ECONOMICS OF NITROGEN AND ENTERIC MICROBE REDUCTIONS FOR ALTERNATIVE SWINE WASTE TREATMENT TECHNIQUES

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INTRODUCTION

It is the focus of this study to evaluate several potential alternative treatment techniques that can be used in conjunction with primary treatment (*e.g.*, solids separation, anaerobic lagoons) to provide improved, cost-effective treatment of swine waste. Improved nitrogen control is important because nitrogenous compounds can volatilize as ammonia and contribute to odor problems, eutrophication of surface water, and contamination of ground water resources used for drinking water. Swine wastewater can contain human enteric pathogens (e.g., *Salmonella* spp., *Cryptosporidium parvum*) so it is prudent that treatment processes be effective in removing or destroying these microbes. Six microbial indicators were studied: fecal coliforms, *Eschericia coli*, enterococci, *C. perfringens*, somatic coliphages, and male-specific (F+) coliphages. Microbial indicators of fecal contamination are used to evaluate microbiological water quality and treatment effectiveness because they are typically present at greater concentrations than enteric pathogens when fecal contamination is present, are absent from water when fecal contamination is absent, and respond similarly to pathogens during treatment (although some indicators are thought to be more representative of potential pathogen responses than others under different environmental conditions).

GERALD KNOWLES SWINE NURSERY FARM, KENANSVILLE, NC

Samples for nitrogen and microbial analysis were collected monthly between March and December 1997, from alternative treatment systems at a 2600-head swine nursery in North Carolina. The anaerobic lagoon, constructed in accordance with the NRCS Conservation Practice Standard for Waste Treatment Lagoons (Code 359), had an average liquid volume of 4100 m^3 during the study period and an estimated hydraulic detention time of 270 days. Lagoon liquid was pumped in parallel to the constructed wetland, media filter, and overland flow cell.

TREATMENT TECHNIQUES

Constructed Wetlands

Constructed wetlands are a promising low-cost innovative treatment technique that has been investigated for secondary treatment of swine waste (Hammer *et al.*, 1993; Hunt *et al.*, 1994). Constructed wetlands tend to be reducing environments, especially when treating high-strength wastewaters, and therefore remove reduced nitrogen species (i.e., ammonium) through volatilization and oxidized nitrogen species through denitrification.The constructed wetland was designed as a two-cell, surface flow wetland system USDA Soil Conservation Service (SCS) guidance (SCS 1991). Each constructed wetland cell had dimensions of 3.6 m by 33.5 m and a slope of 0.2%. Cell 1 was dominated by burr-reed and Cell 2 by broad-leaf cattail. The average areal hydraulic loading rates to Cells 1 and 2 were 4.0 and 2.7 cm d^{-1}, respectively.

Media Filter

Media filter reactor (MFR) treatment can achieve nitrification of swine wastewater by enhancing oxygen availability to biofilm-covered granular media (Szögi *et al.*, 1997). The media filter reactor was a 1.5-m diameter tank containing a 0.6-m deep layer of marl gravel (a marine deposit containing calcium carbonate), as used by Szogi *et al.* (1997). The media filter was operated at an areal hydraulic loading rate of 126 L m^{-2} hr^{-1} (300 cm d^{-1}) applied to the surface of the media and had a hydraulic detention time of 6.6 hrs due to recirculation.

Overland Flow

Overland flow systems can provide low-cost treatment of wastewater (Carlson, *et al.*, 1974). Nitrification occurs in the aerobic surface soil layer and denitrification in the anaerobic subsurface soil zone (Hunt *et al.*, 1976). The overland flow cell had dimensions of 4 m by 20 m and a slope of 2.5. Lagoon liquid was applied to the overland flow cell at an average rate of 3 cm in 4 hours.

ECONOMIC ANALYSIS

Treatment systems were analyzed for their ability to reduce the mass of nitrogen that must be land-applied at agronomic rates. The OF and MFR are primarily nitrification technologies, so they were analyzed in conjunction with the constructed wetlands system, a denitrification technique. The three treatment system scenarios evaluated were the constructed wetland (CW), media filter-to-constructed wetland (MFR-CW), and overland flow-to-constructed wetland (OF-CW). In the absence of one of these secondary treatment systems, the lagoon effluent was assumed to be applied to a bermuda grass field.

To calculate the costs of the systems, the construction requirements were estimated based on scaling-up the pilot-scale systems to treat the entire waste stream. Nitrogen outflow from the lagoon was 5.22 kg d^{-1} during the study period. The total nitrogen in effluent from each treatment system was calculated using the measured total nitrogen removal efficiency in each system component and an assumption of complete removal of nitrate in the constructed wetlands. The total nitrogen remaining in each system's effluent was then assumed to be completely removed during land application by adjusting the size of the sprayfield area required for complete removal, assuming aerial application on a bermuda grass field. With complete denitrification, the wastewater can be applied at hydraulic rates rather than nitrogen loading rates, but currently cannot be discharged directly into surface water.

The construction costs for each system component were taken from the 1997 North Carolina Agriculture Cost Share Program Average Cost Guide (NRCS) for the Coastal Plain region of North Carolina. A discount rate of 5% and 20-year life was assumed to calculate the annual depreciation and interest for each component using the capital recovery method (Boehlje and Eidman, 1984). Any property tax or insurance cost changes were assumed to be minor and were ignored. Operating costs were based on observations at the site and assumptions regarding electricity usage and daily maintenance of each scaled-up system. Total annual costs were calculated by adding the annualized capital cost to the operating cost of each system. The annualized cost of irrigation was not included because irrigation is still required in all systems because of the non-discharge rule for swine wastewater. However, if a landowner were to adopt one of these systems, the land area needed for treatment would be reduced. To take account of the land savings, the average annual cropland rental rate in the county where the swine operation is located is multiplied by the spray field area saved. The value of land saved is then subtracted from annual system costs to determine net cost.

RESULTS

Reductions in Mean Indicator Concentrations

The two-cell constructed wetlands reduced fecal coliforms by 1.4 $\log_{10}$ (96%), *E. coli* by 1.7 $\log_{10}$ (98%), and the more environmentally-resistant enterococci by 1.1 $\log_{10}$ (92%). Total reduction of *C. perfringens*, somatic coliphages, and F+ coliphages in the wetlands was 1.5 $\log_{10}$ (97%), 2.5 $\log_{10}$ (99.6%), and 2.3 $\log_{10}$ (99.5%), respectively. In the MFR, little reduction (0.2 to 0.6 $\log_{10}$) in bacterial indicators was observed; slightly greater reductions of 0.9 to 1.2 $\log_{10}$ were observed for viral indicators. Indicator reductions in the OF system were also modest, ranging from 0.1 to 0.4 $\log_{10}$ for bacterial indicators to 0.4 to 0.6 $\log_{10}$ for viral indicators.

Cost-Efficiency of Treatment Systems for Nitrogen Removal

According to cost efficiency criteria, the optimal treatment system achieves the largest reduction in nitrogen/pathogen concentration per dollar of net cost. The results from the economic analysis of the nitrogen treatments are shown in Table 1. The constructed wetland alone is the most cost-effective system for N-removal, removing 2.61 kg N per dollar of net cost.

TABLE 1. Reductions in Nitrogen Per Dollar of Net Cost for Alternative Treatment Systems

Treatment System	Nitrogen Removal (kg yr^{-1})	Reduction in Sprayfield Size (ha)	Net Cost (\$ yr^{-1})*	Nitrogen Removed Per Net Cost (kg $\$^{-1}$ yr^{-1})†
Constructed Wetland	1600	5.41	728	2.61
Media Filter-to-Constructed Wetland	1810	6.12	1614	1.18
Overland Flow-to-Constructed Wetland	1728	5.84	1944	0.98

* Annualized cost less savings in land application area required

† Includes nitrogen removed by treatment systems and sprayfield

Cost-Efficiency of Treatment Systems for Pathogen Reductions

Most of the indicator reductions for the MFR and OF were modest, so the MFR and OF reduction efficiencies were each added to the CW reduction efficiencies for the lagoon-nitrification-CW scenarios. Table 2 summarizes the cost-efficiency of the alternative treatment systems for pathogen reduction in terms of percent mean indicator reduction per thousand dollars of net cost for the systems. The results show that the constructed wetland system operated alone was the most cost-effective treatment system for each of the microbial indicators. Addition of the media filter resulted in lower performance cost-effectiveness than for the constructed wetlands operated alone. The overland flow component did not provide cost-effective additional treatment in this study.

TABLE 2. Percent Reductions in Mean Indicator Concentrations Per $1,000 Annual Net Cost for Alternative Treatment Systems

Treatment System	Indicator Type					
	Fecal Coliforms	*E. coli*	Enterococci	*C. perfringens*	Somatic Coliphages	F+ Coliphages
Constructed Wetlands	98.7	99.4	97	99.2	99.96	99.93
Media Filter-to Constructed Wetlands	90	96	87	92	99.2	99.4
Overland Flow-to-Constructed Wetlands	88	92	76	87	97	97

CONCLUSIONS

The results of this economic analysis indicate that a surface-flow constructed wetland system alone can provide the most cost-effective secondary treatment for removal of nitrogen and microbial indicators of fecal contamination in swine wastewater compared to composite MFR-CW and OF-CW systems. The results of this study raise the prospect that swine waste treatment systems using primary treatment techniques other than lagoons (e.g., solids separators) in conjunction with constructed wetlands may be capable of providing similar, or improved, nutrient and enteric microbe removal as is achieved using lagoon treatment, thereby avoiding the use of anaerobic lagoons.

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