Treatment of animal wastewater in constructed wetlands.

Traitement des efflunets d'élevage à l'aide de zones humides construites.

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Abstract

Swine production is a major enterprise in the USA that has monumental waste treatment problems. These problems are related to confined, high density production, flushing of waste to anaerobic lagoons, and the subsequent land application of wastewater. With this treatment method, it is easy to overload an area with nitrogen. One of the alternative treatment methods is the use of constructed wetlands. Our research had two objectives: 1) to better understand the function of constructed wetlands in a total swine waste management system and 2) to assess the ability of wetlands to remove nitrogen and thereby decrease the required land application area. The treatment wetlands consisted of six 3.6-m x 33.5-m cells. Three systems comprised of two cells connected in series were evaluated. A nitrogen loading rate of 3 kg ha^{-1} day^{-1} was used during the first year of operation, but the rate was increased up to 25 kg ha^{-1} day^{-1} in the subsequent three years. At the low loading rate, 94 % of the nitrogen was removed, but at the higher loading rates, 80 to 90% was removed.
Keywords: nitrification, denitrification, soybean, swine, pre-wetland treatment

Résumé

La production porcine est une industrie majeure aux USA et qui présente de colossaux problèmes de traitement des effluents. Ces problèmes sont liés notamment à la production hors-sol intensive, avec « flushing » des effluents vers des lagunes anaérobies et épandage de ces effluents. Avec ce mode de traitement il est aisé de surdoser les terres en azote. Notre recherche poursuit deux objectifs : (i) mieux comprendre les fonctions de zones humides aménagées dans un système total de gestion des effluents porcins et (ii) évaluer la faisabilité de zones humides à éliminer de l'azote et ainsi à réduire les surfaces nécessaires pour l'épandage. Les zones humides construites consistent en six unités de 3,6 m x 33,5 m. Trois systèmes comprenant ainsi deux unités connectées en série ont été étudiés. Une charge en azote de 3 kg ha^{-1} j^{-1} a été appliquée la première année de fonctionnement mais ce taux a été augmenté à 25 kg ha^{-1} j^{-1} au cours des 3 années suivantes. Aux doses d'apports faibles, plus de 94% de l'azote est éliminé, alors que pour les doses plus importantes, 80 à 90% de l'azote est éliminé.
Mots-clés : nitrification, dénitrification, soja, porc, pré-traitement zone humide.

1. Introduction

Swine production is an important part of the US agricultural economy that has shifted from small private production to large, confined, corporate production. This industrial production of swine generates large amounts of waste. Currently, most enterprises apply both solid and liquid waste to forage and crop land. Land application of waste becomes a problem when more manure nitrogen is produced than crop or forage land can assimilate. Consequently, public concern and changing environmental regulations are stressing the need for alternative treatment methods that require less land area for manure treatment. These alternative methods include constructed wetlands (Hunt et al., 1995b).

Wetlands have been successfully used for advanced treatment of municipal and residential wastewaters in the USA and around the world for over three decades (Kadlec and Knight, 1996). Compared to conventional systems, they have 1) less - construction, operation, and energy costs and 2) more - flexibility in pollutant loading. They can be built on aerated upland soils; the necessary hydric soil conditions and aquatic plant life will develop when the soils are flooded. Two types of wetlands are typically used: subsurface and water-surface-flow (Hammer, 1989). Subsurface systems are subject to clogging and limited oxygen diffusion. Consequently, research on constructed wetlands for animal waste treatment in the USA has focused on water-surface-flow systems with emergent plants (Cathcart et al. 1994; McCaskey et al. 1994; Payne Engineering and CH2M Hill, 1997).

Our research had two objectives: 1) to better understand the function of constructed wetlands in a total swine waste management system, and 2) to assess the ability of wetlands to remove nitrogen and thereby decrease the required land application area.

2. Materials and Methods

The research site, a 2,600-pig nursery (average weight = 13 kg) in Duplin Co., NC, USA, used a flushing system to recycle liquid from a single-stage lagoon. The average liquid volume of the lagoon was 4,100 m^3. Typically, the lagoon liquid contained 365 mg L^{-1} TKN (> 95% NH_3-N), 93 mg L^{-1} TP, and 740 mg L^{-1} COD.

Six 3.6- by 33.5-m wetland cells were constructed adjacent to the treatment lagoon in 1992. The wetland cells were built by soil excavation. Cell bottoms were graded to a 0.2% slope and sealed by a compacted clay liner. The clay liner was covered with a 0.25-m layer of loamy sand soil.

Wetland cells were planted either to a polyculture of natural wetland plants or to water-tolerant agronomic plants. Three systems were evaluated; each consisted of two cells connected in series. System 1 contained rush (Juncus effusus) and bulrush (Scirpus americanus, Scirpus cyperinus and Scirpus validus); system 2 contained bur-reed (Sparganium americanum) and cattails (Typha angustifolia and Typha latifolia). System 3 consisted of one cell that contained soybean (Glycine max) grown in saturated-soil culture connected to a second cell that contained flooded rice (Oryza sativa). Six soybean cultivars were planted in replicated microplots within system 3 each year (1993 - 1996).

Water level at the end of each cell of the two wetland plant systems and the flooded rice cell was maintained at about 150 mm. In system 3, soybean in saturated-soil culture was planted on 1.4-m-wide beds that were surrounded by approximately 100 mm-deep ditches. Water level in the ditches was held at about 50 mm below the bed surface.

Flow was measured by use of six V-notch weirs and six ultra-sonic flow meters at the inlet and outlet of each system. In addition, tipping bucket flowmeters with mechanical counters were used on the inflow as a backup to the ultra-sonic 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 samples into three-day composites. A data logger with three multiplexers was installed for hourly acquisition of weather parameters and soil redox potential (Eh) data. Soil redox potential was monitored with a total of ninety Pt electrodes. Electrodes were arranged in clusters of five electrodes; three clusters were installed per cell with one Ag/AgCl reference electrode per cluster.

In order to prevent potential damage to wetland plants, wastewater was initially diluted with fresh water and applied at a N rate of 3 kg ha^{-1} day^{-1}. This low, daily, N application rate required a high dilution rate (1:15) in order to maintain the hydraulic conditions of a wetland (i.e., wastewater diluted to 25 mg L^{-1} N provides 3 kg ha^{-1} day^{-1} of N with a loading depth of only 12 mm day^{-1}). Since 6-mm hydraulic loading would not meet evapotranspiration demands during the summer months, the fresh water dilution and hydraulic loading were increased as needed to maintain the wetland outflow and the 3 kg ha^{-1} day^{-1} N application rate. The dilution rates were decreased when higher N loading rates were applied in subsequent years. The N loading rates were increased to 8, 15, and 25 kg ha^{-1} day^{-1} in the subsequent three years. Wastewater was not applied to the soybean and rice cells after grain maturity.

Wetland plants were sampled each month, during the growth season, from three 0.25-m^2 quadrats chosen at random along each wetland cell. Samples were transported in plastic bags to the laboratory where living and dead tissues were separated within 24 hrs. Plant materials were oven-dried at 60°C to constant weight. Oven-dried weights of living and dead tissues were used to estimate the net dry matter productivity according to Kirby and Gosselink (1976). Soybean and rice were harvested at maturity, oven-dried, threshed, and weighted for grain yields.

Plant material subsamples were ground and digested using a block digestion technique. Digestates were analyzed for nitrogen using a TRAACS 800 Auto-Analyzer[1]. Water samples were analyzed for 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).

Denitrification enzyme assays were done on disturbed soil samples by the acetylene blockage method (Tiedje, 1982). Measurements were made on soil samples that were both unamended and amended with nitrate, glucose, or nitrate plus glucose. They were incubated under both aerobic and anaerobic conditions.

A microcosm wetland study with 18 cells was established to assess pre-wetland nitrification. Each of the 18 microcosm cells had a surface area of 1 m^2 (2.0 m x 0.5 m). Each cell was lined with PVC film, filled with sandy loam topsoil to a depth of 22 cm, and planted to a mixture of Scirpus validus and Juncus effusus. The treatments were three C sources: soil with wetland plants, soil with no plants (control), and soil + C source (glucose amended) with no plants. Nitrified wastewater was applied at full strength and 50 % diluted. The experiment was a 3 x 2 factorial (six 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 with a retention time of four days.

3. Results and Discussion

Growth was good for wetland and agronomic plants (Table 1). Although the > 200 kg ha^{-1} yr^{-1} of N accumulated by plants would be significant for the nutrient balance of an agronomic system, it was a relatively small portion of the total nutrient load to the wetlands. Nevertheless, plants were vitally important in the treatment wetland systems. Their stems transported oxygen into sediment; their residues contributed organic carbon and surfaces for microbial process.

Soybean seed yields ranged from 0.8 to 4.4 Mg ha^{-1} during 1993 -1996 for the cultivar 'Young.' These yields were low compared to the > 5 Mg ha^{-1} soybean yields obtained in Australia using saturated-soil culture (Lawn and Byth, 1989). Rice yields were similarly moderate with a mean of 3.7 Mg ha^{-1}. At the 3 and 8 kg N ha^{-1} day^{-1} loading rates, N reduction by the soybean-rice system was comparable to the wetland plants. However, once they were mature, they required dry conditions for harvest. Weed invasion during the off season was also a problem. Nonetheless, the results show that the saturated-soil culture soybean and rice system can be used in the treatment of swine wastewater.

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Plants	Dry matter	N uptake
	Mg ha^{-1}	kg ha^{-1}
Scirpus/Juncus	19	338
Typha/Sparganium	23	428
Soybean*	7	222
Rice	10	216

*Soybean and rice total dry matter production at harvest = grain + stalks.

Table 1.

Dry matter and nitrogen uptake for plants in the wetlands during 1993 and 1994.

Nitrogen removal efficiency was similar in both rush/bulrushes and cattails/bur-reed plant systems (Table 2). At a N loading of 3 kg ha^{-1} day^{-1}, a mass N reduction of 94% was obtained. During the second year, the N loading rate was increased to 8 kg ha^{-1} day^{-1}, and mass N reduction was 87%. In the third year, the loading rate was doubled to 15 kg N ha^{-1} day^{-1}, and removal efficiency was 83%. During 1997, the removal rates did not decrease even though the application rate was 25 kg N ha^{-1} day^{-1}. At this rate and 300 application days, wetlands could remove >6 Mg N ha^{-1} yr^{-1}. These high rates of nitrogen removal were likely due to denitrification of NO_3-N that was formed in the upper portion of the liquid layer (Szogi and Hunt, unpublished data). However, some loss of NH_3-N by volatilization cannot be disregarded.

Nitrogen Load	System	
	Rush/bulrush	Cattails/bur-reed
kg ha^{-1} day^{-1}	Mass Removal, %	
3	94	94
8	88	86
15	85	81
25	90	84

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

Table 2.

Mass removal of N in constructed wetlands, NC, USA (June 1993-November 1997).

Anaerobic conditions were prevalent in the wetland soils. We found Eh at the 20-mm soil depth in the first cells to be consistently below 100 mv (Fig. 1). The second cells were similarly reduced except on the occasions when the hydraulic load was limited. This indicated that nitrification was likely limited and that denitrification was predominant. However, the main form of N in the wastewater is ammonia, which requires nitrification before denitrification. The lack of ammonia-N removal via nitrification has been identified as the cause of failure for many municipal wetland systems (Reed, 1993). Thus, it would be likely to find that denitrification was nitrate limited. This assumed limitation was tested by Denitrification enzyme assay (DEA) in order to ascertain that nitrate was the most limiting factor for denitrification in the wetland cells.

DEA results were as expected; the wetlands were nitrate limited (Fig. 2). Denitrification was greatly increased by additions of nitrate-N. Conversely, it was not greatly increased by glucose addition. Thus, it is reasonable to expect that the overall rate of N removal could be increased by pre-wetland nitrification. This nitrification would also eliminate the need for dilution in order to avoid ammonia-N damage to wetland plants and potential losses by ammonia volatilization. We are currently investigating several promising approaches to nitrification of swine wastewater (Vanotti et al., 1998; Vanotti and Hunt, 1998).

We confirmed the hypothesis that large amounts of nitrogen (49 kg ha^{-1} day^{-1}) could be removed from wetlands if pre-nitrified wastewater was added (Fig. 3). The nitrate-N application rates of 26 and 49 kg ha^{-1} day^{-1} are very high application rates relative to those possible with agronomic crops. We also confirmed the hypothesis that wetland plants would be required to provide the carbon for denitrification. Both the wetland and carbon-amended soil treatments were very effective in the mass removal of N; 80% of the applied N was removed. In contrast, the control (soil) treatment with no plants was very ineffective; only 14% of the applied N was removed.

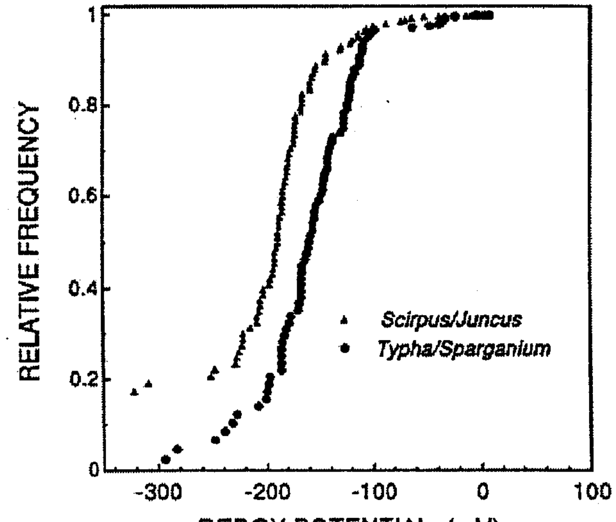

Figure 1
Relative frequency of daily redox potentials at 20 mm depth in soils of constructed wetlands during growing season.

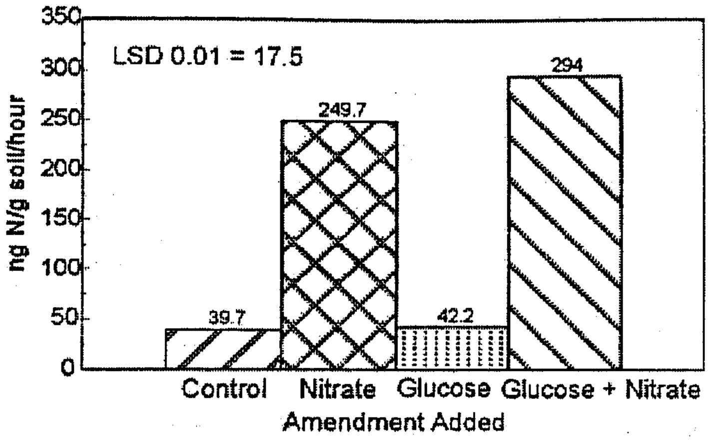

Figure 2
Mean denitrification potential as influenced by soil amendment.

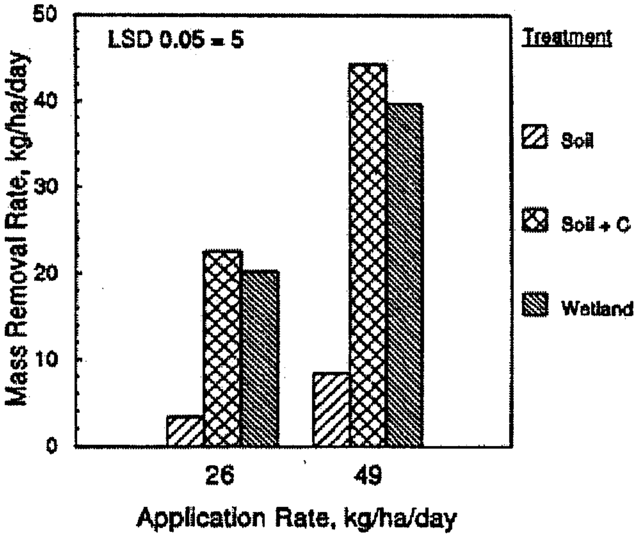

Figure 3
Nitrogen removal from wetlands microcosms with three types of carbon regimes and batch wastewater applications every four days.

4. References

Cathcart, T.P., D.A. Hammer, and S. Triyono. 1994. Performance of a constructed wetland-vegetated strip system used for swine waste treatment. p. 9-22. In P.J. DuBowy and R.P. Reaves (eds.) Constructed Wetlands for Animal Waste Management. Purdue Research Foundation, West Lafayette, IN.

Hammer, D.A. (ed.) 1989. Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers, Chelsea, MI. 831 p.

Hunt, P.G., W.O. Thom, A.A. Szögi, and F.J. Humenik. 1995b. State of the art of animal wastewater treatment in constructed wetlands. p. 87-97. In C.C. Ross (ed.) Proceedings of the Seventh International Symposium on Agricultural and Food Processing Wastes (ISAFPW95). June 18-20, 1995, Chicago, IL. ASAE Publication 7-95, St. Joseph, MI.

Kadlec, R. H., and R. L. Knight. 1996. Treatment wetlands. Lewis Publishers, Boca Raton, FL. 893 p.

Kirby, C.J., and J.G. Gosselink. 1976. Primary production in a Louisiana gulf coast Spartina alterniflora marsh. Ecology 57:1052-1059.

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. 521 p.

Lawn, R.J., and D.E. Byth. 1989. Saturated soil culture. A technology to expand the adaptation of soybean. p. 576-581. In A.J. Pascale (ed.) IV World Soybean Research Conference. Publ. Realizacion, Orientacion Grafica Ed. SRL, Buenos Aires, Argentina.

McCaskey, T.A., S.N. Britt, T.C. Hannah, J.T. Eason, V.W.E. Payne, and D.A. Hammer. 1994. Treatment of swine lagoon effluent by constructed wetlands operated at three loading rates. p. 23-33. In P.J. DuBowy and R.P. Reaves (eds.) Constructed Wetlands for Animal Waste Management. Purdue Research Foundation, West Lafayette, IN.

Payne Engineering and CH2M Hill. 1997. Constructed wetlands for animal waste treatment. Report prepared for the EPA's Gulf of Mexico Program; pub. Alabama Soil and Water Conservation Committee, Montgomery, AL.

Reed, S.C. 1993. Subsurface flow constructed wetlands for wastewater treatment: Technology assessment. EPA-832-R-93-001. Office of Water, USEPA, Wash., DC.

Tiedje, J.M. 1982. Denitrification. In A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of Soil Analysis. Agronomy 9 (Part 2):1011-1026.

Vanotti, M.B., A.A. Szögi, P.G. Hunt, F.J. Humenik, and J.M. Rice. 1998. Nitrification options for swine wastewater treatment. Proc. Animal Production Systems and the Environment: An International Conference on Odor, Water Quality, Nutrient Management, and Socioeconomic Issues. Iowa State Univ., July 19-22, Des Moines, IA.

Vanotti, M. B., and P. G. Hunt. 1998. Ammonia removal from swine wastewater using immobilized nitrifiers. In Ramiran 98, Proceedings of the 8th International Conference on Management Strategies for Organic Waste Use in Agriculture. 26-29 May 1998. Rennes. France. Martinez J., Maudet M.N. (eds). FAO-Cemagref Editions. 427-432.