Selected Soil Chemical Properties and Corn Grain Yield Under Different Manure Systems[1]

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Introduction

The Iowa Department of Agriculture and Land Stewardship estimated 1987 farm animal populations to be 4.6 million cattle and calves and 13.8 million hogs and pigs (26% of the nation's hogs). The animals produced about 141,987 tons of plant available N if 50% of the excreted N is available the first year of application. This amounts to 22 lb of N for every corn acre in Iowa. Most of the livestock operations are intensive with high populations of animals on a small land area. Nutrients in feed are imported to meet the demands of the animals, but no system exists to redistribute the nutrients contained in the animal manure. The manure is often disposed of on a small land area, sometimes creating an environmental hazard to local surface water and groundwater. The objectives of this project were to evaluate changes in soil NO_3-N and determine the effect on corn grain yield and the potential for groundwater contamination from different manure systems. Soil reaction was measured to estimate the salinity hazard to corn from repeated applications of manure.

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Materials and Methods

In the spring of 1989 a field experiment was established in central Iowa (Hamilton County) at the Cenex/Land O'Lakes Answer Farm. Soil at the plot site was Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls) on a 2% slope. The field had been in a corn/soybean rotation and was planted to soybeans prior to the start of the experiment. A second experiment was established near Ames, Iowa on the ISU Curtiss Farm in the fall of 1989. Soil at the Curtiss Farm site was Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludolls) on a 1% slope. This site had been in continuous corn production for several years before the start of the experiment. Manure had not been applied at either site within 10 y of the start of this experiment. Selected initial soil properties for the two sites are shown in Table 1.

Table 1. Initial values of selected chemical characteristics of the soils in this study to a depth of 36 inches.

	Nicollet l			Webster sicl		
Depth (in)	0-12	12-24	24-36	0-12	12-24	24-36
NH_4-N, ppm	4.0	2.7	2.2	3.7	2.8	2.7
NO_3-N, ppm	2.5	3.6	3.7	9.8	7.7	8.9
Bray-P, ppm P	14.7	6.8	4.1	31.8	15.5	2.6
O.C., %	4.6	2.6	1.4	5.6	3.3	1.5
pH	6.1	6.8	7.5	6.8	7.2	7.2
EC, mmhos cm^{-1}	0.4	0.5	0.5	0.6	0.5	0.7

Manure was applied at two rates based on total N concentration: a low rate that would supply approximately 165 lb total-N a^{-1} and a high rate that would supply 330 lb total-N a^{-1}. Control plots were included for each method of application. Published values of liquid manure nutrient content were used to determine the quantity of manure needed for each plot. Dairy manure was applied at approximately 3600 gal a^{-1} for the low rate and 7200 gal a^{-1} for the high rate. Poultry manure rates were calculated to be about 2200 gal a^{-1} and 4400 gal a^{-1}. Swine manure was applied at 3000 gal a^{-1} and 6000 gal a^{-1}.

A standard 3000 gal pressure/vacuum tank equipped with two knives spaced about 50 in apart was used to apply the manure. Manure flow from the injector knives was measured to calibrate the equipment. The proper amount of manure was applied by adjusting the speed of the tractor. Two overlapping passes were made on each plot to more evenly distribute the manure. Broadcast applications were made with the knives in an upright position. The knives were lowered to a depth of about 6 in for injected treatments. Within 2 d of manure application the plots were disked to prepare a seedbed for planting. Manure samples were collected at the time of application and preserved in tightly capped plastic bottles by refrigeration at 40°F until analysis by the Analytical Services Laboratory at Iowa State University (Table 2). Storage time was generally about one week.

Six-row plots (15 by 40 ft) were arranged in a split-plot design with four replications. The main-plot was the method of manure application and the sub-plots

Table 2. Selected chemical analyses of the different manures used in this study.

Manure	Date	Total-N	Total-P	Total-K	Solids
		----------- ppm	---------		wt. %
Dairy	4/89	9070	4470	15.3	3.7
	1/90	3328	2068	3870	8.6
	4/90	2700	587	3140	7.7
	1/91	2800	680	2520	7.5
	6/91	1470	380	1690	3.5
Poultry	4/89	7780	2466	2140	15†
	4/90	8240	3770	4810	9.7
	6/91	7190	2040	4030	6.9
Swine	1/90	6142	4349	3280	5.4
	4/90	8130	2390	4160	8.1
	1/91	6150	2340	2760	5.8
	5/91	10 600	3780	4850	12.9

† Estimated value.

were the application rates. In the spring of 1989, 1990, and 1991, prior to planting, liquid dairy manure was broadcast and injected and liquid poultry manure was injected at the Answer Farm site. In 1990 and 1991 liquid swine manure was broadcast and injected at the Curtiss Farm site. Urea-ammonium nitrate (UAN, 28% N w/w) was also applied at the Curtiss Farm site by broadcasting over the surface and then incorporating just before planting. During the winters of 1990 and 1991 liquid dairy manure was broadcast over frozen ground at the Answer Farm and liquid swine manure was broadcast at the Ames site. Both winter applications at the Answer Farm took place on very cold days, 14° to 18°F, with 6 to 12 in of snow cover. The first winter application at the Ames site was on a relatively warm day, about 37°F with no snow cover. The second application, in 1991, was on a very cold day, 18°F, with about 8 in of snow cover.

In addition to total-N, subsamples of manure were analyzed in an effort to evaluate inorganic N (N_i; $N_i = NH_4\text{-}N + NO_3\text{-}N$) concentrations of the manure and the relationship between N_i and total-N (Table 3). The proportion of N_i to total-N remained fairy constant throughout the experiment and with the different manures measured. In 1989, the poultry manure was diluted with water to make it thin enough to be applied with the manure tank. A subsample of undiluted manure and a sample of diluted manure were collected and analyzed for N. The undiluted sample was also used to determine solid content. The amount of water added to the diluted sample was

Table 3. N_i and the ratio of N_i to total-N of dairy and swine manures at selected sampling dates.

Manure	Date	NH_4-N	NO_3-N	N_i/Total-N
		----- ppm ------		
Dairy	1/90	1178	1.3	0.35
	1/91	1043	1.4	0.37
Swine	1/90	1828	0.9	0.30
	1/91	2570	1.0	0.42
	5/91	4206	1.1	0.40

determined from the difference in N concentration between the two samples. This dilution factor was used to determine the solid content of the diluted sample

The N content of the manure varied from the average values used in the initial calculations and was unknown until after the manure was applied and analyzed. Therefore, the amount of N actually applied was determined after analysis of the manure was complete. Table 4 shows the amount of N, P, and K actually applied with the manure at the two application rates.

The soil at each plot was sampled throughout the growing season. Three 1-in diameter soil cores, 36 in deep, were collected in 12-in increments from each plot. Core positions were located diagonally across the center portion of each plot. The first samples were collected before spring-manure application and again about one week later. Samples were collected until harvest. The soil was dried and ground to pass a 2-mm sieve. In 1989, subsamples were extracted with 2*M* KCl for NH_4-N analysis and 0.1*M* $Al_2(SO_4)_3$ for NO_3-N analysis using ion specific electrodes (ISE) (Keeney and Nelson, 1982). In 1990 and 1991, soil samples were extracted with 2*M* KCl and analyzed colorimetrically for NH_4-N and NO_3-N by flow injection analysis (FIA) (Lachat Instruments, Milwaukee, WI).

Soil samples were also analyzed for electrical conductivity (EC) and pH. EC is an indicator of the relative salt content of a sample. A water-saturated paste was made of each composite soil sample using standard procedures (Rhodes, 1982) and was analyzed for pH using a combination pH electrode. The saturated paste was then

Table 4. Total N, P, and K supplied with each manure application.

Manure	Date	Total-N		Total-P		Total-K	
		Low	High	Low	High	Low	High
				$lb\ a^{-1}$			
Dairy	4/89	263	527	145	290	0.5	1
	1/90	96	192	67	134	126	252
	4/90	79	156	19	38	102	204
	1/91	81	162	22	44	82	164
	6/91	43	86	12	24	55	110
Poultry	4/89	135	--[†]	48	--	42	--
	4/90	143	286	74	147	94	187
	6/91	125	250	39	79	78	157
Swine	1/90	156	312	117	234	88	176
	4/90	304	407	100	133	172	221
	1/91	147	295	63	126	74	149
	5/91	254	507	101	202	130	260

[†] The high rate of poultry manure was not applied in 1989.

vacuum filtered and the soluble salt content (EC) of the extract was determined by resistance measurements.

In the fall of each year, corn grain yield was determined by hand harvesting 20 ft of the two center rows in each plot. Yields are reported at 15.5% moisture content.subsample of the grain was dried and ground for total-N analysis with an H_2SO_4/H_2O_2 digestion (HACH Company, Loveland, CO). Total-N was determined colorimetrically by using Nessler reagent.

The effect of manure treatment on soil N_i concentrations was statistically analyzed using the GLM (General Linear Models) procedure (SAS Institute, 1982). The independent parameters of the statistical model were manure treatment, which was defined as type of manure application (spring broadcast, spring injected, or winter broadcast manure), rate of manure application (no manure, low rate, and high rate), sampling depth, and sampling time. The model evaluated the effects of the independent variables and their interactions on soil NH_4-N and NO_3-N for each year of the experiment. The analysis was completed for each year of the experiment independently of the other years. The effects of manure application on corn grain yield were analyzed using ANOVA (Analysis of variance). The difference between means was evaluated using the SAS LSD procedure (SAS Institute, 1982).

Results and Discussion

Conditions at each site varied greatly from 1989 until 1991. Because of the variability between years each site was treated separately for the statistical analysis.

Poultry Manure

Poultry manure was applied at the Answer Farm site before planting in 1989, 1990, and 1991. In 1989, the low rate of poultry manure supplied about 135 lb total-N a^{-1} and average yield from these plots was 217 bu a^{-1} which did not differ significantly from the control plot yield of 192 bu a^{-1} (Table 5). All plots at the Answer Farm yielded relatively high during the first year of the experiment which suggested the presence of a pool of readily mineralizable organic N in the soil profile.

In subsequent years, 1990 and 1991, poultry manure treated plots produced average yields that were higher than yields from other treated plots at the site that had received higher amounts of total-N from dairy manure. This, in part, may be due to higher N availability from poultry manure. It has been reported that poultry manure has a higher concentration of inorganic N than other animal manures. However, some of the response to poultry manure may also have been from P added with the manure. Poultry manure applied in 1990 and 1991 had 5 to 6 times as much P as dairy manure applied at the same time. This additional P may have provided an advantage to corn, especially in cool, wet conditions. All corn growing on poultry manure treated plots was darker green and more vigorous than corn from dairy manure treated plots early in the season. The improved growth was noticeable until harvest. In addition, in 1990 and 1991, corn on all plots treated with injected manure had better growth than corn on plots that received broadcast manure.

Dairy Manure

In 1989, dairy manure was only applied in the spring. The first winter applied dairy manure was put out in January 1990. Corn grain yield after the first year of the experiment showed no significant difference between injected and broadcast dairy manure (Table 5). In 1990, injected dairy manure tended to produce higher yields than broadcast dairy manure. Spring applied dairy manure (injected and broadcast) produced higher yields than winter broadcast dairy manure and yield increased with increasing application rate. Under winter broadcast dairy manure yields decreased as manure application

Table 5. Corn grain yields from the Answer Farm site.

	Rate	0 N	Dairy				Poultry	
			N	Winter	Spring	Spring	N	Spring
Year	Category	Yield	Rate	Bcst.	Bcst.	Inj.	Rate	Inj.
		bu a^{-1}	lb a^{-1}	------- bu a^{-1} -------			lb a^{-1}	bu a^{-1}
1989	Low		263		187	180	135	217
	High		527		224	213		
Ave.		192			206	197		
1990	Low		78, 96[†]	59	63	74	143	100
	High		156, 192	58	66	89	286	108
Ave.		57		59	65	82		104
1991	Low		43, 81	91	80	93	125	100
	High		86, 162	106	83	92	250	97
Ave.		72		99	82	93		99

[†] N Rate is for the winter and spring dairy manure applications, respectively.

rate increased. Severe N deficiencies were observed in plots that received winter manure which may help explain the lower yields. In these plots resistant, undecomposed litter, like bedding straw and undigested feed was preserved on the soil surface until spring. This residue appeared after snowmelt as distinct bands across all winter treated plots. Incorporating this material into the soil during spring tillage could result in N immobilization in the soil profile. In 1991, spring injected dairy manure again tended to produce higher yields than spring broadcast dairy manure. However, winter applied dairy manure produced some of the highest yields at the site. The concentration of total-N in the winter manure was almost double the amount in the spring dairy manure and the N deficiencies of the year before were not as apparent.

Swine Manure

Swine manure was applied at the Curtiss Farm site in 1990 and 1991. Yield from this site is shown in Table 6.

It seemed that the potential for N immobilization found with dairy manure was not a factor with swine manure. Yields with winter applied swine manure were comparable to yields from plots that received a spring application of UAN. UAN-treated plots produced the highest yields at the site.

Spring injected swine manure tended to produce higher yields than spring broadcast swine manure. Some visual differences were observed between these plots. The difference in corn appearance was not as striking as at the Answer Farm site, however, corn growing in plots that had received injected manure treatments appeared more vigorous.

Table 6. Corn grain yields from the Curtiss Farm site.

			Swine				UAN	
	Rate	0 N	N	Winter	Spring	Spring	N	Spring
Year	Category	Yield	Rate	Bcst.	Bcst.	Inj.	Rate	Bcst.
		bu a^{-1}	lb a^{-1}	------- bu a^{-1} -------			lb a^{-1}	bu a^{-1}
1990	Low		156, 303[†]	85	83	117	165	104
	High		312, 407	123	82	91	330	136
Ave.		76		104	83	104		120
1991	Low		147, 254	89	87	134	165	82
	High		295, 507	73	107	105	330	146
Ave.		59		81	97	120		114

[†] N Rate is for the winter and spring swine manure applications, respectively.

Soil Profile NO_3-N

There were temporary increases in soil NO_3-N concentrations each year. Soil NO_3-N concentrations increased in the spring after treatments were applied and soil temperature increased but, in general, they decreased over the three years of the experiment. As the crop became established each year, soil NO_3-N concentrations decreased, most likely the result of plant uptake.

The highest soil NO_3-N concentrations were found in plots that received the urea-ammonium nitrate fertilizer (Fig. 1). Nitrate-N concentration of the soil surface was almost twice that at the bottom of the sampled profile. Nitrate-N concentrations had returned to initial levels by harvest each year.

Soil NO_3-N concentrations in plots treated with poultry manure were also relatively high at the beginning of the experiment (Fig. 2). Other manure treatments supplied higher total-N than poultry manure (Table 4), however, poultry manure had higher concentrations of soil NO_3-N. This suggested that the poultry manure had a greater concentration of inorganic N or the organic fraction was more readily mineralized than with dairy or swine manure. Soil treated with poultry manure also had higher concentrations of NO_3-N deeper in the profile than dairy or swine manure indicating some NO_3-N leaching may have occurred. Soil NO_3-N concentrations were relatively low, less than 10 ppm, however, at higher application rates the potential exists for NO_3-N movement through the soil profile.

Soil NO_3-N levels in plots treated with spring injected dairy manure (Fig. 3) showed a seasonal increase after manure was applied. During the three years of the experiment soil NO_3-N concentration in the bottom of the sampled profile was usually close to soil NO_3-N concentrations in untreated control plots. This indicates that at these application rates there was no more NO_3-N leaching from these treated plots than under the control plots. In general, all plots treated with dairy manure exhibited N deficiency symptoms each year of the experiment. The low concentration of NO_3-N in these soils indicated that the crop was probably extracting as much NO_3-N from the soil as possible. Corn grown in plots treated with swine manure also showed N deficiency symptoms suggesting similar conditions.

Manure applied over frozen ground during the winter showed soil NO_3-N concentrations increased in the spring (Fig. 4). Again, as the corn crop developed, soil NO_3-N concentrations decreased. At harvest soil NO_3-N concentrations were near initial levels.

The figures presented are representative of the other manure treatments and application rates. In all manure treated plots, at each rate, there was the characteristic increase in soil NO_3-N concentration early in the season followed by a decrease at later stages of plant growth when nutrient requirements are greater. In general, soil NO_3-N concentrations were relatively low, suggesting that there was not a major threat to groundwater quality.

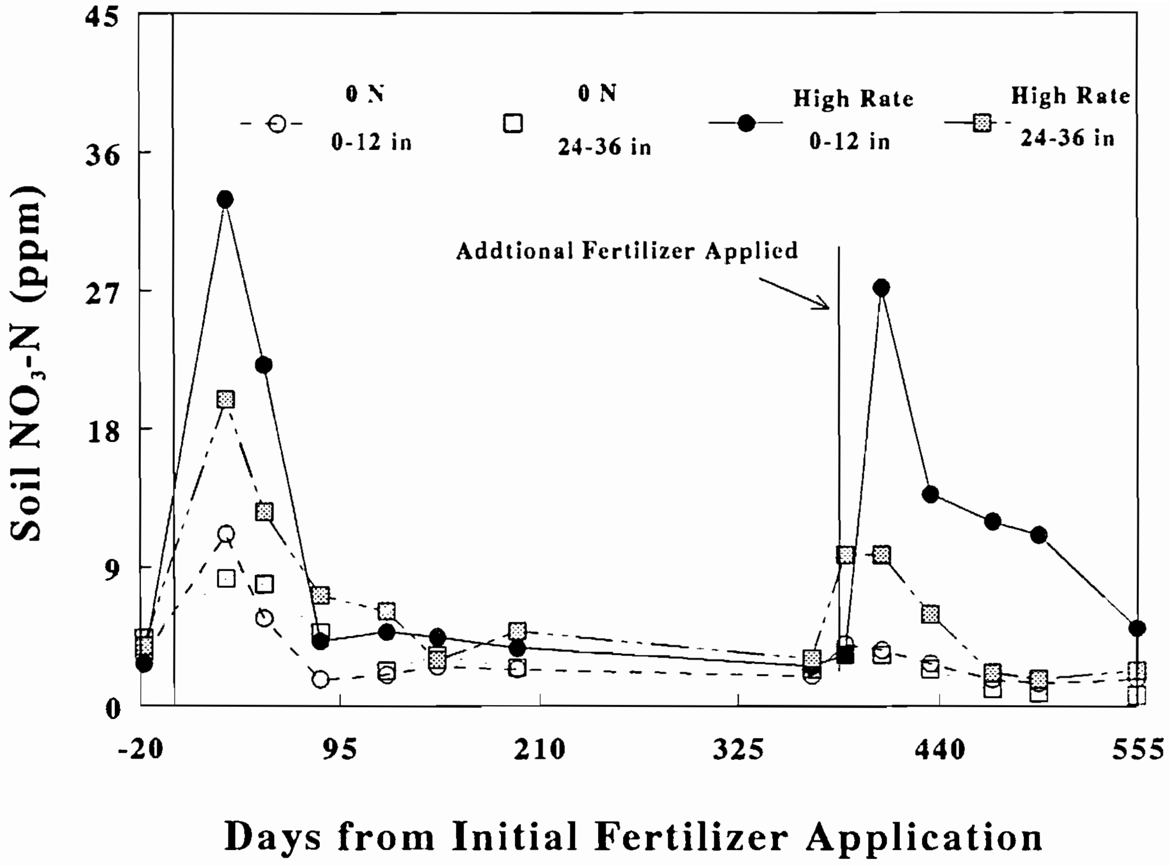

Figure 1. NO_3-N concentrations at two depths of soil treated with urea-ammonium nitrate fertilizer at the Curtiss Farm site for the two years of the experiment.

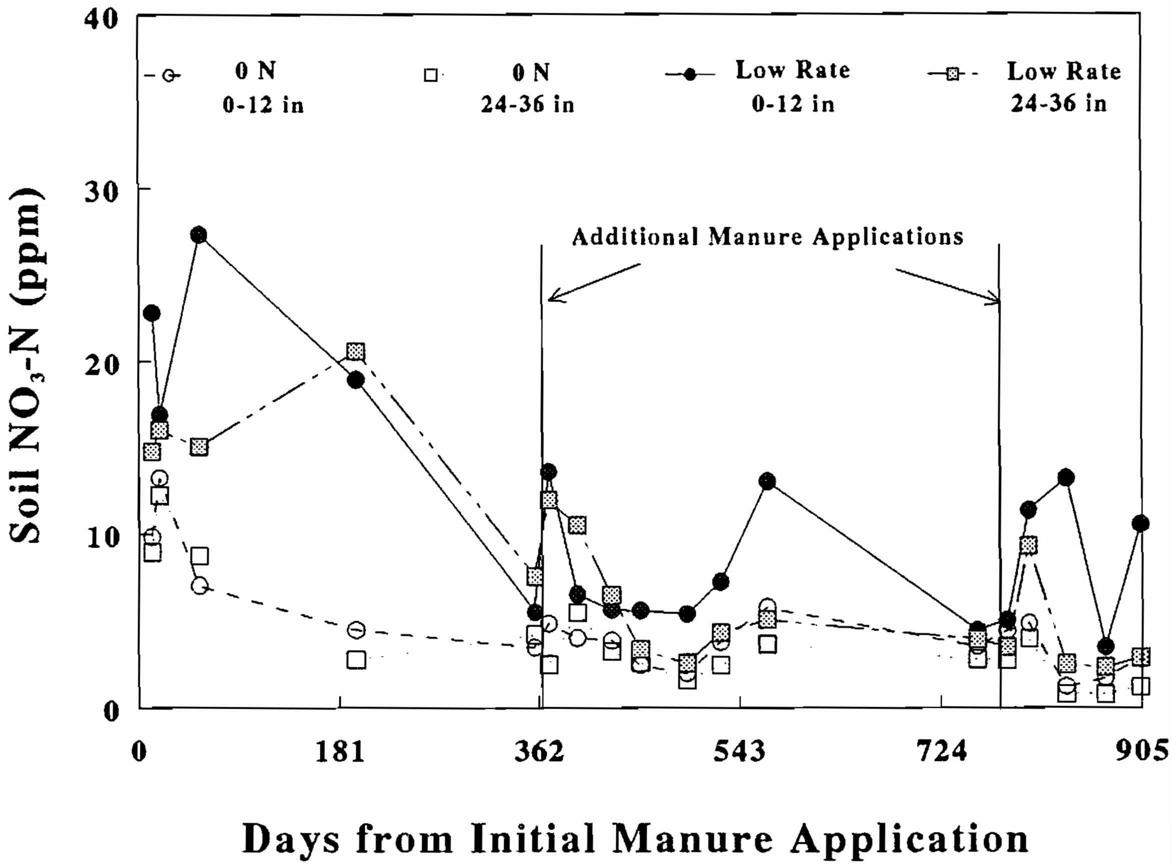

Figure 2. NO_3-N concentrations of at two depths of soil treated with injected poultry manure.

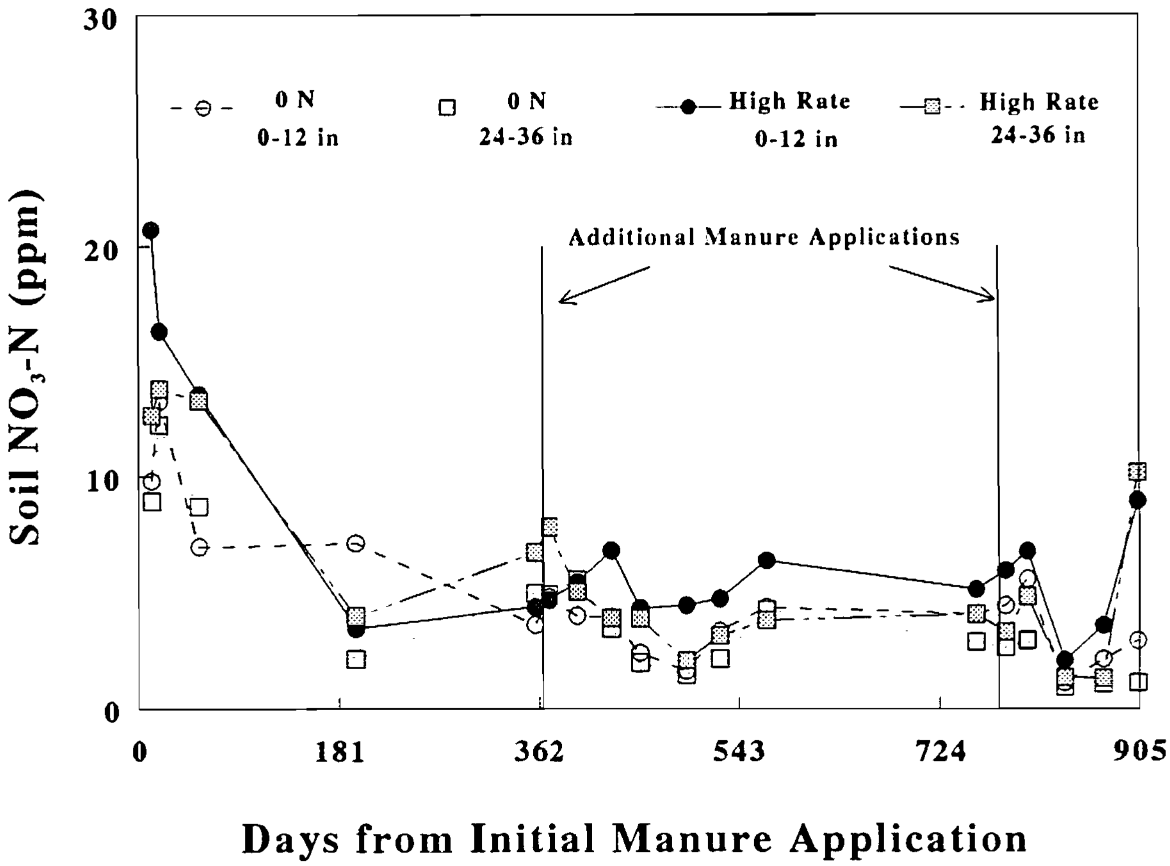

Figure 3. NO_3-N concentrations at two depths of soil treated with injected dairy manure at the Answer Farm site for the three years of the experiment.

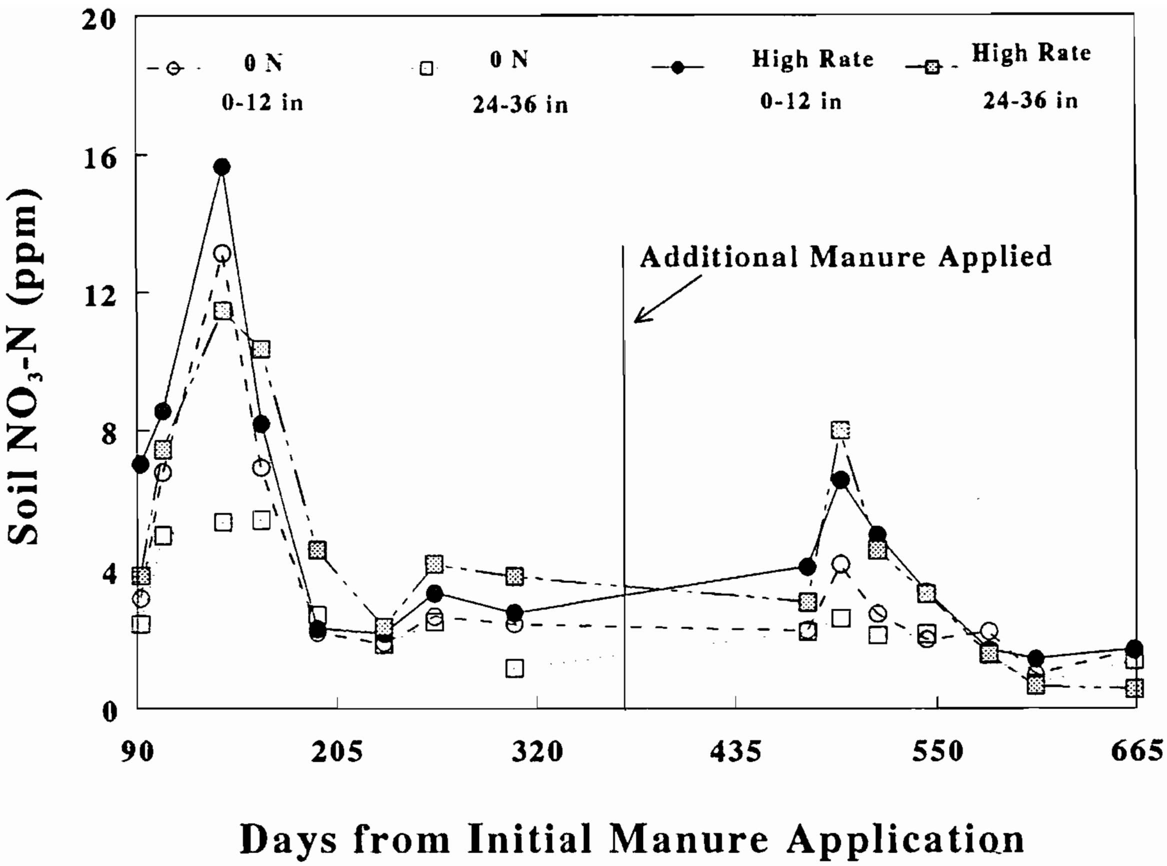

Figure 4. NO_3-N concentrations at two depths of soil treated with winter broadcast swine manure at the Curtiss Farm site during the two years of the experiment.

Soil Reaction

Soil samples were collected from the experimental plots throughout each growing season to measure the effect of manure application on soil electrical conductivity (EC) and pH. A threshold EC value of 1.7 mmhos cm^{-1} for corn has been reported. Above the threshold level yield decreases may be expected. A 10% yield reduction may occur if EC levels reach 5 mmhos cm^{-1} and at EC values of 7 mmhos cm^{-1} yields may be reduced by 50%.

In plots where poultry manure was applied soil EC values were as high as 1.2 mmhos cm^{-1}. Poultry manure produced some of the highest EC values at the Answer Farm site (Fig. 5). When dairy manure was applied EC values were up to 0.8 mmhos cm^{-1}. The highest values occurred early in the season after manure application. By the next spring sampling time EC levels in all plots had returned to initial levels.

Swine manure injected at the Curtiss Farm produced EC values as high as 2.1 mmhos cm^{-1}. The injected treatments showed the highest EC values and also the greatest variability across the plot because of the concentration of manure in bands. In all plots EC values had returned to initial levels before planting the next crop.

Manure applied in the winter showed relatively small increases in EC and the level generally was similar to EC values in control plots (Fig. 6).

Relative changes in soil pH from the application of manure at the two

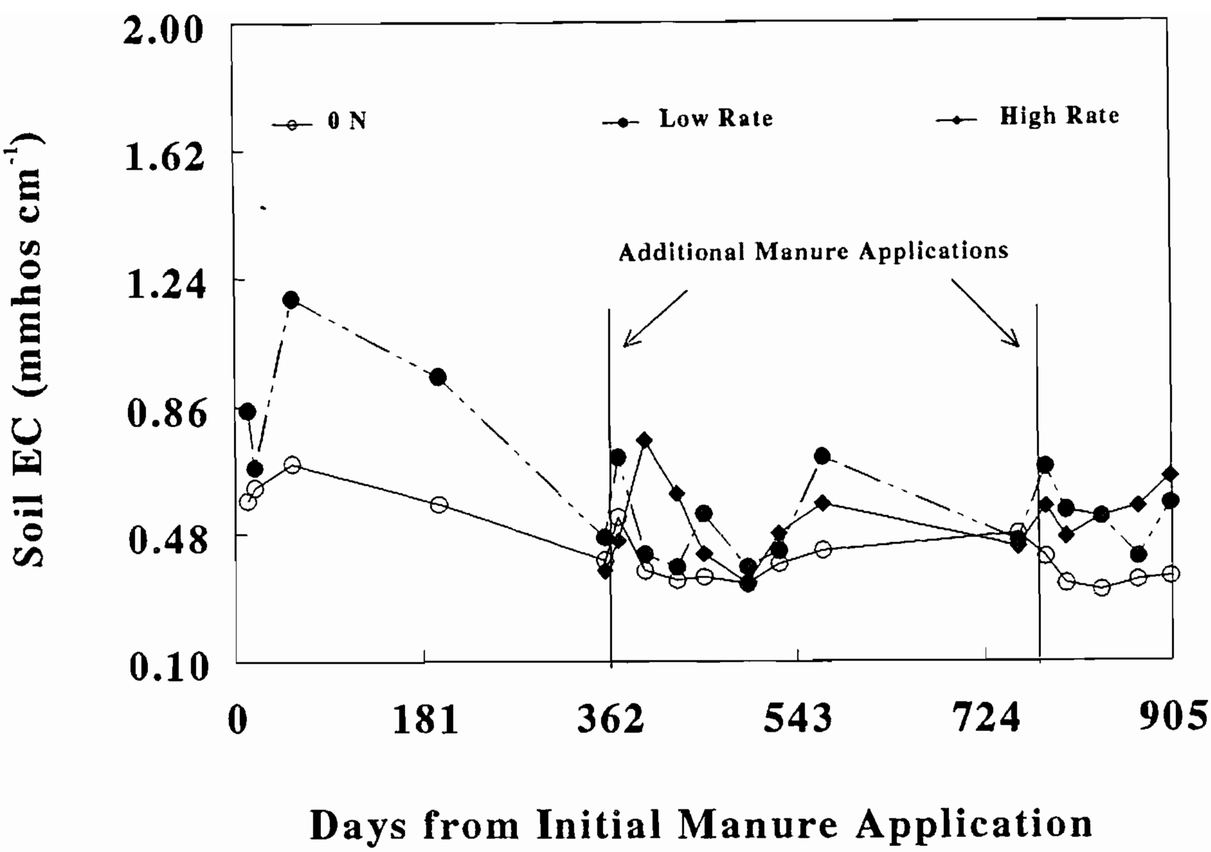

Figure 5. Soil electrical conductivity (EC) in the surface foot of soil treated with poultry manure injected in the spring at the Answer Farm site.

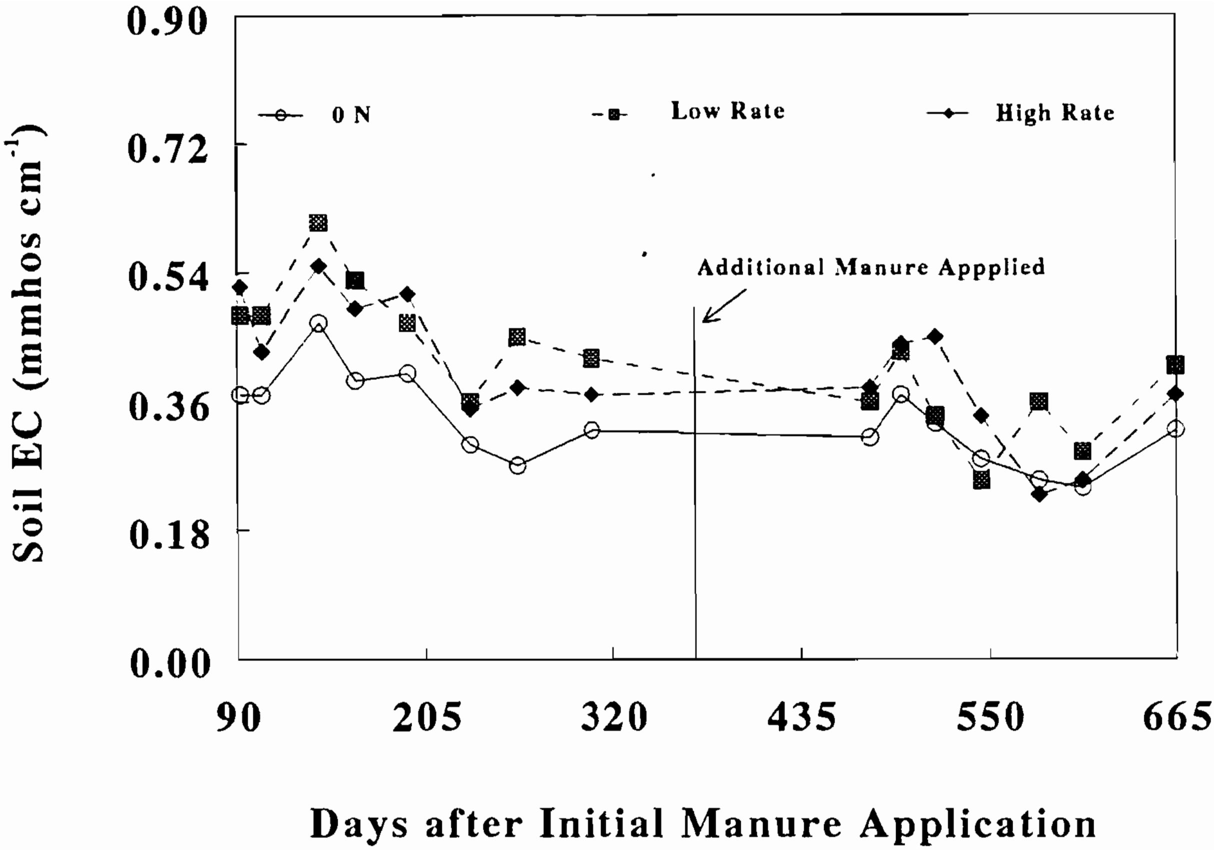

Figure 6. Soil EC in the surface foot of plots treated with swine manure broadcast over frozen ground at the Curtiss Farm site.

sites were small. Soil pH varied less than 1 unit from initial values over the entire experiment. Moreover, these differences were not significant. The only significant source of pH variation at either site was sampling depth. Soil pH increases naturally with depth in these soils and was not influenced by manure applications. The general trend showed small increases of soil pH with high rates of dairy manure. High rates of poultry manure produced slightly lower soil pH values. Higher soil pH values from plots that received broadcast manure may be due to volatilization of ammonia-N from the manure. Applying manure during the winter produced pH values that were similar to values from control plots. When swine manure was applied soil pH generally was slightly lower than control plot pH values.

Summary

Liquid dairy, swine, and poultry manures were evaluated at two sites in central Iowa. Manure was broadcast in the winter and was broadcast and injected in the spring. Urea-ammonium nitrate (UAN, 28% N w/w) was also broadcast in the spring before planting at one site. No other source of plant nutrients was provided. Soil samples were collected from the plots to observe the effect of treatment on N_i concentrations during the growing season. Corn grain yield was also measured at harvest.

First year corn grain yields at the Answer Farm site showed little difference among treatments. Yield from all Answer Farm plots was relatively high, suggesting the possibility of the presence of a pool of readily mineralizable organic N in the soil profile. High manure rates did produce higher yields than other plots.

In subsequent years, corn grain yields were lower and treatment differences were observed at both sites. Moderate to severe N deficiencies occurred on manure-treated plots suggesting that the manure did not adequately supply the N requirement of the crop.

The concentration of N_i in the soil profile was low. There were indications of NO_3-N movement in the profile. The concentration of NO_3-N in the soil profile was low enough to suggest that there was not a major threat to groundwater quality. In addition, the lower part of the soil profile was wet at various times during the growing seasons at both sites. The potential for denitrification in the profile was not evaluated; however, conditions did exist that make N loss from denitrification a possibility. When the last soil samples were collected in 1991, profile NO_3-N concentrations decreased with depth, indicating very little downward movement of NO_3-N. At higher application rates NO_3-N leaching could become a problem.

When manure was applied during the winter over snow-covered frozen ground the greatest potential for NO_3-N movement may be in run-off as the snow cover melts.

Poultry manure produced the highest average EC value during the first year of the experiment, 1.2 mmhos cm^{-1}. This was below the threshold level of 1.7 mmhos cm^{-1} reported for corn, therefore, EC was not considered to be a major factor affecting grain yield. Each application of poultry manure increased soil EC early in the season and levels generally remained higher than the EC of control plots. Soil EC returned to initial levels before the next manure application the following spring suggesting the possibility of water movement through the profile after harvest. Broadcast dairy manure also increased soil EC early in the season. Again, EC levels had dropped in samples collected at later dates but were higher than control plot EC values at harvest and had returned to initial values before the next manure application. Spring injected manure showed moderate increases in soil EC spread out over the growing season. Higher variability of EC in soil samples collected from injected manure plots was noticed. The concentration of manure in isolated bands across the plot may produce small areas with EC values above the threshold level for corn. Given these conditions, corn growing in the areas with high EC could suffer yield reductions, while the average EC values across the remainder of the plot may be considerably lower.

The rates and types of manure applied to these soils had no significant effect on soil pH.

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