Effect of Swine Effluent Application Rate and Timing on Nitrogen Utilization and Residual Soil Nitrogen in Common Bermudagrass

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ABSTRACT

Frequent summer precipitation may delay the application of swine effluent to bermudagrass [*Cynodon dactylon* (L.) Pers.] until late summer or early fall. A concern with late-season irrigations is declining day length and air temperatures in fall greatly reduce the growth and nutrient uptake of this warm-season forage crop. Field studies were conducted in 2000 and 2001 near Pheba, MS on a Prentiss sandy loam soil (coarse-loamy, siliceous, semiactive, thermic Glossic Fragiudult) with no known history of effluent application. The objectives were to determine if irrigation rate and timing influence crop N utilization and residual NO_3-N in the soil profile. Small plots were arranged in completely randomized design with four replicates. Effluent was applied at 10 and 20 cm ha^{-1} (about 260 and 480 kg ha^{-1} N, respectively) during four spray seasons: April to September (full season), April to May, June to July, and August to September. Soil was sampled in fall and spring to estimate the amount of N not recovered by forage. Application of 20 cm effluent in April-May, June-July, and April-Sept treatments resulted in the greatest annual forage yield of about 11.5 and 18.1 Mg ha^{-1} in 2000 and 2001, respectively; the corresponding values for N uptake were 306 and 335 kg ha^{-1}. Averaged across rates, the Aug-Sept treatment had the lowest N utilization efficiencies of 55% in 2000 and 34% in 2001. Application of 20 cm effluent in Aug-Sept treatment increased residual soil NO_3, particularly in fall 2000 and spring 2001. Nitrogen in swine effluent applied in fall is less likely to be utilized by common bermudagrass due to either dry summer conditions or declining growth rate.

Keywords: Agriculture, Ecology, Irrigation, Ground Water, Wastewater

Introduction

Growth of confined, contract swine production in southeastern USA and widespread use of swine manure as a nutrient source for forage production has focused research on nutrient uptake by southern forages (Welsh and Hubbell, 1999; Adeli et al., 2003; Rowe et al., 2006). The swine manure produced by a farm is typically flushed into anaerobic lagoons to facilitate digestion. The resulting effluent is a solution containing multiple nutrients, including N, P, K, Ca, and Mg, and micronutrients. To prevent lagoon overflow, permits require surrounding pasture land to be irrigated with effluent. Nitrogen, P, and K are the most agronomically important nutrient elements, while N and P also pose an environmental hazard (Mississippi NRCS, 2000).

Efficient use of effluent N should be a priority because N application rates in excess of crop N requirements contribute to increased levels of NO_3 in the soil profile, and high concentration of post harvest soil NO_3 increases the risk of leaching into ground water (Burns et al., 1990). Bermudagrass is the predominant forage crop grown in the region and responds readily to increasing N rates from either organic or inorganic sources (Read et al., 2006). Because hay production represents an important component of nutrient management, improving N management in bermudagrass fertilized with effluent requires a better understanding of irrigation rate and timing effects relative to the N removal capacity of the crop. By minimizing soil loss and nutrient runoff and by harvesting nutrients in the form of hay, the rate of nutrient accumulation in the soil and potential for ground and surface water impairment is reduced (McLaughlin et al., 2005).

Water quality impacts from land-applied swine effluent are dependent on many variables, including soil, rainfall, plant species, waste characteristics, and application rate. Due to frequent precipitation earlier in the growing season, swine producers in the Southeast may be forced to apply effluent to bermudagrass in late summer or early fall. But declining day length and temperature reduce the growth and nutrient uptake of this tropical forage grass during the fall (Ball et al., 1996). Consequently, late-season applications of effluent increase the potential for excessive N accumulations in soil and nitrate leaching. Our objective was to determine effluent application date and rate effects on bermudagrass yield, N uptake, and post-season residual soil N concentration.

Materials and Methods

The study site was a common bermudagrass hay meadow on a commercial swine farm near Pheba (33.588 N, -88.950 W) in Clay County, MS. A site was selected with no known history of swine effluent application and adjacent to an earthen lagoon used for holding swine effluent. Soil is a Prentiss sandy loam, which consists of deep, moderately well drained, moderately permeable soils with a fragipan. They formed in loamy marine or stream sediments. In April 2000, the existing bermudagrass sward was cleared of senesced weeds by mowing, and weed regrowth was controlled using selective herbicides [Weedmaster (8 oz acre^{-1}) and MSMA (4 oz acre^{-1})]. Soil was sampled at 0-5, 5-10, 10-20, 20-30, 30-40 cm depths at several sites within the experimental area. Chemical characteristics of the Prentiss soil are presented in Table 1. The pH was determined in a 1:1 soil and water suspension, total N was determined using the Dumas method (Bremner, 1996), and nutrient concentrations were determined using Mehlich-3 extractant (Mehlich, 1984).

Plots (2 x 6 m) were arranged in randomized complete block design with four replicates. Adjacent plots were separated by a 2-m alley and adjacent blocks were separated by a 4-m alley. Experimental treatments were repeated on the same plot area each year. Treatments comprised non-irrigated and unfertilized (control) plots, plots irrigated with swine effluent at the recommended annual rate of 10 cm ha^{-1} (approximately 264 kg N ha^{-1}), and plots irrigated at 20 cm ha^{-1}. The amount of effluent provided to each plot was about 1294 ± 58 L for 10 cm ha^{-1} rate and 2335 ± 228 liters for 20 cm ha^{-1} rate (Table 2). Application timing was varied by applying effluent at regularly spaced times during the season with 0.5 cm per irrigation event in four spray seasons: (i) April through September (full season), (ii) April through May, (iii) June through July, and (iv) August through September. These treatments were applied by hand from 26 April to 10 October 2000, and from 17 April to 4 October 2001 using

Table 1. Bulk-density (BD), pH, and the concentration of selected mineral elements (Mehlich-3 extractant) at various depths in Prentiss sandy loam soil at the beginning of the experiment.

Depth	BD	pH	N	K	Ca	Mg	P	Fe	Mn
cm	Mg m^{-3}		g kg^{-1}				mg kg^{-1}		
0-5	1.11	6.1	2.11	0.44	1.14	0.23	31	306	83
5-10	1.38	5.9	1.48	0.32	0.81	0.08	1	208	76
10-20	1.50	6.0	1.07	0.12	0.71	0.03	0	110	78
20-30	1.54	4.3	0.64	0.03	0.44	0.02	0	103	12
30-40	no data	4.1	0.52	0.03	0.25	0.02	0	115	7

Table 2. Total amount of swine effluent and nitrogen in effluent applied to bermudagrass in different spray seasons during the experimental period.

Effluent Rate and Period	Effluent applied		Total N applied	
	2000	2001	2000	2001
	kiloliters		kg ha^{-1}	
10 cm ha^{-1}				
Apr - Sep	1.25	1.25	241	286
Apr - May	1.25	1.32	258	304
Jun - Jul	1.32	1.40	247	318
Aug - Sep	1.25	1.32	197	249
20 cm ha^{-1}				
Apr - Sep	2.34	2.49	447	520
Apr - May	2.41	2.34	499	533
Jun - Jul	1.95	2.26	378	512
Aug - Sep	2.18	2.72	348	510

a garden hose attached to a centrifugal pump. The pump, which was centrally located in the plot area, drew effluent through a buried, PVC pipe that ran to a lagoon approximately 30 m from the pump. Once inside the earthen wall of the lagoon, the intake pipe floated on the surface to a 90° elbow mounted on a flotation device that allowed effluent to be withdrawn from a depth of 30 cm. Flow rate of the pump was checked at the time of each application so that a 0.5 cm event was equivalent to 3 minutes of irrigation. All water was applied carefully to minimize runoff from the plots. A sample of effluent (~ 250 ml) was collected on each application date and stored in the lab in a freezer. Total N concentration was determined using Kjeldahl procedure with a salicylic acid modification. Values for effluent N concentration and corresponding volume applied each week were used to calculate the annual N rate for each spray season (Table 2).

Forage was harvested every 7 to 9 weeks. Harvest dates in 2000 were 13 June, 7 August, and 11 October. Harvest dates in 2001 were 14 June, 16 August, and 12 October. Corresponding harvest intervals were 6.8, 7.8, and 9.3 weeks in 2000, and 8.2, 9.0, and 8.1 weeks in 2001. Forage biomass was determined by cutting a 1- by 6-m swath at a 3-cm stubble height through the center of each plot using a sickle-bar mower. Fresh weights were recorded and subsamples of oven-dried forage were used for determination of percent moisture in order to calculate forage dry matter (DM) yield. Forage N concentration was determined from duplicate samples using an automated dry combustion analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy). The quantity of N removed in harvested forage was calculated as a product of DM yield and percent N concentration at each harvest. Apparent N recovery was calculated by subtracting annual N uptake for control treatment from annual N uptake for the effluent treatments and dividing by the amount of N applied. Nitrogen recovery is an important indicator of N use efficiency and potentially reflects relative quantities of N remaining in the soil.

In order to determine residual inorganic N, NO_3 and NH_3, in the soil profile, soil samples were taken after a killing frost (5 December 2000 and 14 November 2001) at depths of 0-5, 5-10. 10-15, 15-20, 20-25, 25-30, and 30-40 cm. Profiles also were sampled before 'greenup' in spring (April of both years) at depths of 0-5, 5-10, 10-20, 20-30, 30-40, 40-50, and 50-60 cm. Sampling depth was deeper in spring because relatively more NO_3 leaching was expected during the winter and spring seasons due to increased rainfall amounts and less plant growth, as compared to summer and fall seasons. Two cores were obtained from each plot using a Giddings Soil Probe mounted on a tractor. Samples of soil were composited by depth, placed in plastic bags, and stored in a freezer to prevent N transformations prior to analysis. Subsamples were extracted with 2 M KCl (1:10 soil:KCl) and the filtrate analyzed colorimetrically for NO_3 and NH_4 using a Technicon autoanalyzer (Mulvaney, 1996). Total inorganic N was expressed as the summation of NO_3 and NH_4, using mass units (mg N kg soil^{-1}, parts per million). At the end of the experiment, soil was sampled at 5-cm intervals to a depth of 30 cm at five randomly-selected locations in order to estimate soil bulk density (g cm^{-3}). A micrometer was used to determine the volume of each 5-cm section (~ 62 cm^3). Soil samples were placed into pre-weighed tin cans and dried to a constant weight in an oven at 100 C. Values for bulk density were used to transform mass units for inorganic N to area units (kg ha^{-1} N) for estimation of applied N remaining in soil in the different treatments.

Results and Discussion

Swine Effluent Analysis

The amount of effluent N applied in each treatment is presented in Table 2. Somewhat lower N provided in August-September 2000 was due to lower than average effluent N concentration. Effluent N existed primarily as NH_4-N (87% in 2000; 88% in 2001) with low percentage of NO_3-N (2.8% in 2000, and 1.5% in 2001). Total N in the effluent averaged about 65-76% of the values reported in a separate study (Adeli et al., 2003); however, values for total P are similar between the two studies. As a result, N/P ratio was lower than reported by Adeli et al. (2003) and averaged 3.72 in 2000 and 4.29 in 2001. Build up of soil P is predictable, because the N/P ratio of effluent is much lower than the ratio of N and P absorbed from the soil by bermudagrass (~4:1 vs. 10:1; Evers, 2002).

Forage Yield, Nitrogen Recovery, and Residual Soil Nitrogen

Averaged across the different spray seasons, doubling the effluent rate significantly increased forage DM yield by about 57% in 2000 and 24% in 2001 (Table 3). Relatively high yields in 2001 were likely related to greater monthly rainfall received during the growing season, May to October, as compared to 2000. Additionally, the total amount of N applied was somewhat greater in 2001 than 2000 (Table 2). Bermudagrass response to swine effluent has varied in different studies, and can be attributed to, among other things, difference in soil type (Adeli et al., 2006) or variety (Brink et al., 2003). In a study with 'Alicia' hybrid bermudagrass on Vaiden soil, Adeli et al. (2003) reported little advantage to N application rates exceeding 373 kg ha^{-1}. Our results suggest common bermudagrass irrigated with swine effluent can be as or more productive than Alicia bermudagrass when grown on Prentiss soil, as compared to either Vaiden or Okolona soil.

Due to increased DM yield, the amount of N recovered by bermudagrass was significantly greater at 20 cm ha^{-1} than 10 cm ha^{-1} (Table 3). But doubling the effluent rate did not lead to consistent changes in N utilization efficiency in the different spray seasons, as values for N efficiency relative to controls (100% efficient) were related inversely to the amount of N applied in 2000, but not in 2001. Doubling the effluent rate led to accumulations of NO_3-N in the surface soil, 0-20 cm depth (Fig. 3). At the recommended rate of 10 cm ha^{-1}, the soil contained about 40 kg N ha^{-1} to 30-cm depth, or about 15% of the total N applied, and 36-75% was taken up and harvested with the forage across the different irrigation seasons. At 20 cm ha^{-1} rate, the 0-30 cm soil depth contained just 10-12% of the total N applied, and 31-87% was taken up by bermudagrass. With regard to spray seasons, applying effluent in August-September resulted in significantly low values for forage DM yield and N recovery, and sometimes greater residual soil NO_3-N at either 0-5 cm or 5-10 cm depth.

In summary, bermudagrass yield, forage N concentration and apparent N recovery increased relative to unfertilized controls when effluent application preceded the harvest

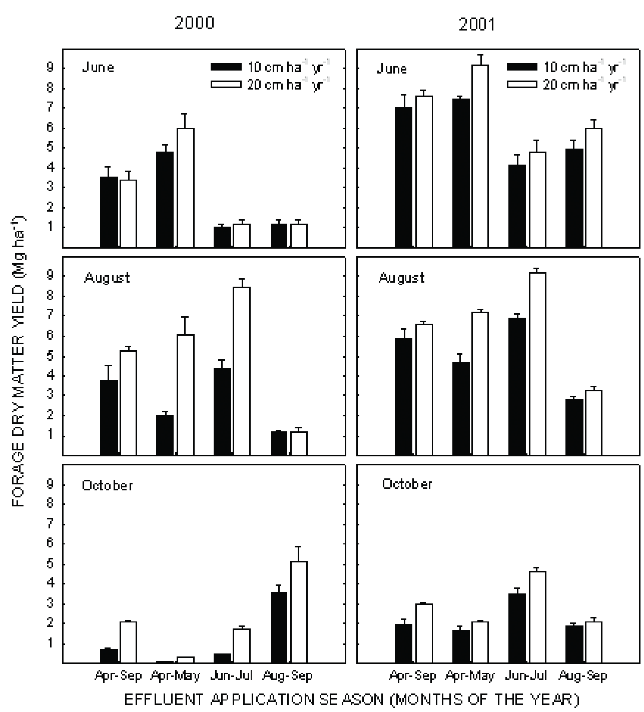

Figure 1. Treatment effects on yield of common bermudagrass forage by year and harvest.

Table 3. Forage dry matter (DM) yield, N uptake, and N utilization efficiency by common bermudagrass grown under rain-fed conditions (control) and irrigated with different rates of swine effluent in four application seasons in 2000 and 2001.

Elluent rate and spray season	DM yield		N recovery*		N efficiency	
	2000	2001	2000	2001	2000	2001
	Mg ha^{-1}		kg ha^{-1}		%	
Control	2.27	5.45	40.8	102.6	100	100
10 cm ha^{-1}						
Apr - Sep	8.03	14.78	151.2	215.3	62.73	75.29
Apr - May	6.90	13.81	136.8	208.9	53.04	68.71
Jun - Jul	5.85	14.45	122.9	238.7	49.77	75.07
Aug - Sep	5.86	9.64	109.7	93.5	55.69	37.56
20 cm ha^{-1}						
Apr - Sep	10.69	17.21	282.3	286.2	63.16	55.04
Apr - May	12.30	18.43	306.1	358.7	61.34	67.31
Jun - Jul	11.36	18.54	329.4	359.3	87.13	70.18
Aug - Sep	7.50	11.34	186.6	156.5	53.62	30.68
AOV Source^						
Rate	P<0.01	P<0.01	P<0.01	P<0.01	P<0.05	P<0.01
Season	P<0.01	P<0.01	P<0.01	P<0.01	NS	P<0.01
Rate x Season	NS^	NS	P<0.05	P<0.05	NS	NS
CV^, %	19.2	9.3	21.7	11.2	24.2	12.3
LSD^ (Season)	1.71	1.43	46	28	15.33	7.65

*Apparent N recovery was calculated by subtracting N uptake by unfertilized (control) plots from that of each treatment in each replicate block; values presented are average annual N uptake of about 41 kg ha^{-1} in 2000 and 103 kg ha^{-1} in 2001.
^AOV source, treatment variables analyzed statistically using analysis of variance; NS, not significant according to Fisher's F test at 5% level of probability; CV, coefficient of variation; LSD, least significant difference at 5% level of probability.

(Figs. 1 and 2). Annual forage yield and N utilization were somewhat lower in 2000 due to less rainfall and less N applied in effluent than in 2001. This difference was reflected in post season soils analysis, which found increased NO_3-N at 0-20 cm soil depth when 20 cm ha^{-1} effluent was applied, particularly in August-September spray season, which had significantly more residual soil NO_3 in spring 2001 than other spray seasons (Fig. 3). The effect of effluent rate and timing on soil NO_3 was most apparent at 0-5 cm soil depth. With the exception of August-September spray season, forage N utilization increased as effluent rate increased from 10 to 20 cm. At 10 cm rate, the amount of effluent N not removed by bermudagrass was similar for all spray seasons.

Conclusions

Swine producers have interest in using effluent N efficiently without the associated risks to water quality that may arise from excessive or untimely applications of effluent N. The present study assessed the effect of irrigation rate and timing on N recovery by applying effluent to common

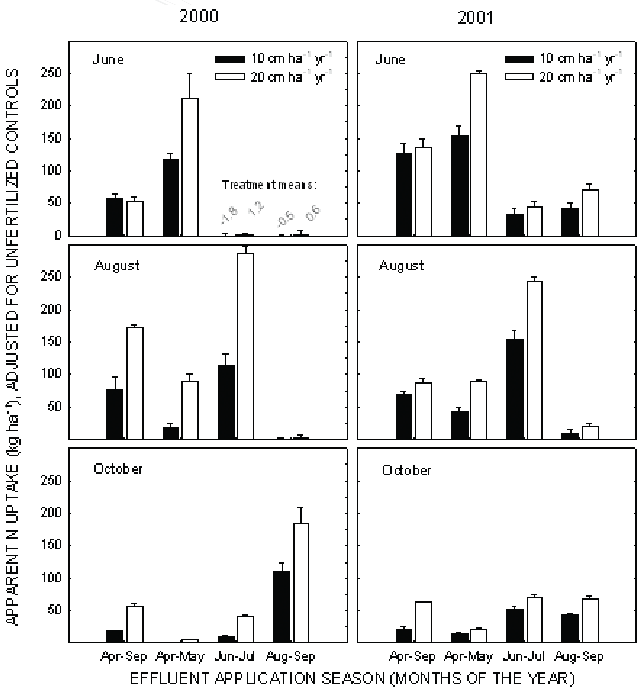

Figure 2. Treatment effects on nitrogen recovery in common bermudagrass by year and harvest.

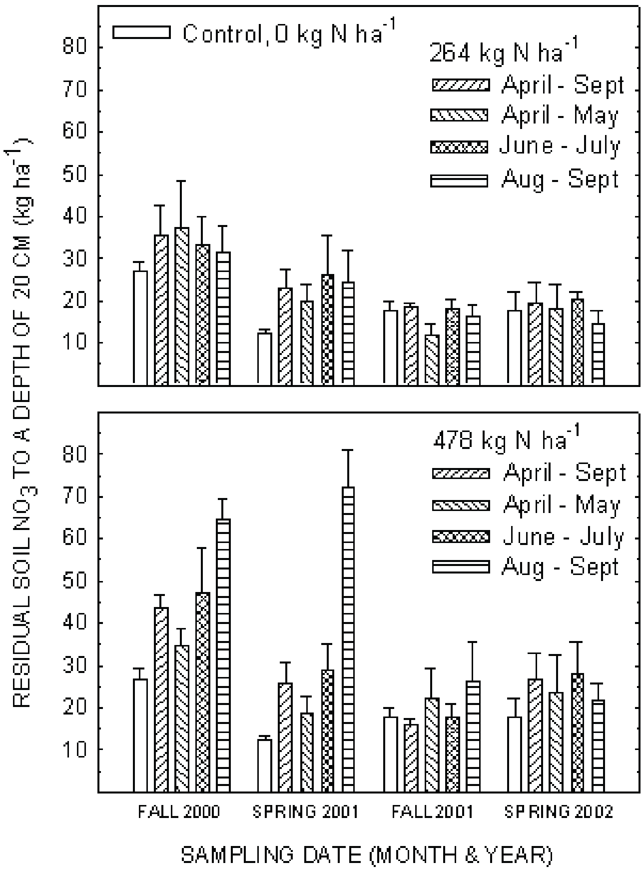

Figure 3. Effect of no irrigation (control) and four swine effluent spray seasons on the amount of residual soil nitrate to 20-cm depth in Prentiss sandy loam soil. Values represent the mean of four observations, and bars represent standard error of the mean.

bermudagrass from April to September (full season), as compared to shorter, 60-d periods during the growing season. Results indicate the risk of nitrate loss to the environment is increased when effluent application to bermudagrass is delayed until late in the growing season, particularly at higher application rates.

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