Recirculating Vertical Flow Constructed Wetland for On-Site Sewage Treatment: An Approach for a Sustainable Ecosystem

Alfredo GARCÍA-PÉREZ*, **Mark HARRISON****, **Bill GRANT***

**LaGrange County Health Department, Environmental Health Office, LaGrange, Indiana 46761, U.S.A.*
***Bernardin, Lochmueller and Associates, Inc., Indianapolis, Indiana 46268, U.S.A.*

ABSTRACT
Sewage can be considered one of the richest and most productive waters for crops since it contains nitrogen (5 - 7%) and phosphorus (3 - 5%) and in constructed wetlands it could be used as fertilizer. The feasibility of growing corn on a recirculating vertical flow constructed wetland (RVFCW) treating sewage on-site was examined. Corn was planted at 107,000 seeds/ha. Effluents from a septic tank and a RVFCW were analyzed for water quality variables. Treatment efficiencies (removal) were high for fecal coliform bacteria (99.9%), biochemical oxygen demand (98.4%), total suspended solids (95.6%), ammonium-nitrogen (95.3%), total Kjeldhal nitrogen (94.7%), total nitrogen (79.5%), and total phosphorus (75.5%), while relatively low for potassium (48.8%). Corn yield (only kernel) was 10,026 kg/ha. These results show that a RVFCW could be a sustainable alternative technology to grow corn providing a mechanism to remove pollutants from wastewater, reduce sanitation problems, and improve economic and social benefits.

Keywords: corn, recirculating constructed wetland, *Zea mays*.

INTRODUCTION

Septic tank effluent, which is a kind of sewage, can be chemically considered one of the richest and most productive waters for crops. Sewage is rich in nitrogen (5 - 7%) and phosphorus (3 - 5%), the two valuable nutrients, and main components of most chemical fertilizers, which are often called limiting factors to plant growth because of their relative scarcity and irreplaceable value. Constructed wetlands are considered a viable green alternative to remove conventional pollutants from septic tank effluents. The treatment performed by constructed wetlands using recirculating vertical flow can reach over 99% removal efficiency of contaminants before land application and surface or underground discharge (García-Pérez *et al.,* 2006). To maximize pollutants removal, especially with respect to the removal of phosphorus and metals, constructed wetlands' vegetation must be cut or harvested frequently during the growing season (Arias *et al.,* 2005).

On the other hand, the primary feedstock for alternative energy production is coming from commodities such as corn, soybeans, sunflower and sugarcane among others, which are used as food for humans and animals and it could unintentionally cause a rapid rise in food costs (Huber and Dale, 2009), as biofuel sources compete with food supplies around the globe (Weissman, 2009). Sewage nutrients on constructed wetlands could have the potential to be used as alternative technology to grow primary feedstock for biofuel, to produce biomass for green energy generation, or to feed domestic animals.

Address correspondence to Alfredo García-Pérez, LaGrange County Health Department,
Email: agarcia@lagrangecounty.org
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García-Pérez *et al.,* (2009) suggested that a practical environmental sound application for recirculating vertical flow constructed wetlands (RVFCW) could be to use them to grow agricultural commodities such as corn to produce biofuel.

Depending on the soil conditions or variables, and yield goal, a high grain yielding corn crop (> 11,000 kg/ha) requires more than 1,000 m^3 of water, 100 kg of nitrogen (NO_3^-), 30 kg of phosphorus (P_2O_5), and 50 kg of potassium (K_2O) (Shapiro *et al.,* 2008). These water and nutrient requirements could be provided on a subsurface constructed wetland treating sewage effluent. Sewage sludge, sewage water and septic waste effluents have been used before to irrigate agriculture crops such as grapevines (McCarthy and Downton, 1981), rice and banana plants (Nelson *et al.,* 1998), edible foods (Boom *et al.,* 2008), ornamental flowers (Zurita *et al.,* 2009), and for fish farming (Lin *et al.,* 2002; Gabr and El-Alfy, 2009). This paper presents the preliminary findings of the feasibility to grow corn on a RVFCW treating sewage effluent on site in LaGrange County, Indiana.

MATERIALS AND METHODS

A RVFCW (6 m × 6 m; 1.2 m deep) to treat sewage from a local church was built during the spring and summer seasons of 2008 in LaGrange County, Northeast Indiana. The system did start receiving sewage early fall of 2008 and it was completely operational for the winter 2008 - 2009. The system was designed to treat a daily sewage volume of approximately 2,124 L, however, pump count events and a running timer inside the electric panel box controlling the submersible pump provided a real daily flow of 1,400 L only considering the Sunday congregational church services. During the weekdays when the church facility was not in use, the design of the system allowed operation of the constructed wetland if water was available in the recirculating chamber.

The wastewater was collected in a 1,136 L grinder station and pumped out by demand to two 3,800 L septic tanks installed in series. From the last septic tank the sewage was gradually released by gravity to the feeding inlet bottom of the wetland cell, which used plastic chambers to spread the incoming effluent at the front end. The last septic tank held an outlet plastic filter with a high level water mechanism to trigger the maintenance alarm to clean the plugged filter. The wetland cell was built with a 0.762 mm PVC liner and filled with a bottom layer of 61 cm depth of 13 - 25 mm diameter stone and a top layer of 61 cm depth of 4 mm diameter gravel (pea gravel). The two layers of stone were separated by a second PVC liner extended over most of the top area of the bottom gravel layer leaving the 25% nearest the wetland inlet uncovered (Fig. 1).

The effluent from the constructed wetland was collected in one 3,800 L septic tank functioning as recirculating chamber housing the submersible pump. During five minutes for each 30-minute interval of the whole operation period, the wetland effluent collected in the recirculating chamber was recycled back to the RVFCW using a 2.54 cm PVC manifold pipe located over the entire top of the pea gravel bed area where it was planted symmetrically with corn seeds. The recirculating pump (N151-A, Zoeller, USA) with a maximum flow of 189 liters per minute was controlled by an electronic repeat cycle timer (H3CR-F8, Omron, Japan). Theoretically, the sewage generated

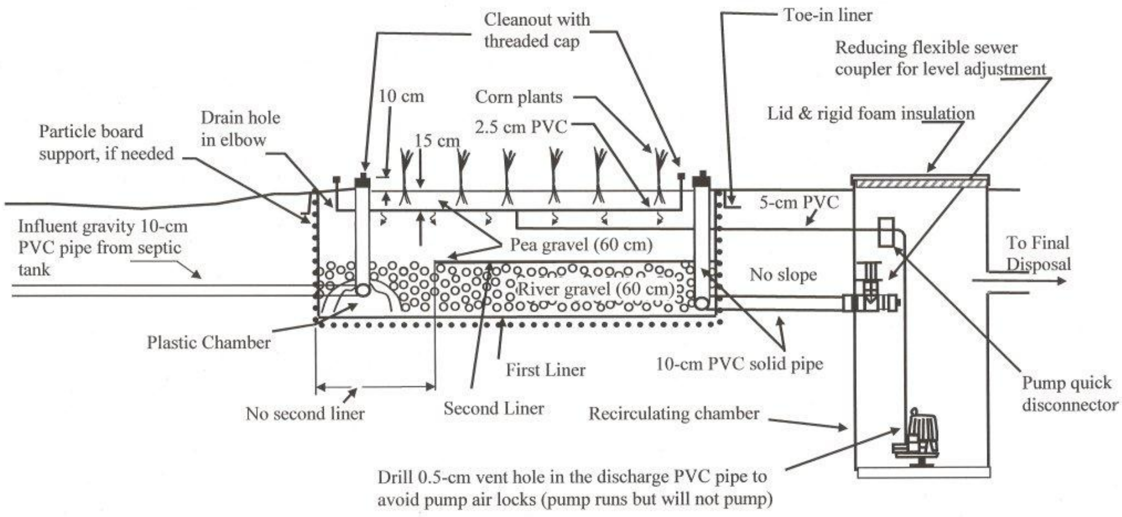

Fig. 1 - Longitudinal section of the recirculating vertical flow constructed wetland

during the Sunday services trickled down through the wetland column at least 12 times per day before new sewage was added on the next Sunday service.

Corn seeds (Beck's Hybrids YieldGard VT Triple (5444VT3) RM 110) were planted on the RVFCW late May for the growing season of 2009 at a rate equivalent to 110,000 plants/ha. The final growing density was 107,000 plants/ha after 97% seed germination. Corn plants were left on the RVFCW until very late fall and harvested before winter started. This general technique is used by farmers in order to thoroughly dry the grain for winter storage. The corn ears were counted during the harvesting time. All the hubs and the grains were manually removed from the cob. The kernels were weighed in bulk to determine shelled (kernel) yield but the quality of the kernel was not determined. During the growing season, pesticides, herbicides or fertilizers were not added to the crop, nor was there irrigation to provide additional water. A water balance measuring rainfall, infiltration and evapotranspiration was not determined.

During the regular growing season (May-November, 2009), water samples of the effluent from the septic tank and the constructed wetland were collected and periodically submitted to a certified Environmental Protection Agency (EPA) testing laboratory and analyzed using the methodology described in Standard Methods (SM) for the Examination of Water and Wastewater (1998) and in the EPA Manual of Methods for Chemical Analysis of Water and Wastes (1983) for the following parameters: 5-day biochemical oxygen demand (BOD_5, SM-5210-B), nitrate (NO_3^--N, EPA-353.2), ammonia-nitrogen (NH_4^+-N, SM-4500-NH_3), total suspended solids (TSS, SM-2540), fecal coliform bacteria (*E. coli,* SM-Quanti-Tray/2000), total phosphorus (TP, SM-4500-P), potassium (K, EPA-200.7), and total Kjeldhal nitrogen (TKN, EPA-351.2). Parameters collected on-site included temperature (air and water) and oxygen concentration using a dissolved oxygen meter (D06, Oakton Eutech Instruments, USA), oxidation reduction potential using an ORP meter (RE300, ExStik Extech Instruments, USA) and pH using a pH meter (340, WTW, Germany). The removal efficiency was calculated according to the equation used by Ebeling *et al.,* (2003).

RESULTS AND DISCUSSION

The results of water quality measurements of effluents from the RVFCW for DO, pH, BOD_5, TSS, air and water temperature, K, TP, fecal coliform bacteria (Table 1), and nitrogenous compounds (Table 2) fluctuated during the growing season. The presence of high oxygen concentration (final mean DO = 5.3 mg/L) in the filter bed necessary for bacteria to remove sewage pollutants explains the relatively low final concentration of pollutants and the high removal efficiency of the system (Table 3). The constructed wetland used in this research provided similar high treatment efficiencies to the system used by Cooper and Green (1995) and better efficiency to remove contaminants in comparison with the systems used by García-Pérez *et al.,* (2006, 2009), and Zurita *et al.,* (2009). In addition to the high oxygen concentration created by the intermittently recirculating loading of the wetland cell, another reason to explain the high efficiency of the system used in this research to remove contaminants could be that the system was designed for 2,124 L per day but it only received 1,400 L, which is 66% of the designed daily flow. Also, the presence of the top liner creating a second upper compartment completely aerobic, and a bottom lower compartment working as an anaerobic environment could explain the high efficiency of the system. These aerobic and anaerobic conditions are well delimited allowing microorganisms a more efficient processing of the nitrogenous compounds.

The nitrification process was efficient in decreasing ammonium from 80 to 3.8 mg/L (95.3%), TKN from 93 to 4.9 mg/L (94.7%), and TN from 93 to 19.1 mg/L (79.5%). Final nitrate concentration reached to 14.2 mg/L, which was probably the result of the "summer effect" (García-Pérez *et al.,* 2006) as less than 5% of the total effluent treated during the experimental period was finally discharged to the disposal absorption field. Additional treatment could be possible but the low concentration of carbon (final BOD_5 = 2.6 mg/L) probably indicates that the system may be carbon limited for any additional denitrification. However, minimizing nitrate loss is important if the water is intended to be used for crop irrigation reducing or eliminating fertilizer requirements.

Table 1 - Water quality parameters

Water quality parameters	Testing Day						Mean ± SD
[*mg/L]	30	112	130	160	180	220	
Dissolved Oxygen*	4.5	7.1	6.2	5.3	5.4	3.4	5.3 ± 1.3
pH [standard units]	7	7.4	7.1	7	7.2	7.5	N.A.
Air Temperature [°C]	23.3	28.2	31.5	23	16.6	15.4	23 ± 6.3
Water Temperature [°C]	11.2	20.1	20.3	15.1	12.8	11.2	15 ± 4.2
Biochemical Oxygen Demand*	2.8	1.9	1.7	1.9	5.9	1.5	2.6 ± 1.7
Total Suspended Solids*	2.5	1.9	1.7	1.9	1.9	4	2.3 ± 0.9
Total Phosphorus*	6.2	0.3	2.2	6.2	0.3	0.9	2.7 ± 2.8
Potassium*	17.1	37.2	12.3	21	22.2	23.2	22.2 ± 8.4
Fecal Coliform [Org/100 mL]	3400	N.D.	8350	5790	579	3880	4400 ± 289

N. A. : Not applicable; N. D. : No data; S. D. : Standard deviation.

Table 2 - Concentrations of nitrogenous compounds [mg/L]

Testing [Day]	Ammonia-N [NH_4^+-N]	Nitrate-N [NO_3^--N]	Total Kjeldhal Nitrogen [TKN]	Total-Nitrogen [TKN+NO_3^--N]
30	8.3	0.5	7.5	8
112	0.1	18.5	1.9	20.4
130	10.5	0.5	13.7	14.2
160	1.5	13.4	2.1	15.5
180	0.8	21.3	1.9	23.2
220	1.8	31.2	2.5	33.7
Mean	3.8	14.2	4.9	19.1
S.D.	4.4	12.1	4.8	8.8

S. D. : Standard deviation.

Table 3 - Water quality parameters and pollutant removal efficiency

Water quality parameters [*mg/L]	Constructed wetland Influent	Constructed wetland Effluent	Removal efficiency [%]
Fecal Coliform [Org/100 mL]	3.0×10^6	4.4×10^3	99.9
Biochemical Oxygen Demand*	164	2.6	98.4
Total Suspended Solids*	52	2.3	95.6
Ammonia-Nitrogen*	80	3.8	95.3
Total Kjeldhal Nitrogen [TKN]*	93	4.9	94.7
Total-Nitrogen [TN=TKN+NO_3^--N]*	93	19.1	79.5
Total Phosphorus*	11	2.7	75.5
Potassium*	43	22	48.8
Nitrate [NO_3^--N]*	0.5	14.2	N.A.
Dissolved Oxygen*	1.2	5.3	N.A.
pH [standard units]	6.9-7.1	7.0-7.5	N.A.
Water Temperature [°C]	17.4	15.1	N.A.
Oxidation-Reduction Potential [mV]	-199	-78	N.A.

N. A. : Not applicable.

Phosphorus is considered an environmental nuisance and its presence in aquatic systems can allow an excessive growth of algae that consume the oxygen, thus creating eutrophic ecosystems. Recycling of nutrients to grow corn, shows that phosphorus removal reached 76% by adding a byproduct (corn) which could potentially generate some benefits. Other mechanical systems could be used to remove phosphorus but the initial investment could be much less cost-effective. Also, special media with high phosphorus sorption capacity could be used to reach high TP reduction (77%) as reported by Vymazal (2004) but this option generates an additional cost if the special media is not locally available. Despite studies to identify an economical artificial media to efficiently remove phosphorus continually over time, it has not been possible to find that material (Arias *et al.,* 2005).

Plant harvesting as a strategy to remove phosphorus has been efficient in this research (76%), and it can reach an efficiency of up to 81% as reported by Zurita *et al.,* (2006). Initially, phosphorus uptakes by the corn plants could be considered as transient phenomenon, or more linked to the life sorption capacity of the gravel bed and the aerobic zones of the wetland cell where phosphorus can precipitate into insoluble and immobile oxidized forms. However, the phosphorus removal efficiency reported in this research (76%) is much better than those of the previous studies with constructed wetlands, for instance using typical wetland plants as reported by García-Pérez *et al.,* (2009), which only reached 33%, or the 50% removal reported by Zurita *et al.,* (2009) using a non-RVFCW growing ornamental flowers. In addition, regular gravel without any specific P-removing chemicals enrichment has provided to be a low-efficient substrate in removing phosphorus (Korkusuz *et al.,* 2004, García-Pérez *et al.,* 2009, Tang *et al.,* 2009).

Corn is a produce that specifically uses large amounts of phosphorus during growth, helping plants to mature efficiently and to reach high blooming levels. Therefore, assuming that the corn plants removed the phosphorus is not misleading or misunderstanding the nutrient mass balances occurring inside the constructed wetland. Vymazal *et al.,* (2010) found that multiple harvest of the above-ground biomass in constructed wetlands is beneficial and enhances the removal of trace elements from wastewater. Previous researches have shown a significant role of plant uptakes on nutrient removal in constructed wetlands treating sewage (Tanner, 1996, Koottatep and Polprasert, 1997).

According to the product label of the corn seed brand used in this study, the potential corn yield could reach 14,506 kg/ha. Performance trials done by Purdue University, Indiana, using the same corn seed brand produced 15,189 kg/ha (DeVillez and Foster, 2009). Our research reports corn yield equivalent to 10,046 kg/ha which is a higher value than the Indiana's average corn production (9,503 kg/ha) during the period 2000-2008 (National Corn Growers Association, 2009) using recommended fertilizer applications.

The results obtained in this research including feedstock production (corn in this case) and the high removal efficiency of contaminants to discharge high quality clean effluent are similar to studies done by Nelson *et al.,* (1998), Ferreira *et al.,* (2007), and Zurita *et al.,* (2009) showing a practical application for constructed wetlands to reduce sanitation problems, a mechanism to potentially generate income while treating sewage and helping to protect the environment. Pictures and information of the constructed wetland system are available at the LaGrange County Health Department webpage link: http://www.lagrangecountyhealth.org/constructedwetlands.aspx.

CONCLUSIONS

This study shows that the RVFCW built in the LaGrange County, Indiana, had high treatment efficiency in decomposing organic material and removing harmful pathogens and suspended particulate material. The constructed wetland effluent shows low concentration for BOD_5, TSS and for the different forms of nitrogen. Up to 99% of fecal coliform bacteria (*E. coli*) were removed. These results indicated that a RVFCW is a viable engineered green alternative technology to treat sewage and grow more useful products before land application and surface or underground discharges of final effluents, thus providing a mechanism to remove pollutants from wastewater, which could add economic and social benefits without reducing its performance.

Additional research needs to be done to maximize the corn production including testing of different varieties and stocking density, microbial quality of the kernel, and economics. Furthermore, other kinds of commodities such as sunflower or soybeans could be used in future studies to compare these results. This eco-friendly practical environmental application for constructed wetlands to treat sewage on site appears to be a viable green alternative to reduce sanitation problems and to grow commodities for biofuel, or energy biomass.

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