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Constructed Wetlands for Swine Wastewater Treatment in the Eastern Coastal Plain, USA[1]

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Abstract

Swine production is an important agricultural enterprise that requires significant attention to waste management. An investigation of the treatment of swine wastewater using constructed wetlands was initiated in Duplin Co., NC, in 1993. The investigation used three sets of two, 3.6- by 33.5-m constructed wetland cells that contained either natural wetland or water tolerant agronomic plants. Sets of cells contained rush/bulrushes, bur-reed/cattails, or soybean in soil saturated culture and rice. Nitrogen loading rates were obtained by mixing wastewater from an anaerobic lagoon with fresh water. Nitrogen loading rates of 3 and 10 kg ha^{-1} d^{-1} were used for the first and second year of treatment, respectively. Nutrient concentrations were reported on a quarterly mean basis, and nutrient removal efficiencies were estimated by mass balances. Ammonia-N inflow ranged from 22 to 90 mg L^{-1}. Orthophosphate-P inflow ranged from 6 to 17 mg L^{-1}. Ammonia-N outflow ranged from 1 to 11 mg L^{-1}. Orthophosphate-P outflow ranged from 2 to 14 mg L^{-1}. Total mass removal for N and P was very high (> 90%) with the low loading rate, but it substantially decreased (%) with the higher loading rate. Nitrate-N outflow levels increased up to 31 mg L^{-1} during the fall and winter periods, probably due to more oxidative conditions and lower denitrification activity. Phosphorus removal decreased substantially (%) with the high loading rate, probably due to anaerobic conditions and limited storage capacity of the wetland soil. Dissolved organic carbon removal efficiency was low (< 58%) at low and high loading rates. Our data suggests that more oxygen would be beneficial in our cells for improved long-term removal of both N and P. Enhanced oxidation and treatment efficiency, and sustainability of the constructed wetland system may be obtained by sequencing with other land treatment methods such as overland flow or media.

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Keywords: Nitrogen, Phosphorus, Reduction, Oxidation, Nitrification

Introduction

In the past, land application of animal wastes in the U.S. Eastern Coastal Plain (ECP) was an environmentally safe practice because a few animal producers were scattered across the landscape. Nowadays, confinement of hogs in large-scale production units in this region generates enormous per-unit-area quantities of wastes. Currently, most hog producers apply both liquid and solid waste to land for terminal treatment. Application of liquid swine wastes to land has several problems, such as nuisance odor, high solids content, high nutrient concentrations, and limited pumping distances (Hunt et al., 1995). In addition, land application of liquid wastes to landscapes with shallow unconfined aquifers may contribute to the nutrient enrichment of surface waters in the ECP. Therefore, wastewater disposal must be accomplished in a reliable and sustainable manner to avoid environmental damage to shallow groundwaters, nutrient-sensitive streams, and wetlands. In addition to these technical problems, new state and federal regulations on non-point source pollution, residential development, and increased animal populations severely limit the number of treatment sites available. Thus, hog producers need wastewater treatment systems that are more efficient, low cost, less labor intensive, and require less land.

Constructed wetlands have been used successfully for advanced treatment of municipal wastewaters in the USA and other parts of the world for over the past three decades (Watson et al., 1989). In recent years, constructed wetlands have been used for animal wastewater treatment (Hunt et al., 1995). However, there are limited results on the management and sustainability of constructed wetland systems for swine waste treatment. Therefore, in 1993 an investigation was initiated to evaluate the efficiency of constructed wetlands for swine wastewater treatment in Duplin Co., NC. Specifically, this study sought to answer questions about loading rates, oxidative/reductive conditions, denitrification potentials, N and P removal efficiency, and NH_3-N tolerance of wetland plants. This paper reports on the seasonal water solution chemistry changes and removal efficiencies of a surface-flow constructed wetlands using natural wetland or water-tolerant agronomic plants to treat swine wastewater.

Materials and Methods

Six, 3.6- x 33.5-m, wetland cells were constructed in Duplin Co., NC, in 1992. They were divided into three parallel sets of two end-on-end connected cells (Hunt et al., 1994). The cell bottoms and sidewalls were lined with clay, and covered with 20 to 30 cm of loamy sand soil. Slopes were 0.2% or less, and water depth at the end of the cell was maintained below 15 cm.

Table 1. Characteristics of non-diluted wastewater after primary lagoon treatment (Hunt et al., 1994).

Parameters	Units	Mean	Std. Dev.
pH		7.53	0.14
Total Solids	g kg^{-1}	1.86	0.47
Volatile Solids	g kg^{-1}	0.73	0.32
Total Organic Carbon	mg L^{-1}	235.00	124.00
Chemical Oxygen Demand	mg L^{-1}	737.00	237.00
Biochemical Oxygen Demand	mg L^{-1}	287.00	92.00
Total Kjeldahl Nitrogen	mg L^{-1}	365.00	41.00
Ammonia-Nitrogen	mg L^{-1}	347.00	52.00
Nitrate-Nitrogen	mg L^{-1}	0.04	0.03
Total Phosphorus	mg L^{-1}	93.00	11.00
Orthophosphate-Phosphorus	mg L^{-1}	80.00	9.00

Four cells were planted in 1992 to natural wetland vegetation. Wetland system one consisted of cells 1 and 2 interconnected, and it contained rush (*Juncus effusus*) and bulrushes (*Scirpus americanus, Scirpus cyperinus,* and *Scirpus validus).* Wetland system two consisted of cells 3 and 4 interconnected, and it contained bur-reed (*Sparganium americanum*) and cattails *(Typha angustifolia* and *Typha latifolia).* Wetland system three consisted of cells 5 and 6 interconnected, and it contained agronomic crops. Cell 5 contained soybean (*Glycine max*) grown in saturated-soil culture on 1-m-wide beds that were surrounded by ditches approximately 10 cm deep (Cooper et al., 1992; Nathanson et al., 1984). Water level in the ditches was maintained about 5 cm below the bed surface. Cell 6 contained flooded rice (*Oryza sativa* cv. Maybelle).

Six V-notch weirs and six PDS-350 ultrasonic open-channel flowmeters (Control Electronics, Morgantown, PA) were installed at the inlet and outlet of each set of cells. Seven ISCO 3700 samplers (ISCO, Lincoln, NE) were installed; one sampler collected 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.

The continuous flow loading was automated with float control valves in a mixing tank, which provided automated loading of the desired proportion of lagoon liquid and dilution water. In order to prevent the possible damage to wetland plants, wastewater application to the cells started with low NH_3-N loading rates. Therefore, wastewater from the lagoon (Table 1) was diluted +10 fold with fresh water and applied at a N rate of 3 kg ha^{-1} day^{-1} from July 1993 to September 1994.

A higher loading rate has been applied since October 1994 at a N rate of 10 kg ha^{-1} day^{-1} using a £ 6-fold dilution.

Water samples were analyzed for nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), and orthophosphate-phosphorus (*o*-PO_4-P) in accordance with the USEPA recommended methodology (Kopp and McKee, 1983) by use of a TRAACS 800 auto analyzer. Dissolved organic carbon (DOC) was analyzed with a Dhorman DC-190 carbon analyzer.

Mass balances were calculated for C, N, and P using flowmeter and nutrient concentration data on a three-day basis. The mass balance was used to estimate the specific reduction measured as mass reduction of nutrient per cell area per day. The mass removal or treatment efficiency was expressed as percentage of mass reduction of a nutrient in the effluent with respect to the nutrient mass inflow.

Results and Discussion

Anaerobic conditions of the non-diluted wastewater from the storage lagoon are indicated by the concentrations of total organic carbon (TOC), chemical oxygen demand, and biological oxygen demand (Table 1). Table 1 shows that 95% of total Kjeldahl N was in the soluble NH_3-N form, 86% of total P was in soluble form as *o*-PO_4-P, and NO_3-N concentrations were very low.

Mean NH_3-N concentration in the diluted wastewater during the Jul-Sep '93 quarter (Fig. 1 A) decreased from 22 to 1 mg L^{-1} after treatment in the rush/bulrushes or bur-reed/cattails cells, and it decreased to 0.3 mg L^{-1} after treatment in the soybean-rice cells. A similar trend was observed in Jul-Sep '94 with an inflow concentration of 41 mg L^{-1}. The mass removal of NH_3-N by wetlands with all three vegetative communities was high (96% to 99%) with the low loading rate (3 kg N ha^{-1} d^{-1}) in the first year (Table 2). The substantial decrease of NH_3-N in the effluent was probably due to plant absorption and some NH_3-N volatilization. However, some of the NH_3-N was probably nitrified. The NH_3-N concentration in inflow wastewater was 49 and 31 mg L^{-1} during the Oct-Dec '93 and Jan-Mar '94 quarters, respectively, when plants were dormant. However, the rush/bulrushes and bur-reed/cattails cells reduced NH_3-N concentrations of 2 and 8 mg L^{-1}, respectively. This reduction was most likely a result of increased nitrification (Fig. 1 B shows the corresponding increase of NO_3-N in the effluent during the same periods). Ammonia-N effluent concentrations returned to 1 and 2 mg L^{-1} for the rush/bulrushes and bur-reed/cattails, respectively, in Apr-Jun '94. The Jul-Sep '94 quarter was a transition period to adjust to a higher nutrient load. The anaerobic lagoon was diluted by high rainfalls (49.6 cm over the quarter), and the mean NH_3-N concentration in the inflow was 41 mg L^{-1}. The inflow and outflow concentrations increased during Oct-Dec '94 and Jan-Mar '95 with the high loading rate of 10 kg ha^{-1} d^{-1} (Fig. 1 A). Data in Table 2 shows that N removal

Table 2. Nitrogen, phosphorus and carbon mass removal efficiencies from swine wastewater treated in constructed wetlands.

Loading Rate[a]	System[b]	% Mass Removal[c]		
		N[d]	P	C
Low	1	94	90	41
	2	94	93	11
	3	96	97	33
High	1	63	42	58
	2	73	48	42
	3	—[e]	—	—

[a] Low Rate: NH_3-N = 3 kg ha^{-1} d^{-1}, *o*-PO_4-P = 0.8 kg ha^{-1} d^{-1};
High Rate: NH_3-N = 10 kg ha^{-1} d^{-1}, *o*-PO_4-P = 2.6 kg ha^{-1} d^{-1}.

[b] System 1: Rush/Bulrushes; System 2: Bur-reed/Cattails; System 3: Soybean-Rice.

[c] % Mass Removal = % mass reduction of a nutrient in the effluent with respect to the nutrient mass inflow.

[d] N = NH_3-N + NO_3-N; P = *o*-PO_4-P; C = DOC.

[e] No data.

efficiency was lower with the higher loading rate (rush/bulrushes and bur-reed/cattails cells). The soybean-rice system seems to be as efficient as the other two systems (96%), and its efficiency was estimated only with low loading rate treatment data from Jul-Sep '93 and Jul-Sep '94.

Mean NO_3-N inflow concentrations were usually low (<3 mg L^{-1}) because of the anaerobic conditions in the lagoon (Fig. 1 B). Very little NO_3-N accumulated in the treated wastewaters during Jul-Sep '93; inflow and outflow mean concentrations were 0.8 and 0.1 mg L^{-1}, respectively. These low NO_3-N concentrations, along with anaerobic conditions and the presence of NH_3-N in the outflow, suggest that little nitrification occurred. However, NO_3-N was high in the outflow during Oct-Dec '93 and Jan-Mar '94; mean values ranged from 2 to 10 mg L^{-1}. These values suggest that the decreased microbial respiration and increased O_2 solubility associated with the cooler weather probably allowed sufficient O_2 dissolution for increased nitrification. During Jul-Sep '94, the mean NO_3-N inflow concentration of 8 mg L^{-1} was probably a product of nitrification promoted by oxygen saturated rain water, which was higher than normal during this quarter. However, nitrification seems to be the limiting factor in N removal. This view is supported by preliminary denitrification enzyme assays data recently obtained in our laboratory indicating that NO_3-N is the limiting factor for denitrification in

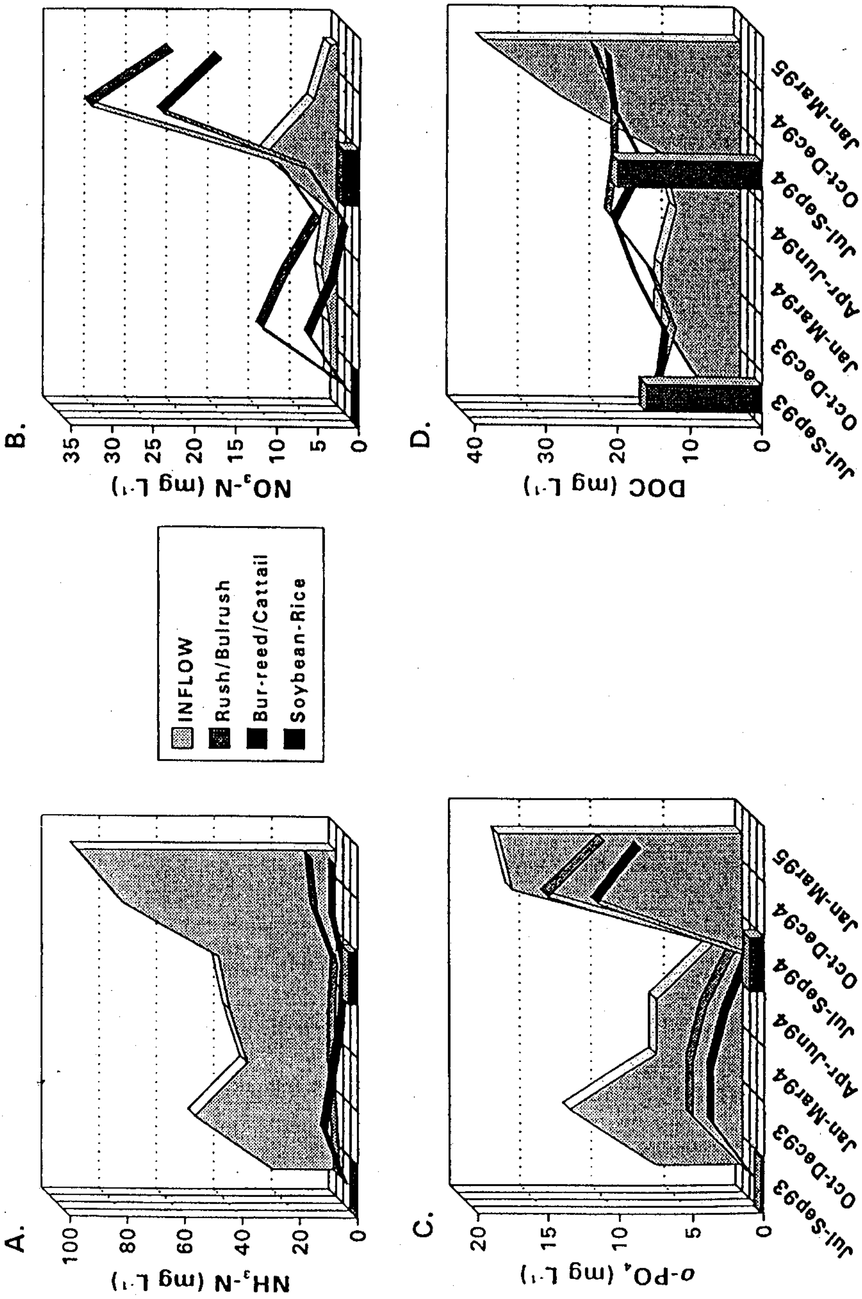

Figure 1. Treatment of swine wastewater by constructing wetlands with three different plant communities. Figure shows quarterly mean inflow and effluent concentrations of a) NH_3; b) NO_3-N; c) o-PO_4-P; d) DOC.

soils of the wetland cells. With a higher loading rate and cooler weather during Oct.-Dec '94 and Jan-Mar '95, the NO_3-N increased to higher levels than in the previous year (Fig. 1 B).

Inflow *o*-PO_4-P concentration fluctuated from 6 to 12 mg L^{-1} during the first year (Fig. 1 C). In this first year the *o*-PO_4-P removal with the lower loading rate was high (90% to 97%) for the three systems (Table 2). The efficiency dropped rapidly when the higher load was applied in Sep-Oct '94 (Table 2). This decrease in efficiency is also shown in Fig. 1 C in the high effluent concentration observed during this period. The rice-soybean system seems to be more efficient, but the comparison is not valid because P removal efficiencies were calculated only on Jul-Sep '93 and Jul-Sep '94 data periods. We think that a pre/post-wetland phosphorus precipitation and clarification treatment is needed to improve P mass removal efficiency.

Analyses of TOC in the diluted wastewater (data not shown) indicated that most TOC occurred as DOC. Quarterly means of DOC inflows ranged from 22 to 49 mg L^{-1} between Jul-Sep '93 and Jul-Sep '94 (Fig. 1 D). The DOC inflow concentrations increased during Oct-Dec '94 and Jan-Mar '95 periods due to the increase of the loading rate. The DOC removal efficiency was low (< 58%) the three systems. The treatment efficiency for DOC was lower for system 2 (bur-reed/cattails) at low and high loading rates (Table 2).

Conclusions

Constructed wetlands are an acceptable method for mass removal of N from animal wastes. However, the anaerobic condition of the wetland soil may limit the rates of nitrification while low temperatures may limit denitrification rates. Phosphorus removal is limited by the P adsorption characteristics of the wetland soil and plant litter layers, as well as the soil anaerobic conditions. Yet, a pre/post-oxidative step seems advantageous for increased, sustainable N and P removal. Currently, we are investigating the aeration of swine wastewater by pre-treatment of the wastewater via overland flow (Overcash et al., 1976) and media filter (Rubin et al., 1994). In overland flow, a thin film of water is in close contact with the nitrifying population of the soil surface. Overland flow also offers the advantage of partial denitrification of NO_3-N in the underlying anaerobic layer. However, P needs to be precipitated before overland flow by adding alum or lime to improve the P removal efficiency of the overland flow and wetland sequence. The media filter has the same purpose of increasing nitrification efficiency, and it removes P using a marl gravel as filter material.

Ultimately, the necessary treatments for livestock wastewater will depend upon the amount of land available for wastewater application. Where land is very limited and there is environmental concern with the sustainability of the terminal land treatment site, high percentages of the wastewater nutrient load need to be removed in a total animal waste management system. This system may include a wetland and pre/post- wetland treatments arranged in a way that maximizes the total mass removal efficiency in an area basis.

References

Cooper, R.L., N.R. Fausey, and J.G. Streeter. 1992. Crop management to maximize the yield response of soybeans to a subirrigation/drainage system. **In** Drainage and Watertable Control. Proceedings of the Sixth International Drainage Symposium, Am. Soc. Agr. Eng., St. Joseph, MI. pp. 446-476.

Hunt, P.G., F.J. Humenik, A.A. Szögi, J.M. Rice, K.C. Stone, and E.J. Sadler. 1994. Swine Wastewater Treatment in Constructed Wetlands. **In** K.L. Campbell, W.D. Graham, and A.B. Bottcher (eds.) Environmentally Sound Agriculture. Proceedings of the Second Conference, 20-22 April 1994, Orlando, FL. Am. Soc. Agric. Eng., St. Joseph, MI. pp. 268-275.

Hunt, P.G., W.O. Thom, A.A. Szögi, and F.J. Humenik. 1995. State of the art for animal wastewater treatment in constructed wetlands. **In** Proceedings of the Seventh International Symposium on Agricultural and Food Processing Wastes, 18-20 June, Hyatt Regency, Chicago. Am. Soc. Agric. Eng., St. Joseph, MI. (In Press).

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.

Nathanson, K., R.J. Lawn, P.L.M. DeJabrun, and D.E. Byth. 1984. Growth, Nodulation, and Nitrogen Accumulation by Soybean in Saturated Soil Culture. Field Crop Res. 8:73-92.

Overcash, M.R., D.M. Covil, G.W. Gilliam, P.W. Westerman and F.J. Humenik. 1976. Overland flow pretreatment of wastewater. Water Resources Research Institute of the University of North Carolina Report #76-117. Raleigh, NC.

Rubin, A.R., S. Greene, T. Sinclair, and A. Jantrania. 1994. Performance evaluation of drip disposal system for residential treatment. **In** Proc. of the 7th International Symposium on Individual and Small Community Sewage Systems. Am. Soc. Agric. Eng. Publication 18-94, St. Joseph, MI. pp. 467-474.

Watson, J.T., S.C. Reed, R.H. Kadlec. R.L. Knight, and A.E. Whitehouse. 1989. Performance expectations and loading rates for constructed wetlands. **In** D.A. Hammer (ed.) Constructed Wetlands for Wastewater Treatment - Municipal, Industrial, and Agricultural. Lewis Publishers, Chelsea, MI. pp. 319-351.