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Influence of vegetation to removal organic load and nutrients in a septic waste treatment system

Influência da vegetação na remoção de carga orgânica e nutrientes em sistema de tratamento de resíduos sépticos

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Abstract

The use of constructed wetlands for septic waste treatment has been little explored in developing countries, mainly due to the limited information available about the technology. The real influence of vegetation on waste treatment is one of the points in question. This paper aims to evaluate the influence of vegetation vetiver grass (Chrysopogon zizanioides) on the removal of pollutants and the stability of a mineral beds system for septic waste treatment. Two beds were built (with and without vegetation) for the disposal and treatment of septic waste in tidal flow. Raw waste and treated effluent were analysed in both cells. The percentage efficiency of removal of pollutants from each bed was evaluated. In addition, dispersion and correlation analysis of applied pollutant loads and effluent concentrations were carried out at each bed. Planted cell showed better results in percentage efficiency of removal of pollutants. Effluent concentrations were lower in planted cell for the applied loads of biochemical oxygen demand (BOD) and total phosphorus (TP). For ammonia, the cell without plants had lower effluent concentrations. In general, in both cells were observed low-medium associations between applied loads and effluent concentration. The bed with plants was shown to be more stable and with greater capacity of amortization of the pollution for the parameters BOD and TP.

***Keywords**: Septic waste. Environmental pollution. Constructed wetlands. Pollutants remoting.*

Resumo

O uso de wetlands construídas para tratamento de resíduos sépticos vem sendo pouco explorado nos países em desenvolvimento, principalmente devido às poucas informações disponíveis sobre a tecnologia. A real influência da vegetação no tratamento dos resíduos é um dos pontos em questão. Este trabalho teve por objetivo avaliar a influência da vegetação Capim Vetiver (Chrysopogon zizanioides) na remoção de poluentes e na estabilidade de um sistema de leitos minerais para tratamento de resíduos sépticos. Foram construídos dois leitos (com e sem vegetação) para disposição e tratamento dos resíduos sépticos em fluxo vertical subsuperficial por bateladas. Realizaram-se coletas e análises laboratoriais do resíduo bruto e efluente tratado em ambas células de tratamento. Avaliou-se a eficiência percentual de remoção de poluentes de cada leito. Além disso, fez-se a análise de dispersão e correlação das cargas poluentes aplicadas e as concentrações efluentes a cada leito. A célula plantada apresentou melhores resultados na eficiência percentual de remoção de poluentes. As concentrações efluentes foram menores na célula com plantas para as cargas aplicadas de demanda biológica de oxigênio (DBO) e fósforo total (PT). Para amônia, a célula sem plantas apresentou menores concentrações de saída. Em geral, observou-se baixa-média associação entre as cargas aplicadas e concentração de efluente em ambas células. O leito com plantas demonstrou-se mais estável e com maior capacidade de amortização da poluição para os parâmetros DBO e PT.

***Palavras-chave:** Resíduos sépticos. Poluição ambiental. Alagados construídos. Remoção de poluentes.*

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1 Introduction

Septic waste (SW) is a sanitary problem in developing countries, especially in regions without infrastructure that do not have sites for treatment or adequate environmental disposal.

Pathogenic organisms, heavy metals and toxic organic compounds may be present on this waste and are detrimental to the quality of human life and environmental stability (HALALSHEH et al, 2011). In addition, the presence of high organic and nutritional load can lead to environmental damages, mainly to aquatic systems. In this context, its treatment and adequate final disposition becomes of extreme necessity (VINCENT et al, 2011).

The global use of constructed wetlands (CW) in treatment of residues of diverse origins and characteristics is an emerging technology, showing to be an efficient and low-cost alternative to conventional systems (WU et al, 2015).

According Brasil and Matos (2008), due mainly to the simplicity of operation and maintenance, associated to its efficiency, CW should be deployed primarily in regions lacking sanitation and with little infrastructure, situation very common in Brazil.

Even with proven efficiency in the treatment of several types of waste, the use of this technology has been little explored in SW treatment at the national level, highlighting only works such as those developed by Suntti, Magri and Philippi (2011).

One of the main factors to be researched relates to the real and effective contribution of plants in SW treatment, that is, the difference between beds with and without vegetation. This contribution is not only related to the percentage efficiency in removal of pollutants, but also in the behaviour of the system over time, in its stability through application of varied rates of organic and nutritional load, among other aspects.

These factors are important, because an adequate SW treatment system must be stable and efficient to be applicable in practice, especially in accordance with the current environmental legislation (STEFANAKIS and TSIHRINTZIS, 2011; VINCENT et al, 2011). Even through various organic and nutritional loads (characteristic of SW) applied over time, the system should not present significant loss and/or efficiency variation in the removal of pollutants, and above all this, it must be in accordance with the environmental legislation all the time.

In this context, the study of vegetation capacity to act in treatment and stability of a SW treatment system is of paramount importance, since its results can foster practical applications of this technology.

The objective of this paper was to evaluate the influence of vegetation vetiver grass (*Chrysopogon zizanioides*) on removal of organic and nutritional load, and on the stability of a system of mineral beds for treatment of septic waste in the initial phase of operation.

2 Material and methods

2.1 Place of study

This study was carried out in the Hélio Seixo de Brito Sewage Treatment Plant, in the city of Goiânia, Brazil.

2.2 Treatment beds

An experimental station, CW type, was created for SW treatment generated in the metropolitan region of Goiânia. Two treatment cells (Figure 1) with descending vertical subsurface flow were built. In one of them, the species vetiver grass (*Chrysopogon zizanioides*) was planted and the other remained without vegetation, as a control environment.

Figure 1 - General view of the experimental septic waste treatment plant built

Both beds were excavated in the soil, waterproofed with geosynthetic blanket and filled with overlapping layers of substrate. From the bottom to the surface, 40 cm of gravel #1, 15 cm of gravel #0 and 10 cm of medium sand were arranged, totalling 65 cm of support medium. The cells have an inverted pyramid trunk shape with 3.0 m x 4.0 m in lower base dimensions, 4.15 m x 5.15 m in the top base and 1.20 m of total depth.

A barrier of bags filled with soil was built around the cells in order to avoid rainwater drained by the terrain to penetrate them.

Planted cell received twenty seedlings of the plant vetiver grass (*Chrysopogon zizanioides*), spaced 60 cm apart.

At the bottom of the beds, leachate drainage systems were installed to drain the treated liquid fraction.

On the outside of each drainage system, a hydrometer, to measure the effluent volume, a tap, to collect sample of the treated liquid, a vertical tube, to control the internal level of liquid in the cell and a record for its exhaustion (Figure 2) were installed. The liquid level was designed to stabilize 10 cm below the surface of the substrate in order to maintain subsurface flow.

The sizing of the treatment system followed the parameters and design criteria based on Koottatep et al. (2004).

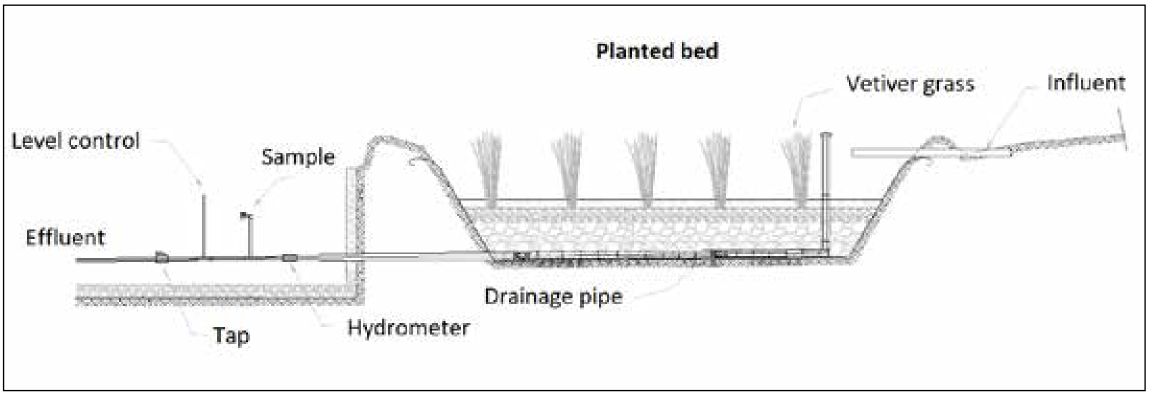

Figure 2 - Longitudinal section representative of the hydraulic system of experimental treatment station of septic waste

2.3 Operation of the treatment system

SW arrangement in treatment beds occurred in non-continuous flow (tidal). On average, there was 3.3 m^3 of SW per bed, weekly, by the exhaustion of "clean-pit" trucks. Higher or lower values than this were applied to both beds, depending on the net volume contained in each truck (no controllable factor in the survey).

Before SW disposal in the treatment beds, it was subjected to the process of removing of coarse solids through railing.

After grating, the residue volume was divided equally, falling on the surface of the beds and liquid fraction percolated filling the empty spaces of the substrate until reaching the level of control. Part of the solid fraction was retained on the surface of the substrate, accumulating throughout the applications.

Six days after the application of SW, both treatment beds were emptied by opening the taps. A new application was made in next day. The cycle was repeated for a period of 98 consecutive days, totalling 14 applications.

2.4 Treatment efficiency

To estimate the percentage fraction of pollutant removals in the study beds, a calculation of SW treatment efficiency was carried out considering the removal of the pollutant load (concentration x volume).

In total, 13 inlet loading values of SW were obtained from both treatment beds. From these date, the efficiency relative to each application was calculated.

The net volume effluent of each bed was measured by hydrometers. The input volume was estimated by weighing the trucks before and after unloading process. Thus, the value of the exhausted mass was obtained. SW samples were collected to evaluate their specific mass for later calculation of SW input volume in the beds.

To the volume of waste entry into the cells, it was added the volume of rainfall in the place. The difference between the applied volume (SW and precipitation) and the drained volume was attributed to evapotranspiration of the system. For this, it was considered that there was no accumulation of liquid into the cells during the studied period.

For evaluation of pollution parameters concentrations, samples were collected from raw SW and after treatment. Raw residues were sampled during the feeding of the beds, collecting them directly in SW application tube. Treated effluents samples were collected on the installed taps, on the 6th day after application, before draining the beds.

To evaluate the efficiency of removal of organic load and nutrients in both systems, laboratory analyses of biochemical oxygen demand (BOD), ammonia and total phosphorus (TP) were performed.

At each SW arrangement, the organic loading rate (kg BOD.m^{-2}.week^{-1}) and nutritional load (kg of nutrient.m^{-2}.week^{-1}) were varied, since it was not possible to control such oscillations, mainly because of the main characteristic of this residue is to present high alternation in its chemical composition.

2.5 Statistical analysis of treatment system

With 13 datas (in each bed) of treatment efficiency, a basic statistical analysis was performed. Mean, maximum, minimum and median treatment efficiency, as well as the standard deviation (SD) and variation coefficient (VC) in both systems were calculated.

Subsequently, degree of normality of raw and treated SW data were evaluated to show the sample distribution according to each parameter. Kolmogorov-Smirnov, Shapiro-Wilk and Anderson-Darling tests were performed, with 0.05 significance level.

Then, a correlation matrix analysis was used to evaluate the association between the applied loads (input) and effluent concentrations (output) of each parameter in both treatment cells. Due to the trend of non-normal distribution of data, Spearman correlation coefficient (ϱ) was used as an estimator of the relation between input and output variables. Scatter plots of values were also done to evaluate the behaviour of both treatment systems.

3 Results and discussion

Based on results of Table 1, there is a clear superiority in efficiency for SW treatment in cell with plants, except for average of ammonia. These results corroborate with those found in the literature for CW (ZHANG et al, 2014), mainly with high removal efficiency of BOD (above 90% on average) and low-medium (values close to 40%) for ammonia.

Table 1 - Descriptive statistics of treatment efficiency of control and vegetation cells

Efficiency		Maximum	Mean	Minimum	Median	SD	VC
Without vegetation	Ammonia (%)	87,44	40,45	-11,85	36,45	27,07	0,67
	BOD (%)	98,51	-30,63	-333,33	41,92	150,87	-4,92
	TP (%)	99,96	-25,66	-886,22	88,44	323,72	-12,61
With vegetation	Ammonia (%)	90,58	36,47	-20,50	48,98	34,31	0,94
	BOD (%)	99,40	91,17	82,29	89,54	6,29	0,07
	TP (%)	99,50	38,10	-391,13	89,29	161,04	4,22

Negative values indicate that in both systems, for certain parameters, there was negative efficiency, that is, pollutant loads of output larger than input. This occurred (40% of the studied period) in the cell without vegetation and sporadically in the planted cell (but never for BOD).

These data initially suggest that the control system is more variable in terms of removal efficiency of pollutant load at the beginning of its operation (highlighting the very high values of standard deviation found for BOD and TP) than the system with plants.

There may be outliers within the analysed points (occasioned by specific situations such as extreme local climatic events, introduction of SW with toxic characteristics to microorganisms and plants, etc.). Therefore, the median is more reliable than the average in this case. Even so, considering only the median efficiency, the environment with plants showed higher results than the environment without vegetation.

In order for a liquid waste treatment system to be fully efficient, these outliers must be null, since only one point outside the scope of environmental legislation is already non-compliant and compromises the quality of the local environment and compliance with environmental regulations.

Planted system has always met local environmental legislation (for disposal in aquatic environments) in terms of outflow concentration (< 60 $mg.L^{-1}$) and removal efficiency (> 80%) of BOD. On the other hand, values of nutrients did not behave in the same way, since they presented periods with negative efficiency values, even median values of TP and ammonia are consistent with literature (89.29% and 48.98%, respectively).

Statistical distribution of raw SW concentrations of BOD and TP presented a normal trend, according to the Kolmogorov-Smirnov test, and non-normal, according to Shapiro-Wilk and Anderson-Darling tests. As for ammonia, data distribution was normal based on Kolmogorov-Smirnov and Shapiro-Wilk tests, and non-normal, according to Anderson-Darling. These results (trend of non-normal distribution) are similar to those presented in the national literature for the characterization of raw SW (INGUNZA et al, 2009; SUNTTI, MAGRI and PHILIPPI, 2011).

Concentrations of BOD and TP from treated SW (exit) by control cell showed a non-normal trend distribution for Shapiro-Wilk and Anderson-Darling tests and normal for Kolmogorov-Smirnov test. For the effluent concentrations of ammonia, the distribution was normal according to the three tests performed.

The effluent treated by the cell with vegetation presented concentration of BOD with normal distribution for the three tests used. For the TP and ammonia parameters, the sample distribution presented a non-normal trend for the Shapiro-Wilk and Anderson-Darling tests and normal for the Kolmogorov-Smirnov test.

Based on these tests, the predominance of the non-normal distribution was also observed for effluent concentrations, except for BOD and ammonia values, in planted and control cells, respectively. These results demonstrate the need to evaluate the ability of both treatment beds to promote the removal of pollutants without there being great variability in the exit concentrations of the treatment beds, thus, considering them to be stable and susceptible to variations in applied loads.

Dispersion of points that correlate TP load applied to the beds with and without vegetation and their respective responses (exit concentration) is presented in Figure 3.

In general, there is greater instability and less predictability in the behaviour of the treatment system without vegetation for TP parameter.

It is observed that for the same pollutant load applied to each bed, effluent concentrations are different, being higher, in most cases, in the cell without vegetation. Thus, even with high dispersion of points in both treatment systems, planted bed was more effective.

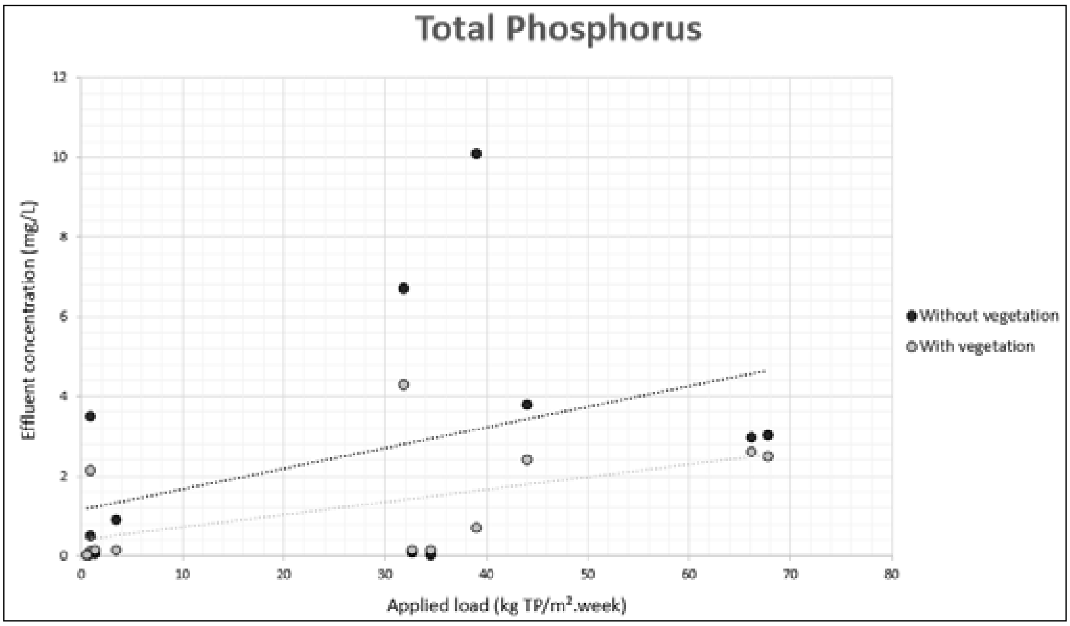

Figure 3 – TP effluent concentration versus TP applied load in both treatment cells

There is strong evidence that treatment beds stored the pollutant inside it for a certain period, releasing it (in effluent) after new applied loads, based on the drag effect. It is estimated that environment with plants minimizes this effect, amortizing the flow of this pollutant. In addition, according to Ghosh and Gopal (2010), it is added the fact that vegetation is able to absorb certain chemical species of the studied contaminant.

Based on Spearman coefficient analysis, a low-mean correlation between variables influent load and effluent concentration in both treatment cells were found. For the environment without plants, value of ϱ was 0.42 and for planted bed, ϱ = 0.56. Thus, increasing the value of the TP applied pollution load does not necessarily imply an increase in the effluent concentration

Vincent et al. (2011) found an inverse situation in their work. In it, the increase of applied solids load (theoretically also TP) promoted reduction of average effluent concentration. However, this was due to the greater variability (in terms of standard deviation) of TP in the effluent with lower applied loads. Thus, it was observed that depending on the applied load, there would be a greater or less variation in the effluent concentration.

For ammonia, according to Figure 4, the inverse situation occurred in relation to TP. Effluent concentrations to cell without vegetation were, in most cases, lower. In this sense, in terms of concentration, the bed without vegetation was more effective.

As noted in researches, CWs have limitations on ammonia removal (SAEED and SUN, 2012). However, higher values of exit concentration of the planted bed can be explained mainly by estimated evapotranspiration of water in this environment. The percentage of water loss to atmosphere in vegetated cell was 40%, against 25% in cell without plants (SILVA JÚNIOR et al, 2015). This implies a higher concentration of pollutants in cell effluent with plants.

There was a strong correlation (ϱ = 0.87) in control cell between the variables influent load and effluent concentration. This implies that value of applied pollution load will directly influence the effluent concentration in this type of treatment environment. For environment with plants, value of ϱ was 0.46, indicating a low correlation between the variables.

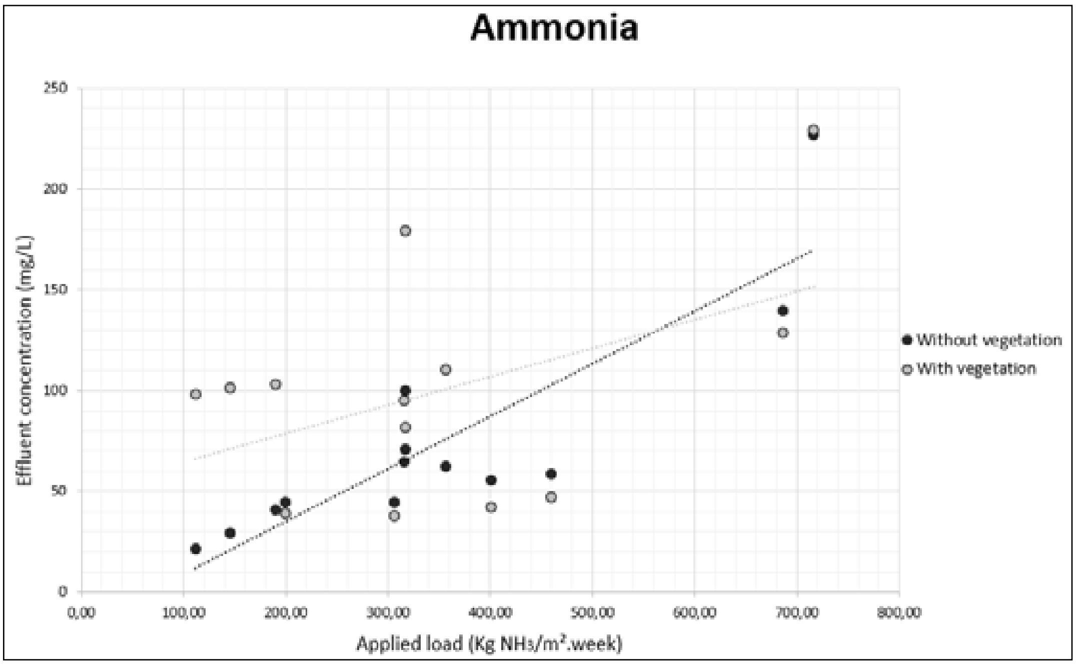

Figure 4 – Ammonia effluent concentration versus ammonia applied load in both treatment cells

In his works, Suntti, Magri and Philippi (2011) and Vincent et al. (2011) observed that the increase of applied solids load (it can be said intuitively the same about ammonia) promotes elevation in ammonia concentration in effluent of the treatment system. Application load of suspended solids of 50 kg.m^{-2}.year^{-1} presented average removal efficiency of ammonia of 82% and average effluent concentration of 53 mg.L^{-1}.

Regarding to BOD, in Figure 5, it can be observed that in all analysed weeks the effluent concentrations to cell without vegetation were superior to those of planted cell. Clearly, it is estimated that, in terms of effluent concentration and treatment efficiency, bed with vegetation is more recommended.

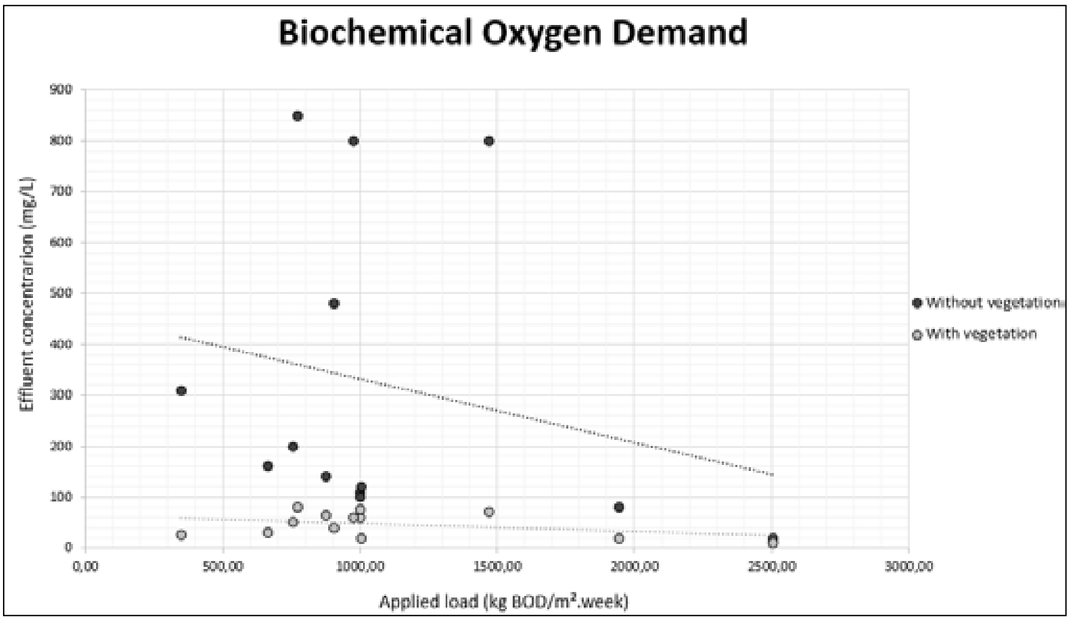

Figure 5 – BOD effluent concentration versus BOD applied load in both treatment cells

As described by several authors, CWs are quite efficient in removal of organic load (KADLEC and WALLACE, 2009; INGUNZA et al, 2009).

Low and negative correlations were observed in both treatment cells between the variables affluent load and effluent concentration. For controlled environment, value of ϱ was - 0.23, while for the vegetation system, ϱ = - 0.37. These values indicate that the pollution load applied has a weak influence on the effluent concentration of both treatment beds. Thus, output concentration in terms of BOD does not depend on the waste input load.

In their book, Kadlec and Wallace (2009) observed different behaviour in analysed vertical flow CWs. These authors observed that increase in BOD loads also increases the effluent concentrations, that is, that there is a strong dependence between applied load and output concentration. Factors such as hydraulic detention time, hydrodynamics of residue in cells, type of treated residue or local climate may have influenced the divergence of results. On the other hand, there is a possibility that such divergence has occurred because monitoring times are different.

It should be noted that vegetated environment presented little variation of the effluent concentration as a function of applied loads, while the control cell had a high dispersion of results. In this context, vegetation use was more favourable to amortization of introduced pollution loads (in terms of BOD), making the treatment environment less susceptible to variations in pollutant loads.

In order to elaborate an engineering project it is not reliable and adequate to have a treatment system with as much instability and lack of standardization as it is the case of the removal of BOD load in beds without vegetation.

It is also noted that effluent concentrations of BOD met 100% of the occasions the brazilian environmental legislation.

4 Conclusions

Based on analyses of data and discussions exposed, it is possible to infer certain conclusions for studied experimental conditions:

1 - Considering median values of percentage efficiency of removal of pollutants, planted cell presented better results for all studied parameters.

2 - Under applied loads of BOD and TP, effluent concentrations were lower in planted cell. For ammonia, cell without plants had lower concentrations of exit.

3 - There was a strong correlation only between the applied load and the ammonia effluent concentration in controlled environment. For others situations, correlations were low to medium, indicating little association between the studied variables.

4 - System with plants was shown to be more stable and with a greater capacity of amortization of pollution for BOD and TP.

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