CONSTRUCTED WETLAND SYSTEMS FOR SWINE WASTEWATER TREATMENT

J. MARK RICE,[1] ARIEL A. SZOGI,[1] STEPHEN W. BROOME,[2] FRANK J. HUMENIK[3] AND PATRICK G. HUNT[4]

[1]Biological and Agricultural Engineering Department, NC State University, Raleigh, NC [2]Soil Science Department, NC State University, Raleigh, NC [3]College of Agriculture and Life Sciences, Animal Waste Management Programs, NC State University, Raleigh, NC [4]USDA-ARS, Coastal Plains Soil, Water, and Plant Research Center, Florence, SC

ABSTRACT

Wastewater problems associated with confined swine production have created a national urgency to find functional and affordable alternative treatment methods. An investigation was conducted on one of the promising methods, constructed wetlands, to treat swine lagoon liquid. Six treatment wetlands (3.6-m x 33.5-m) were used; they contained either wetland plants or agronomic crops. In these wetlands, mass reduction of N (ammonia plus nitrate) was 94% when N loading was at 3 kg/ha/day. At the current loading rate of approximately 25 kg/ha/day the mean N removal efficiency was 87%.

It was determined that the wetlands were nitrate-N limited for denitrification; hence, treatment experiments were also conducted with nitrified wastewater. When nitrified wastewater was added in batch applications to wetland microcosms the nitrogen removal rate was four to five times higher than when non-nitrified wastewater was added. Wetland microcosms with plants were more effective than those with bare soil. This was likely due to the low soluble carbon of the nitrified wastewater. These results suggest that vegetated wetlands with nitrification pretreatment are viable treatment systems for removal of large quantities of nitrogen from swine wastewater.

Three conclusions were obtained from these studies: 1) wetlands by themselves cannot produce an effluent which will consistently meet stream discharge requirements; 2) wetlands show promise for high rates of nitrogen mass removal especially when inflow N is predominately in the nitrate form; 3) nitrification-wetland treatment systems should reduce odor and ammonia volatilization.

Keywords: Lagoon liquid, Nitrogen, Mass removal, Stream discharge

SITE CHARACTERISTICS

The research site, a nursery operation of 2600 pigs (average weight = 13 kg) uses a flushing system to recycle liquid from a single-stage lagoon. The average liquid volume of the lagoon was 4,100 m^3. On a mass basis, the lagoon liquid contained only 17% of TN[5] which entered the lagoon (Szögi et al, 1996). Typically, the lagoon liquid contained 365 mg/L total TKN, mostly (> 95%) as ammonia-N (NH_3-N), 93 mg TP/L and 740 mg COD/L.

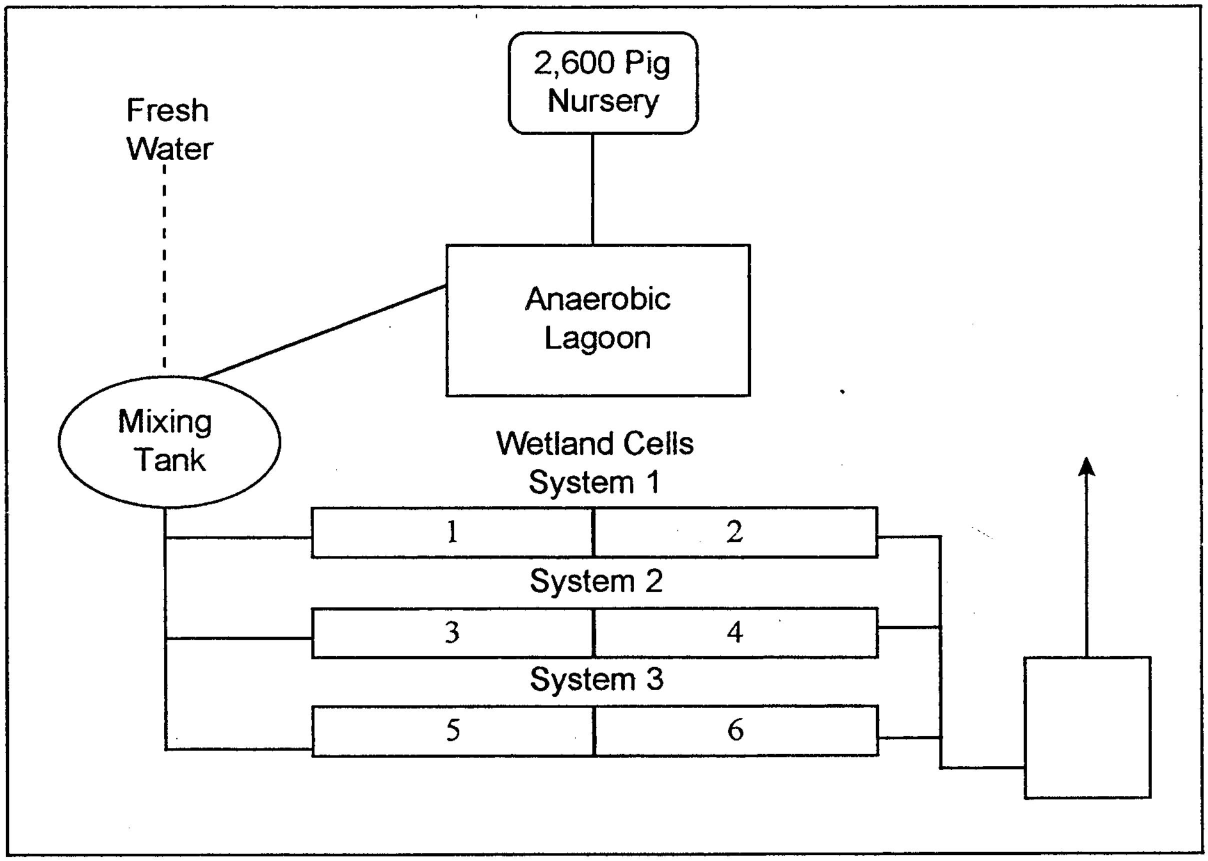
---

[5] Total nitrogen is the sum of Total Kjeldahl -N (TKN) and nitrate-N.

CONSTRUCTED WETLANDS

Three sets of two 3.6- by 33.5-m wetland cells were constructed adjacent to a treatment lagoon in 1992 (Figure 1). They contained either natural wetland plants or water-tolerant agronomic plants. Wetland plants included; rush (*Juncus effusus*) and bulrush (*Scirpus americanus, Scirpus cyperinus* and *Scirpus validus*) in System 1, bur-reed (*Sparganium americanum*) and cattails (*Typha angustifolia* and *Typha latifolia*) in System 2. System 3 contained soybean (*Glycine max*) and rice (*Oryza sativa* cv. Maybell). Although the agronomic plant experiments have had nitrogen removal efficiencies similar to the wetland plants, they were managed differently, and those results are not presented here.

Figure 1. Schematic diagram of the constructed wetland site.



Six V-notch weirs and six ultra-sonic flow meters were installed at the inlet and outlet of each system (Fig. 1). In addition, tipping buckets with mechanical counters were used on the inflow as a backup to the flow meters. Seven automated water samplers were installed. One sampler took samples of the wastewater inflow, and the other six sampled the water at the end of each single cell. The water sampler combined hourly samples into three day composites. Weather data was collected from an onsite automated weather station and supplemented by data from a nearby NC State University weather station.

Water samples were analyzed for nitrate-nitrogen (NO_3-N), NH_3-N, and TKN in accordance with the USEPA recommended methodology by use of a TRAACS 800 Auto-Analyzer (Kopp and McKee, 1983).

Nitrogen results are reported as ammonia plus nitrate-N because these are the predominant forms of nitrogen in the inflow and outflow. Initially, a N (NH_3-N+NO_3-N) loading rate of 3 kg/ha/day was used to evaluate if stream discharge requirements could be achieved. This low loading rate was selected to meet the Tennessee Valley Authority criteria for advanced wastewater treatment (Hammer, 1994). Because stream discharge requirements could not consistently be achieved, the loading was increased to 8 kg/ha/day during the second year, 15 kg/ha/day the third year, and to 25 kg/ha/day in the fourth year with the goal of maximum nitrogen mass reduction. These loading rates were obtained by mixing the lagoon liquid with fresh water before it was applied to the wetland. Nitrogen removal efficiency was similar in both rush/bulrushes and cattails/bur-reed plant systems (Table 1). Mean mass removal of N was 94% at the N loading rate of 3 kg/ha/day and decreased to 84% at the rate of 8 kg/ha/day. The mass removal rates for the 15 kg/ha/day and 25 kg/ha/day rate were between 84 and 90%, respectively. Redox conditions were highly anaerobic in the soils of all wetlands. Denitrification enzyme assays indicated that the wetland soils were nitrate limited for denitrification (Hunt et al., 1995). In related studies, overland flow, media filtration, and encapsulted nitrifiers are being investigated for pre-wetland nitrification of swine wastewater (Vanotti et al., 1998).

Table 1. Nitrogen loading rates and mass removal efficiencies for the constructed wetlands, Duplin Co., NC (June 1993-November 1997).

Nitrogen	System	% Mass Removal
3 kg/ha/day	Rush/bulrush	94
	Cattails/bur-reed	94
8 kg/ha/day	Rush/bulrush	88
	Cattails/bur-reed	86
15 kg/ha/day	Rush/Bulrush	85
	Cattail/Bur-reed	81
25 kg/ha/day	Rush/Bulrush	90
	Cattail/Bur-reed	84

% Mass Removal = % mass reduction of N (NH_3-N + NO_3-N) in the effluent with respect to the nutrient mass inflow.

Conclusions

These results suggest that constructed wetlands are excellent for mass removal of N from swine lagoon liquid. However, at the high loading rates necessary for substantive mass removal, constructed wetlands do not produce an effluent acceptable for discharge. Odor was not judged to be a problem with the wetland systems.

MICROCOSM STUDIES

Effects of Swine Lagoon Liquid on the Growth of Wetland Plants

The objectives of the microcosm study were to determine the effect of swine lagoon liquid on two wetland plant species, *Juncus effusus* and *Scirpus validus,* and the effects of the vegetation on N removal. The experimental design was a randomized complete block, 2x3 factorial with 3 replications. The three lagoon liquid variables were full strength, half strength, and a freshwater control. The vegetation variables were a mixed planting of *Scirpus validus* and *Juncus effusus* compared with no plants. Each of the 18 microcosms had a surface area of one m^2 (2.0 m x 0.5 m). Each microcosm was lined with PVC film, filled with sandy loam topsoil to a depth of 22 cm, and planted with eighteen plants of each species.

The lagoon liquid and freshwater treatments were applied using pumps controlled by timers set to apply a total of 7 liters per day in three equal applications. Outflow pipes were set to maintain a water depth of no greater than 10 cm, and the outflow was collected in barrels buried at the end of each microcosm. The collection barrels were sampled every two weeks to determine water volume and nutrient concentrations in the water. The hydraulic loading rate of 7 liters per day of full strength lagoon liquid supplied about 3 $g/m^2/day$ (30 kg/ha/day)of nitrogen and 0.7 g/m^2 /day (7kg/ha/day) of phosphorus.

During the spring (March to mid-May) plant growth was greatest in the full strength liquid treatment. Total above-ground biomass harvested on May 18, 1995 was 422 g/m^2 for the control, 989 g/m^2 for the half strength treatment and 1810 g/m^2 for the full strength. The amount of N present in the plant tissue at the time of harvest was 4.5 g/m^2 (control), 46.9 g/m^2 (half- strength), and 61.1 g/m^2 (full strength). These amounts are equivalent to the N contained in only two days lagoon liquid applications.

During most of the growing season, there was no outflow from the vegetated microcosms receiving either half of full strength liquid. With no outflow there was, in effect, 100% treatment. The wetland microcosms were a sink for 15 kg/ha/day for the half strength treatment and 30 kg/ha/day for the full strength. The hydraulic loading rate was well below optimum for the amount of growth that occurred in response to nutrient inputs from both of the lagoon liquid treatments. In early June, water requirements for growth in the 100% effluent treatment exceeded the supply, resulting in a die back of the vegetation.

Sequencing Nitrification-Wetland Treatments

A microcosm wetland study was established to assess the possibility of sequencing nitrification-wetland treatments. The treatments were three C sources: wetland soil, mineral soil with no plants (control), and mineral soil + C source (glucose amended) with no plants. Two loading rates of nitrified wastewater were applied: full strength and diluted strength. The experiment was a 3x2 factorial (6 treatments) in a randomized block design with three replications per treatment.

Wastewater enriched with nitrate was applied to the microcosm wetland units at a rate of 190 kg nitrate-N/ha and a retention time of four days. Results showed that differences between wetland plant and soil + C with no plants treatments were not significant, and that the soil with wetland plants removed about 80% of the nitrate applied compared to 14% removal by the control treatment with no plants. This removal potential is equivalent, on an annual basis, to about 14,000 kg N/ ha, which is 5.4 times higher than the N removal without nitrification pretreatment. This indicates that the capacity of mass N removal by wetlands can be significantly increased by nitrification pretreatment.

In a subsequent experiment, the wetland plant treatment removed just 58% of the initial nitrate applied (102 kg/ha, full strength) compared to the mineral soil + C with no plants treatment that removed 100% of the initial nitrate, while the control (soil) treatment had the lowest removal rate with 31% of the initial nitrate level. This second experiment indicated that constructed wetlands may become C limited for denitrification when a high mass load of nitrate is applied continuously.

Conclusions

Conclusions on the effect of swine lagoon effluent on the growth of wetland plants were: 1) *Scirpus validus* and *Juncus effusus* grew vigorously in lagoon effluent of 50% concentration; the effect of the 100% concentration on growth was inconclusive because of confounding with inadequate moisture; 2) During periods of maximum plant growth, water use by plants receiving 50% effluent was twice that of treatments receiving fresh water only.

When nitrified wastewater was added in batch applications to wetland microcosms the nitrogen removal rate was four to five times higher than when untreated wastewater was added. Wetland microcosms with plants were more effective than those with bare soil. These results suggest that wetlands with nitrification pretreatment are viable treatment systems for removal of large quantities of nitrate-N from swine wastewater.

SUMMARY

The goal of studied wetland treatment systems was to maximize nitrogen and phosphorus removal to protect soil, air, and water quality. Wetlands by themselves cannot remove sufficient amounts of N to meet stream discharge requirements, but do show promise for high rates of N mass removal. Since wetlands are nitrate limited the mass removal rate can be increased by nitrifying the effluent prior to wetland application. With nitrification pretreatment, wetlands have the potential to annually remove more than 14,000 kg N/ha.

By sequencing nitrification and denitrification unit processes, advanced wastewater treatment levels can be achieved. Such systems could provide a safer alternative to anaerobic lagoons with reduced ammonia volatilization and odor.

REFERENCES

Hammer, D.A. 1994. Guidelines for design, construction, and operation of constructed wetlnads for wastewater treatment. Guidlines, NPS, Community Partnerships, Tennessee Valley Authority.

Hunt, P.G., T.A. Matheny, A.A. Szögi, and F.J. Humenik. 1995. Denitrification in constructed wetlands for swine wastewater treatment. p. 329. Agronomy Abstracts.

Kopp, J.F. and G.D. McKee. 1983. Methods for chemical analysis of water and wastes. USEPA Report No. EPA-600/4-79020. Environmental Monitoring and Support Lab., Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH, 521p.

Szögi A.A., P.G. Hunt, F.J. Humenik, S.W. Broome, and J.M. Rice. 1996. Assessment of constructed wetlands for mass removal of nitrogen from swine wastewater. In Proceedings of the 2nd National Workshop on Constructed Wetlands for livestock Treatment. May 15 to 18, 1996, Fort Worth, TX.

Vanotti, M.B.. A.A. Szogi, P.G. Hunt, F.J. Humenik, and J.M. Rice. 1998. Nitrification options for swine wastewater treatment. In Proceedings of Animal production systems and the environment: An international conference on odor, water quality, and nutrient management and socio-economic issues. Iowa State University, July 19-22, Des Moines, Iowa.