2001

Soil Infiltration and Wetland Microcosm Treatment of Liquid Swine Manure

Shannon R. Prantner
Iowa State University

Ramesh S. Kanwar
Iowa State University, rskanwar@iastate.edu

Jeffery C. Lorimor
Iowa State University

Carl H. Pedersen
Iowa State University

Soil Infiltration and Wetland Microcosm Treatment of Liquid Swine Manure

Abstract

Management systems are needed to minimize water quality concerns associated with liquid swine manure from large swine production facilities. Experiments were conducted to investigate the removal of ammonium–N, nitrate–N, and total phosphorus from liquid swine manure through the use of a soil infiltration and wetland system. Experimental treatments applied directly to the soil infiltration areas included a full–rate application of liquid swine manure, a mixture of 3/4 manure and 1/4 water, and a control application of water only. For three months during both summers of 1998 and 1999, nutrient concentrations were determined in the infiltration area influent, the infiltration area effluent, and the wetland effluent on a weekly basis. Approximately 93% of the ammoniacal nitrogen (NH3–N and NH4–N) from the applied swine manure was removed by the soil infiltration areas with a corresponding 99% increase in the nitrate nitrogen (NO3–N) concentrations were found. The wetland systems removed 94% of the remaining NH3–N and NH4–N and 95% of the NO3–N. The total P levels were decreased in the soil infiltration areas and wetlands by 89 and 84%, respectively.

Keywords

Animal waste, Manure treatment, Liquid manure, Swine waste

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Water Resource Management

Comments

This article was published in Applied Engineering in Agriculture. Vol. 17(4): 483–488, doi:10.13031/2013.6472. Posted with permission.

SOIL INFILTRATION AND WETLAND MICROCOSM TREATMENT OF LIQUID SWINE MANURE

S. R. Prantner, R. S. Kanwar, J. C. Lorimor, C. H. Pederson

ABSTRACT. *Management systems are needed to minimize water quality concerns associated with liquid swine manure from large swine production facilities. Experiments were conducted to investigate the removal of ammonium–N, nitrate–N, and total phosphorus from liquid swine manure through the use of a soil infiltration and wetland system. Experimental treatments applied directly to the soil infiltration areas included a full–rate application of liquid swine manure, a mixture of 3/4 manure and 1/4 water, and a control application of water only. For three months during both summers of 1998 and 1999, nutrient concentrations were determined in the infiltration area influent, the infiltration area effluent, and the wetland effluent on a weekly basis. Approximately 93% of the ammoniacal nitrogen (NH_3–N and NH_4–N) from the applied swine manure was removed by the soil infiltration areas with a corresponding 99% increase in the nitrate nitrogen (NO_3–N) concentrations were found. The wetland systems removed 94% of the remaining NH_3–N and NH_4–N and 95% of the NO_3–N. The total P levels were decreased in the soil infiltration areas and wetlands by 89 and 84%, respectively.*

Keywords. *Animal waste, Manure treatment, Liquid manure, Swine waste.*

Wetlands have been used as wastewater treatment systems for water quality improvement throughout history. Humans have traditionally dumped their waste into low–lying areas that often contain water. Within the past century, wetlands have provided benefits such as aesthetics, recreation, flood prevention, waterfowl breeding grounds, and waste management and treatment. High nutrient levels, especially total ammonium–N (TAN), and high biochemical oxygen demand (BOD) are of particular concern when using wetlands for waste treatment. Wetland plants cannot tolerate TAN levels greater than 100–200 mg/L (Skarda et al., 1994). For this reason, it is necessary to use some type of pretreatment of liquid swine manure to reduce manure TAN concentrations, which can range from several hundred milligrams per liter in lagoons to several thousand in pits, prior to introduction to wetlands. Soil infiltration is one type of potential pretreatment.

Article was submitted for review in August 2000; approved for publication by the Soil & Water Division of ASAE in January 2001. Presented at the 1999 ASAE Annual Meeting as Paper No. 99–2195.

Journal Paper No. 18733 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project No. 3415, and supported by Hatch Act and State of Iowa funds. Research was partly supported with funding from the Leopold Center for Sustainable Agriculture, Ames, Iowa, the CSREES–USDA Project on Management Systems Evaluation Areas (MSEA), and the state of Iowa through the Agriculture Experiment Station.

The authors are **Shannon R. Prantner**, ***ASAE Member Engineer,*** Graduate Research Assistant, **Ramesh S. Kanwar**, ***ASAE Member Engineer***, Professor and Assistant Director of the Agricultural Experiment Station, **Jeffery C. Lorimor**, ***ASAE Member Engineer***, Assistant Professor, and **Carl H. Pederson**, Research Associate, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. **Corresponding author:** J. C. Lorimor, 3224 NSRIC Bldg., Iowa State University, Ames, IA, 50011; phone: 515–294–9806; fax: 515–294–4250; e–mail: jclorimo@iastate.edu.

The main process that occurs in the soil infiltration area is the conversion of ammonium to nitrate by the aerobic bacteria, *Nitrosomonas* and *Nitrobacter*. After nitrification has occurred the water can enter the wetlands for further conversions. Nitrogen enters wetland areas either through atmospheric deposition or by surface and sub–surface hydrologic inputs (Whigham, 1995). Organic nitrogen can be transformed into the ammonium ion (NH_4) during the ammonification process. These ions can be absorbed by plants or can be converted to nitrate through nitrification. Nitrification is a limiting step in the nitrogen cycle in many wetlands because of the necessity for oxygen. The nitrate can then be anaerobically converted to nitrous oxide (N_2O), other nitrogenous gases (NO_X), or N_2 gas (Mitsch and Gosselink, 1993). Hiley (1995) states that constructed wetlands commonly have 40–70% nitrogen removal efficiency. This process, known as nitrification, occurs in soil infiltration areas since aerobic bacteria dominate in a properly designed system.

Phosphorus is removed from the wastewater but accumulates in the sediments and biomass, and is often sorbed to the soil. Kadlec (1995 a, b) found that removal of phosphorus into new soils is proportional to the concentration in surface waters, to the surface area of the wetted soils, and that phosphorus removal does not slow down to a great extent in winter months. This continued removal concept contradicts the idea that wetlands do not function in the winter, which many researchers believe to be true. In a unique study conducted by Yin and Shen (1995), it was found that winter operation of wetlands is possible. Other studies conducted during the cold winter months also validate these findings (Kadlec and Knight, 1996).

The overall objective of this study was to investigate the effectiveness of using a soil infiltration area and constructed wetland to reduce TAN and P from liquid swine manure. Different manure application rates were studied to determine what levels of swine manure could be directly applied to such systems.

Materials and Methods

Assembly

Eighteen plastic containers (9 sets) with a capacity of 210 L (55 gal) each were used as soil infiltration areas and wetland areas. The soil infiltration containers were partially buried on a slope, above and directly behind the wetland containers. The wetland containers were completely buried (fig. 1). A visual layout of the eighteen containers used in the experiment is shown in figure 2.

The wetland containers were buried to ensure that temperatures in the containers were similar to those encountered under actual field situations, and to provide a beneficial environment for the growth of microorganisms and macrophytes. In 1999 it was necessary to build up the soil surrounding the infiltration areas because of erosion over the year. Sod was planted around the containers to prevent future erosion.

To facilitate liquid removal a 2.5–cm perforated polyvinyl chloride (PVC) pipe was installed at the bottom of each soil infiltration container. The percolated effluent entered the wetlands via this piping to simulate a field tile drainage system. The soil infiltration areas were separated from the wetland areas by a valve that could be turned on to allow immediate flow between the two containers, or closed to simulate the lag time that could exist in a field tile drainage system. A strainer cup positioned in the valve apparatus allowed samples to be taken as necessary. The flow then emptied into the wetland through a perforated ring around the top circumference of the wetland, which allowed equal distribution of the effluent. A perforated 2.5–cm PVC pipe was also positioned at the bottom of each wetland to allow for additional water sampling as needed.

Figure 1. Close–up view of an individual system and its components.

Figure 2. Panoramic view of the nine microcosms.

Both the soil infiltration areas and the wetlands were filled with topsoil (A horizon) of the Clarion loam soil from the surrounding land. The soil was packed into the containers to a bulk density of 1.3 gm/cc, similar to that of local field conditions. Cattails (*Typha* spp.) were planted in the wetland containers and allowed to establish in saturated conditions. Although duckweed (*Lemna* spp) was not specifically planted in the wetlands, they emerged in 1998, but not in 1999. A grass mixture was planted into the infiltration areas in 1999, but did not survive in the manure treatment containers because of high ammonium–N concentrations and ponding of the manure for extended periods of time.

Experimental Treatments

Three application rate treatments were imposed on the experimental soil infiltration area containers. Application rates were 100% swine manure which was essentially liquid swine manure with no water added (full– rate), 75% swine manure consisting of three parts manure and one part water (3/4 rate), and the control with no manure (water only). The experiment used a completely randomized design with each treatment replicated three times

Equal volumes of the three manure concentrations were applied every two weeks. Twenty–one L (6 gal) was applied to each soil infiltration area. The quantity of 21 L (6 gal) was calculated to fill the estimated available pore volume assuming 50% total pore space, and 30% moisture at field capacity. In 1999, the application volume was decreased to 19 L (5 gal) to adjust for moisture holding capacity.

Mixing the 3/4–rate application was accomplished by measuring the desired amounts of manure and water in calibrated 19–L (5–gal) buckets and stirring to adequately mix and homogenize the sample. The bi–weekly application rate was chosen to allow sufficient time for the microbes to perform the chemical transformations and allow ease in application times. During the odd weeks between applications, 21 L (6 gal) of water in 1998 and 19 L (5 gal) in 1999 was applied to provide sufficient water for the cattails and to flush the infiltration areas. Precipitation was not controlled and was not specifically addressed in this experiment. However, during the drier months extra water was applied to the cattails to meet the needs of the plants to prevent desiccation. In 1999, the cattails were denser and required a larger volume of water. Water was applied to the wetlands on the day preceding the bi–weekly applications in order to provide adequate moisture for the cattails and allow sufficient water samples to be taken.

Influent samples of the liquid swine manure were taken before the treatments were applied to the soil infiltration areas. These samples were tested for TAN, NO_3–N, and total P. The applications were allowed to infiltrate until a large proportion of the fluid had passed through the system. In 1998 the soil infiltration effluent was collected and measured in calibrated buckets. The samples were taken for chemical analysis after about one–half of the influent liquid had percolated through the soil profile. In 1999, a collection system of plastic bushel baskets and tubing was assembled to obtain a more homogeneous infiltration effluent sample and to accurately measure the volume of the effluent. The treatments were allowed to infiltrate and were held in the infiltration area soil mass for 24 hours before collection. Wetland samples were taken prior to manure application to the soil infiltration areas and also taken prior to the bi–weekly water application. This second set of samples was taken to determine if the wetlands were performing as expected over the two–week period.

The quality of the manure that was applied to the system was variable, particularly in 1998. Some samples contained high concentrations (about 2000 mg/L of TAN), while others had significantly lower levels (about 450 mg/L of TAN). At these low TAN levels, each application provided 84 and 62 kg/ha (75 and 56 lb/acre) of nitrogen. These rates are quite low for a single cropland application rate in Iowa, but were used because of frequent applications.

After applications ceased in the fall of 1998, mulch consisting of grass clippings was placed on the wetlands to ease difficulties associated with harsh freezing. The mulch was removed the following spring of 1999. Treatments were not applied over the winter months. In the spring of 1999, the soil infiltration areas were tilled using a spade to invert and then stir the top to a depth of 15 cm (6 in.) in order to facilitate better infiltration. Soil was added to the containers to raise the soil surface to provide 18 cm (7 in.) of free space in all the containers.

Liquid swine manure was obtained from the Iowa State University Swine Nutrition and Management Research Center confinement building in 1998. Manure was drawn from the pit every two weeks and transported in sealed 19–L (5–gal) buckets to the experimental site 8 km (5 mi) from the Swine Research Farm. In 1999, the liquid swine manure was obtained from the Iowa State University Bilsland Memorial Swine Breeding Research Unit, about 11 km (7 mi) from the experimental site. The manure used in early 1999 was obtained from a storage lagoon lift station. During the latter part of 1999, manure was drawn from a pig growing facility storage pit. The change in manure was necessary due to lower than desired ammonium–N levels in 1998. The experiment was performed at the Iowa State University Agronomy and Agricultural Engineering Research Center (AAERC).

The water used as dilution for the 3/4–treatment, for the water application, and for cattail subsistence was pumped from a nearby tile outlet. This tile outlet was the closest source of sufficient water. Because this water was derived from tile lines, a significant amount of nitrate–N was already present, as shown in the results.

Infiltration problems were a source of concern, especially towards the latter portion of 1998 and all of 1999. Crusting of manure solids on top of the infiltration area prevented rapid infiltration (fig. 3). For this reason the infiltration areas were tilled in the beginning of 1999. In 1999, manure with a higher solids concentration made infiltration rates very slow, allowing for evaporation of the manure, and lessening the volume of the effluent entering the soil mass. Tillage and/or deep–rooted grasses may help control crusting, unless removal of the top layer is feasible.

Chemical Analysis

The American Public Health Association, Method 4500–NH_3–A (APHA, 1992), was used for ammonia analysis. Nitrate–N (NO_3–N) and nitrite–N (NO_2–N) were analyzed by the automated cadmium reduction method using a Technicon Autoanalyzer II (APHA, 1992). The process used to analyze total elemental phosphorus was adapted from the *EPA Methods and Guidance for Analysis of Water* (April 1997) as EPA 821–C–97–001. Samples were heated after the addition of sulfuric acid, K_2SO_4, and $HgSO_4$ for 2.5 h. After the residue cooled, it was diluted to 25 mL and was placed on an AutoAnalyzer for interpretation.

Results and Discussion

Nutrient Analysis

In the short term this combination of a soil infiltration and wetland treatment appears to have the capacity to remove environmental contaminants. Season average nutrient concentrations for the influent and effluent of both the soil infiltration and wetland areas for 1998 are shown graphically in figure 4. Movement through the soil infiltration areas decreased the average TAN concentrations by about 91% and led to a dramatic increase in NO_3–N levels. The wetland areas then decreased TAN levels by an additional 93% and NO_3–N levels by about 97%. Total P levels were decreased by about 81% in both the soil infiltration areas and wetlands.

Figure 4 shows that the TAN concentration in the 3/4–rate treatment from the infiltration areas was reduced by 91%, a reduction similar to the full rate treatment. The wetlands reduced the infiltration effluent concentrations by another 93%.

Only a small amount of NO_3–N (1.3 and 0.2 mg/L in 1998 and 1999, respectively) was present in the liquid swine manure that was applied to the infiltration areas. The NO_3–N levels increased dramatically in the infiltration area effluent when compared to the influent. This increase supports the

Figure 3. Infiltration containers in this photograph exhibit crusting and accumulation of the manure at the surface, decreasing the rate of infiltration over time.

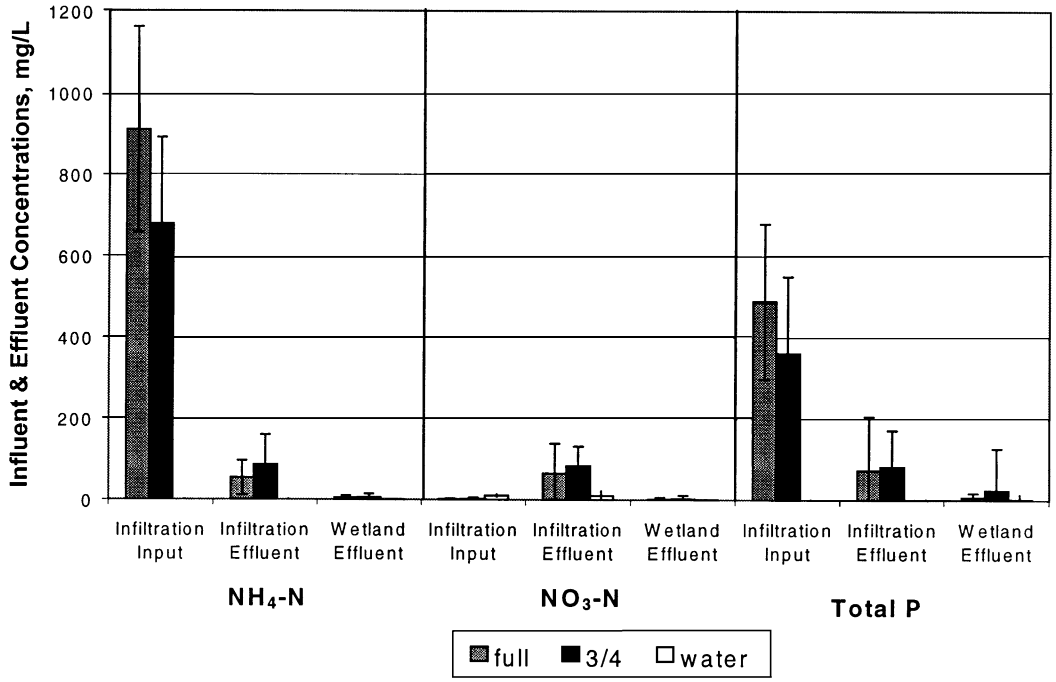

Figure 4. Average nutrient concentrations for the soil infiltration and wetland treatment system for 1998. Bars indicate the standard deviation of each value.

hypothesis that nitrification has taken place in the aerobic soil mass. Wetlands then reduced the concentrations of NO_3–N by 97%. Some NO_3–N (10.5 and 17.9 mg/L) was initially present in the water application treatment because of the nature of the source water.

Total phosphorus levels were initially quite high in the manure (fig. 4). The effluent levels from the soil infiltration areas show that about 81% of the total P was apparently sorbed to the soil. The wetland areas removed an additional 81% of the remaining total P. Total P was thus retained within both the soil infiltration and wetland system, resulting in a significant reduction in P.

The 1999 results are comparable to the 1998 data (fig. 5). Compared to 1998 higher influent ammonium–N and total P levels occurred in 1999, and slightly higher nitrate–N influent concentrations were observed. Infiltration area effluent ammonium–N and nitrate–N levels were found to be quite similar, while total P levels were lower. Wetland effluent samples in 1999 had higher nitrate concentrations and lower ammonium–N and total P concentrations than those of 1998. Elevated levels of nitrate in the wetland effluent may have occurred in part because of the water application directly to the wetlands preceding sampling, to provide moisture and allow the samples to be taken. This application consisted of tile water, which contained high nitrate levels.

Soil infiltration areas decreased the average TAN concentration by about 94%, similar to the 91% reduction in 1998. The large increase in NO_3–N levels in the effluent from the soil infiltration areas was also similar to the increases obtained in 1998. The wetland areas decreased TAN levels by an average of 98% and NO_3–N levels by about 90%, compared to 93 and 97%, respectively in 1998. Total P levels were decreased in the soil infiltration areas by 97% and in wetlands by about 86%.

Statistical analyses were performed on the individual years' data from 1998 and 1999 (tables 1 and 2, respectively). The infiltration areas for both treatments (full and 3/4–manure application rates) significantly reduced the TAN concentrations in the influent in both years. Since TAN concentrations in the water treatment were so low, the water treatment showed no significant differences among the TAN levels.

Tables 1 and 2 show that infiltration areas have significantly ($p < 0.05$) increased the nitrate–N and reduced the total P concentrations in the infiltration effluent. The increase in nitrate–N is due primarily to nitrification. The wetland areas significantly reduced the nitrate–N and total P concentrations.

CONCLUSIONS

TAN and P levels were significantly reduced from initial concentrations in liquid swine manure by the infiltration and wetland system in both 1998 and 1999. Nitrate levels were reduced in the water treatment. The main processes that occur with this system are nitrification and sorption in the soil infiltration areas and denitrification and sorption in the wetland areas. Statistical results confirm the differences among the infiltration influent, infiltration effluent, and wetland effluent for the TAN, NO_3–N, and total P.

Conversion of highly concentrated TAN is not possible with wetlands only. The TAN concentrations in the infiltration influent in this project would be toxic to wetland plants. To reduce initial TAN concentrations in liquid swine manure entering wetlands, it is essential that either dilution or some type of pretreatment be used. This study shows that soil infiltration is a potential pretreatment candidate. Soil infiltration areas are capable of converting initial TAN to NO_3–N through a limited aerobic zone. Phosphorus adsorption occurred in both the soil infiltration and wetland areas both years as expected. Although phosphorus removal

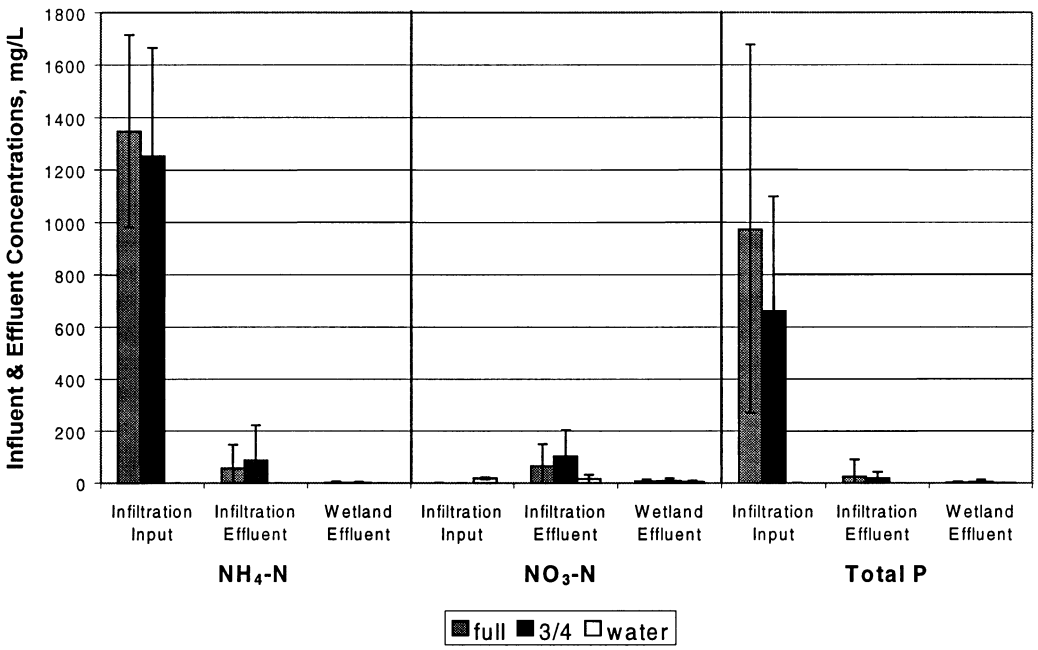

Figure 5. Average nutrient concentrations for the soil infiltration and wetland treatment system for 1999. Bars indicate the standard deviation of each value.

Table 1. Statistical analysis of the 1998 nutrient data from the soil infiltration and wetland system.[a]

	Ammonium–N Concentrations (mg/L)		
	Manure	3/4 Manure	Water
	LSD = 60.23	LSD = 52.15	LSD = 0.26
Influent	875.6 a	657.9 a	0.3 a
Effluent	52.7 b	86.1 b	0.2 a
Wetland	4.4 b	5.5 c	0.2 a
	Nitrate–N Concentrations (mg/L)		
	Manure	3/4 Manure	Water
	LSD = 23.72	LSD = 15.43	LSD = 3.90
Influent	1.3 b	2.9 b	10.5 a
Effluent	61.8 a	76.9 a	10.5 a
Wetland	0.2 b	0.2 b	0.5 b
	Total P Concentrations (mg/L)		
	Manure	3/4 Manure	Water
	LSD = 63.84	LSD = 55.11	LSD = 0.60
Influent	488.4 a	360.6 a	1.0 a
Effluent	74.6 b	81.1 b	0.5 ab
Wetland	7.4 c	7.1 c	0.2 b

[a] Means with the same letter in each set of data are not significantly different.

Table 2. Statistical analysis of the 1999 data from the soil infiltration and wetland system. [a]

	Ammonium–N Concentrations (mg/L)		
	Manure	3/4 Manure	Water
	LSD = 87.21	LSD = 102.31	LSD = 0.07
Influent	1344.5 a	1263.9 a	0.0 a
Effluent	58.3 b	79.6 b	0.0 a
Wetland	1.6 b	1.8 b	0.1 a
	Nitrate–N Concentrations (mg/L)		
	Manure	3/4 Manure	Water
	LSD = 27.02	LSD = 32.01	LSD = 5.54
Influent	0.2 b	0.1 b	17.9 a
Effluent	64.9 a	103.0 a	15.8 a
Wetland	7.1 b	8.9 b	4.6 b
	Total P Concentrations (mg/L)		
	Manure	3/4 Manure	Water
	LSD = 168.30	LSD = 98.44	LSD = 0.14
Influent	973.4 a	659.7 a	0.2 b
Effluent	22.1 b	18.4 b	0.2 b
Wetland	2.0 b	3.7 b	0.4 a

[a] Means with the same letter in each set of data are not significantly different.

in this experiment appeared to improve in year 2 for unexplained reasons, accumulation in the soil may cause future problems.

The results of this study show that a soil infiltration and constructed wetland system performed well for the treatment of liquid swine manure for two years. Swine manure can be applied to a constructed wetland treatment system if it is pretreated using a soil infiltration area. TAN , NO_3–N, and total P levels can be decreased by over 80%. Long–term studies are needed to determine the ultimate potential for this type of technology.

REFERENCES

American Public Health Association (APHA). 1992. *Standard Methods for the Examination of Water and Wastewater,* 18th Ed. Baltimore, Md.: APHA, American Water Works Association, and Water Environment Federation.

Environmental Protection Agency (EPA). 1976. *Quality Criteria for Water.* Washington, D.C.: U.S. EPA.

_____. 1997. *EPA Methods and Guidance for Analysis of Water.* Version 1.0. CD–ROM. Washington, D.C.: EPA.

Hiley, P. D. 1995. The reality of sewage treatment using wetlands. *Water Sci. and Tech.* 32(3), 329–338.

Kadlec, R. H. 1995a. Phosphorous uptake in Florida marshes. *Water Sci. and Tech.* 30(8): 225–234.

_____. 1995b. Design models for nutrient removal in constructed wetlands. *Animal Waste and the Land–Water Interface,* 173–184. Boca Raton, Fla.: CRC Press, Inc.

Kadlec, R. H., and R. L. Knight 1996. *Treatment Wetlands.* Boca Raton, Fla.: CRC Press, Inc.

Mitsch, W. J., and J. G. Gosselink. 1993. *Wetlands, 2nd Ed*. New York: Van Nostrand Reinhold Co., Inc.

Skarda, S. M., J. A. Moore, S. F. Niswander, and M. J. Gamroth. 1994. Preliminary results of wetland for treatment of dairy farm wastewater. *Constructed Wetlands for Animal Waste Management*, 34–42, 4–6 April 1994. West Lafayette, Ind.: Purdue Research Foundation.

Whigham, D. F. 1995. The role of wetlands, ponds, and shallow lakes in improving water quality. *Animal Waste and the Land–Water Interface*, 163–172. Boca Raton, Fla.: CRC Press, Inc.

Yin, H., and W. Shen. 1995. Using reed beds for winter operation of wetland treatment system for wastewater. *Water Sci. and Tech.* 32(3): 111–117.