PERFORMANCE OF SUBSURFACE FLOW CONSTRUCTED WETLANDS WITH AND WITHOUT CALLA LILIES (*ZANTEDESCHIA AETHIOPICA*) FOR SWINE WASTE WATER TREATMENT IN THE TROPICS

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ABSTRACT

Two subsurface flow constructed wetlands were designed, built and evaluated. In one system, calla lilies (*Zantedeschia aethiopica*) were cultivated and the other system was used as a control. This research was developed in a swine farm located in La Trinitaria, Chiapas, Mexico. An anaerobic lagoon was used for pretreatment of the swine waste. After stabilizing the wetlands, samples were taken during a three-month period at the effluent of the anaerobic lagoon (EAL), the effluent of the system with plants (WP) and the effluent of the control (W/OP). Results indicated better removal efficiency of pollutants in the system with plants. Measurements for chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total phosphorous as PO_4, nitrogen as NH_3, total suspended solids (TSS), conductivity, turbidity, color, sulfates as SO_4, and total and fecal coliforms, were evaluated according to the Standard Methods.

INTRODUCTION

Constructed Wetlands for Wastewater Treatment

The discharges of residual waters to wetlands are not a new practice, many societies have done so for many centuries. Since natural wetlands are not always available, building

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wetlands can be a good alternative. Constructed wetlands are built to replicate natural systems as close as possible. Vegetation is believed to improve the quality of the water. The plant roots produce small quantities of organic compounds such as sugars or amino acids that favor certain microorganisms to grow around the root zone known as rhizosphere. This "created environment" around the plant's roots facilitates the degradation of organic matter.

Constructed wetlands are systems with aquatic plants that have either surface (SF) or subsurface flow (SSF). SSF wetlands have an impermeable layer consisting of low permeable soil (i.e. clays), plastic membrane, or cement. These wetlands have a porous substratum, usually sand or gravel, to support emergent aquatic plants. The residual water flows by gravity and usually moves horizontally through the substratum. This water stays in contact with microorganisms that live in close proximity to the plants' roots. *Typha*, *Scirpus* and *Phragmites* are among the plants' genera more used in SSF constructed wetlands. Plants that have been used for animal wastewater treatment are: *Hidrocotyle umbrellata*, *Iris versicolor*, *Vriginicus*, *Juncus effusus*, *Phragmites australis*, *Sagitaria* spp, *Scirpus* spp, *Typha* spp (EPA, 1988; 1998). Plants used in constructed wetlands such as calla lilies can have an economic value in local markets.

Study Area

This research was carried out in a swine farm located in La Trinitaria, Chiapas, Mexico (15° 07 ' north latitude and 92° 03 ' west 1ongitud). The town is located at 1,540 meters above see level with an annual average temperature of 18.6°C. Minimum and maximum temperature recorded are 12.5ºC and 24.8°C, respectively. The annual precipitation and evaporation is 908 mm and 1,535 mm, respectively (INEGI, 1995).

METHODS

Description of the System

The system (Figure 1) consists of a pig pen (3.15 x 4.15 m) with 5 pigs, an anaerobic lagoon (3.7 m diameter and 1.25 m water depth), and two subsurface flow constructed wetlands (2.4 x 1.2 m with a water depth of 0.7m) with a sand porous media (hydraulic conductivity around 366 $m^3/m^2/d$, a media porosity of 32% and a nominal diameter, D_{10}, of 0.086 cm). In one of the SSF constructed wetlands (WP) calla lilies (*Zantedeschia aethiopica*) were planted every 30 cm. The other wetland (W/OP) used as a control, had the same characteristics of the first one with the exception of the plants. Plants were planted mature and allowed to adjust for two months once established. Samples were taken weekly from a three month period in the effluents of the anaerobic lagoon (EAL) and the two constructed wetlands (WP and W/OP).

The system was designed according to the procedure presented by EPA (1997 and 1998). The daily flow in the system was of 0.4 m^3/d with a biochemical oxygen demand (BOD_5) of 2,625 mg/l and an organic load of 1.05 kg BOD_5/d. Total flow was discharged to the anaerobic lagoon with a hydraulic retention time (HRT) of 33.4 days. The design specified a retention time of 4 days for the constructed wetlands. The flow was divided equally between the two wetlands. The effluent from the wetlands was discharged onto pasture land.

The samples and laboratory analyses were done using standard methods. Effective hydraulic retention time in the wetlands was measured in the field using a dye indicator. Dissolved oxygen, water temperature and pH were measured in the field every time samples were collected.

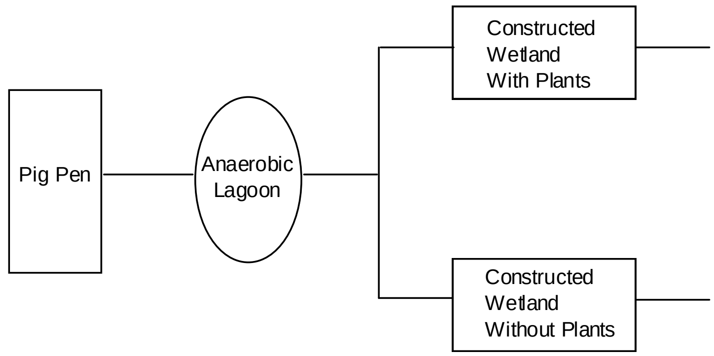

Figure 1. Diagram of the Wastewater Treatment System.

RESULTS AND DISCUSSION

Field Results

The hydraulic retention time (HRT) of the constructed wetlands was at 2.5 days measured in the field using a dye technique. This was less than the HRT of 4 days calculated in the design. Possible explanations are: 1) the filter media had a higher permeability (K) than the one calculated theoretically which was a function of water temperature and the nominal size of the material, or 2) there was a short circuit in the system.

No significant difference of dissolved oxygen (DO) was found in the constructed wetland with plants (WP) at the depth of 5 cm. Different measurements of DO at 5 cm depth for the wetlands with and without plants averaged 1.6 mg/l and 1.3 mg/l, respectively. However, at depths greater than 10 cm, the DO of the wetland with plants averages 0.1 mg/l while in the wetland without plants (W/OP), all the measurements were zero. Water closer to the surface was under aerobic conditions, possibly because of oxygen transfer from the atmosphere, while deeper layers were in anaerobic conditions. DO measurements taken in the effluents of the lagoon and wetlands were 0 mg/l.

The temperature of the water was a reflection of the ambient temperature, and the values do not show remarkable differences (Figure A-1). The mean average temperature for the three components of the system (Figure 1) was around 20 ^{o}C.

The pH of the system's componentes was around neutral. The pH, measured at the effluent of the anaerobic lagoon averaged around 7 (n=10), while in the wetlands with and without plants pH averaged 7.16 and 7.24, respectively (n=10, Figure A-2). During the three-month study, the pH in the anaerobic lagoon (EAL) and the wetland without plants (W/OP) became acidic, while in the wetland with plants (WP) stayed around neutral (pH=7).

Laboratory Results

Chemical Oxygen Demand (COD) reduction in the wetland with plants (WP) was higher. The COD in the effluent of the anaerobic lagoon averaged 1,152 mg/l. COD concentration was reduced in 68% in the wetland with plants compared to 55% in the control (Figure A-3). In both wetland's effluents, a clear difference was not observed in its concentrations during the first 5 samples; however, the advantages of the wetlands with calla lilies in removing more COD was observed after sample 6. This coincided with the flowering and pruning of the plants (months of February and March).

Biochemical oxygen demand (BOD_5) measurements have trends and reduction concentrations very similar to those found for COD. COD/BOD_5 ratios found for the anaerobic lagoon and in the systems with and without plants were 2.03, 1.92 and 1.94, respectively. The measured mean average BOD_5 influent for both wetlands was 567 mg/l less than the theoretical effluent BOD_5 of 1,663 mg/l calculated in the design of the anaerobic pond. This could be due to an overestimation of the organic load going to the ponds (EPA, 1997).

During the first four samples, total phosphorus as PO_4, showed a similar reduction in both wetlands. However, from sample 5, the wetland with calla lilies showed a bigger reduction (Figure A-5). This could be due to a bigger phosphorus uptake by plants that coincides, like in the cases of COD and BOD_5, with the flowering and pruning of the plants. Overall, total phosphorus reduction in the system with plants was 63% compared to 45% in the system without plants.

Nitrogen as ammonia (NH_3) did not show significant reductions in the constructed wetlands. However, bigger reduction of nitrogen (34%) as NH_3 was observed in the wetland with calla lilies compared with the system without plants (23%). The average values (n=10 for each unit) for ammonia in the effluents of the anaerobic pond and the two systems with and without plants were 60, 40 and 46 mg/l, respectively (Figure A-6). The only reported value of Nitrogen as NO_3 was found in sample no. 6 in the system with plants (WP) with a concentration of 0.25 mg/l. In the rest of the samples, values for nitrogen as NO_3 were not detected and were reported by the laboratory as non detectable (ND). This can be explained by the really low amounts of dissolved oxygen measured in the systems at different depths.

Both constructed wetlands showed a total suspended solids (TSS) reduction greater than fifty percent. The wetland with calla lilies had a TSS reduction of 65% compared to 56% in the wetland without plants (Figure A-7). Mean values in the effluents for TSS were 160, 55 and 71 mg/l for the anaerobic lagoon and the systems with and without plants, respectively.

In all three areas sampled, electrical conductivity and color did not indicate significant reduction. The electrical conductivity reduction in the systems with and without plants was 14 and 8 %, respectively (Figure A-8). Mean values for electrical conductivity plants was 14 and 8 %, respectively (Figure A-8). Mean values for electrical conductivity in the effluent of the anaerobic lagoon and the systems with and without plants were 1,306, 1,128 and 1,197 umhos/cm, respectively. Color reductions were 9 and 8 % for the wetlands with and without calla lilies, respectively (Figure A-10).

On the average turbidity had lower concentration in the effluent of the wetland with plants. Mean average turbidity were 98, 31 and 41 NTUs for the effluent of the anaerobic lagoon, and the with and without plants wetlands, respectively. Turbidity reductions were around 69 and 58% for the wetlands with and without plants (Figure A-9). Average Total Sulfate as SO_4 concentrations were in the range of 10 and 13 mg/l in the wetlands (Figure A-11). Reduction in Total Sulfate were 67 and 58% for the wetland with and without calla lilies, respectively.

Although both constructed wetlands reduced total and fecal coliforms in more than 98% of the influent concentration, none of the effluent wetlands complied with the standards. Fecal coliforms should be less than 1,000 MPN/100 ml (CNA, 1999) before discharging into most rivers and agricultural land. Total coliforms were 7.3E08, 5.5E05 and 9.4E06 MPN/100ml in the effluents of the anaerobic lagoon, the with and without plant wetlands, respectively (Figure A-12). Fecal coliforms were 6E08, 5E05 and 9.2E06 MPN/100 ml in the effluents of the anaerobic lagoon, and the wetlands with and without plants, respectively (Figure A-13). Higher coliform reduction was observed in the wetland with plants (99.9%) compared to the system without plants (98.6). Further treatment is required to reduce coliforms to comply with the standards.

The percentage difference between the wetland system with plants (*Zantedeschia aethiopica*) and the system without plants was in the range of 1 to 17 % for all parameters that were measured (Table 1). The greatest percentage difference was found in total phosphates, COD and BOD_5 with values of 18, 13 and 13%, respectively. The parameters with the least percentage reduction were those for coliforms and color in the range of 1.5 and 1.2%.

Table 1. Percentage Difference in the wetlands with and without plants.

Parameter	**%**
Total phosphorus as PO_4	17.7
Biochemical oxygen demand (BOD_5)	13
Chemical oxygen demand (COD)	13
Turbidity	11
Nitrogen as NH_3 (N-NH_3)	10.6
Total suspended solids (TSS)	9.6
Total sulfates as SO_4	9.3
Electric conductivity	5.3
Fecal coliforms	1.5
Total coliforms	1.2
Color	1.2

CONCLUSION

Two subsurface flow constructed wetlands were designed, built and evaluated. In one system, calla lilies (*Zantedeschia aethiopica*) were cultivated and the other system was used as a control.. The hydraulic retention time (HRT) in the constructed wetlands measured in the field by using a dye technique, in the constructed wetlands was 2.5 days, less than the HRT of 4 days calculated in the design. No significant difference of dissolved oxygen (DO) at the depth of 5 cm was found in the constructed wetland with calla lilies. However, at depths greater than 10 cm, the DO of the wetland with plants had an average of 0.1 mg/l (n=3) while in the wetland without plants all measurements reported zero value. Chemical Oxygen Demand (COD) and Biochemical oxygen demand (BOD_5) reduction in the wetland with plants were higher than in the system without plants. The wetland with calla lilies showed a bigger reduction in total phosphorus, COD and BOD_5 during the spring when the plants were flowering and were pruned. Nitrogen as ammonia (NH_3) did not show significant reductions in either constructed wetlands. However, a bigger reduction of nitrogen (21%) as NH_3 was observed in the wetland without plants compared with the one with calla lilies (14%). Significant values for nitrogen as NO_3 were not found in the effluent of either wetlands due to the anoxic conditions of the system. Both constructed wetlands showed a total suspended solids (TSS) reduction greater than fifty percent. Electric conductivity and color did not have significant reductions in the system. Turbidity as an average had lower concentration (31 NTUs) in the effluent of the wetland with plants. Although both constructed wetlands reduced total and fecal coliforms more than 98% of the influent concentration, none of the effluent wetlands comply with the standards.

Overall, we can conclude that 1) the calla lilies (Zantedeschia aethiopica) naturally grow well in subsurface flow constructed wetlands, and besides their efficiency treatment, these plants (when flowering) have an economic value in the local market, and 2) the overall difference efficiency between the wetland system with plants (*Zantedeschia aethiopica*) and the system without plants was in the range of 1 to 17 % for all parameters that were reported. Future monitoring is required to evaluate the overall performance of the system in the long run.

BIBLIOGRAPHY

EPA (1988). Design Manual. Constructed Wetlands and Aquatic Plant System for Municipal Wastewater Treatment.

EPA (1997). Constructed Wetlands and Wastewater Management for Confined Animal Feeding Operations.

EPA (1998). Constructed Wetlands for Animal Waste Treatment. A Manual on Performance, Design and Operation with Case Histories.

INEGI. (1995). Anuario Estadístico del Estado de Chiapas.

National Commission of Water (CNA). 1999. Mexican Official Norms. Mexico.

APPENDIX

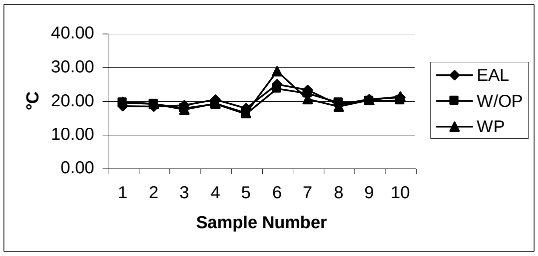

Figure A-1. Temperature (°C)

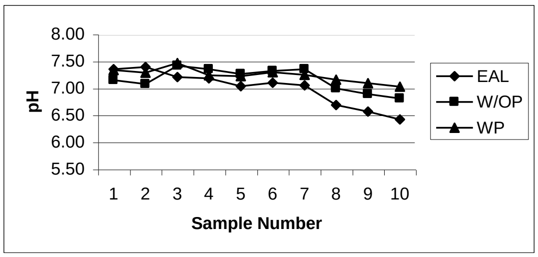

Figure A-2. pH

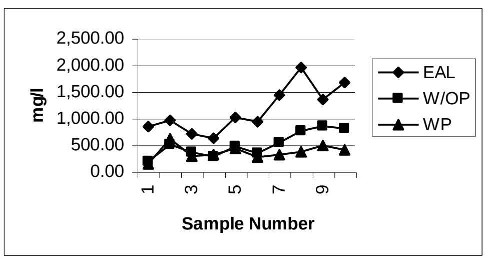

Figure A-3. Chemical Oxygen Demand (mg/l)

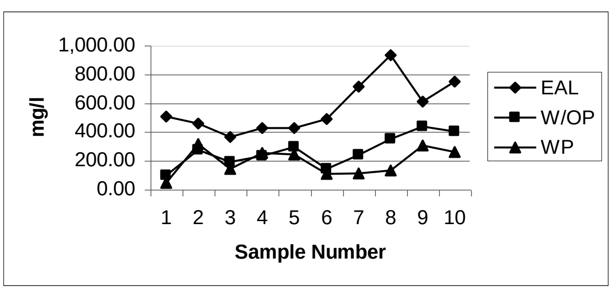

Figure A-4. Biochemical Oxygen Demand (mg/l)

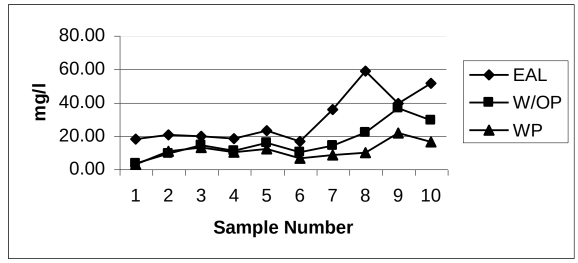

Figure A-5. Total Phosphorus as PO_4 (mg/l)

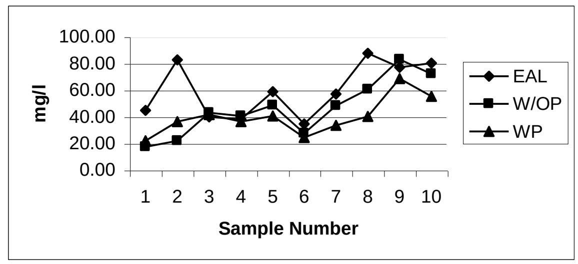

Figure A-6. Ammonia (NH_3) (mg/l)

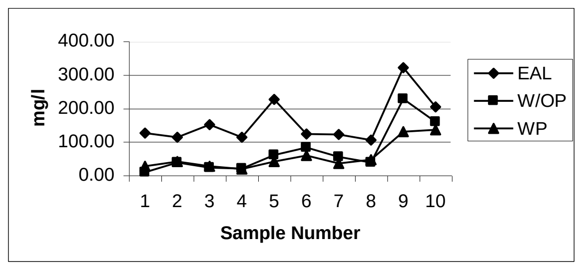

Figure A-7. Total Suspended Solids (mg/l)

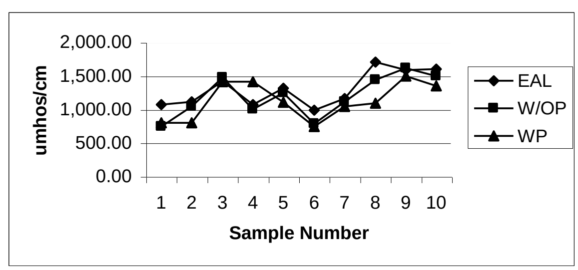

Figure A-8. Electrical Conductivity (mg/l)

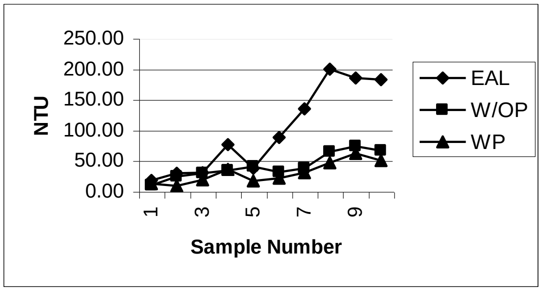

Figure A-9. Turbidity (UTN)

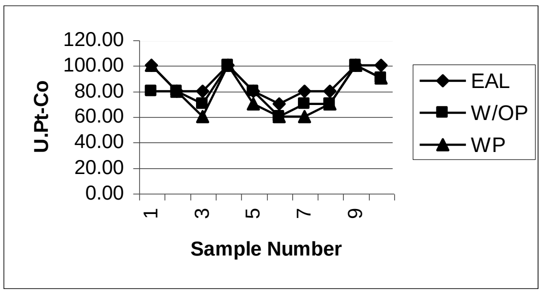

Figure A-10. Color (U. Pt-Co)

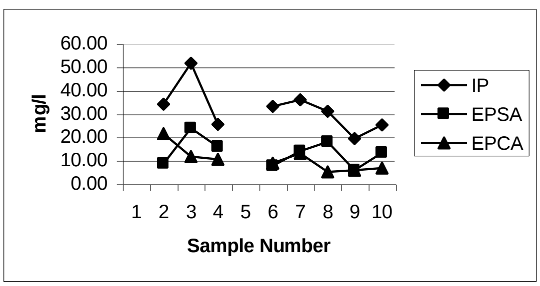

Figure A-11. Total Sulfur as SO_4 (mg/l)

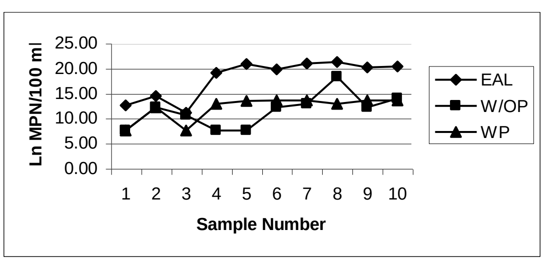

Figure A-12. Total Coliform (MPN/l00 ml)

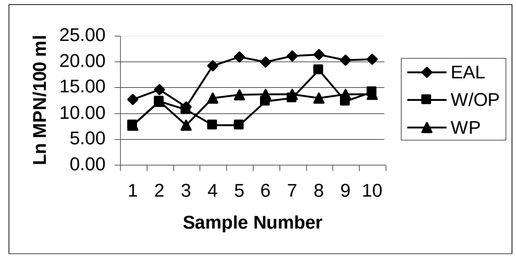

Figure A-13. Fecal Coliform (MPN/l00 ml)