NITRIFICATION OPTIONS FOR SWINE WASTEWATER TREATMENT

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ABSTRACT

Nitrification is a necessary but often limiting process in animal waste treatment for removal of nitrogen as N_2 through biological nitrification/denitrification systems. One such system, constructed wetlands, has the potential to remove large amounts of nitrogen from swine wastewater when nitrate is available. We evaluated three technologies for enhancing nitrification of swine lagoon wastewater prior to wetland treatment: overland flow, media filter, and a bioreactor using nitrifying pellets. In *overland flow*, nitrification occurs when a thin film of water is in close contact with a nitrifying population at the soil surface. The system consisted of a 4-(20-m plot with 2% slope receiving a total N loading rate of 64 to 99 kg N ha^{-1} d^{-1}. Total N removal efficiency ranged from 35 to 42%, and 7% of the total N application was recovered in the effluent as nitrate. A recirculating *media filter* unit consisted of a 1-m^3 tank filled with marl gravel media which supported a nitrifying biofilm. Lagoon wastewater was applied as a fine spray on the surface at hydraulic loading rates of 684 L m^{-3} d^{-1} and total N loading rates of 249 g m^{-3} d^{-1}. The media filter treatment transformed up to 57% of the inflow total N into nitrate when wastewater was supplemented with dolomite lime. The new *nitrifying pellets* technology uses acclimated nitrifying cells immobilized in 3- to 5-mm polymer pellets . Swine wastewater was treated in an aerated fluidized reactor unit with a 15% (w/v) pellet concentration and a screen to retain the pellets. Nitrification efficiencies of more than 90% and quantitative ammonia removal were obtained in continuous flow treatment using total N loading rates of 438 g N m^{-3} d^{-1} and hydraulic residence time of 12 h. Two conclusions are suggested from this work: (1) that nitrification of lagoon swine wastewater can be attained using aerobic treatments with enriched nitrifying populations; and (2) that large mass removal of N from swine wastewater may be possible by sequencing nitrification and denitrification unit processes.

Keywords: Swine wastewater, Nitrification treatment, Lagoon, Constructed wetlands

INTRODUCTION

Livestock waste disposal has become a major environmental problem in the USA due to the rapid growth of large scale, confined animal production. These concerns include ammonia emissions, contaminated ground and surface water, fish kills, and unexpected ecological shifts. Modern swine facilities in the USA use flush or pit-recharge systems to remove manure from the confinement houses. The flushed waste is mostly treated and stored in anaerobic lagoons before land application. The problem is that large, concentrated herds generate large amounts of waste in a relatively small area. As a consequence, many counties in the Southeast region produce more manure nitrogen (N) than available cropland can absorb (Barker and Zublena, 1995). These land limitations result in overloaded land applications causing pollution of ground and surface water. The problem is exacerbated at a regional level due to additional N loadings from atmospheric deposition. Hutchinson et al. (1972) showed that plants can serve as sinks of significant quantities of NH_3 from the air even at low atmospheric concentrations. Recent estimates of ammonia (NH_3) emissions in North Carolina indicates that 29.4 Mg of NH_3 per day volatilizes from a total of 2,030 ha of swine lagoons (Crouse et al., 1997). It is critical, therefore, to find alternative methods of N management that are functional and affordable.

NITRIFICATION ENHANCEMENT

Nitrification is becoming an increasingly important component in total farm management systems, to the point that the effectiveness of any biological nitrogen removal treatment depends on the ability of nitrifying organisms to oxidize ammonia. Nitrifiers oxidize ammonia to nitrite, then to nitrate nitrogen. Nitrification is a very limiting process in animal waste treatment, but a necessary condition to be able to remove large amounts of nitrogen using biological nitrification/denitrification systems. Once in a nitrate form, the transformation into N_2 (or denitrification process) needs two conditions: a source of carbon and an anaerobic environment. These conditions are typically found in wetlands or liquid manure storage units. In a related study, Rice et al. (1998) showed that constructed wetlands can remove large amounts of nitrogen from swine wastewater through denitrification; but their performance is limited by nitrate availability. Using a nitrification pretreatment in constructed wetlands, they obtained N removal potentials of 14,000 kg ha^{-1}, which was more than five times the N removal obtained without nitrification pretreatment.

With wastes rich in carbonaceous materials, such as swine wastewater, the nitrifying bacteria compete poorly with heterotrophic microorganisms. Nitrifiers need oxygen, lower organic carbon, a surface area, and a growth phase before sufficient numbers are present for effective nitrification. These concepts are illustrated in the nitrification experiments of Blouin and coworkers (1989). They first tried to nitrify stabilized swine waste through aerobic treatment. Ammonia nitrogen, which was in high concentration ($\sim$ 1000 mg L^{-1}), was not oxidized after 49 days of incubation. However, when the same waste was first inoculated with enriched nitrifying populations (10^6-10^7 MPN/mL), only 5 days were needed to obtain complete nitrification.

The purpose of this project is to examine options for nitrification treatment of swine wastewater. The nitrification options include overland flow, media filter, and encapsulated nitrifiers. The research site, a nursery operation of 2600 pigs (average weight=13 kg) near Kenansville, Duplin Co., NC, uses a flushing system to recycle liquid from a single-stage lagoon. The average liquid volume of the lagoon was 4100 m^3. Typically, the lagoon effluent contained 365 mg L^{-1} of total Kjeldahl nitrogen (TKN), mostly ($>$ 95%) as ammonia-N, 93 mg L^{-1} of total phosphorus (TP), a COD concentration of 740 mg L^{-1}, and a pH of 8.2.

OVERLAND FLOW

In overland flow, nitrification occurs when a thin film of water is in close contact with a nitrifying population at the soil surface. It also offers the advantage of partial denitrification in the underlying saturated soil layer (Hunt and Lee, 1976). The treatment unit consisted of a 4 x 20 m plot with 2% slope. The sides and bottom of the unit were lined with plastic after excavation to a 20-cm depth, and filled with the same sandy topsoil. Vegetation consisted of a mixture of fescue, coastal bermuda grass, and reed canary grass. Lagoon liquid was applied five days a week with hydraulic rates of 2.5 to 3.0 cm/day. Preliminary tests on application timing showed that the sandy soil was highly permeable and that applying these hydraulic rates during 8-hour periods often failed to provide a surface runoff of the lagoon wastewater. Therefore, in order to obtain a functional surface flow, applications during the evaluation period (1996 and 1997) were made during only four hours each day. Hydraulic losses were similar to the expected evapotranspiration losses (0.5 to 0.8 cm per day).

Spatial sampling of the surface runoff water along the plot revealed that no nitrification activity occurs in the first 5 m of the plot. Beyond this point, the concentration of nitrate gradually increased up to a maximum occurring at 17 m down slope. The rate of nitrification also changed with time during the 4-hr application period. Highest activities were generally observed during the first two-three hours of application. Nitrogen budgets showed that losses of ammonia through volatilization were usually small (< 13%).

Table 1. Treatment of lagoon swine wastewater with overland flow.

Year	Total N application rates†	Evaluation period	Total N removal efficiency‡	NO_3-N Recovery§
	kg/ha/day	days	%	%
1996	64	85	35	7
1997	99	60	42	7

†Total N = TKN + NO_3-N. (Inflow nitrate concentration=0)
‡Total N Efficiency = ((TN mass inflow - TN mass outflow)/ TN mass inflow) x 100
§ Nitrate-N Recovery = (NO_3-N mass outflow/TKN mass inflow)*100.

Performance data of the overland flow treatment during 1996 (August-December) and 1997 (March-August) indicates that this treatment can remove large amount of nitrogen per unit area (Table 1). The higher application rate in 1997 reflects changes in lagoon N concentration. On a mass basis, average total N removal efficiency was 35% in 1996 and 42% in 1997, which is equivalent to 22.4 to 41.6 kg N/ha/day, respectively. These efficiencies are in agreement with previous work (Humenik et al.,1975) showing also total N removal efficiencies of 35% for swine lagoon wastewater treated on 17-m overland flow and hydraulic loads of 1.8 cm/day. The lower nitrate recovery values observed after treatment (Table 1) suggest that simultaneous denitrification occurred in the saturated soil layer, a typical feature of overland flow systems (Hunt and Lee, 1976).

MEDIA FILTER

The unit consisted of a 1.5-m dia.×0.6-m height tank filled with the marl gravel (Szögi et al., 1997). Marl gravel was used instead of typical sand media to avoid clogging by swine wastewater. The distribution of the gravel particles was 85% in the 4.7- to 12.7-mm size class and 14% in the 12.7- to 19-mm size class, providing a pore space of 57%. The filtration unit was placed inside a tank with a slightly larger diameter to collect the effluent for recirculation. The system was completed with a second tank used for storage of the liquid waste during treatment.

Lagoon wastewater was applied as a fine spray on the surface of the media filter at a hydraulic loading rate of 684 L/m^3 reactor volume/day. The corresponding average total N loading rate was 249 g N m^{-3} d^{-1}. The pilot unit was operated from March to July, 1997, five days a week during 12-h periods (6 am to 6 pm) under a intermittent flow mode in order to enhance aeration inside the media. The intermittent flow was controlled by a timer that turned a pump on and off in 12 minute intervals. During the pump operation, the liquid was pumped from the storage tank at a rate of 9.5 L min^{-1}. This flow was proportionally split by a ball-valve to maintain a flow rate of 7.6 L min^{-1} to the surface of the filter and 1.9 L min^{-1} rate to the outflow of the system. During the same time interval, the lagoon wastewater flowed by gravity into the storage tank with a float-valve maintaining a 757-L volume of wastewater in the tank.

Table 2. Treatment of lagoon swine wastewater with media filter.

Nitrogen Form	No Lime		Lime	
	Inflow	Outflow	Inflow	Outflow
TKN (mg L^{-1})	366	221	363	114
NH_4-N (mg L^{-1})	340	193	334	106
NO_3-N (mg L^{-1})	0	133	2	208
TN† (mg L^{-1})	366	354	365	321
Nitrification ‡	26%		57%	

†Total N = TKN + NO_3-N.
‡ Nitrification efficiency = (NO_3-N conc. outflow/TN conc. inflow)*100

An acclimation period of six weeks was needed to develop a functional nitrifying biofilm on the surface of the media, indicated by stabilization of the nitrification activity. Performance of the unit was evaluated for 90 days after acclimation (Table 2). A lime supplement consisting of 100 g/day of crushed dolomitic lime was applied to the surface of the media filter during the second half of the evaluation period. Although the natural alkalinity of the lagoon wastewater (1950 mg L^{-1}) was enough to neutralize the H^+ generated by full nitrification of ~270 mg L^{-1} of NH_4-N, the nitrification performance of the unit was greatly enhanced by the lime supplement (Table 2). Furukawa et al.(1993) indicated that inorganic carbon availability is usually the rate limiting factor for nitrification of high strength NH_4-N wastewater. Therefore, our results suggest that the positive effect of lime was due to increased CO_2 availability to nitrifiers, supplied by the dolomite in equilibrium with the progress of nitrification and acid formation. Losses by ammonia volatilization during treatment were small as represented by the total N balance.

ENCAPSULATED NITRIFIERS

The immobilization of microorganisms in polymer resins is a widely applied technique in drug manufacturing and food processing. The application for municipal wastewater treatment has been recently developed in Japan (Takeshima et al., 1993). Through the immobilization process the nitrifying microorganisms are provided with a very suitable environment to perform at maximum effectiveness. The nitrifiers are entrapped in polymer pellets that are permeable to NH_3, O_2, and CO_2 needed by these microorganisms, resulting in a fast and efficient removal of NH_3-N.

An active culture of acclimated swine wastewater nitrifying bacteria was prepared from overland flow soil seed. The ammonia strength of the salts medium was gradually increased to to overcome inhibitory effects caused by high levels of free ammonia in swine wastewater, similar to procedures used for acclimation of marine nitrifiers (Furukawa et al., 1993). Acclimated nitrifying cells were immobilized in 3-5 mm polyvinyl alcohol polymer cubes. Swine lagoon wastewater was treated under continuous flow in a nitrification tank equipped with a screen to retain the pellets, and an aeration system to ensure appropriate fluidization of the pellets (Vanotti and Hunt, 1997). Pellets were added at 15% (w/v) pellet to total tank volume ratio. Alkalinity was supplemented using a pH 8.5 $CO_3^{=}/HCO_3^-$ buffer.

Table 3. Treatment of lagoon swine wastewater with encapsulated nitrifiers

HRT	Total N Loading rate†	Ammonia Removal Rate‡	Nitrate Production Rate§	Nitrification efficiency¶
hours	----------g N/m^3 reactor volume/day		----------------	%
24	238	223	240	100
20	272	254	279	100
16	342	311	327	96
12	438	363	397	91
8	668	402	417	62
6	926	498	499	54
4	1349	604	567	42

†Total N = TKN + NO_3-N. (Inflow nitrate concentration=0)
‡Ammonia Removal Rate = flow*(NH_4-N conc. inflow - NH_4-N conc. outflow)
§ Nitrate Production Rate = flow*(NO_3-N conc. outflow)
¶ Nitrification Efficiency = (NO_3-N conc. outflow/TN conc. inflow)*100

Nitrogen loading rates were increased by gradually decreasing the hydraulic residence time (HRT) from 24 h to 4 h (Table 3). Nitrification efficiencies of more than 90% were obtained with total N loading rates lower than 438 g N m^{-3} d^{-1} and HRT higher than 12 h. Although higher loading rates resulted in lower treatment efficiencies, the total amount of nitrate produced was higher, with the maximum nitrate production rate obtained with HRT of 4 h. Higher efficiencies may be useful for total systems designed to meet stream discharge requirements. However, if the objective is to remove large amounts of N from the lagoon, then a retrofit nitrification unit operated at shorter retention times would be recommended. This strategy has the advantage of reducing the total cost of aeration per unit of nitrate-N produced.

SUMMARY

Animal waste treatment is a significant agricultural and environmental challenge that needs additional options as a result of expanded, confined animal production. Three technologies were evaluated for enhancing nitrification of swine lagoon wastewater prior to wetland treatment. *Overland flow* is a low-intensity system that can remove large amounts of N per unit area through nitrification and partial denitrification. Performance data showed N removal rates of 22 to 42 kg N/ha/day. *Media filter* is a medium-intensity system that is popular among small waste generators. Our adaptation for animal waste consisted on selection of a marl gravel media, design of an intermittent application schedule to enhance aeration, and lime supplementation. Nitrification efficiency was 57% at total N loading rates of 249 g/m^3/day. *Nitrifying pellets* technology is a high-intensity system using fluidized bioreactors designed for fast and efficient removal of NH_3. Nitrification efficiencies of 91% were obtained at total N loading rates of 438 g/m^3/day, and 42% at 1349 g N/m^3/d. Current research efforts at the Kenansville site in Duplin Co., NC, focus in the development of integrated systems sequencing nitrification and denitrification unit processes.

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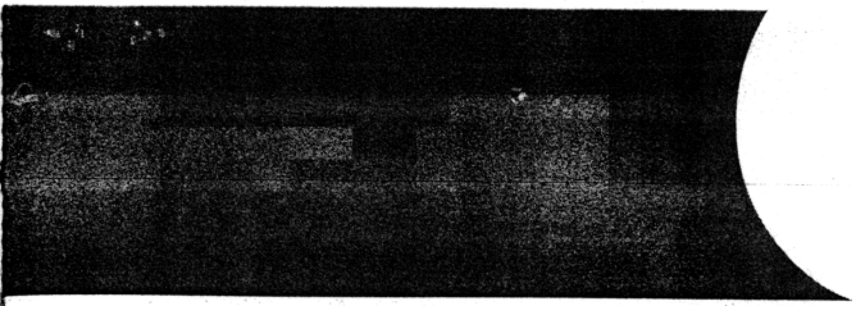

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