Wastewater Utilization: A Place for Managed Wetlands* - Review -

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ABSTRACT : Constructed wetlands are being used for the removal of nutrients from livestock wastewater. However, natural vegetation typically used in constructed wetlands does not have marketable value. As an alternative, agronomic plants grown under flooded or saturated soil conditions that promote denitrification can be used. Studies on constructed wetlands for swine wastewater were conducted in wetland cells that contained either natural wetland plants or a combination of soybeans and rice for two years with the objective of maximum nitrogen reduction to minimize the amount of land required for terminal treatment. Three systems, of two 3.6 by 33.5 m wetland cells connected in series were used; two systems each contained a different combination of emergent wetland vegetation: rush/bulrush (system 1) and bur-reed/cattail (system 2). The third system contained soybean (*Glycine max*) in saturated-soil-culture (SSC) in the first cell, and flooded rice (*Oryza sativa*) in the second cell. Nitrogen (N) loading rates of 3 and 10 kg ha^{-1} day^{-1} were used in the first and second years, respectively. These loading rates were obtained by mixing swine lagoon liquid with fresh water before it was applied to the wetland. The nutrient removal efficiency was similar in the rush/bulrush, bur-reed/cattails and agronomic plant systems. Mean mass removal of N was 94% at the loading rate of 3 kg N ha^{-1} day^{-1} and decreased to 71% at the higher rate of 10 kg N ha^{-1} day^{-1}. The two years means for above-ground dry matter production for rush/bulrushes and bur-reed/cattails was 12 and 33 Mg ha^{-1}, respectively. Flooded rice yield was 4.5 Mg ha^{-1}, and soybean grown in saturation culture yielded 2.8 Mg ha^{-1}. Additionally, the performance of seven soybean cultivars using SSC in constructed wetlands with swine wastewater as the water source was evaluated for two years. The cultivar Young had the highest yield with 4.0 and 2.8 Mg ha^{-1} in each year. This indicated that production of acceptable soybean yields in constructed wetlands seems feasible with SSC using swine lagoon liquid. Two microcosms studies were established to further investigate the management of constructed wetlands. In the first microcosm experiment, the effects of swine lagoon liquid on the growth of wetland plants at half (about 175 mg/l ammonia) and full strength (about 350 mg/l ammonia) was investigated. It was concluded that wetland plants can grow well in at least half strength lagoon liquid. In the second microcosm experiment, sequencing nitrification-wetland treatments was studied. When nitrified lagoon liquid was added in batch applications (48 kg N ha^{-1} day^{-1}) to wetland microcosms the nitrogen removal rate was four to five times higher than when non-nitrified lagoon liquid was added. Wetland microcosms with plants were more effective than those with bare soil. These results suggest that vegetated wetlands with nitrification pretreatment are viable treatment systems for removal of large quantities of nitrogen from swine lagoon liquid. *(Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 4 : 629-632)*

Key Words : Wetlands, Wastewater Utilization, Constructed Wetlands

INTRODUCTION

Traditionally, animal wastes have been recycled through the soil environment with little impact on water resources. Swine production in the Southeastern United States generates large amounts of waste mostly in the form of liquid manure that are treated and stored in anaerobic lagoons prior to land application. Application of liquid manure to land can have several problems, such as nuisance odor, high solids content, high nutrient concentrations, and limited pumping distances. Although a high degree of nutrient removal may not be necessary in animal wastewater treatment systems, one of the ways to minimize nutrient enrichment of water resources is to remove nutrients prior to land application. Constructed wetlands have received considerable attention as a method of wastewater treatment that could reduce the land requirements by mass removal of nutrients (Hunt et al., 1995, 1997). Constructed wetlands remove N by both plant uptake and denitrification (Hammer, 1989, and Hunt et al., 1995). However, natural vegetation such as cattail and bulrush typically used in constructed wetlands do not have marketable value. As an alternative, agronomic plants such as rice or soybean grown in SSC can be used (Nathanson et al., 1984). Saturated-soil-culture with soil conditions that promote denitrification can be created on raised flat beds that are surrounded by furrows. Irrigation water in these furrows is kept at a constant level and below the surface of the bed to provide a thin aerobic surface layer. (Lawn and Byth, 1989). Soybean can acclimate and grow well under such SSC conditions (Hartley et al., 1993).

This paper summarizes the studies on swine lagoon liquid utilization and treatment conducted in wetland cells that contained either natural wetland plants or a combination of soybeans and rice with the objective of maximum nitrogen reduction to minimize the amount of land necessary for terminal treatment. Additionally, microcosm studies were conducted to investigate the

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effects of swine lagoon effluent on the growth of wetland plants, and to research the renovation of swine wastewater by sequencing nitrification-wetland treatments.

WETLAND STUDIES

Site characteristics

The research site is located in Duplin Co., NC. It has a nursery operation of 2600 pigs (average weight = 13 kg) that uses a flushing system to recycle lagoon liquid to clean the house and a single-stage lagoon for primary treatment. The average liquid volume of the lagoon is 4,100 m^3. On a mass basis, lagoon liquid contained only 17% of the N which entered the lagoon (Szogi et al, 1996). Typically, the lagoon liquid contained 365 mg/l of total Kjeldahl nitrogen(TKN), mostly (> 95%) as ammonia, 93 mg/l total phosphorus (TP) and 740 mg/l Chemical Oxygen Demand (COD).

Constructed wetlands

The research focus was to determine wetland treatment efficiency of swine lagoon liquid using natural wetland plants, to determine if a dischargeable effluent can be achieved at the low loading rate of 3 kg N/ha/day specified for advanced treatment for stream discharge and to define agronomic cropping potentials of constructed wetlands used for swine wastewater treatment (Hunt. et al., 1994; Szogi et al., 1996). Three systems, of two 3.6 by 33.5 m wetland cells connected in series, were constructed adjacent to the lagoon in 1992; they contained either natural wetland plants or water-tolerant agronomic plants. Two systems each contained a different combination of emergent wetland vegetation: system 1 contained a mixture of rush (*Juncus effusus*) and bulrush (*Scirpus validus*), system 2 contained a mixture of bur-reed (*Saprganium americanum*) and cattail (*Typha latifolia*). The third system contained soybean (*Glycine max*) in the first cell and rice (*Oryza sativa*) in the second cell. Nitrogen loading rates of 3 and 10 kg ha^{-1} day^{-1} were used in the first and second years, respectively. These loading rates were obtained by mixing the lagoon liquid with fresh water before it was applied to the wetland. The nutrient removal efficiency was similar in the rush/bulrush, bur-reed/cattail and agronomic plant systems (table 1). Mean mass removal of N was 94% at the loading rate of 3 kg N ha^{-1} day^{-1} and decreased to 71% at the higher rate of 10 kg N ha^{-1} day^{-1}. Phosphorus mass removal efficiencies ranged from 40 to 100% at P loading rates < 1 kg P ha^{-1} day^{-1} and varied from 20 to 80% when P loading rates were 1 to 4 kg ha^{-1} day^{-1}. The two years means for above-ground dry matter production for rush/bulrushes and bur-reed/cattail was 12 and 33 Mg ha^{-1}, respectively (Szogi et al., 1995a). Flooded rice yield was 4.5 Mg ha^{-1}, and soybean grown in saturation culture yielded 2.8 Mg ha^{-1}. Redox conditions were highly anaerobic in the soils of all wetlands. Denitrification enzyme assays indicated that the wetland soils were nitrate limited for denitrification (Hunt et al., 1995).

Table 1. Nitrogen loading rates and mass removal efficiencies for the constructed wetlands, Duplin Co., NC (June 1993-January 1995). Data from Szogi et al. (1995a,b)

Nitrogm loading rate[1]	System	Removal (%)[2]
3 kg ha^{-1} d^{-1}	Rush/bulrush	94
	Bur-reed/cattail	94
	Soybean-Rice	92
10 kg ha^{-1} d^{-1}	Rush/bulrush	63
	Bur-reed/cattail	73
	Soybean-Rice	78

[1] Expressed as TN.
[2] % Mass Removal = % mass reduction of N (TN = NH_3-N + NO_3-N) in the effluent with respect to the nutrient mass inflow.

These results suggest that constructed wetlands either with natural wetland or agronomic plants are excellent for mass removal of N from swine lagoon liquid. However, at the high loading rates necessary for substantive mass removal a high concentration of nitrogen remains in the effluent thus, subsequent land application is necessary. Crop lands, vegetative strips, and woodlands are viable options for the final treatments. Terminal land application does not require discharge permits and monitoring of discharge water quality. The capacity of mass N removal by wetlands can likely be increased by pre-wetland treatment of lagoon liquid such as overland flow, or media filtration.

Soybean in soil-saturated-culture

The performance of seven soybean cultivars using SSC in constructed wetlands with swine wastewater as the water source was evaluated in 1993 and 1994. These soybean cultivars were: Brim, Centennial, Essex, Holladay, Hutcheson, and Young. Soybean was planted on 1.4 m wide beds and grown using saturated-soil-culture. The beds were surrounded by 0.15 m deep furrows in which the water level was maintained about 0.05 m below the surface of the beds. A total of 94 and 161 cm of wastewater was applied in 1993 and 1994, respectively. In 1993, Young, Brim, and Centennial had the highest seed yields (4.02, 3.34, and 3.03 Mg ha^{-1}, respectively). In 1994, the highest seed yields were 2.79, 2.47, and 2.46 Mg ha^{-1} for Young, Pearl, and Brim, respectively. Lower seed yields were obtained for Centennial, Essex, and Holladay (2.0, 1.6, and 1.1 Mg ha^{-1}). Production of acceptable soybean yields in constructed wetlands seems feasible with SSC using swine lagoon liquid.

Microcosms studies

Two microcosms studies were established to further investigate the management of constructed wetlands. The first study evaluated the effect of different nitrogen loadings on the growth of wetland plants, and the second one the potential of nitrogen removal by different nitrification-wetland treatments.

Different nitrogen loadings

The objectives of the first microcosm study were to determine the effect of different swine lagoon liquid strengths on a mixed planting of two wetland plant species, *Juncus effusus* and *Scirpus validus*, and the effects of the vegetation on N removal. The experimental design was a randomized complete block, 3 ×2 factorial with 3 replications. The three treatment variables were full strength lagoon liquid (about 350 mg/l ammonia), half strength lagoon liquid (about 175 mg/l ammonia), and a freshwater control. The vegetation variable was a wetland plant treatment of *Scirpus validus* and *Juncus effusus* compared with no plants. Each of the 18 microcosms had a surface area of one m^2 (2.0×0.5 m). Each microcosm was lined with PVC film, filled with sandy loam topsoil to a depth of 22 cm, and planted with eighteen plants of each species.

The lagoon liquid and freshwater treatments were applied using pumps controlled by timers set to apply a total of 7 liters per day in three equal applications. Outflow pipes were set to maintain a water depth of no greater than 10 cm and the outflow was collected in barrels buried at the end of each microcosm. The collection barrels were sampled every two weeks to determine water volume and nutrient concentrations. The hydraulic loading rate of 7 liters per day of full strength lagoon liquid supplied about 30 kg ha^{-1} day^{-1} of nitrogen and 7kg ha^{-1} day^{-1} of phosphorus.

During the spring (March to mid-May) plant growth was greatest in the full strength treatment. Total above ground biomass harvested on May 18, 1995 was 422 g m^2 for the control, 989 g/m^2 for the half strength treatment and 1810 g/m^2 for the full strength. The amount of N present in the plant tissue at the time of harvest was 4.5 g/m^2 (control), 46.9 g/m^2 (half strength), and 61.1 g/m^2 (full strength).

During most of the growing season, there was no outflow from the vegetated microcosms receiving either half or full strength liquid. With no outflow there was, in effect, 100% treatment. The wetland microcosms were a sink for 15 kg $ha^{-1}day^{-1}$ for the half strength treatment and 30 kg $ha^{-1}day^{-1}$ for the full strength. The hydraulic loading rate was well below optimum for the amount of growth that occurred in response to nutrient inputs from the effluent. In early June, water requirements for growth in the full strength effluent treatment exceeded the supply, resulting in a die back of the vegetation. Data from the full strength treatment collected after that time were disregarded.

Conclusions on the effect of different nitrogen loadings on the growth of wetland plants were: 1) *Scirpus validus* and *Juncus effusus* grew vigorously in half strength lagoon liquid; the effect of the full strength lagoon liquid on growth was inconclusive because of confounding effects with inadequate moisture; 2) *Scirpus validus* was better adapted to the conditions imposed by the experiment than Juncus effusus; 3) During periods of maximum plant growth, water use by plants receiving half strength lagoon liquid was twice that of treatments receiving fresh water only; and 4) plant growth was greatest at 30 kg N/ha/day until water requirements exceeded supply.

Nitrification-wetland treatments

A second microcosm wetland study was established in 1996 to assess sequencing nitrification-wetland treatments. The three treatments were 1) wetland plant treatment; 2) mineral soil + C source (glucose amended) with no plants; and 3) mineral soil with no plants (control). The experiment was a 3x2 factorial (6 treatments) in a randomized block design with three replications per treatment. The wastewater was applied in two consecutive batches.

In the first batch application, wastewater enriched with nitrate was applied to the microcosm wetland units at a rate of 190 kg nitrate-N/ha and a retention time of four days. Differences in removal were not significant between the wetland plant treatment and the mineral soil + C source. Results showed about 80% removal of nitrate by treatment 1 (wetland plants) and 2 (mineral soil + C) compared to 14% by treatment 3 (the control with no plants). This removal potential is equivalent, on an annual basis, to about 14,000 kg N/ ha, which is 5.4 times higher than the N removal without nitrification pretreatment. This indicates that the capacity of mass N removal by wetlands can be significantly increased by nitrification pretreatment.

In the second batch application, the wetland plant treatment removed just 58% of the initial nitrate applied (107 mg/L) compared to the mineral soil + C with no plants treatment that removed 100% of the initial nitrate, while the control (soil) treatment had the lowest removal rate with 31% of the initial nitrate level. These consecutive treatments indicated that constructed wetlands may become C limited for denitrification when a high mass load of nitrate is applied continuously.

In conclusion, when nitrified wastewater was added in batch applications to wetland microcosms the nitrogen removal rate was four to five times higher than when non-nitrified wastewater was added. Wetland microcosms with plants were more effective than those with bare soil and no C addition. These results suggest that wetlands with nitrification pretreatment are viable treatment systems for removal of large quantities of nitrate-N from swine wastewater. Increased nitrate removals recorded for wetland systems with carbon addition indicate wetlands may become carbon limited for denitrification.

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