SWINE EFFLUENT IRRIGATION RATE AND TIMING EFFECTS ON BERMUDAGRASS GROWTH, N AND P UTILIZATION, AND RESIDUAL SOIL N

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INTRODUCTION

Proper and efficient management of swine lagoon effluent on cropland is important for improving the economics of crop production and for minimizing adverse impacts on soil and water quality. Confined swine feeding operations in Mississippi produce large quantities of waste which is flushed into anaerobic lagoons to facilitate digestion. To prevent lagoon overflow, surrounding crop land and pasture is irrigated with the effluent. The resulting effluent is a solution containing multiple nutrients including N, P, K, Ca, and Mg (Sutton et al., 1982). Nitrogen and P make up the most agronomically and environmentally important proportion (Sutton et al., 1982). Sutton et al. (1978) reported concentrations of 480 µg N ml^{-1} and 103 µg P ml^{-1} in swine effluent Irrigation with swine lagoon effluent requires crops that assimilate large quantities of nutrients. Hybrid bermudagrass [*Cynodon dactylon (L.)*] has the potential to remove greater amounts of N and P compared to other crops due to its extensive root system and high biomass production potential (Woodhouse and Griffith, 1973). Efficient crop utilization of N and P derived from anaerobic swine lagoon effluent is critical to minimizing offsite nutrient movement. Burns et al. (1990) showed a bermudagrass yield response up to 670 kg N ha^{-1} derived from swine effluent. Nitrogen recovery by 'Coastal' bermudagrass for a seven year period averaged 73%, 57%, and 34% for swine effluent application rates equivalent to 335, 670, and 1340 kg N ha^{-1} (Burns et al., 1990). Phosphorus recovery by bermudagrass was 41%, 28%, and 17% with effluent application rates equivalent to 78, 153, and 301 kg P ha^{-1}, respectively (Burns et al., 1990). Effects of swine effluent on forage yields and nutrient removal has generally been with excessive N loading and more of a means of disposing the waste rather than efficient utilization of nutrients. King et al. (1990) reported NO_3^--N accumulation below 60 cm with excessive N rates. Improving the utilization efficiency of nutrients derived from effluent by forage grasses require a better understanding of irrigation timing and rate effects. Morris and Celecia (1972) found more efficient N removal by bermudagrass when N was applied during the summer compared with fall application. Eichhorn (1989) found maximum bermudagrass yields at 448 kg N ha^{-1} from fertilizer, while N removal continued to increase at N rates up to 672 kg N ha^{-1}. Percent N recovery decreased as rates increased from 224 to 672 kg N ha^{-1} (Eichhorn 1989).

Timing and rates of fertilizer N application can affect both the availability of N for crop growth and the amount of NO_3^--N remaining in the soil profile (Jokela and Randall, 1989). Zebarth and Paul (1993) reported that there is negligible N benefit for corn following fall applied dairy cattle manure. Application of fertilizer N during the most active period of bermudagrass growth resulted increased yield, N removal and fertilizer N recovery compared with late season applied N (Shannon et al., 1999). To reduce the potential for environmental degradation due to the high content of nutrients especially N in the swine effluent, application rates must not exceed the plant and soil buffering capacities. Application rates greater than optimal can cause an accumulation NO_3^--N in the soil profile (Bundy and Malone, 1988; Jokela and Randall, 1989; Roth and Fox, 1990). Although N sources and rates have been comprehensively evaluated for bermudagrass, relatively little is known about bermudagrass yield and nutrient utilization from swine effluent. Currently swine producers are permitted to begin swine effluent irrigation 1 March and continue until 31 October. This time interval is longer than the most active growth period of summer grasses such as bermudagrass. The objective of this study was to determine the effects of swine effluent irrigation rate and timing on bermudagrass growth, N and P recovery, and post-season soil profile NO_3^--N.

MATERIALS AND METHODS

Research was conducted in 1998 and 1999 on the premises of a commercial swine facility located near Brooksville, MS. The soil type was chosen for this study is an acid Vaiden silty clay (very fine, montmorillonitic, thermic, Typic Hapludalf) soil. This is representative of the Blackland Prairie major land resource area. Physical and chemical characteristics of this soil are shown in Table 1. Alicia bermudagrass was used as based forage systems. Swine effluent irrigation was initiated each May and continued through August. Swine effluent was applied at rates of 0, 5, 10, 15, and 20 ha-cm which was equivalent to approximately 0, 213, 391, 528, and 660 kg N ha^{-1}. Additionally, 2.5 ha-cm was applied 1 September and 1 October in addition to a base rate of 10 ha-cm applied from May through June (Table 2). This was done to determine the effect of late season swine effluent application on N and P removal by bermudagrass and residual soil N. The experiment was arranged as a randomized complete block and treatments were replicated four times. Individual plot dimensions were 3.66-m by 3.66-m with 3.05 m alleys.

Swine effluent was applied in 0.64 cm increments up to 1.27 cm in a given day depending on antecedent soil moisture content. For each effluent irrigation event, 1.25 ha-cm of clean water was applied to check plots. This was done to minimize growth differences between treatments as a result of water availability. A 1500 litter water-wagon was used for delivery of irrigation water and swine lagoon effluent to the plots. The wagon was filled using a transfer pump with the inlet of the suction hose placed near the irrigation inlet used by the facility. Effluent samples were obtained for every tank-full and stored on ice in a cooler for transport to the laboratory. Electrical conductivity and pH of effluent samples were determined immediately. Samples were preserved by acidifying with sulfuric acid (H_2SO_4, 2 ml per litter) and frozen until analysis (Methods of Chemical Analysis of Water and Wastewater, 1984).

Effluent samples were digested for total N using a modified micro-kjeldahl procedure described by Nelson and Sommer (1977). The digest was analyzed using a colorimetric assay (Cataldo et al., 1974). Total inorganic N (NH_4^+ + NO_3^- -N) of the effluent was analyzed using steam distillation (Bremner and Keeney, 1965). Total P of the effluent was analyzed by using a H_2SO_4-HNO_3 acid digestion procedure (Standard Methods for the Examination of Water and Wastewater, 1989). Digested samples were analyzed for ortho-P using a colorimetric assay developed by Murphy and Riley (1962).

Forage grasses were harvested after completing each incremental treatment application (either 2.5 ha-cm or 5 ha-cm) allowing at least 21 days of growth. Two swaths (total of 2.77 m^2) were harvested from each plot using a commercial rotary mower set at a cutting height of 7 cm. Fresh weight of harvested forage were taken prior to oven drying subsamples at 65 °C for 48 h in a forced - air oven. Dried plant material was ground in a Wiley mill to pass a 2- mm sieve. To determine total P of the forage samples, 1-g samples were dry-ashed according to procedures outlined by Isaac and Kerber (1971). Total P was measured using a Perstorp Flow Solution III Analyzer. Nitrogen content of forage was determined using a Carlo Ebra NC 1500 dry combustion analyzer.

The quantity of N and P removal by the harvested forage was calculated using N and P concentration and dry matter yield for each harvest.

At the end of each growing season, soil samples were taken at depths of 0- to 5 cm, 5- to 15 cm, 15- to 30 cm, 30- to 60 cm, and 60- to 90 cm. Composited soil samples consisted of nine randomly cores per plot each 5 cm in diameter. Samples frozen at - 4 °C to prevent any N transformations before analysis.

Soil NO_3^- -N was determined by extracting the soil samples with 1 N KCL (Keeney and Nelson, 1982). Extracts were analyzed for NH_4^+-N and NO_3^-- N using an automated colorimetric segmented flow analyzer(Methods for Chemical Analysis of Water and Wastes, 1984). Soil NO_3^-- N accumulations were weighted for each depth and summed over depths for each treatment to obtain total NO_3^-- N accumulation in the soil profile.

All statistical analyses were performed using the Statistical Analysis System (SAS Inst., 1989). The general linear and quadratic model (GLM) procedure were used to perform analysis. Analyses of variance were conducted by year. Statistical tests were performed at a 0.05 level of significance.

RESULTS AND DISCUSSION

Effluent analysis

Yearly average analyses of swine effluent samples obtained from each irrigation event are shown in Table 3. Effluent N existed primarily as NH_4^+ -N (82%) with minimal NO_3^- -N (9%). This is in agreement with the original work by Sutton et al. (1978). The predominant of NH_4^+ -N reflects the nature of anaerobic decomposition processes in the lagoon. Similar to N, most of the P existed as water soluble ortho-P (82%) indicating the swine lagoon effluent is chemically very similar to commercial fertilizers.

Dry matter yield

Bermudagrass dry matter yield was significantly increased with increasing application rate of swine effluent during the most active period of growth. Dry matter yield responded quadratically to increasing swine effluent application rates and ranged from 3112 and 1900 kg ha^{-1} with no effluent applied to 13000 and 11670 kg ha^{-1} with application of 20 ha-cm effluent in 1998 and 1999, respectively (Table 4). Although residual build up of soil P and K increased from swine effluent application in 1998 (data not shown), dry matter production and response to effluent rates decreased in 1999 compared to 1998. This is likely related to a low rainfall condition (Table 5). Little advantage in yield of bermudagrass yield was obtained from effluent application at rates greater than10 ha-cm or equivalent to 380 kg N ha^{-1}. It appears that application of swine effluent N at rates greater than 10 ha-cm to agricultural land would have negative environmental consequences.

In 1988 for late-season irrigation, bermudagrass yield ranged from 1220 kg ha^{-1} (no effluent applied to the base rate of 10 ha-cm, control plot) to 2975 kg ha^{-1} with 2.5 ha-cm effluent applied in September). Dry matter production was 2115 kg ha^{-1} with 2.5 ha-cm effluent applied in October (Table 4). In 1988 for late-season irrigation, bermudagrass yield ranged from 278 kg ha^{-1} for the control plot to 1069 kg ha^{-1} and 714 kg ha^{-1} with a September or October 2.5 ha-cm irrigation, respectively. Averaged across years, October irrigation produced 30 % less dry matter than September. The results of this study are in agreement with the works of other researchers (Shannon et al., 1999; Morris and Celecia, 1972) who found that application of N fertilizer during the most active period of bermudagrass growth was more efficient than late-season applied N.

Nitrogen uptake and recovery

Maximizing efficiency in recovery of applied N decreases the potential for NO^3-N leaching. In 1998, regression analysis indicated a strong quadratic trend in N uptake ($P< 0.01$, $r^2 = 0.95$) with increasing swine effluent application rates during active period of growth. In 1999, N utilization by bermudagrass had similar trend ($P< 0.05$, $r^2 = 0.92$), but the absolute quantity removed was dependent on yield (Table 6). In 1998 and 1999, total N uptake ranged from 40 kg N ha^{-1} and 27 kg N ha^{-1} with no effluent to 302 kg N ha^{-1} and 265 kg N ha^{-1} with application of 20 ha-cm effluent , respectively (Table 6).

In 1988 for late-season irrigation, N uptake by bermudagrass ranged from 19 kg N ha^{-1} with no effluent applied to the base rate of 10 ha-cm(control plot) to 61 kg N ha^{-1} with application of 2.5 ha-cm effluent in September. At the same rate, N removal by bermudagrass was 31 kg ha^{-1} with October irrigation (Table 6). In 1999 for late-season irrigation, N utilization ranged from 8 kg N ha^{-1} with no effluent (control) to 25 kg N ha^{-1} and 12 kg N ha^{-1} with September and October irrigation, respectively (Table 6). Averaged across years, bermudagrass utilized 50% less N from effluent N applied in October than in September. Low N uptake in October is related to cooler temperature and shorter days. Apparent N recovery was calculated by subtracting N uptake for the check treatment (no swine effluent applied) from uptake of effluent treatments and dividing by the N rate applied (Table 7). Recovery of N by the harvested portion is an important indicator of N-use-efficiency and potentially reflects relative quantities of N remaining in the soil. In 1998 and 1999, apparent N recovery tended to decrease with increasing swine effluent application. In 1998 during active growth period, apparent N recovery decreased from 64 % with irrigation of 5 ha-cm (213 kg N ha^{-1}) effluent to 40 % with 20 ha-cm (660 kg N ha^{-1}). This is in agreement with the results of study conducted by Eichhorn (1989) who found apparent N recovery by bermudagrass decreased as fertilizer N rates increased from 224 to 672 kg N ha^{-1}. In 1999, apparent N recovery ranged from 49 % to 36 % with 5 ha-cm effluent (215 kg N ha^{-1}) and 20 ha-cm effluent (670 kg N ha^{-1}), respectively. Low N recovery in 1999 could be related to dominant dry and hot conditions in summer which probably increased N lose through NH_3 volatilization.

In 1998 and 1999 for late-season irrigation, apparent N recovery of September applied effluent N was 50 % and 27 % , respectively, while N recovery for October irrigation was 20 % and 10 %, respectively. Low N recovery in October was probably related to limited forage growth. Thus, application of swine lagoon effluent greater than 10 ha-cm and late-season irrigation in October can result in accumulation of N in the soil which increases the potential contamination of water systems. This is in agreement with the works of King et al. (1990) who found soil NO_3^- -N accumulation with excessive N rates..

Phosphorus uptake and recovery

In 1998 and 1999, P uptake by bermudagrass quadratically increased with increasing swine effluent loading rates (r^2 = 0.93 and r^2 = 0.92, respectively) (Table 6). In 1998 and 1999, total P uptake ranged from 7 kg P ha^{-1} and 4 kg P ha^{-1} with no applied effluent to 34 kg P ha^{-1} and 22 kg P ha^{-1} with 20 ha-cm effluent, respectively. The lower P removal by bermudagrass in 1999 is related to lower yields than in 1998.

In 1988 for late-season irrigation, P uptake ranged from 2.2 kg P ha^{-1} with in-season base rate of 10 ha-cm(control plot) to 6.1 kg P ha^{-1} with application of 2.5 ha-cm effluent in September and 3.1 kg P ha^{-1} for October irrigation (Table 7). In 1999, late-season P uptake was 0.4 kg ha^{-1} for the control and 2.2 kg P ha^{-1} with September irrigation. For October irrigation, P removal was 0.8 kg ha^{-1}.

Although total P removal in harvested forage increased with increasing effluent rates, apparent recovery of applied P decreased (Table 7). In 1998, apparent P recovery decreased from 40 % with 5 ha-cm effluent to 18 % with 20 ha-cm effluent. In 1999, apparent P recovery ranged from 28 % to 11 % with application of 31 kg P ha^{-1} and 163 kg P ha^{-1}, respectively.

Recovered P dramatically decreased when swine lagoon effluent was applied late in the season. In 1998 and 1999 for late-season irrigation, apparent P recovery of applied effluent P in September was 19 % and 11 %, while P recovery of applied effluent P for October irrigation was 10 % and 5%, respectively (Table 7). It appears that either application of swine effluent greater than 10 ha-cm (75 kg P ha^{-1} or late-season irrigation in October may result in excessive P accumulation in the soil and potentially increase P in runoff water.

Residual Soil Nitrate

Total soil profile (0- to 90- cm) residual NO_3^-- N is shown in Table 8. Nitrate accumulation in the soil profile varied slightly from 1998 to 1999. In 1998, residual NO_3^-- N ranged from 5 kg ha^{-1} with no effluent to 41 kg ha^{-1} with 20 ha-cm effluent. However, in 1999, residual NO_3^-- N ranged from 2 kg ha^{-1} with no applied effluent (0 kg N ha^{-1}) to 32 kg ha^{-1} with application of 20 ha-cm (670 kg N ha^{-1}). Since applied effluent N was primarily NH_4^+ - N (Adeli, et al., 1995; Schmidt, 1998; and Evans, 1977) lower accumulation of soil profile NO_3^-- N and plant recovery in 1999 was probably related to greater NH_3 volatilization due to drier and hotter conditions (Klausner and Guest, 1981). In both years, the greatest accumulation of soil profile NO_3^--N was obtained when swine effluent was applied at the greatest rate (20 ha-cm) which was equivalent to 660 kg N ha^{-1}. This response to N is similar to NO_3^--N accumulation patterns reported by Broadbent and Carlton (1997) and Jolley and Pierre (1977) who concluded that NO_3^-- N accumulation increased rapidly with excessive application rate applied to corn.

For both years, the pattern of NO_3^-- N distribution in the soil profile showed that the largest amount of residual NO_3^-- N accumulated in the top 30 cm of soil profile (Figs. 1 and 2). Only in 1998, with the greatest effluent N rate, there was an increase in residual soil NO_3^-- N at the 30 to 60 cm depth. It is not likely that large amounts of NO_3^-- N leached below 90 cm depth. In 1988 and 1999for late-season irrigation, total NO_3^-- N in the top 90 cm of soil profile ranged from 10 kg ha^{-1} and 11.4 kg ha^{-1} with no effluent applied (control plot) to 11 kg ha^{-1} and 13 kg ha^{-1} with 2.5 ha-cm effluent applied in September and 24 kg ha^{-1} and 25 kg ha^{-1} with October irrigation, respectively. For both years, October irrigation significantly increased total residual soil NO_3^-- N by approximately 50 % compared to control.

CONCLUSIONS

Results from this study indicate little advantage in bermudagrass dry matter production and uptake of N and P from applying swine effluent at rates greater than 10 ha-cm (380 kg N and 75 kg P ha^{-1}) during the summer months .

Late-season irrigation in October decreased N and P recoveries and resulted in accumulation of NO_3^- -N in the soil profile which could lead to an increase in the potential contamination of water resources.

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Table 1. Chemical and physical properties of Vaiden soil used in this study.

Soil parameter	
pH	5.5
Total N, %	0.15
CEC, $Cmol_c\ kg^{-1}$	15
Texture	Silty clay
Bulk density, $g\ cm^{-3}$	1.32

Table 2. Nitrogen and P applied from swine lagoon effluent irrigation in 1998 and 1999.

Effluent irrigation		1998		1999	
		N	P	N	P
In-season	Late-season				
------ha-cm-----		kg ha^{-1}			
0	--	0	0	0	0
5	--	213	43	215	31
10	--	381	75	365	74
10	2.5 (Sept.)	464	96	444	94
10	2.5 (Oct.)	459	94	446	95
15	--	528	108	516	118
20	--	660	145	670	163

Table 3. Average swine lagoon effluent analysis for irrigation performed in 1998 and 1999.

Parameters	1998	1999	Average
pH	7.6	7.8	7.8
EC, mmhos cm^{-1}	3.6	3.8	3.7
Total solid, g L^{-1}	2.5	2.3	2.4
TKN, mg L^{-1}	327	354	341
NH_4^+ - N, mg L^{-1}	261	294	280
NO_3^- - N, mg L^{-1}	11	7	9
Total P,mg L^{-1}	71	80	76
Water soluble P, mg L^{-1}	58	65	62

Table 4. Effects of swine lagoon effluent in-season and late-season irrigation on bermudagrass yield in 1998 and 1999.

Effluent irrigation	Dry matter	
In-season	1998	1999
(ha - cm)	kg ha^{-1}	
0	3112	1900
5	10184	6709
10	11722	8407
15	12421	9909
20	13071	11673
Linear	*	**
Quadratic	**	**
Late-season		
10 (Control)	1220	278
10 + 2.5 (1 September)	2975	1074
10 + 2.5 (1 October)	2115	714
Contrast		
September vs October	**	**

* Significant at P = 0.05 level

** Significant at P = 0.01 level

Table 5. Monthly precipitation for experimental site.

Month	1998	1999
	cm	
April	12.5	8.3
May	11.8	6.2
June	15.3	10.8
July	19.5	2.2
August	7.6	1.9
September	4.3	3.5
October	5.5	3.5
November	10.9	5.02

Table 6. Effects of swine lagoon effluent in-season and late- season irrigation on N and P uptake by bermudagrass in 1998 and 1999.

Effluent irrigation	1998		1999	
In-season	N	P	N	P
(ha-cm)	kg ha^{-1}			
0	40	7	27	4
5	176	24	129	12
10	231	26	188	16
15	257	27	220	19
20	302	34	265	22
Linear	*	**	**	**
Quadratic	**	*	*	*
Late -season				
10 (Control)	19	2.2	8	0.4
10 + 2.5 (September)	61	6.1	25	2.2
10 + 2.5 (October)	31	2.7	12	0.8
Contrast				
September vs October	**	**	**	**

* Significant at P = 0.05 level

** Significant at P = 0.01 level

Table 7. Effects of swine lagoon effluent in-season and late- season irrigation on N and P recovery by bermudagrass in 1998 and 1999.

Effluent irrigation	1998		1999	
In-season	N	P	N	P
(ha-cm)	%			
5	64	40	47	28
10	50	25	44	17
15	41	19	37	13
20	40	18	36	11
$LSD_{(0.05)}$	7.7	5.2	5.6	5.4
Late-season				
10 + 2.5 (September)	51	19	27	10
10 + 2.5 (October)	20	11	12	5
Contrast				
September vs October	**	**	**	**

* Significant at P = 0.05 level

** Significant at P = 0.01 level

Table 8. Effects of swine lagoon effluent in-season and late-season irrigation on residual soil NO_3^--N in the top 90 cm of soil profile in 1998 and 1999.

Effluent irrigation	1998	1999
In-season	---------------------- kg ha^{-1}	---------------------
(ha-cm)		
0	5	2
5	10	3.5
10	12	11
15	14	26
20	41	32
LSD$_{(0.05)}$	28	11
Late-season		
10 (Control)	10	11
10 + 2.5 (September)	11	13
10 + 2.5 (October)	24	25
Contrast		
September vs October	**	**

** Significant at P = 0.01 level

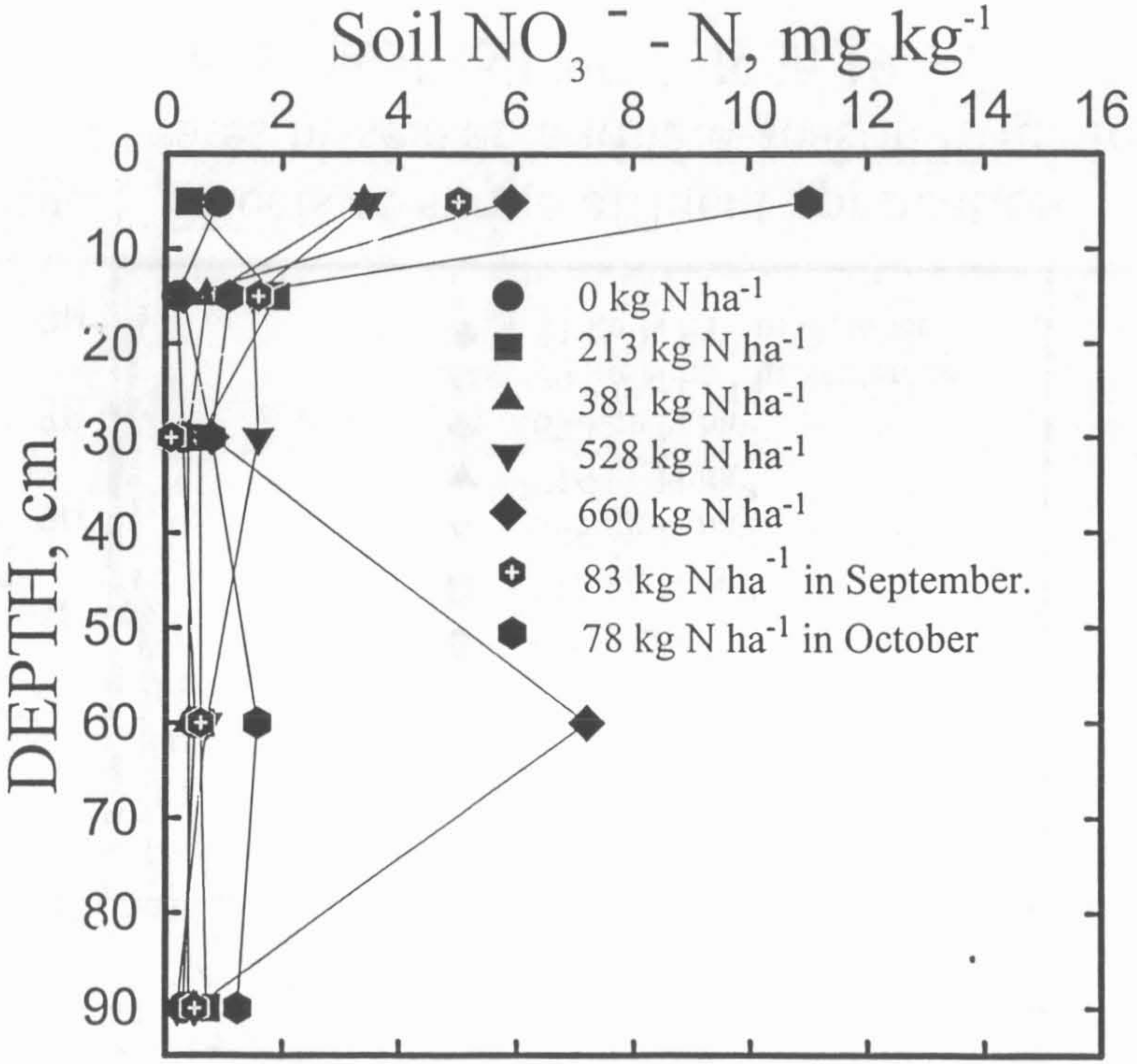

Fig. 1. Effects of swine effluent application rates in-season and late-season irrigation on residual soil NO_3^- -N in 1998.

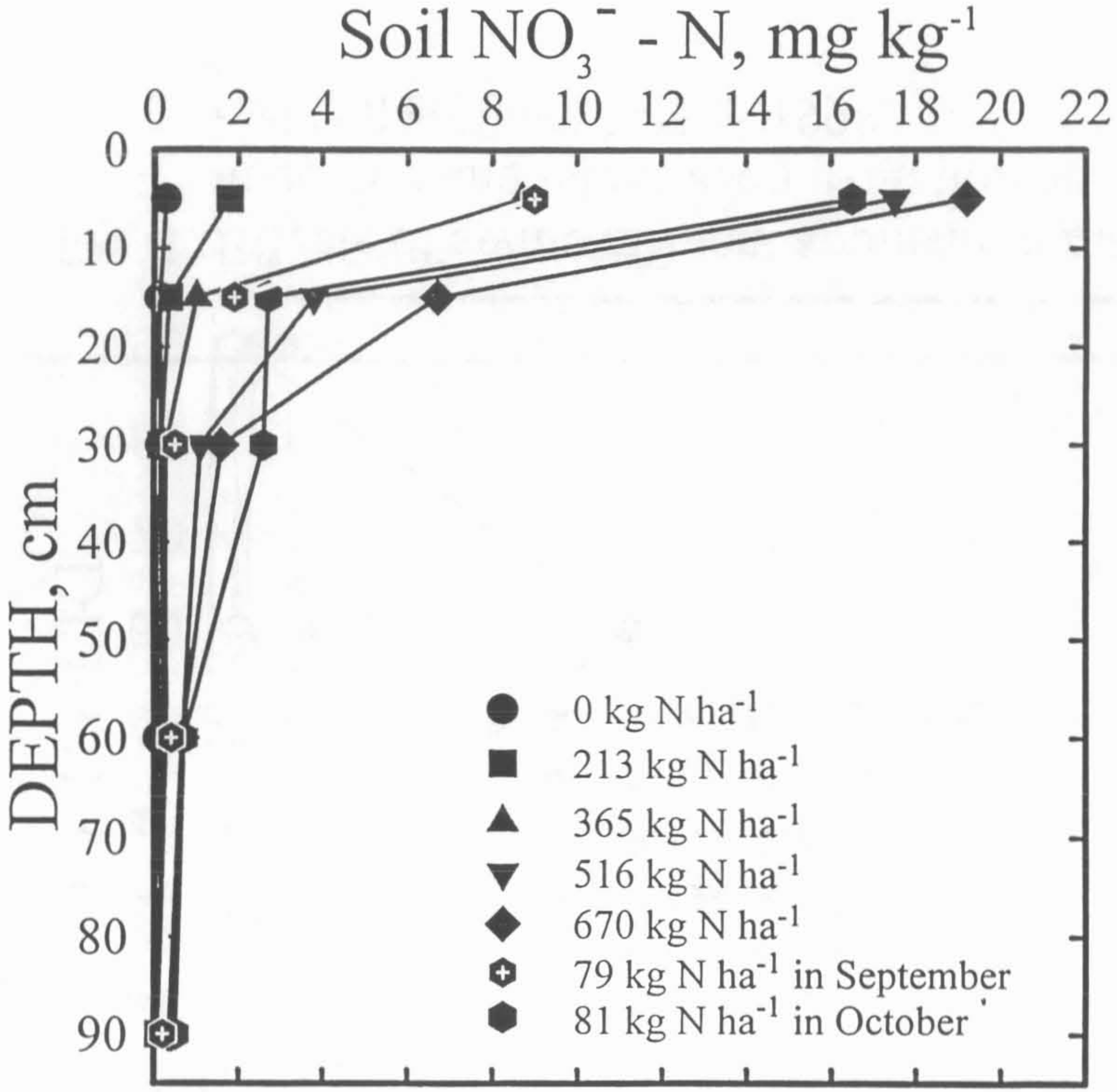

Fig. 2. Effects of swine effluent application rates in-season and late-season irrigation on residual soil NO_3^- -N in 1999.