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TREATMENT OF SWINE WASTEWATER IN CONSTRUCTED WETLANDS CULTIVATED WITH TANGOLA GRASS

This study aimed to evaluate the efficiency of constructed wetlands (CWS) cultivated with Tangola grass (*Urochloa purpuracens* and *Urochloa arrecta*) in the treatment of wastewater from pig farming. The CWS were subjected to an organic loading rate of 300 kg of BOD/(ha·day) from swine wastewater. We analyzed total solids, turbidity, color, total Kjeldahl N, and total P in the influent and effluent to the CWS every 30 days for a duration of 4 months. The whole plot factor was vegetation (CWS with and without Tangola grass). The subplot factor was assessment time (15, 45, 75, and 105 days of CWS operation). There was no statistical difference between CWS with and without in terms of the removal efficiency. After 105 days, average removals of 90–95% turbidity, 79–80% total solids, 76–82% color, 42–70% total Kjeldahl N, and 51–63% total P were obtained in all CWS. While Tangola grass did not enhance the removal efficiency of the parameters assessed in this study, it may be harvested to provide fodder for animals, making it a valuable addition to CWS.

1. INTRODUCTION

Pig farming stands out as an activity of great importance in the social and economic development of Brazil, generating employment and income for farmers, especially those with small operations. However, this activity can cause several adverse environmental

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impacts if wastewater, generated during the bay sanitation stage, is not properly managed.

Pig farming wastewater (PFW) contains organic matter, pathogenic organisms, solids, and several nutrients such as nitrogen, phosphorus, potassium, sodium, calcium, magnesium, manganese, iron, copper, and zinc derived from the diet of these animals [1]. When released without treatment into water bodies, they cause several negative environmental impacts [2], affecting water quality [3] and harming fauna and flora [4]. Due to excessive N and P, swine manure can cause problems of eutrophication of surface waters, causing loss of biodiversity, water contamination, and waterborne diseases [5]. Matos et al. [6] highlighted that, in addition to the pollution of surface and groundwater, the inappropriate application of these materials to the soil can lead to salinization, pollution, and damage to its structure.

Thus, wastewater treatment becomes essential before being released into water bodies. Constructed wetland systems (CWS) are among the possible solutions proposed for the treatment of wastewater rich in organic material [7]. According to [6], CWS are characterized as robust, low-cost, simple to operate and maintain, and most importantly, highly effective at purifying wastewater. These aspects make CWS ideal for application in regions lacking basic sanitation, such as small family farms in Espírito Santo state, Brazil.

CWS are reservoirs filled with porous materials, usually made up of gravel, which supports the cultivation of macrophytes. In the support medium, a biofilm intermingled with plant roots is developed [8] which enables the degradation of organic matter in solution in addition to the removal, through physical processes of sediment and suspended solids. Thus, in the CWS, waste purification occurs [9]. The choice of plant species is, along with other variables, of fundamental importance for the success of wastewater treatment in CWS [10, 11].

Plant species selected for cultivation in CWS must be perennial, have a high tolerance to excess water and eutrophic environments, be easily propagated, possess rapid growth, be simple to manage and harvest, and have a high capacity for removing nutrients and pollutants [12]. Several studies using tropical forage grasses, such as Tifton 85 [13–16] and Elephant grasses [6, 15], have shown grasses can be highly efficient in extracting nutrients and pollutants from swine wastewater in CWS.

Tangola grass is well-adapted to tropical environmental conditions, easily propagated, fast-growing, and widespread in Espírito Santo State, Brazil. According to Figueiredo et al. [17], Tangola grass has physiological characteristics such as aerenchyma, adventitious roots, chloroplasts close to the epidermis, and thin epidermis, contributing to its adaptation to flooding. Due to the aforementioned characteristics, we hypothesized that the cultivation of Tangola grass in CWS would effectively N and P loads treat swine wastewater compared to CWS without Tangola grass. The objective of this study was to evaluate the efficiency of CWS cultivated with Tangola grass in the treatment of wastewater from pig farming.

2. EXPERIMENTAL

The experiment was implemented and conducted in the area adjacent to the Water Quality and Solid Wastes Laboratory of the Federal Institute of Espírito Santo – Campus Santa Teresa, Santa Teresa, Espírito Santo State, Brazil. The site is 150 m above sea level, 19°48′ south latitude and 40°40′ west longitude. Four CWS were built, two without vegetation and two cultivated with Tangola grass, and subjected to an organic loading rate (OLR) of 300 kg/(ha·day) of biochemical oxygen demand (BOD) PFW, based on the mean BOD value of the wastewater. This BOD value was used to calculate the PFW application rate. For the assembly of the CWS, "trough" type containers were used, made of high-density polyethylene (HDPE), 35 cm high, 49 cm wide, and 195 cm long. At the exit of the troughs, there were drains with flanges and 32 mm PVC pipe. As a support media, gravel #0 was used (diameter D_{60} = 7.0 mm, the uniformity coefficient D_{60}/D_{10} = 1.6, and porosity of 48.4%), up to a height of 30 cm. Each CWS had a useful volume of 0.118 m³. The PFW was stored in a polyethylene reservoir with a capacity of 2000 dm^3 positioned upstream of the CWS, and was supplied by gravity to the 4 CWS, through PVC pipes (Fig. 1).

Fig. 1. Experimental bench showing the reservoirs and CWS filled with gravel

Tangola grass seedlings were obtained from cuttings collected (Fig. 2) from the Large Animals sector of IFES – Campus Santa Teresa. Cuttings were planted in 200 cm^3 plastic cups, containing a substrate consisting of a mixture of soil and cattle and poultry manure in a ratio of 2:1:1. After rooting, the seedlings were carefully removed from the substrate and transplanted to the CWS (Fig. 3), totaling 19 seedlings in each of the two cultivated CWS.

After transplanting the seedlings, the CWS were filled to a height of 25 cm (leaving a free edge of 5 cm) with chlorine-free water to facilitate plant adaptation to the environment in the support media. Fifteen days after planting, CWS were filled with PFW and left for 15 days to facilitate the adaptation of the plants to the new support medium and form the biofilm. After the adaptation period, swine wastewater was applied daily at a pre-defined rate, beginning the experimental monitoring phase, which lasted for a period of 105 days. The CWS without Tangola grass were subjected to the same treatments as CWS containing Tangola grass.

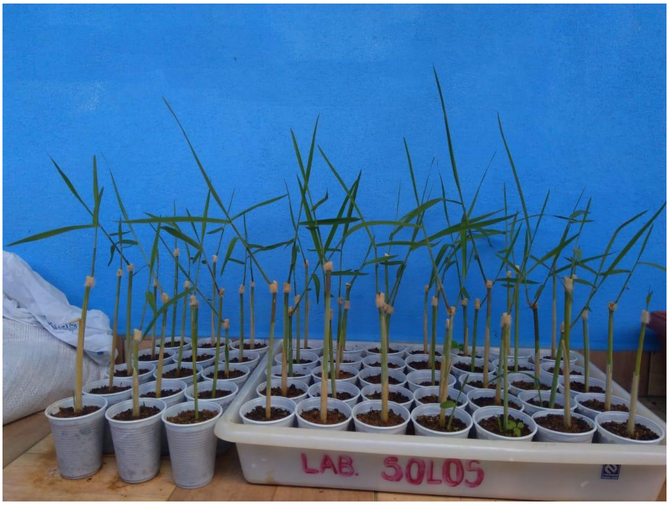

Fig. 2. Tangola grass cuttings

Fig. 3. Tangola grass seedlings transplanted to the CWS

The wastewater application rate was controlled, being adjusted four times a week, using a valve installed in the wastewater conduction piping positioned upstream of the CWS. Measurements, to adjust the flows, were made by the direct method, using a graduated container.

To quantify the productivity of Tangola grass in the CWS, biomass was collected every 30 days after uniformly cutting the plant stands. The collection of the aerial part of the plants was carried out through a cut, at a height of 10 cm above the support medium, to proceed with weighing and subsequent quantification of the biomass. Materials were then oven-dried with forced air circulation at 65 °C to determine the dry mass, according to the methodology described by Tedesco et al. [18]. After weighing the material (fresh and dry), the average productivity of the 2 vegetated CWSs was determined by dividing the obtained masses (in kg) by an area of 0.627 m^2, which was the surface area of each CWS. To assess the efficiency of the systems, we measured total solids (TS), turbidity (T), color, total Kjeldahl nitrogen (TKN), and total phosphorus (TP) in the influent and effluent from the CWS every 30 days during the functioning of the system. All analyzes were performed at the Water Quality and Solid Wastes Laboratory of IFES – Campus Santa Teresa, by the method described by Matos [19]. The variables evaluated and the respective methods are shown in Table 1.

Fig. 4. CWS cultivated with Tangola grass before cutting

Fig. 5. CWS cultivated with Tangola grass immediately after cutting

Table 1

Variables assessed and the respective methods used in the analysis

Variable	Method
Total solids (TS)	gravimetric method
Turbidity (T)	nephelometric method
Color	colorimetry
Total Kjeldahl nitrogen (TKN)	Kjeldahl semi-micro process
Total phosphorus (TP)	nitric-perchloric digestion of the sample quantified spectrophotometrically

Table 2 shows the characteristics of the raw swine wastewater of the samples taken during the experimental period.

Table 2

Characteristics of raw wastewater during the experimental period

Time [days]	pH	Color [HU]	Turbidity [UNT]	Total solids [mg/dm^3]	Total Kjeldahl N [mg/dm^3]	Total P [mg/dm^3]
15	7.20	394.0	74.3	720.0	392.0	56.2
45	7.30	428.0	75.3	703.3	224.0	26.0
75	6.95	377.0	124	636.7	192.5	41.9
105	7.15	880.0	509	2,285.0	175.0	37.1

The physical characteristics of raw water showed lower quality in the last evaluation. This happened because there was sedimentation inside the reservoir that could change the PFW characteristics, increasing color, turbidity, and total solids on the bottom of the reservoir. This part of PFW was collected in the last analysis.

The pollution removal efficiency (*Ef*) was calculated from the concentrations and flow rates of influents and effluents, obtained on the various occasions on which the samples were collected

$$Ef = \frac{C_A Q_A - C_E Q_E}{C_A Q_A} \times 100\% \tag{1}$$

where: *Ef* is the mass removal efficiency, %, C_A is the influent load, mg/dm^3 or UNT, Q_A is the influent flow rate, dm^3/day, C_E is the effluent load, mg/dm^3 or UNT, Q_E is the effluent flow rate, dm^3/day.

A factorial experiment was arranged in a randomized complete block design ($r = 4$) with a split-plot restriction on randomization, where two levels of vegetation were assigned to main plot units and four levels of sampling time were assigned to subplot units. Vegetation levels consisted of CWS with and without Tangola grass. Two CWS were left without vegetation, while two contained Tangola grass. Sampling times were 15, 45, 75, and 105 days after wastewater application. All variables were subjected to tests of normality (Shapiro–Wilk) and homoscedasticity (Levene). Statistical analyzes were conducted using mixed linear models that considered the vegetation levels in CWS and sampling dates as fixed effects, with different CWS as random effects. To assess significance at different sampling times, ANOVA for the model was conclusive (only two treatments). To determine significant differences for response variables at different sampling times, the *t* test with Holm adjustment was used. For all comparison procedures, 5% was used for type I error. For the analysis, the *R* program was used [20].

3. RESULTS AND DISCUSSION

Figure 6 shows the time dependences of the mean removal efficiencies of the variables analyzed in CWS vegetated with Tangola grass and non-vegetated.

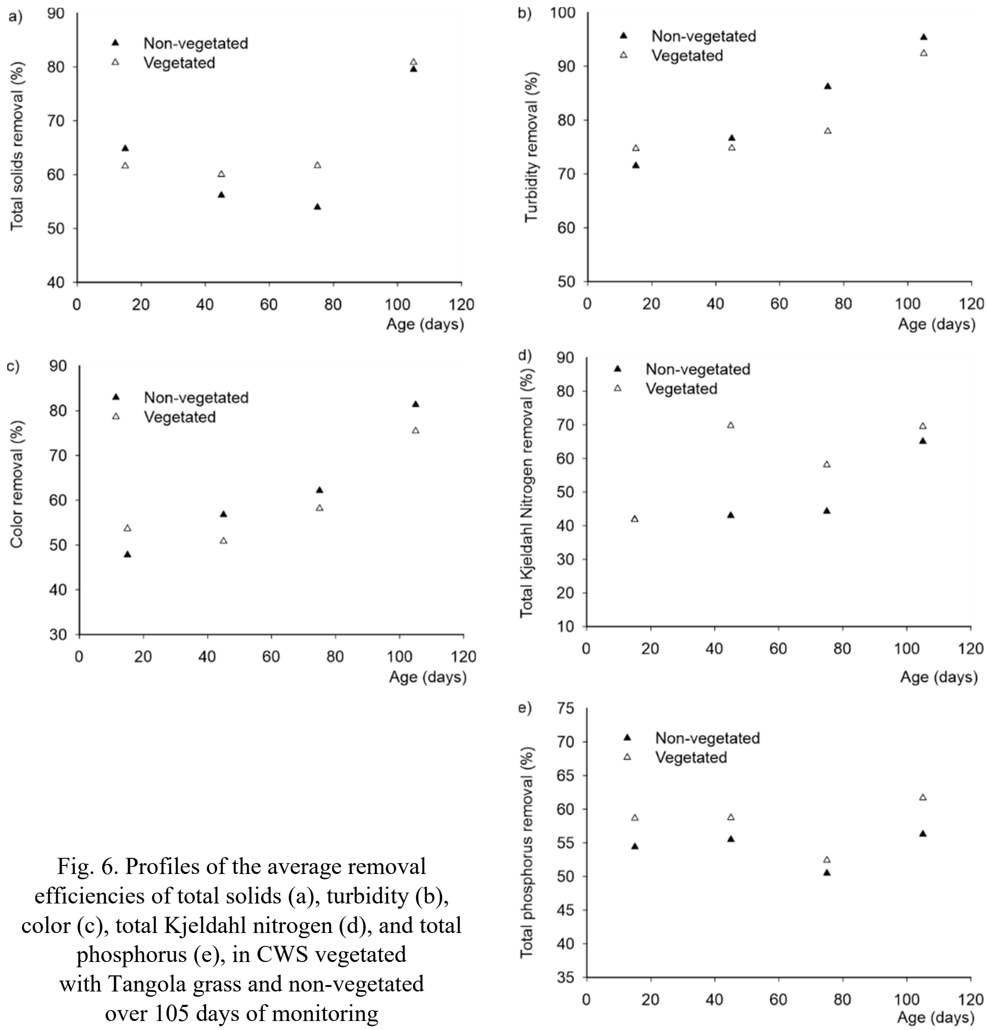

Fig. 6. Profiles of the average removal efficiencies of total solids (a), turbidity (b), color (c), total Kjeldahl nitrogen (d), and total phosphorus (e), in CWS vegetated with Tangola grass and non-vegetated over 105 days of monitoring

An increase in the average removal efficiency of all response variables over time was observed (Fig. 6). There were no statistical differences between the vegetated and non-vegetated CWS in terms of the average efficiencies of the physical attributes evaluated over the 105 days of the study. However, we did observe a trend indicating greater removal efficiency of total solids (TS) in cultivated CWS compared to uncultivated CWS. For color and turbidity, the CWS cultivated with Tangola grass showed lower efficiencies than the non-vegetated CWS, except for the analysis carried out at 15 days of systems operation.

Turbidity is a water quality parameter associated with the presence of suspended solids (SS) in water [21]. The greater the SS concentration in the water, the greater turbidity is. If the effluent is released without treatment into water bodies, the presence of suspended solids can reduce light penetration [22] and rates of photosynthesis by algae and consequently the production of oxygen in the water body [23].

Although there were no statistical differences between vegetated and non-vegetated CWS, the lower turbidity removal efficiency by cultivated CWS (Fig. 6b) may be related to the increased load of suspended solids in the wastewater, especially after 45 days of operation, resulting from the Tangola grass cutting carried out at that time. In addition, the rhizosphere of Tangola grass may have caused the formation of preferential paths that facilitated the dragging of suspended solids out of the CWS, contributing to a lower removal efficiency by the system. This phenomenon has been reported in previous CWS studies with cattail (*Typha*) and Tifton grass (*Cynodon* spp.) [10, 13]. According to Matos et al. [10], this may change with the operating time of the CWS as the roots go deeper into the porous substrate, and/or there is a greater accumulation of solids. There was a high efficiency of turbidity removal both in cultivated CWS (90%) and in non-cultivated CWS (95%), at 105 days of monitoring.

As for the total solids removal efficiency (Fig. 6a), there was no statistical difference between the uncultivated CWS and those cultivated with Tangola grass. In both systems, high efficiencies (around 80%) were achieved. Such results can be considered satisfactory when compared to previous work that showed CWS cultivated with Tifton-85 grass, *Alternanthera*, and *Typha* to treat swine wastewater did not obtain TS removal efficiencies higher than 67% when an average OLR of 158.5 kg of BOD/(ha·day) was applied [6].

Color is associated with the presence of dissolved solids [24] and, although it is not necessarily related to problems of contamination of water bodies, it causes aesthetic problems and hinders light penetration, in addition to being related to recalcitrant compounds which may be toxic to the aquatic community [25]. As for the color removal efficiency, there was no statistical difference between vegetated and non-vegetated CWS (Fig. 6c) during the monitoring period. However, in both systems, removal efficiencies between 76 and 82% were achieved at 105 days of monitoring. These results are satisfactory since there were no preliminary or primary treatments before undergoing treatment for the CWS.

There were no statistically significant differences in TKN removal efficiency from swine wastewater in CWS cultivated with and without Tangola grass (Fig. 6d). However, after 45 days of monitoring, the vegetated CWS showed a trend of greater N removal compared to non-vegetated CWS, reaching removal efficiencies between 60 and 70%. Fia et al. [13] also found no significant difference between CWS cultivated with *Typha* and *Tifton* grass and those not cultivated in the treatment of swine wastewater, obtaining removal efficiencies between 37 and 40%, which were below values obtained in our study.

The N loads applied to the CWS, and the type of runoff presented by the CWS are the main factors influencing the efficiency of N removal [13], which, according to Vymazal [26], varies between 40 and 50%. Thus, it is observed that the CWS cultivated with Tangola grass, which received the organic load of 300 kg of BOD/(ha·day), presented results considered satisfactory when compared with data from previous studies. According to Samson et al. [27], N is strongly associated with organic matter. Thus, it is believed that the N removal efficiency presented by the non-vegetated CWS is related to the retention of organic matter in the support medium of these non-vegetated systems, as reported in several studies [6, 13, 28].

As we can see in Fig. 6e, the vegetated CWS showed a slight superiority in P removal from swine wastewater. However, there was no statistically significant difference in P removal between treatments. The absence of differences in P removal between vegetated and non-vegetated CWS was also verified in other studies [13]. Coelho [29] showed that water hyacinth (*Eichhornia crassipes*) was the species that presented the highest averages in N extraction compared to the control. Regarding P extraction, the species did not differ from each other but differed from the control.

The P removal efficiencies obtained in this study ranged from 51 to 63% being within the range reported by Vymazal [26], who stated that total P removal varies between 40 and 60% among all types of wetland systems. This is like what happens with N where it depends on the applied loads and the way the wastewater flows through the system. Fia et al. [13] stated that generally the greatest removals are related to the smallest loads applied. These authors reached 73–78% of P removal, applying loads around 164 kg of BOD/(ha·day), lower than those applied in this study.

The results related to nutrient removal efficiency obtained in this study were higher than those achieved by Gikas et al. [30], who obtained 38.8% P removal in CWS cultivated with *Phragmites australis*, by Valetim [31], who found mean removal values between 23 and 36% with Typha cultivation, and by Miranda et al. [28], which reached values between 17 and 39% in CWS cultivated with elephant grass cv. Napier (*Pennisetum purpureum* Schum) and Tifton 85 grass in the wastewater treatment of a community milk cooling tank.

Even with no statistical difference between vegetated and non-vegetated CWS, the use of Tangola grass in CWS is a promising alternative in the treatment of swine wastewater, thus minimizing the environmental impacts, if these effluents are discharged without treatment into water bodies. In addition, the use of CWS enables the possibility to harvest biomass, which can be used for animal feed, reducing costs for the farm and making the activity sustainable. Matos et al. [19] also pointed out that the plant and its root system in CWS contribute to increasing the useful life of the units, by attenuating the progressive process of obstruction of the porous medium. Thus, a long-term study must be done to verify this statement.

4. CONCLUSIONS

There was no statistical difference between the CWS cultivated with and without Tangola grass in terms of the efficiency of turbidity removal, total solids, color, total

Kjeldahl N, and total P, in the treatment of swine wastewater. After 105 days of CWS operation, average removals of 90–95% turbidity, 79–80% total solids, 76–82% color, 42–70% total Kjeldahl N, and 51–63% total P were obtained in all CWS in the treatment of swine wastewater. While Tangola grass did not enhance the efficiency of the parameters above, it is a good option for CWS because it can be harvested to provide animal feed, which is important for many pig farmers.

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