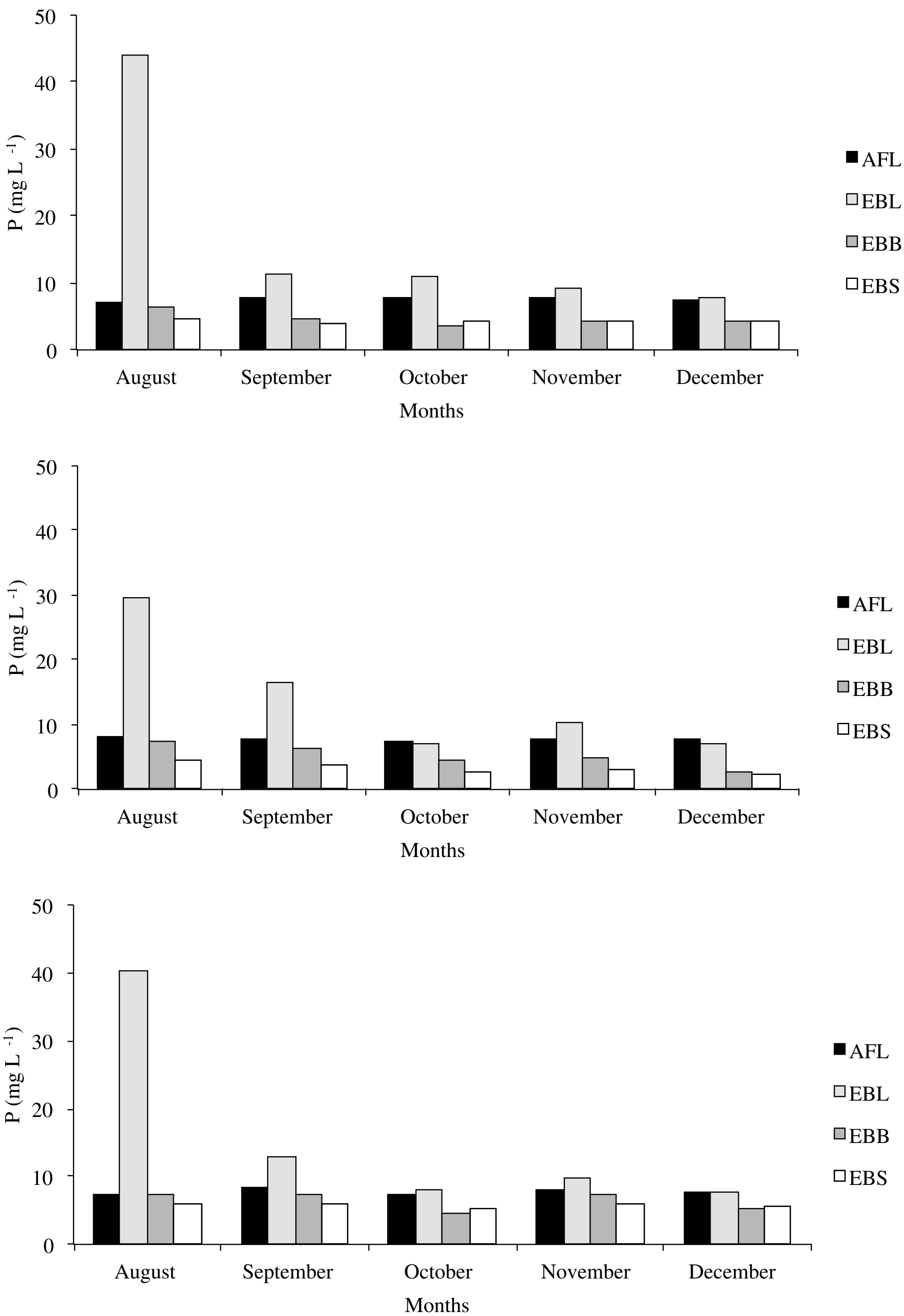

Figure 3. P rates in samples of house sewage collected upstream and downstream of the biological filter prototypes at the application rates of 0.5 (a), 1.0 (b) and 1.5 (c) m^3 m^{-2} d^{-1} (AFL – house sewage without any treatment; EBL – house sewage collected downstream the biological filter with composted urban organic wastes; EBB – house sewage collected downstream the biological filter with sugarcane bagasse; EBS – house sewage collected downstream the biological filter with sawdust).

Table 3. Mean rates of the variable N removal (%) for the factor type of organic material within each level of time application and each level of application rate.

Time of application	Types of organic materials	Application rate ($m^3m^{-2}d^{-1}$)		
		0.5	1.0	1.5
August	Composted urban organic waste	–1215.48 Bc	–1095.25Ac	–1117.96Ab
	Sugarcane bagasse	–62.59 Aba	–11.15Aa	–86.55Ba
	Sawdust	–295.10 Bb	–133.58Ab	–116.34Aa
September	Composted urban organic waste	3.33 Aa	–37.35Ab	–33.33Ab
	Sugarcane bagasse	40.36 Aa	41.62Aa	46.67Aa
	Sawdust	23.33 Aa	21.02Aab	7.39Aab
October	Composted urban organic waste	27.96 Aa	17.24Aa	28.13Aa
	Sugarcane bagasse	51.62 Aa	37.93Aa	39.59Aa
	Sawdust	36.56 Aa	20.69Aa	14.59Aa
November	Composted urban organic waste	12.91 Aa	29.45Aa	27.39Aa
	Sugarcane bagasse	49.80 Aa	55.37Aa	39.75Aa
	Sawdust	51.28 Aa	59.69Aa	39.75Aa
December	Composted urban organic waste	21.37 Aa	17.19Aa	22.23Aa
	Sugarcane bagasse	26.50 Aa	41.08Aa	33.57Aa
	Sawdust	24.79 Aa	37.89Aa	30.33Aa

* Means followed by at least the same capital letter in the columns for each application time and by a small letter on the lines for each application rate do not differ among themselves at 5% probability by Tukey's test.

Table 3 shows mean rates of variable N removal with the type of filtrating material within each level of application time and within each level of rate of application of house sewage. The table does not show any effect of application rates on N removal for each type of organic material during the period September-December 2009.

The release of the pre-existing N in the composted urban organic waste, sugarcane bagasse and sawdust occurred in August 2009 with negative removal rates.

When means of the variable N removal followed by at least a capital letter in the columns of Table 3 are analyzed, it may be noted that there was no statistical difference among the application rates from October to December 2009.

There was no statistical difference among the types of organic materials from October to December 2009 when the means of the variable total N removal followed by at least a small letter on the lines of Table 3 are compared.

Table 4 shows that there was no effect of the application rates on P removal for each type of organic material from September to December 2009. P removal in the biofilters with sugarcane bagasse and sawdust at the application rates 0.5, 1.0 and 1.5 m^3 m^{-2} d^{-1} did not differ between September and December 2009 when the means of the variable P removal followed by at least the same capital letter in the columns of Table 4 are compared

When the means of the variable removal of P followed by at least the same small letter in the lines of Table 4 are compared, P removal in the biofilters with composted urban organic waste at application rates 0.5, 1.0 and 1.5 m^3 m^{-2} d^{-1} differed from that obtained in the biofilters with sugarcane bagasse and sawdust, between August and December 2009.

Conclusions

Whereas the filtrating organic materials sugar bagasse and sawdust were more adequate for N and P removal in house sewage, composted urban organic waste raised the rates of these elements in the effluents collected in the biofilters.

No significant effect in the application rates of house wastes were extant in N and P removals from the effluent by the biofilters filled with composted urban organic waste, sugarcane bagasse and sawdust.

Biofilters' effluents have sufficient N and P rates for the fertilization-irrigation of non-raw consumed cultures.

Table 4. Mean rates of the variable removal of P (%) for the factor type of organic material at each level of time application and each level of application rate.

Time of application	Types of organic materials	Application rate ($m^3m^{-2}d^{-1}$)		
		0.5	1.0	1.5
August	Composted urban organic waste	–513.97Bb	–256.04Ab	–436.98Bb
	Sugarcane bagasse	12.50Aa	10.06Aa	–0.33Aa
	Sawdust	33.00Aa	45.89Aa	17.83Aa
September	Composted urban organic waste	–43.95Ab	–107.57Ab	–55.25Ab
	Sugarcane bagasse	40.66Aa	21.24Aa	10.31Aa
	Sawdust	48.67Aa	52.05Aa	26.75Aa
October	Composted urban organic waste	–41.59Ab	5.22Ab	–12.73Ab
	Sugarcane bagasse	52.71Aa	38.98Aa	36.21Aa
	Sawdust	46.06Aa	62.07Aa	28.66Aa
November	Composted urban organic waste	–16.94Ab	–31.96Ab	–25.41Ab
	Sugarcane bagasse	44.23Aa	35.65Aa	6.40Aa
	Sawdust	44.85Aa	58.86Aa	23.39Aa
December	Composted urban organic waste	–6.76Ab	8.97Ab	2.81Ab
	Sugarcane bagasse	40.19Aa	64.67Aa	32.31Aa
	Sawdust	43.59Aa	68.71Aa	26.69Aa

* Means followed by at least the same capital letter in the columns for each time of application and by small letters in the lines for each rate of application do not differ among themselves by Tukey's test at 5% probability.

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