

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

Order Number 9311542

**Selected soil chemical properties and corn yield under different
manure systems**

Wetterauer, Donald G., Ph.D.

Iowa State University, 1992

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

**Selected soil chemical properties and corn yield
under different manure systems**

by

Donald G. Wetterauer

**A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY**

**Department: Agronomy
Major: Soil Fertility**

Approved:

Signature was redacted for privacy.

In ~~Charge~~ of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

**Iowa State University
Ames, Iowa**

1992

DEDICATION

To my Father with love

He was always encouraging
I wish he could share in this with me

TABLE OF CONTENTS

DEDICATION	ii
INTRODUCTION	1
Explanation of the Structure of this Dissertation	2
PAPER I. SOIL NITRATE AND CORN GRAIN YIELD WITH DIFFERENT TYPES OF LIQUID ANIMAL MANURE	3
INTRODUCTION	4
MATERIALS AND METHODS	9
RESULTS AND DISCUSSION	15
Answer Farm	15
1989 Yield	15
1989 Soil Profile	17
1990 Yield	19
1990 Soil Profile	24
1991 Yield	30
1991 Soil Profile	32
Curtiss Farm	38
1990 Yield	38
1990 Soil Profile	40
1991 Yield	43
1991 Soil Profile	48
SUMMARY	55
REFERENCES CITED	57
PAPER II. SOIL pH AND EC FOLLOWING APPLICATIONS OF LIQUID ANIMAL MANURE	60
INTRODUCTION	61
MATERIALS AND METHODS	64
RESULTS AND DISCUSSION	68
Soil Electrical Conductivity	68
Soil pH	81
SUMMARY	83
REFERENCES CITED	85

GENERAL SUMMARY	87
ACKNOWLEDGEMENTS	89
APPENDIX TABLES	90

INTRODUCTION

There is increasing concern over the environmental impacts of current agricultural practices. Of particular interest is the fate of the large quantities of nitrogen (N) applied to cropland each year, from inorganic and organic sources, and the implications to the quality of our groundwater and surface water. In many areas the problem may be compounded with the presence of livestock confinement facilities. The large quantities of manure produced often become a disposal problem and are a potential risk to the environment if improperly handled.

Of the forms of N in the soil, $\text{NO}_3\text{-N}$ causes the most concern because of its mobile nature. About one-half of the inorganic N (N_i) in animal manure is $\text{NH}_4\text{-N}$. Under normal conditions, when applied to the soil most of the $\text{NH}_4\text{-N}$ is rapidly converted to $\text{NO}_3\text{-N}$ through biological oxidation. As the concentration of $\text{NO}_3\text{-N}$ increases in the soil the potential for leaching into groundwater also increases. Many field studies have shown that when excessive amounts of animal manure are applied to cropland there can be large concentrations of $\text{NO}_3\text{-N}$ reaching the ground water. Few field studies have evaluated the concentrations of $\text{NO}_3\text{-N}$ in the soil profile through the growing season. As manure decomposes and N_i is released into the soil system fluctuations in the concentrations of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ are observed and there may be greater potential for leaching at different times during the growing season. Detailed descriptions of N_i activity during a growing season are needed to develop more effective manure management practices that allow maximum applications to accommodate disposal and maintain acceptable

environmental quality.

Manure may also contain a high concentration of soluble salts. Salts applied with the manure can be detrimental to crop production. Frequently, overapplication of manure leaves a field unproductive as plants are unable to tolerate the amount of salt in the soil profile. In some cases the addition of manure lowers the pH of the soil and solublizes salt already in the profile. The reduction in pH and increase in electrical conductivity (EC) that reflects salt content may be temporary and levels can return to normal after several weeks. Given the right conditions, the increase in soluble salt content of the soil may coincide with seedling emergence slowing growth and ultimately reducing yields. Many studies that evaluate the effects of manure on soil chemical properties do not collect soil samples frequently enough to observe the temporary changes in soil pH and EC.

Explanation of the Structure of this Dissertation

This dissertation contains two papers, each of which was written for submission to scholarly journals. The style follows the format of the Soil Science Society of America Journal. This general introduction precedes the papers of the dissertation and a general summary is found at the end. The first paper deals with manure applied N and the effects of different types of manure, rates, and types of application on corn grain yield and soil inorganic N (N_i) concentrations. The second paper deals with the effects of manure on soil pH and electrical conductivity (EC).

PAPER I. SOIL NITRATE AND CORN GRAIN YIELD WITH DIFFERENT TYPES OF
LIQUID ANIMAL MANURE

INTRODUCTION

Animal manure has long been a resource valued for the essential nutrients it can supply for crop production. The benefits of using animal manure as a source of nutrients for crop production are well known (Jokela, 1992; N'Dayegamiye and Côté, 1989; Shortall and Liebhardt, 1975; Sims, 1987; Sutton et al., 1978; Sweeten and Mathers, 1985; Tiarks et al., 1974). It was common practice in past years for farmers to collect manure from free-roaming range animals for use on cropland. Manure became so important that some farmers began raising animals in confinement, to make manure collection easier (Wadman et al., 1987). With the introduction of mineral fertilizers the need for animal manure decreased. Farmers continue to raise animals in confinement for a variety of other reasons; however, and in many areas the large amount of manure produced is considered waste material and disposal has become a problem (Fratrîc and Parraková, 1977). Of particular concern is the fate of manure applied N.

Sustained production of nonleguminous crops requires large inputs of N to maintain high yields. The use of N fertilizer has been an important factor in increasing agricultural productivity per unit land area. Because of the highly mobile nature of $\text{NO}_3\text{-N}$ in the soil profile, however, there is the potential for movement out of the crop-root zone and into groundwater. Agricultural application of fertilizer N has been shown to be the most significant source of $\text{NO}_3\text{-N}$ found in groundwater and surface water in the U.S. (Hallberg, 1986; Keeney and Follett, 1991). As early as the 1940s the health hazard from drinking water contaminated with $\text{NO}_3\text{-N}$ was known (Fletcher, 1987).

The current maximum concentration limit established by the USEPA is 10 mg $\text{NO}_3\text{-N}$ L^{-1} (CAST, 1985). Even with tremendous quantities of N naturally occurring that are potential sources for $\text{NO}_3\text{-N}$ (Hallberg, 1986; Kenney, 1982), agriculturally applied N is the major concern. There appears to be a linear relationship between increased N fertilizer use and increased $\text{NO}_3\text{-N}$ concentrations of shallow groundwater in areas where the only significant source of $\text{NO}_3\text{-N}$ is applied fertilizer (Hallberg, 1986).

Generally, the amount of fertilizer N applied to cropland has reached a peak. At the current rates in Iowa, approximately 900 000 Mg of inorganic fertilizer N are applied to cropland each year with about 40% of that applied to corn. It has been estimated that only about 45 to 60% of the applied N is actually used by the crop (Smith, 1989). The remainder is lost through leaching, immobilization, or volatilization. The key to controlling the amount of $\text{NO}_3\text{-N}$ leaching from agricultural soils is to regulate the amount of $\text{NO}_3\text{-N}$ in the soil profile. Proper management of applied fertilizers and soil amendments can be effective in reducing the amount of $\text{NO}_3\text{-N}$ reaching water supplies. Decreasing the loss of $\text{NO}_3\text{-N}$ from the soil by leaching can be accomplished by applying less mobile forms of N.

Animal manure contains inorganic ($\text{N}_i = \text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) and organic (N_o) forms of N. In addition, N_o consists of easily decomposed organic compounds with low C/N ratios and resistant, slowly decomposed compounds with high C/N ratios (van Faassen and H. van Dijk, 1987). The amount of each fraction of N is dependent on the type of manure and collection and storage methods. Reported N_i concentration in organic wastes ranges from 20 to 40% of the total N in poultry manure (Sims, 1986; Sims, 1987; Bitzer and Sims, 1988) to around

2% in sewage sludge (Sommers, 1986). When applied, N_i in the manure is immediately available for crop growth, whereas N_0 is mineralized to N_i as manure decomposes. Therefore, with poultry manure for example, about 40% of the N in applied manure is immediately available for uptake or leaching. Losses of relatively immobile N_0 generally occur only as soil is eroded from the field (Martin et al., 1970). Studies have shown that, for comparable N application rates, inorganic fertilizers have greater NO_3 -N leaching losses because of generally higher NO_3 -N concentrations in the soil profile. With manure there is a greater tendency for N loss through denitrification (Kimble et al., 1972; Comfort et al., 1988) rather than from leaching.

Proper management of the large quantities of manure produced each year can supplement and reduce the need for inorganic fertilizers in some areas. There is enough animal manure produced in Iowa to supply about 25 kg plant available N for each hectare of Iowa corn (Killorn et al., 1990). Due to the specialized nature of many farming operations, areas where manure is produced may be separated from cropland where nutrients in the manure can be used. Hauling manure is expensive and time consuming and overapplication to fields near confinement buildings may result. It is well established that when large amounts of manure are applied to small areas of land the potential for environmental contamination greatly increases. In experiments along the East Coast, Liebhardt et al. (1979) found that when poultry manure was applied to coarse-textured soils in excess of crop needs, there was considerable downward movement of NO_3 -N. They found NO_3 -N in the groundwater aquifer at concentrations considerably higher than 10 mg kg^{-1} . Evans et al. (1977) found significant NO_3 -N movement below the rooting zone with two heavy annual

applications of beef and swine manure. Additionally, manure may be applied during the winter months when other farm-related activities are a low priority and the soil may be frozen. Winter-applied manure has a greater potential for reaching surface water supplies (Miner and Willrich, 1970). Mineralization of winter-applied N_0 may also occur and without a crop present leaching and denitrification losses may be expected (Sims, 1986).

A general objective of most work with fertilizer or manure N is to increase fertilizer use efficiency (FUE) minimizing losses of N from the root zone. FUE is defined simply as the percentage of fertilizer N recovered by the crop (Parr, 1973). The ratio NH_4^+/NO_3^- has been used to evaluate the potential for NO_3 -N leaching from a soil profile. In experiments with nitrification inhibitors (NI) Walters and Malzer (1990) used NH_4^+/NO_3^- to determine the effectiveness of NI on decreasing N losses by leaching and improving FUE. They found the NH_4^+/NO_3^- ratios to be consistently higher in the surface 15 cm of soils treated with NI and concluded that nitrification was suppressed reducing the amount of potentially leachable NO_3 -N in the soil profile. In other words, with higher NH_4^+/NO_3^- ratios FUE is potentially greater.

Assessing the potentially leachable NO_3 -N in a soil profile amended with animal manure is difficult at best because there are no simple and reliable methods to determine the rate at which organic matter will decompose and release N. Meer et al. (1987) used apparent N efficiency (ANE) and apparent N recovery (ANR) to evaluate the extent of N losses from manure-soil systems. ANE is defined as the response of dry matter yield per kg applied N in manure and is expressed by:

$$Y = C + ANE * N_g$$

where Y = crop yield
 C = yield from control plots
 N_g = rate of applied N

ANR is the N content of the harvested material expressed as a percentage of N applied:

$$N_y = N_c + ANR * N_g$$

where N_y = N content of harvested material
 N_c = N content of harvested material from control plots
 N_g = rate of applied N

Meer et al. (1987) evaluated the potential for N losses from each system by comparing ANRs and ANEs from manure plots with values from plots that received applications of inorganic fertilizers. They found that broadcast manure systems had ANR values almost one-quarter the value of plots that received inorganic fertilizers and about one-half the value of ANRs from plots where manure was injected.

In the present work, we applied N from different sources of animal manure. The manure was broadcast in winter and spring and injected in the spring before planting corn. An inorganic fertilizer, urea-ammonium nitrate (UAN) was also used. Our objectives were to observe the effect of manure type and method of application on soil $\text{NO}_3\text{-N}$ concentrations during the growing season and to follow the residual effects of the manure on soil N_i concentrations. We also measured corn grain yield to determine the effects of manure application on corn growth.

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 near Fort Dodge. The field had been in a corn/soybean rotation, with the soybean rotation the year prior to the start of the experiment. Soil at the plot site was Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls) on a 2% slope.

A second site was established on the Iowa State University Curtiss Farm near Ames, Iowa (Story County) in the fall of 1989. This site had been in continuous corn production for several years before the start of the experiment. Soil at the Curtiss Farm plot was Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludolls) on a 1% slope. 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.

Two rates of manure, based on the amount of total N applied, were selected: a low rate that would supply approximately 185 kg total-N ha⁻¹ and a high rate that would supply 370 kg total-N ha⁻¹. A control plot was also

Table 1. Initial values of selected physical and chemical characteristics of the soils in this study to a depth of 91 cm.

Depth (cm)	Nicollet l			Webster silcl		
	0-30	30-61	61-91	0-30	30-61	61-91
NH ₄ -N, mg kg ⁻¹	4.0	2.7	2.2	3.7	2.8	2.7
NO ₃ -N, mg kg ⁻¹	2.5	3.6	3.7	9.8	7.7	8.9
Bray-P, mg P kg ⁻¹	14.7	6.8	4.1	31.8	15.5	2.6
O.C., g kg ⁻¹	46	26	14	56	33	15
pH	6.1	6.8	7.5	6.8	7.2	7.2
EC, dS m ⁻¹	0.4	0.5	0.5	0.6	0.5	0.7

included for each method of application. Initial calculations were based on published values of the nutrient contents of liquid manure to determine the quantity of manure needed for each plot. It was determined that dairy manure should be applied at approximately 34 000 L ha⁻¹ for the low rate and twice that amount or 68 000 L ha⁻¹ for the high rate. Poultry manure rates should be about 20 500 L ha⁻¹ and 41 000 L ha⁻¹ and swine manure was applied at approximately 28 000 L ha⁻¹ and 56 000 L ha⁻¹.

The manure was applied by using a standard 11 250 L pressure/vacuum manure tank equipped with two knives spaced about 127 cm apart. Equipment was calibrated by measuring flow from the injector knives and adjusting the tractor speed to apply the proper quantity of manure to the plot. Two overlapping passes were made on each plot to evenly distribute the manure. Manure was broadcast over the surface of the plot with the knives in an upright position. To inject the manure the knives were set in the ground to a depth of about 15 cm. Tillage of the plots consisted of disking within 2 d of manure application 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 4°C until analysis by the Analytical Services Laboratory at Iowa State University (Table 2). Storage time was generally about one week.

Six-row plots (4.5 by 12 m) were arranged in a split-plot design with four replications. The main-plot was the method of manure application and the sub-plots were the application rates. In the spring of 1989, 1990, and 1991, prior to planting, liquid dairy manure was broadcast (SBD) and injected (SID) and liquid poultry manure (SIP) was injected at the Answer Farm. In

1990 and 1991 liquid swine manure was broadcast (SBS) and injected (SIS) at the ISU Curtiss Farm. Urea-ammonium nitrate (UAN, 28% N w/w) was also applied at the Curtiss Farm by broadcasting over the surface and then incorporating before planting. During the winters of 1990 and 1991 liquid dairy manure (WBD) was broadcast over frozen ground at the Answer Farm and liquid swine manure (WBS) was applied at the Curtiss Farm. Both winter applications on the Answer Farm took place on days with very cold air temperatures, -8° to -10°C , with 15 to 30 cm of snow cover. The first application of winter manure at the Curtiss Farm was on a relatively warm day, about 3°C with no snow cover. The second application in 1991 was on a very cold day, -8°C , with about 20 cm of snow cover.

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

Manure	Date	Total-N	Total-P	Total-K	Solids
		-----	mg kg ⁻¹	-----	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.

In addition to total-N, subsamples of manure were analyzed in an effort to evaluate N_i concentrations of the manure and the relationship between N_i and total-N (Table 3). The proportion of N_i to total-N remained fairly constant throughout the experiment and with different manures. In 1989 the poultry manure was diluted with water to thin it enough so it could be applied with the manure tank. A sample 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 determined from the difference in N concentration between the two samples. The dilution factor was then used to estimate 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 material was complete. Table 4 shows the total amount of N, P, and K actually applied with manure at the two application rates.

Soil samples were taken from each plot during the field season. Three soil cores, 2.5 cm in diameter and 91 cm deep, were collected in 30.5-cm sections from each plot. Core positions were located diagonally across the center of the plot. The first samples were collected immediately before spring-manure application and again about one week later. Samples were collected throughout the growing season until after harvest. The soil was dried and ground to pass a 2-mm sieve. In 1989, subsamples were extracted with 2M KCl for NH_4 -N analysis and 0.1M $Al_2(SO_4)_3$ for NO_3 -N analysis using ion specific electrodes (ISE) (Keeney and Nelson, 1982). In 1990 and 1991, soil

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	$N_i/\text{Total-N}$
----- $mg\ kg^{-1}$ -----				
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

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
----- kg ha ⁻¹ -----							
Dairy	4/89	295	590	145	290	0.5	1
	1/90	108	215	67	134	126	252
	4/90	88	175	19	38	102	204
	1/91	91	182	22	44	82	164
	6/91	48	96	12	24	55	110
Poultry	4/89	151	-- [†]	48	--	42	--
	4/90	160	321	74	147	94	187
	6/91	140	280	39	79	78	157
Swine	1/90	175	350	117	234	88	176
	4/90	340	456	100	133	172	221
	1/91	165	330	63	126	74	149
	5/91	284	568	101	202	130	260

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

samples were extracted with 2M KCl and analyzed colorimetrically for $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ by flow injection analysis (FIA) (Lachat Instruments, Milwaukee, WI).

In the fall of each year, corn grain yield was determined by hand harvesting 6 m of the two center rows in each plot. Yields are reported at 15.5% moisture content. A subsample of the grain was dried and ground for total-N analysis with an $\text{H}_2\text{SO}_4/\text{H}_2\text{O}_2$ digestion (HACH Company, Loveland, CO). Total-N was determined colorimetrically at 460 nm by using Nessler's 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 N_i 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 the 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. The Answer Farm site in 1989 was characterized by adequate precipitation and near normal temperatures throughout the growing season. In 1990 and 1991 cool, wet weather conditions occurred early in the year delaying treatment application and planting. The Curtiss Farm site was generally drier than the Answer Farm site both years. Because of the variability between years each site was treated separately for the statistical analysis.

Answer Farm

1989 Yield

Corn grain yields from the first year at the Answer Farm were very good, suggesting the presence of a pool of readily mineralizable organic N in the soil profile. Even the control plots yielded well and differences between treatments were hard to identify. Adequate rainfall and near-normal temperatures seemed to have had a greater influence on crop yields than manure treatments.

Average yield from this site was almost 12.6 Mg ha^{-1} . The county average yield was 9.6 Mg ha^{-1} . The lowest yielding plot was 10.4 Mg ha^{-1} from a control plot. The highest yield was 15.6 Mg ha^{-1} from the high rate of spring broadcast dairy manure (SBD).

Analysis of variance of corn grain yield collected after the first year showed no significant differences between the overall means of each manure treatment averaged over rates. The manure application rate, however, did

Table 5. Answer Farm site 1989 average corn grain yield.

Manure	Application	Total-N rate kg ha ⁻¹	Yield Mg ha ⁻¹
	Control plots	0	10.19
Dairy	Spring Broadcast (SBD)	295	9.93
		590	11.84
	Spring Injected (SID)	295	9.53
		590	11.28
Poultry	Spring Injected (SIP)	151	11.49

LSD(0.05) = 1.38 Mg ha⁻¹.

significantly effect corn grain yields (Table 5).

The high manure rates produced higher yields across all types of manure. Yield from the low rates of SBD and SID were similar to the yield from control plots.

Yield from the low rate of SIP (about 151 kg total-N ha⁻¹) was not significantly different from yield produced by high rates of SBD and SID (about 590 kg total-N ha⁻¹) with approximately four times the applied total-N. This suggests that N availability may be higher with SIP. Other studies have found SIP to have relatively high concentrations of NO₃-N in addition to the high NH₄-N levels commonly found in manure (Sims, 1987; Bitzer and Sims, 1988).

Apparent nitrogen efficiency (ANE) of each treatment is shown in Table 6. It is difficult to know what ANE value would be considered good for a site. Meer et al. (1987) expressed manure values relative to fertilizer values at the same plot area. A large number, however, indicates a better ANE. The optimum value will vary from site to site and across years.

Calculating ANE for this site using standard N recommendations and realistic yield goals gives a value of about -15. Negative values are the result of grain yields from treated plots being lower than control plots. Negative values for ANE simply mean that the applied N did not affect corn grain yields. Therefore, N applied was either unavailable to the crop or there was adequate N in the profile and the crop did not respond to additional N. ANE for poultry manure was 3 to 4 times higher than for SBD and SID treatments. Applied N recovery (ANR) for poultry manure (Table 6) was over six times higher than the highest ANR value from dairy manure (SBD). Higher ANR values mean greater recovery of manure-applied N.

Table 6. Apparent N efficiency (ANE) and apparent N recovery (ANR) for 1989 Answer Farm plots.

Manure	Application	Total-N rate kg ha ⁻¹	ANE	ANR
Dairy	Spring Broadcast (SBD)	295	-0.88	0.02
		590	2.79	3.47
	Spring Injected (SID)	295	-2.25	-0.63
		590	1.84	3.32
Poultry	Spring Injected (SIP)	151	8.59	21.83

1989 Soil Profile

Large amounts of manure-N were applied with the dairy manure treatments (Table 4). ANE and ANR values from the previous section suggest the possibility of a high concentration of profile N_i . Manure application rate did have a significant effect on soil profile NH_4 -N and NO_3 -N (Table 7). Plots treated with SIP had significantly more NH_4 -N in the surface 30 cm and a significantly lower concentration of NH_4 -N at 91 cm. SIP-treated plots also

showed significantly higher soil $\text{NO}_3\text{-N}$ levels during the season and after harvest when there was approximately four times more $\text{NO}_3\text{-N}$ at a depth of 91 cm under SIP than in dairy manure-treated soil (Fig. 1). The N_i concentration of SID and SBD plots was lower than expected, indicating most of the manure-applied N may have been lost from the system or immobilized in the soil organic fraction.

Table 7. Effects of manure treatment, sampling depth, and time on profile N_i from 1989 Answer Farm soil samples.

	df	Mean squares	
		$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$
Manure application method (M)	2	2.08	25.55
Rep*M (error a) [†]	6	11.72	115.03**
N-rate (NR)	3	79.9**	771.07**
M*NR	2	1.74	4.34
Rep*NR*M (error b)	15	11.04	69.95**
Sample depth (D)	2	323.5**	271.59**
D*M	4	0.69	3.66
D*NR	6	51.49**	46.79**
D*M*NR	4	0.20	3.82
Sample date (T)	3	149.51**	750.09**
M*T	6	0.13	1.75
NR*T	9	39.71**	75.43**
M*NR*T	6	0.48	6.71
D*T	6	66.07**	35.39*
NR*D*T	18	62.44**	24.62**
NR*M*D*T	24	0.33	2.06

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

[†] Error a was used to test the significance of M and error b was used to test the significance of NR and M*NR.

Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for the dairy manure treatments (Fig. 2) were low after manure application and increased with time until harvest. SIP $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios were also low after manure application and began to increase at a higher rate than with dairy manure. At harvest the ratio was much lower for SIP plots than in plots treated with dairy manure, indicating a greater concentration of potentially leachable $\text{NO}_3\text{-N}$.

SIP-applied N was apparently more available; however, some of the resulting yield differences may also be a response to improved K availability with SIP. SIP added more K to the soil than was applied with dairy manure in 1989 (Table 4). Even with relatively high initial K in the soil (232 mg K kg^{-1} at this site), it may be possible to observe a corn grain yield response to manure-added K.

1990 Yield

The second year of the continuous corn rotation at the experimental site showed a large decrease in overall corn grain yield. The county average yield also was lower at 7.7 Mg ha^{-1} . In 1990, SIP and SID were the only treatments that had significant effects on corn grain yield (Table 8). Yields from SBD and WBD were similar to yield from control plots, indicating no response to manure-added N. SBD manure did yield slightly higher than control plots, but the differences were not significant.

WBD applied during January produced grain yields that were actually slightly lower than yield from control plots. Severe N deficiencies were observed in these plots during the 1990 growing season. Soil profile N will be discussed in more detail in the next section, however, soil N_i levels in WBD plots were similar to N_i levels in the SBD and SID plots. The observed

Table 8. Answer Farm site average 1990 corn grain yield.

Manure	Application	Total-N rate	Yield
		kg ha ⁻¹	Mg ha ⁻¹
	Control plots	0	3.03
Dairy	Spring Broadcast (SBD)	88	3.32
		175	3.47
	Spring Injected (SID)	88	3.94
		175	4.72
	Winter Broadcast (WBD)	108	3.10
		215	3.06
Poultry	Spring Injected (SIP)	160	5.32
		321	5.71

LSD(0.05) = 1.0 Mg ha⁻¹.

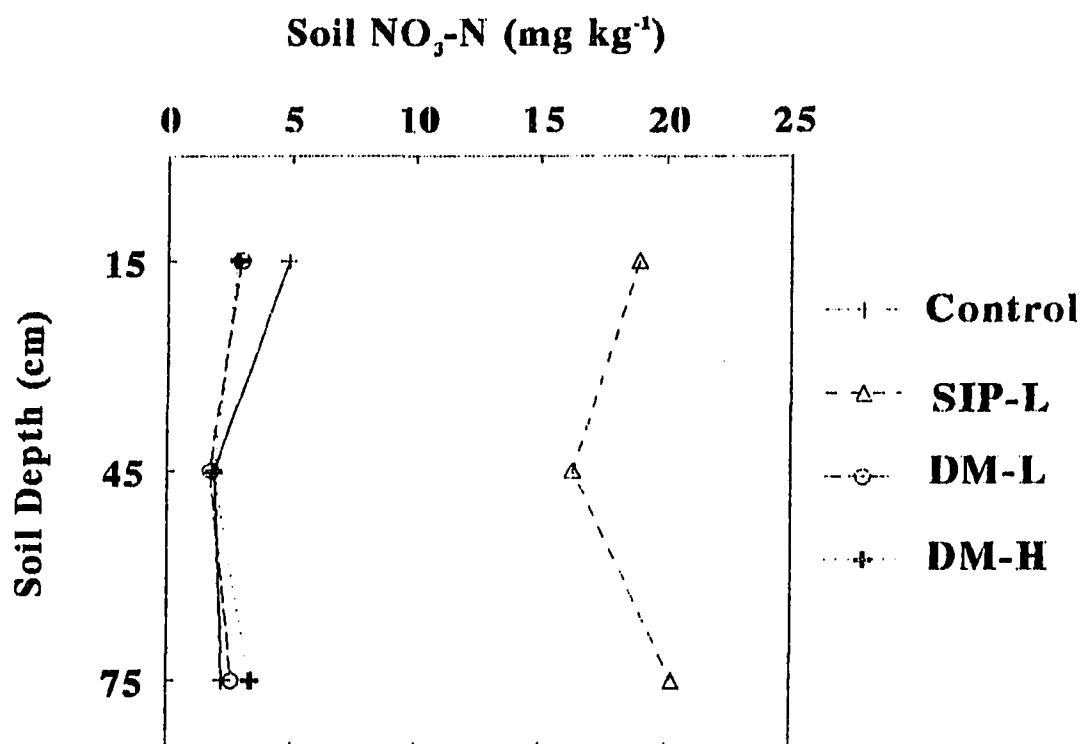


Figure 1. Soil NO₃-N concentration at three levels to a depth of 91 cm in samples collected after harvest at the Answer Farm on 9 Nov. 1989. Three rates of manure were applied: SIP (poultry manure), DM-L (dairy manure, low), and DM-H (dairy manure, high) supplied 151, 295, and 590 kg total-N ha⁻¹, respectively. Dairy manure values are the means of the spring broadcast and injected treatments.

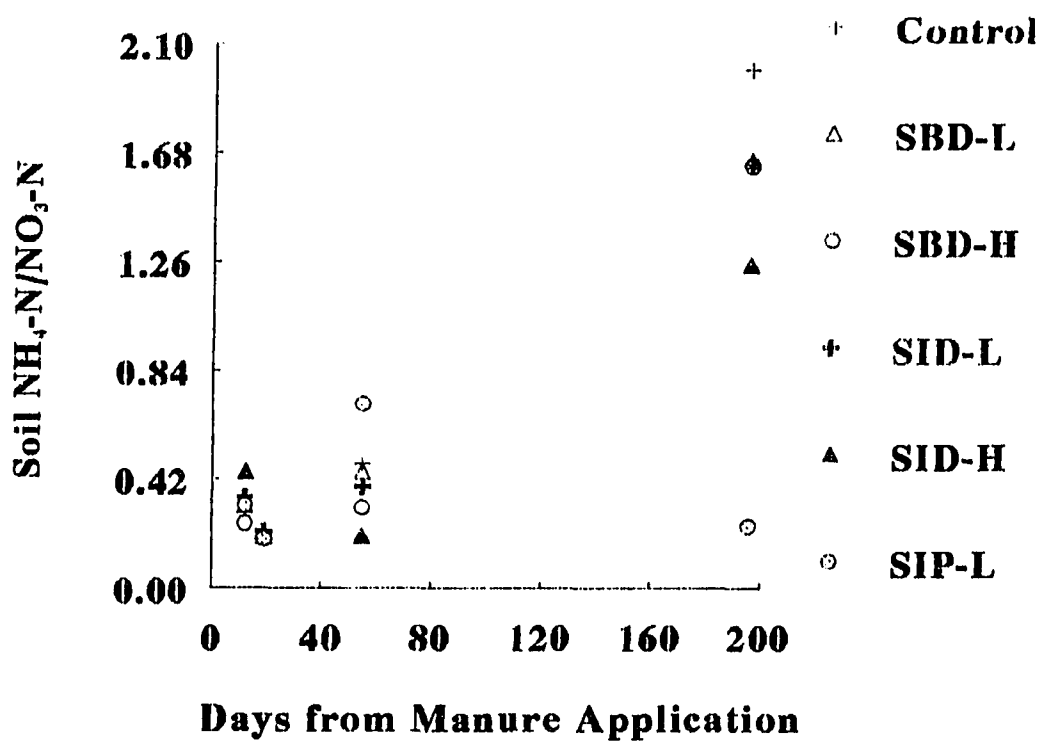


Figure 2. Soil NH₄-N/NO₃-N ratios for the low (L) and high (H) rates of manure in a 91-cm profile from manure application through harvest for 1989 at the Answer Farm (SBD, spring broadcast dairy manure; SID, spring injected dairy manure; SIP, poultry manure).

N deficiencies may have been caused by immobilization as manure applied residue was decomposed. Resistant, undecomposed litter, like bedding straw and undigested feed applied with the manure, was preserved on the soil surface during the cold winter months. This residue appeared after snow melt as distinct bands across all the winter-application plots. Incorporating this material into the soil during spring tillage could help create N deficiencies for the corn crop, especially if it had a high C/N ratio.

In addition, cool, wet weather after planting in 1990 had an impact on corn grain yield. Corn planted in plots injected with manure (SID and SIP) did show a response to the added manure. The low rate of SIP contained a slightly lower concentration of total-N than the high rates of SBD and SID but produced a significantly higher yield. Again, as in 1989, lower amounts of total N were added with SIP but yields were similar to or higher than plots treated with WBD, SBD, or SID where higher levels of total-N were applied.

Cooler weather conditions in 1990 add one possible explanation to improved growth with SIP. In addition to more readily available N, SIP also contained a much higher concentration of P (Table 3). The increased P may have provided an early advantage to corn growing in the cool, wet conditions that occurred after planting. All corn in plots treated with SIP were darker green and more vigorous early in the season. This improved growth was noticeable until harvest. Corn in plots treated with SID also showed somewhat better growth than corn in SBD and WBD-treated plots. In general, corn plants in all plots treated with dairy manure were slightly yellowish and stunted, indicating possible N and P deficiencies.

Injected-manure treatments had the highest ANE (Table 9). Broadcast treatments were lower, indicating greater losses of applied N or lower N availability. SIP had the highest ANE values. WBD at both rates had the lowest ANE values but relatively high ANR values. The low ANE values and high ANR values for WBD indicate that N taken up was less efficiently used for grain production.

1990 Soil Profile

In 1990, obvious soil $\text{NO}_3\text{-N}$ differences across treatments observed in 1989 were absent. Soil $\text{NO}_3\text{-N}$ for all treatments was about 4 mg kg^{-1} (Fig. 3). Concentrations were similar to those found in control plots. Soil $\text{NO}_3\text{-N}$ under SIP was about 6 mg kg^{-1} and increased with depth to $8 \text{ mg NO}_3\text{-N kg}^{-1}$. SIP-treated plots had the highest soil $\text{NO}_3\text{-N}$ levels in the fall 1989 soil samples and some of that $\text{NO}_3\text{-N}$ remained in the profile in the spring of 1990. WBD high rate had as much $\text{NO}_3\text{-N}$ in the surface as the low rate of SIP, showing

Table 9. Apparent N efficiency (ANE) and apparent N recovery (ANR) for 1990 Answer Farm plots.

Manure	Application	Total-N rate	ANE	ANR
		kg ha^{-1}		
Dairy	Spring Broadcast (SBD)	88	3.26	0.67
		175	1.67	1.16
	Spring Injected (SID)	88	10.31	6.24
		175	9.63	3.90
	Winter Broadcast (WBD)	108	0.60	15.13
		215	0.15	14.32
Poultry	Spring Injected (SIP)	160	14.31	21.00
		321	8.34	12.67

the effects of manure applied in January. The treatment with the second highest $\text{NO}_3\text{-N}$ concentration in the lower part of the profile was SBD high rate but $\text{NO}_3\text{-N}$ concentration was not significantly different from the control plots. These soil $\text{NO}_3\text{-N}$ levels were not high enough to be a threat to groundwater quality at the site. There are indications that some of the $\text{NO}_3\text{-N}$ from the manure is moving through the profile and over time this could affect groundwater quality.

Manure rate had a significant effect on soil N_i levels (Table 10). Soil $\text{NO}_3\text{-N}$ levels were low, however, throughout the year which was evident by observed N deficiencies in the crop. Only the injected treatments (SIP and SID) showed higher soil profile $\text{NO}_3\text{-N}$ after harvest (Fig. 4).

The soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratio for each sampling date in 1990 showed little difference between dairy manure and SIP treatments except that SIP-treated plots had slightly lower ratios at the end of the season, indicating a greater potential for $\text{NO}_3\text{-N}$ leaching (Fig. 5). SIP-treated soils also had higher ratios after manure application, suggesting higher concentrations of $\text{NH}_4\text{-N}$ were added with the manure. A high $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratio 33 d after the application of the high rate of SIP was apparently the result of sampling variability. Eliminating the plot with the highest concentration of $\text{NH}_4\text{-N}$ on that sampling date gave an average value that is similar to dairy manure values.

Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for WBD (Fig. 6) do not vary from the control plots except after harvest when the low rate of WBD had a higher ratio.

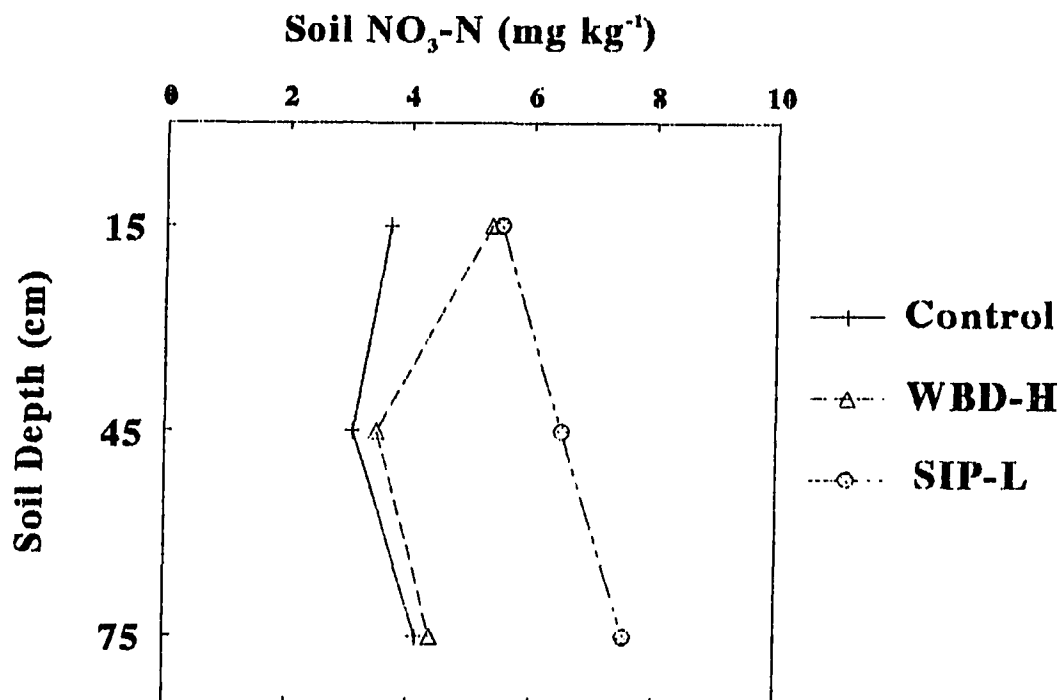


Figure 3. Soil $\text{NO}_3\text{-N}$ at three depths to 91 cm for selected treatments (WBD-H, winter broadcast dairy manure - high rate; SIP-L, poultry manure - low rate). Soil samples were collected before spring manure application in April 1990 at the Answer Farm.

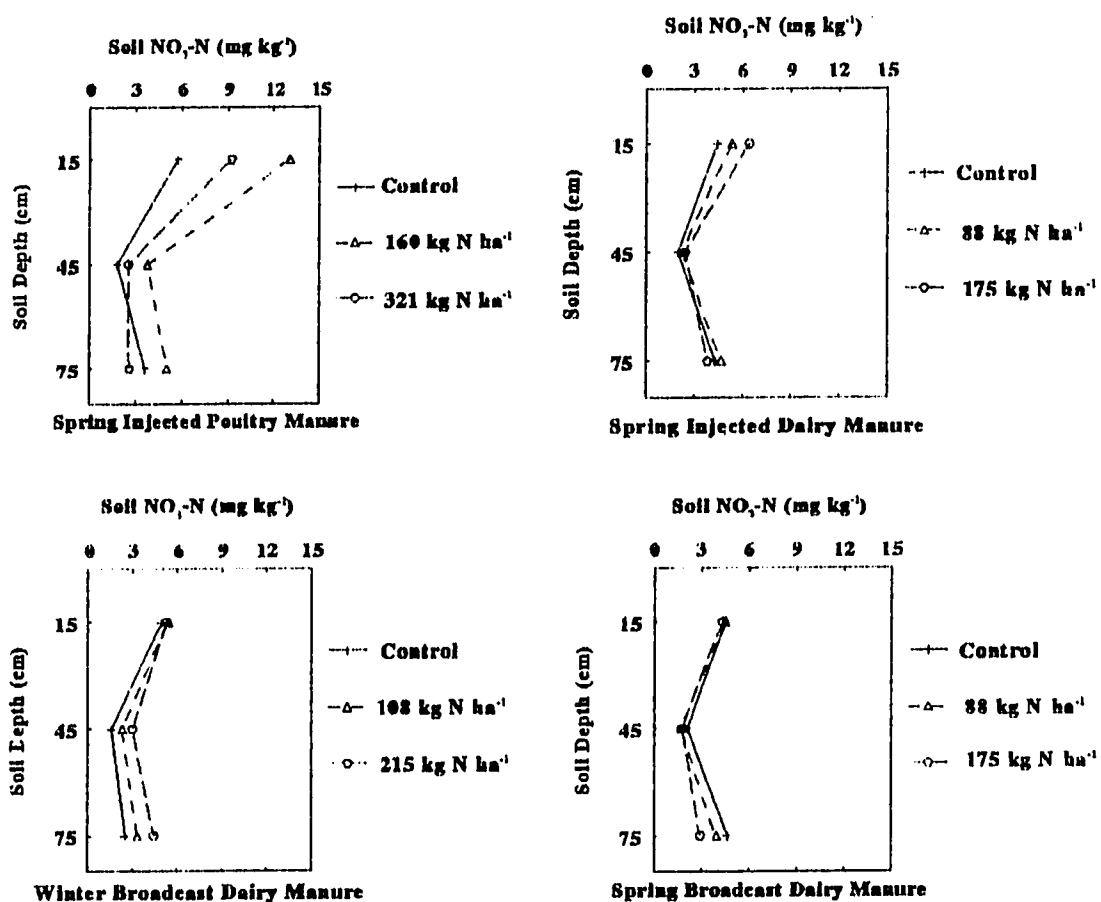


Figure 4. Soil NO₃-N levels for each manure and N application rate after fall harvest at the Answer Farm site on 16 Nov. 1990.

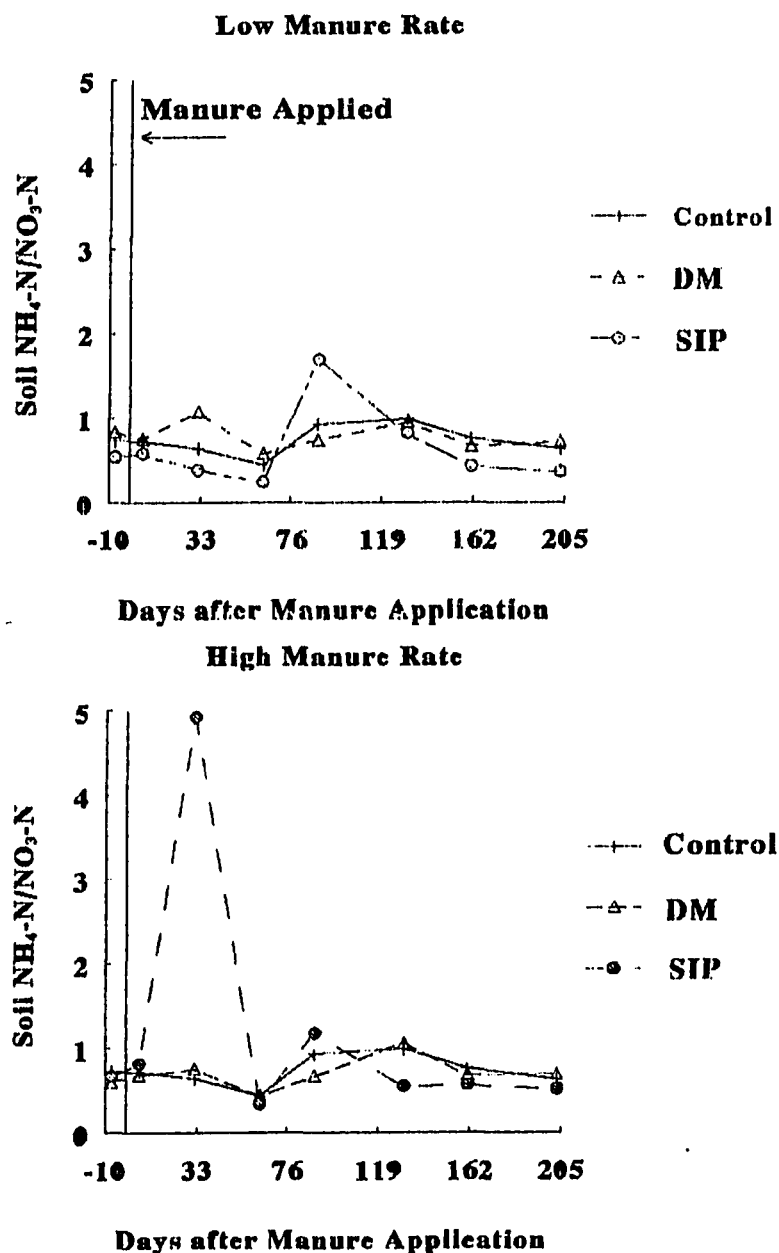


Figure 5. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios to a depth of 91 cm from spring manure application until harvest for spring applied dairy manure (DM) and SIP (poultry manure) treated plots and control plots during the 1990 growing season at the Answer Farm. DM values are means for spring broadcast and injected dairy manure treatments.

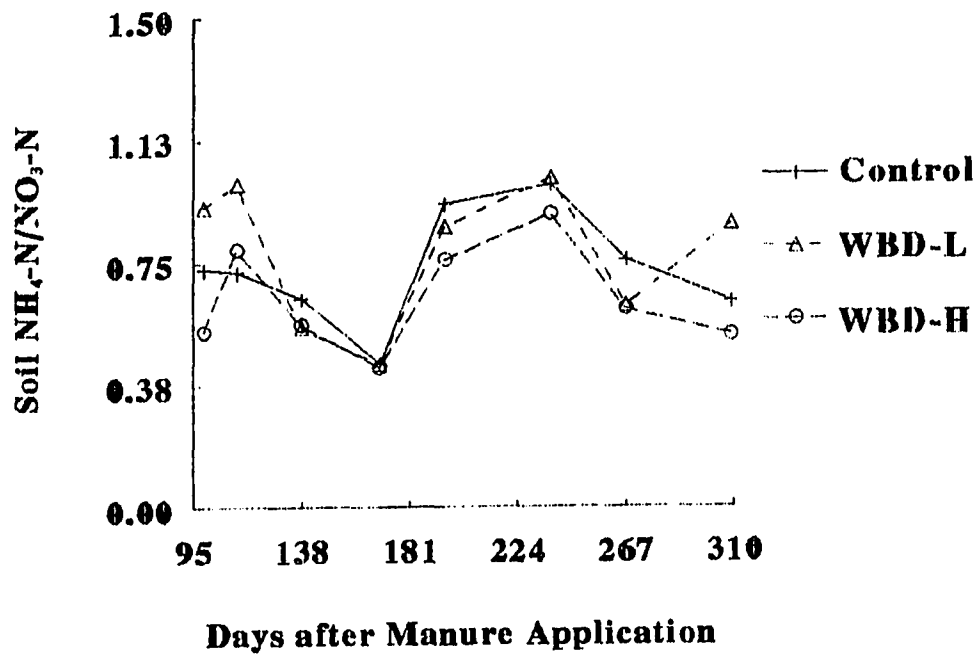


Figure 6. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios to a depth of 91 cm from manure application until harvest for two rates of winter-broadcast dairy manure (WBD) during the 1990 growing season at the Answer Farm.

Table 10. Effects of manure treatment on soil N_i from 1990 Answer Farm soil samples.

	df	Mean squares	
		NH_4-N	NO_3-N
Manure application method (M)	3	5.62	6.71
Rep*M (error a) [†]	9	55.68	8.03**
N-rate (NR)	6	150.71**	97.65**
M*NR	2	1.32	2.82
Rep*M*NR (error b)	22	47.99	8.85**
Sample depth (D)	2	859.49**	282.69**
D*M	6	2.94	1.73
D*NR	12	38.60	14.29**
Sample date (T)	7	230.69**	110.33**
M*T	21	2.00	2.29
NR*T	42	106.95**	10.23**
D*T	14	79.07**	24.84**
NR*D*T	84	42.49	5.00**

** Significant at the 0.01 probability level.

Three and four-way interactions not shown were not significant.

[†] Error a was used to test the significance of M and error b was used to test the significance of NR and M*NR.

1991 Yield

Wet spring weather delayed manure application and planting until June 13. Moreover, N concentration of the spring dairy manure was very low (Table 4) and N deficiency symptoms were observed in all SBD and SID plots.

Even with a shorter growing season and less manure-applied N, yields were generally higher than in 1990. Both manure type and application rate had significant effects on corn grain yield. The high rate of WBD manure produced higher yields than all other treatments (Table 11). Manure-treated

plots produced higher grain yields than untreated control plots.

Higher yields from WBD plots also gave higher ANE than the previous year. WBD also had the highest ANR values for 1990. SID had the highest ANE (Table 12), followed by WBD then SIP.

Table 11. Answer Farm site average 1991 corn grain yield.

Manure	Application	Total-N rate	Yield
		kg ha ⁻¹	Mg ha ⁻¹
	Control plots	0	3.81
Dairy	Spring Broadcast (SBD)	48	4.24
		96	4.41
	Spring Injected (SID)	48	4.91
		96	4.86
	Winter Broadcast (WBD)	91	4.84
		182	5.61
Poultry	Spring Injected (SIP)	140	5.27
		280	5.13

LSD(0.05) = 0.67 Mg ha⁻¹.

Table 12. Apparent N efficiency (ANE) and apparent N recovery (ANR) for 1991 Answer Farm plots.

Manure	Application	Total-N rate	ANE	ANR
		kg ha ⁻¹		
Dairy	Spring Broadcast (SBD)	48	8.91	12.28
		96	6.20	14.70
	Spring Injected (SID)	48	22.86	12.51
		96	10.87	11.16
	Winter Broadcast (WBD)	91	11.27	33.89
		182	9.90	23.31
Poultry	Spring Injected (SIP)	140	10.42	26.12
		280	4.71	12.67

1991 Soil Profile

Rate of manure application had the greatest effect on soil $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in 1991 (Table 13 and Fig. 7). Soil treated with higher rates of manure generally had higher levels of $\text{NO}_3\text{-N}$ in the profile.

The first soil samples of 1991 were collected on 23 May. At that time, plots that had received dairy manure during the winter showed significantly higher levels of soil $\text{NO}_3\text{-N}$, nearly twice the level found in other plots (Fig. 7). In all plots, including controls, soil $\text{NO}_3\text{-N}$ levels decreased with depth to about $4 \text{ mg NO}_3\text{-N kg}^{-1}$ at the bottom of the sampling profile. A wet soil profile helped reduce N loss from volatilization. Moreover, there was not enough water movement in the profile to leach $\text{NO}_3\text{-N}$ to the bottom sampling depth.

Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for spring-applied manure during the 1991 season are shown in Fig. 8. Ratios in dairy manure-treated plots were similar to control plots. SIP-treated soils were highest early in the season probably due to the $\text{NH}_4\text{-N}$ that may be added with the manure but dropped to low levels by harvest as the $\text{NH}_4\text{-N}$ was nitrified. At harvest, all manure-treated plots had lower ratios than control plots, showing higher $\text{NO}_3\text{-N}$ leaching potentials. WBD plots generally had lower ratios than spring dairy-manure plots (Fig. 9).

Soil $\text{NO}_3\text{-N}$ concentration in samples collected after harvest decreased with depth for all treatments except the high rate of SID manure (Fig. 10). SIP plots had as much as $18 \text{ mg NO}_3\text{-N kg}^{-1}$ and SID and SBD plots had as high as $10 \text{ mg NO}_3\text{-N kg}^{-1}$ in the surface 30 cm of the soil profile. WBD plots had less than $6 \text{ mg NO}_3\text{-N kg}^{-1}$ through the profile.

Table 13. Mean squares for main effects and interactions from 1991
Answer Farm soil data.

	df	Mean squares	
		NH ₄ -N	NO ₃ -N
Manure application method (M)	3	1.76	0.60
Rep*M (error a) [†]	9	7.00	26.62**
N-rate (NR)	6	46.05**	114.22**
M*NR	2	0.63	3.12
Rep*M*NR (error b)	24	3.20	20.86**
Sample depth (D)	2	339.3**	171.76**
D*M	6	0.38	0.49
D*NR	12	18.34**	10.94
D*M*NR	4	1.40	2.80
Sample date (T)	5	139.80**	292.79**
M*T	15	0.90	2.23
NR*T	30	46.05**	19.43**
M*NR*T	10	1.21	10.73
D*T	10	95.89**	9.20
NR*D*T	60	43.43**	8.86
NR*M*D*T	50	0.63	1.81

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

[†] Error a was used to test the significance of M and error b was used to test the significance of NR and M*NR.

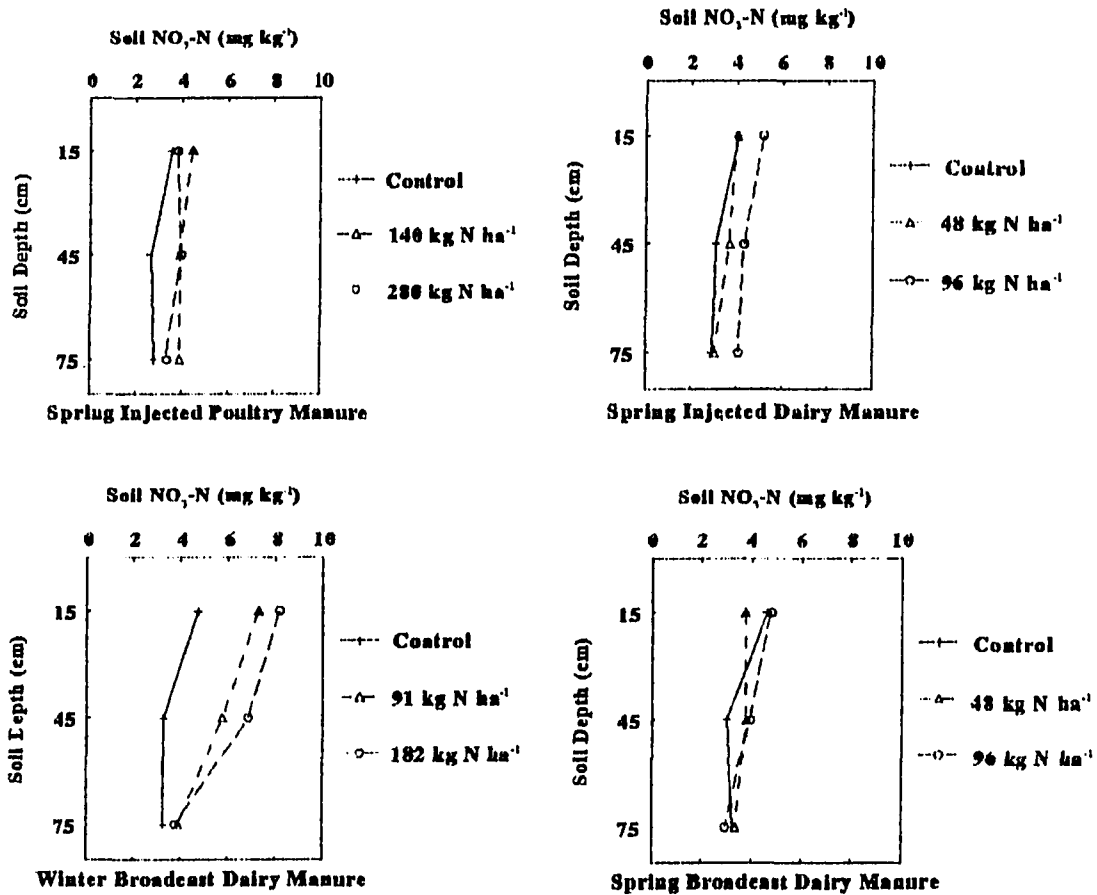


Figure 7. Soil $\text{NO}_3\text{-N}$ concentrations for each manure and application rate on 23 May 1991 before spring-manure was applied at the Answer Farm site.

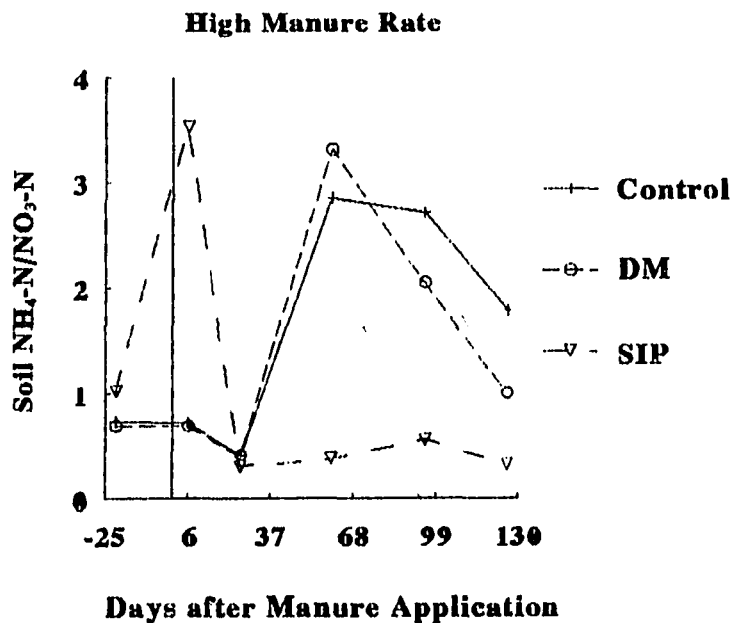
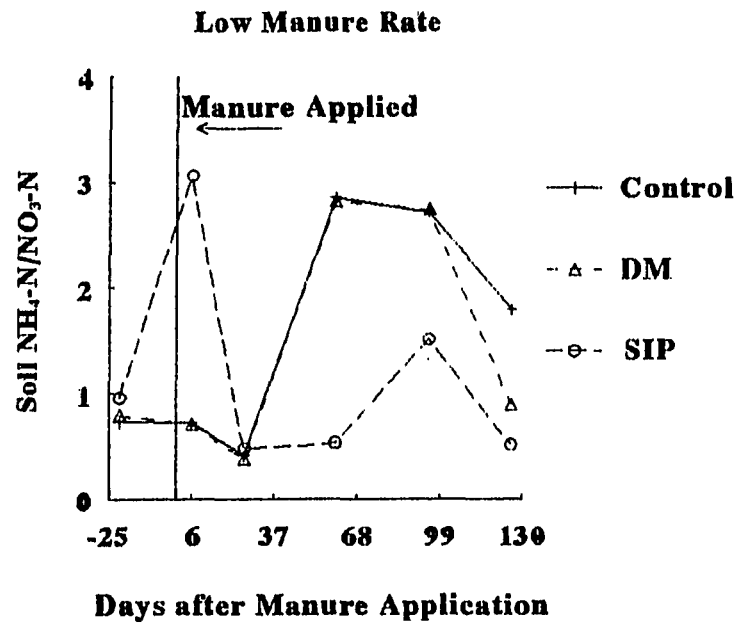


Figure 8. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios to a depth of 91 cm from the time of manure application on 13 June 1991 until harvest on 17 Oct. 1991 at the Answer Farm for spring applied dairy manure (DM) and poultry manure (SIP). DM values are the means of SBD and SID treatments.

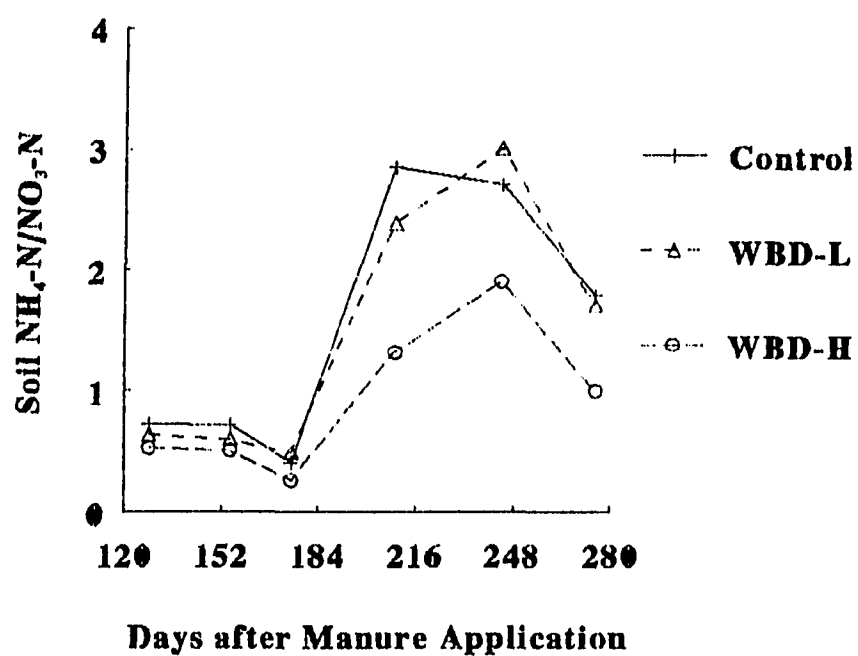


Figure 9. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios during the growing season to a depth of 91 cm for plots with winter-broadcast dairy manure (WBD) applied on 15 Jan. 1991 at the Answer Farm.

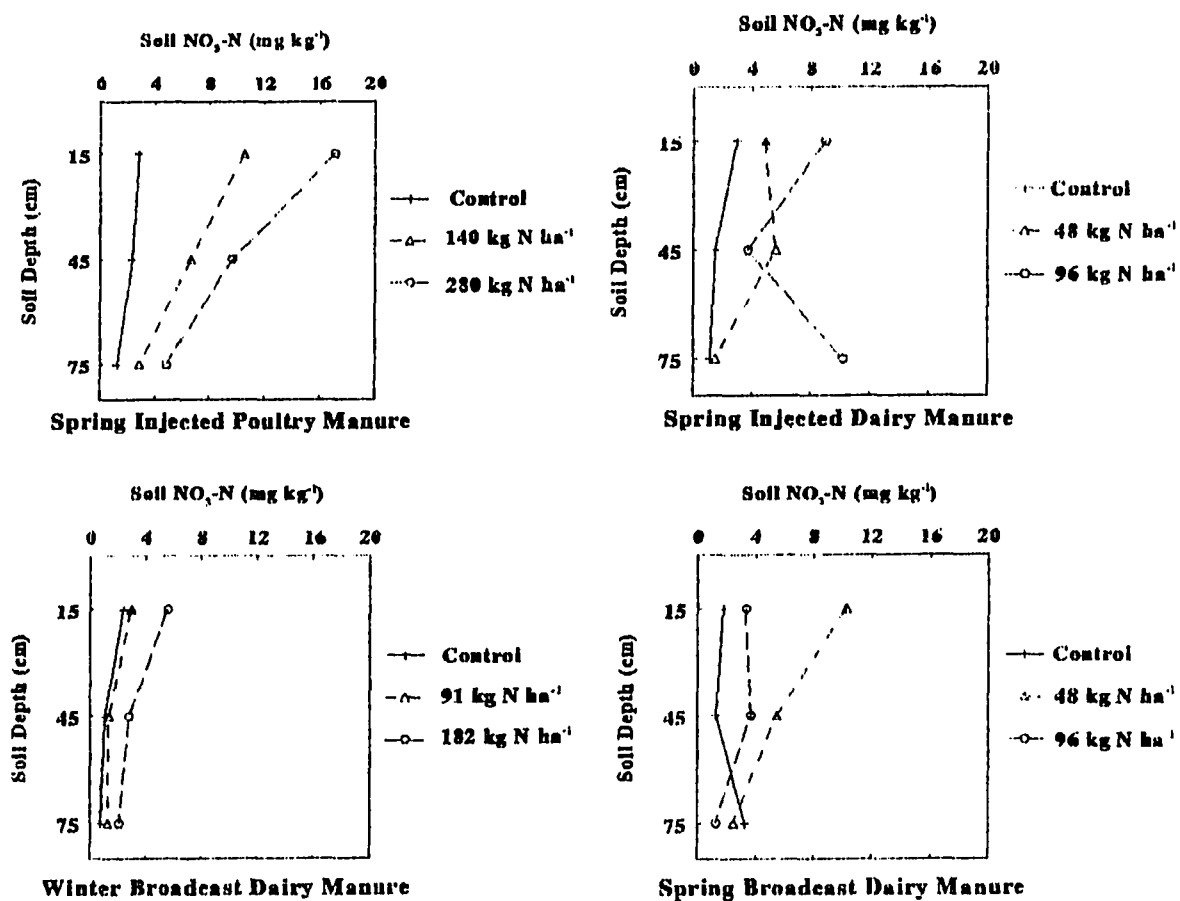


Figure 10. Soil $\text{NO}_3\text{-N}$ concentration at 3 depths for each manure and application rate after harvest on 17 Oct. 1991 at the Answer Farm.

Curtiss Farm

During the winter of 1990, the first swine manure was broadcast at the Curtiss Farm. In the spring of that year swine manure was broadcast and injected to different plots and urea-ammonium nitrate (UAN, 28% N w/w) was applied as an additional treatment for comparisons.

1990 Yield

The Curtiss Farm plot had been conventionally farmed in continuous corn for several years prior to the start of the experiment. In contrast to the Answer Farm site, the corn at Curtiss Farm did not exhibit strong visual differences between injected and broadcast plots. It was possible, however, to observe differences between low-rate plots and high-rate plots. Additionally, all untreated plots showed signs of N deficiencies, yellow, stunted plants, while corn plants in treated plots were larger and noticeably greener as manure rate increased.

Average yield in 1990 at the Curtiss Farm was about 5 Mg ha^{-1} . Lowest yield was 2 Mg ha^{-1} and came from a control plot. The highest yielding plot produced 7.6 Mg ha^{-1} with the low rate of spring broadcast swine manure (SBS). The county average yield was 7.3 Mg ha^{-1} .

Analysis of variance showed first-year grain yield was significantly affected by treatment and N application rate (Table 14). Plots treated with 370 kg N ha^{-1} as UAN produced the highest average yields. All treated plots produced higher yields than control plots but the difference was not always significant. With higher application rates for spring-applied swine manure (SBS and SIS), there was a slight decrease in yield. The largest difference occurred with SIS. SIS-treated plots yielded higher overall than SBS-treated

Table 14. Average corn grain yield from the Curtiss Farm site for 1990.

Source	Application	Total-N rate kg ha ⁻¹	Yield Mg ha ⁻¹
Swine	Control plots	0	4.02
	Spring Broadcast (SBS)	340	4.41
		456	4.36
	Spring Injected (SIS)	340	6.20
		456	4.83
	Winter Broadcast (WBS)	175	4.48
UAN		350	6.50
	Spring Broadcast (UAN)	185	5.52
		370	7.20

LSD(0.05) = 1.64 Mg ha⁻¹.

plots. Winter-broadcast swine manure (WBS) and UAN treatments showed increasing yields with increasing N application rates.

One of the highest yielding treatments was the high rate of WBS. In contrast, results from the Answer Farm for 1990 showed that dairy manure broadcast during the winter produced corn grain yields that were only slightly higher than control-plot yields. While quantitative measurements were not made, residue on the soil surface from winter-applied dairy manure was easily observed. The same was not true for plots treated with swine manure. It should be noted that dairy manure had about one-half the total N of swine manure during the winter of 1990 and almost twice the solid content (Table 2). Apparently some of the conditions that were responsible for N deficiencies seen with dairy manure did not occur with swine manure.

Highest apparent N efficiency (ANE) was achieved with UAN treatments

Table 15. Apparent N efficiency (ANE) and apparent N recovery (ANR) for 1990 Curtiss Farm plots.

Source	Application	Total-N rate kg ha ⁻¹	ANE	ANR
Swine	Spring Broadcast (SBS)	340	1.14	0.94
		456	0.74	8.56
	Spring Injected (SIS)	340	6.41	1.35
		456	1.76	1.19
	Winter Broadcast (WBS)	175	2.59	7.25
		350	7.06	2.04
UAN	Spring Broadcast (UAN)	185	8.05	8.54
		370	8.58	10.97

(Table 15). The lowest ANE was from the SBS treatments.

1990 Soil Profile

The first manure was applied at the Curtiss Farm on 10 Jan. 1990. Spring manure and UAN were applied in April.

When the first soil samples were collected, before spring-manure application, plots treated with WBS had the highest NO₃-N concentrations in the surface 30 cm of soil at about 7 mg NO₃-N kg⁻¹ soil (Fig. 11). At 45 cm, NO₃-N concentrations were about 5 mg NO₃-N kg⁻¹ soil and were still higher than concentrations in untreated plots, indicating some downward movement of winter-applied N. Lower in the sampled profile (60-91 cm), NO₃-N concentrations were similar to concentrations found in all other plots. The winter of 1990 was relatively warm and the soil was frozen for only a short period of time. When manure was applied in January, there was only a thin, shallow frost layer. The warm winter weather may have been the reason for

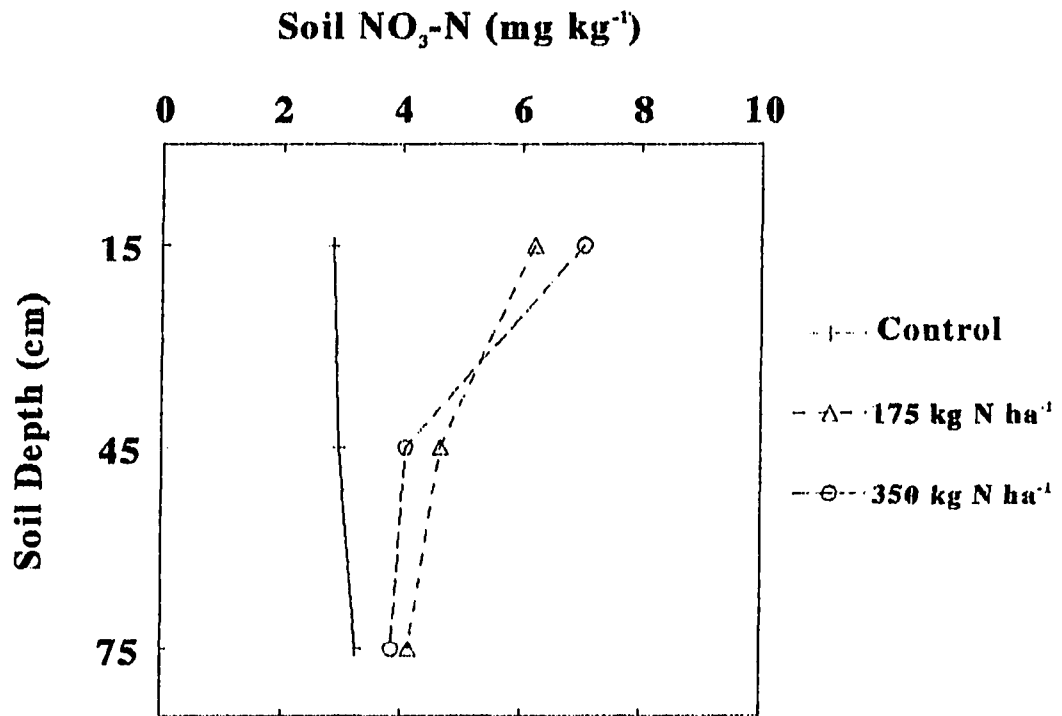


Figure 11. Soil profile NO₃-N at the Curtiss Farm comparing winter-broadcast swine manure (WBS) at two rates with untreated plots. Soil samples were collected on 12 April 1990.

Table 16. Mean squares for main effects and interactions from 1990 Curtiss Farm site soil data.

	df	Mean squares	
		NH ₄ -N	NO ₃ -N
N application method (M)	3	1.74	270.8**
Rep*M (error a) [†]	9	7.99	26.32
N-rate (NR)	2	83.00**	551.1**
M*NR	6	25.20	141.25**
Rep*M*NR (error b)	24	11.65**	40.12**
Sample depth (D)	2	1197.1**	147.51**
D*M	6	3.55	20.19
D*NR	4	13.49	14.11
D*M*NR	12	1.86	24.06
Sample date (T)	7	78.61**	1706.61**
M*T	20	8.86	56.04**
NR*T	14	17.58**	92.79**
M*NR*T	40	11.34**	45.27**
D*T	14	12.97*	79.91**
NR*D*T	28	4.28	18.61
NR*M*D*T	20	3.70	13.04

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

[†] Error a was used to test the significance of M and error b was used to test the significance of NR and M*NR.

some of the downward movement of NO₃-N. Yields from WBS plots, however, were among the highest for 1990, indicating any NO₃-N losses were low. Application method (manure or UAN, broadcast or injected) and N rate significantly affected soil NO₃-N concentrations (Table 16). The rate of applied N also had a significant effect on soil NH₄-N.

In the fall of 1990, plots treated with the high rate of UAN had the highest soil profile concentrations of about 4 mg $\text{NO}_3\text{-N kg}^{-1}$. Deeper in the profile, at 75 cm, the high rate of UAN and the low rate of SIS had concentrations of about 5 mg $\text{NO}_3\text{-N kg}^{-1}$ (Fig. 12). This was only about 2 mg kg^{-1} higher than the $\text{NO}_3\text{-N}$ concentrations found in other treated plots or the control plots; however, it appears that there was some downward movement of $\text{NO}_3\text{-N}$. These levels are low and should not threaten groundwater quality.

Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for 1990 spring-applied N showed little difference between treatments (Fig. 13). All treatments except the high rates of spring-applied manure (SBS and SIS) tended to have ratios lower than control plots, indicating that more of the N_i in these plots was $\text{NO}_3\text{-N}$. The lowest ratios were found in soil treated with UAN. At the end of the season, the high rate of UAN had the lowest $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratio. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for winter-applied manure (WBS) and control plots are shown in Fig. 14. Ratios in manure amended soil samples are similar but slightly lower than ratios in control plots.

1991 Yield

Corn grain yields at the Curtiss Farm in 1991 were similar to 1990 yields. County average yields were 7.7 Mg ha^{-1} . Plots treated with the high rate of UAN again produced the highest yield (Table 17).

As in 1990, all treatments produced corn grain yields that were higher than yield from control plots. SBS and UAN both produced increases in grain yield as N application rate increased. SIS and WBS produced yield decreases as N rate increased. There were noticeable visual differences among corn plants during the growing season. Corn growing on plots treated with lower

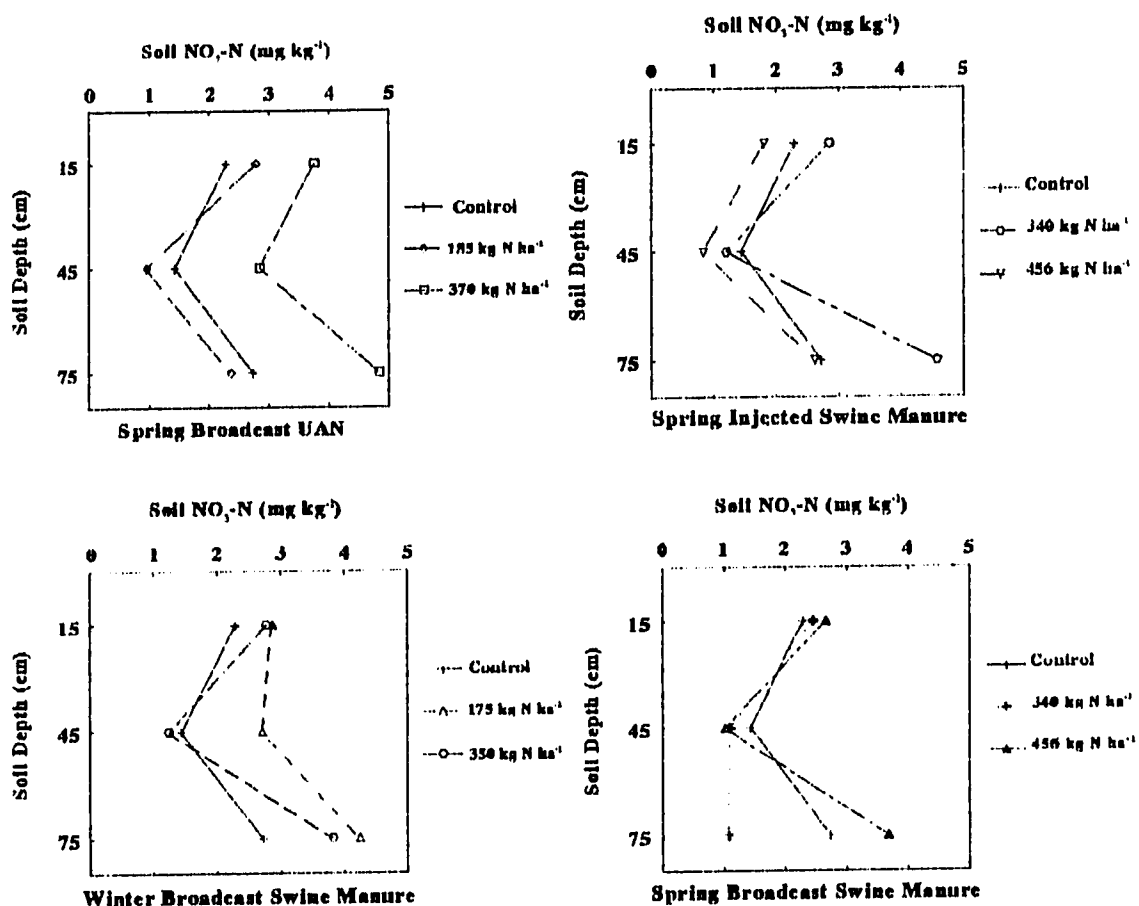


Figure 12. Soil $\text{NO}_3\text{-N}$ concentrations for each manure and application rate at the Curtiss Farm after harvest on 13 Nov. 1990.

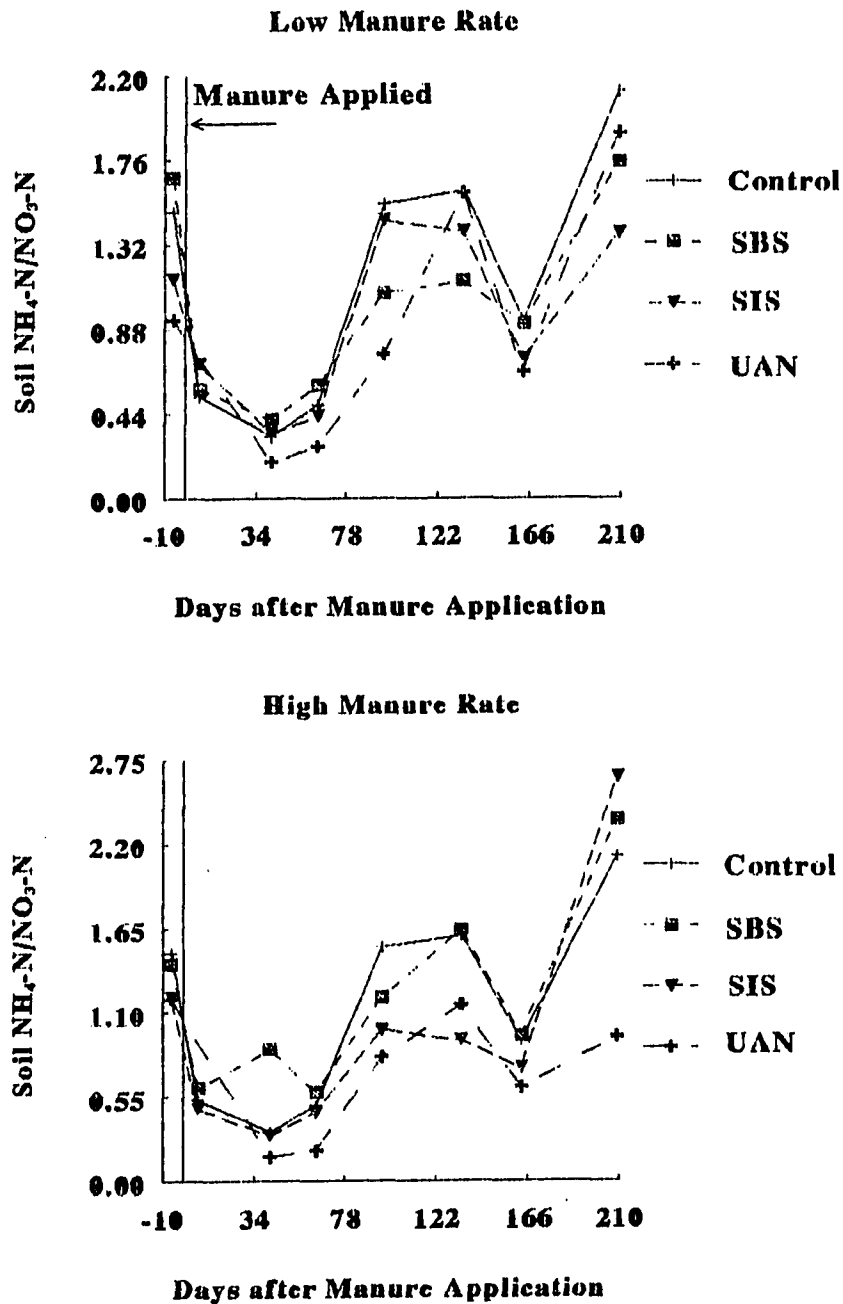


Figure 13. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios in a 91-cm profile for 1990 at the Curtiss Farm for each sampling date for spring-applied manure treatments (SBS, spring broadcast swine; SIS, spring injected swine; UAN, urea-ammonium nitrate).

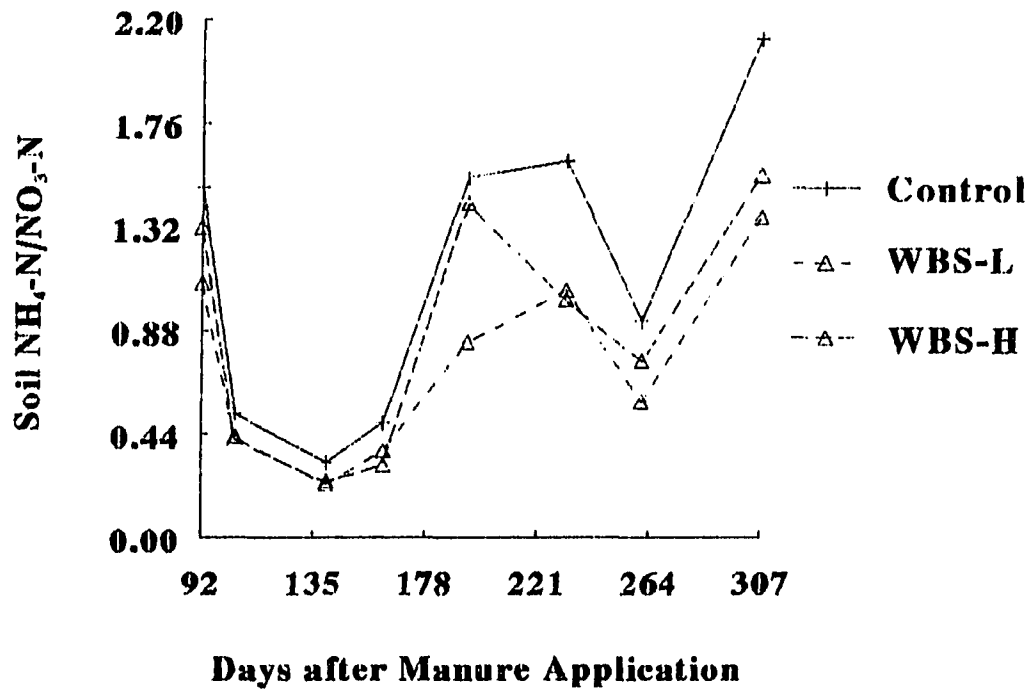


Figure 14. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for a 91-cm profile under two rates of winter-broadcast swine manure (WB) at the Curtiss Farm in 1990.

Table 17. Average corn grain yield from the Curtiss Farm site for 1991.

Source	Application	Total-N rate	Yield
		kg ha ⁻¹	Mg ha ⁻¹
		0	3.14
Swine	Spring Broadcast (SBS)	284	4.60
		568	5.69
	Spring Injected (SIS)	284	7.09
		568	5.58
	Winter Broadcast (WBS)	165	4.70
		330	3.86
UAN	Spring Broadcast (UAN)	185	4.32
		370	7.72

LSD(0.05) = 0.83 Mg ha⁻¹.

Table 18. Apparent N efficiency (ANE) and apparent N recovery (ANR) for 1991 Curtiss Farm plots.

Source	Application	Total-N rate	ANE	ANR
		kg ha ⁻¹		
Swine	Spring Broadcast (SBS)	284	5.14	9.14
		568	4.48	2.59
	Spring Injected (SIS)	284	13.89	7.23
		568	4.29	5.58
	Winter Broadcast (WBS)	165	9.41	18.77
		330	2.18	5.87
UAN	Spring Broadcast (UAN)	185	6.34	7.07
		370	12.36	17.05

rates of manure exhibited some N deficiency symptoms. Corn plants in control plots showed much more yellowing and "firing" of tissue and were shorter than plants in all other plots. The low rate of SIS had the best ANE in 1991 (Table 18).

ANE values were generally higher in 1991 than 1990 with the exception of WBS high rate and UAN low rate. This could be a reflection of lower yields from control plots in the second year while grain yields were generally higher for all treated plots in 1991.

1991 Soil Profile

At the time of the first soil sampling in 1991, $\text{NO}_3\text{-N}$ concentrations from WBS-treated plots were higher than all other treatments, reflecting the manure applied in January (Fig. 15). Soil $\text{NO}_3\text{-N}$ concentrations were low throughout the profile. At the bottom of the sampled profile, $\text{NO}_3\text{-N}$ concentrations under treated plots were only slightly higher than concentrations under control plots, suggesting that with existing conditions very little $\text{NO}_3\text{-N}$ was moving downward in the profile. Even with the relatively low $\text{NO}_3\text{-N}$ concentration of all plots there were some significant treatment effects. The method of manure application and the amount of N applied had a significant effect on concentrations of soil $\text{NH}_4\text{-N}$ (Table 19). Soil $\text{NO}_3\text{-N}$ was significantly affected by N (manure) application rate.

Fall soil samples were collected at harvest on 5 Nov. 1991. Soil $\text{NO}_3\text{-N}$ concentrations for all treatments decreased with depth, showing that $\text{NO}_3\text{-N}$ was removed by the crop and there was very little downward movement (Fig. 16). The high application rate of UAN had the highest $\text{NO}_3\text{-N}$ concentration at the bottom of the profile at about $2.5 \text{ mg NO}_3\text{-N kg}^{-1}$. Concentration of $\text{NO}_3\text{-N}$ for

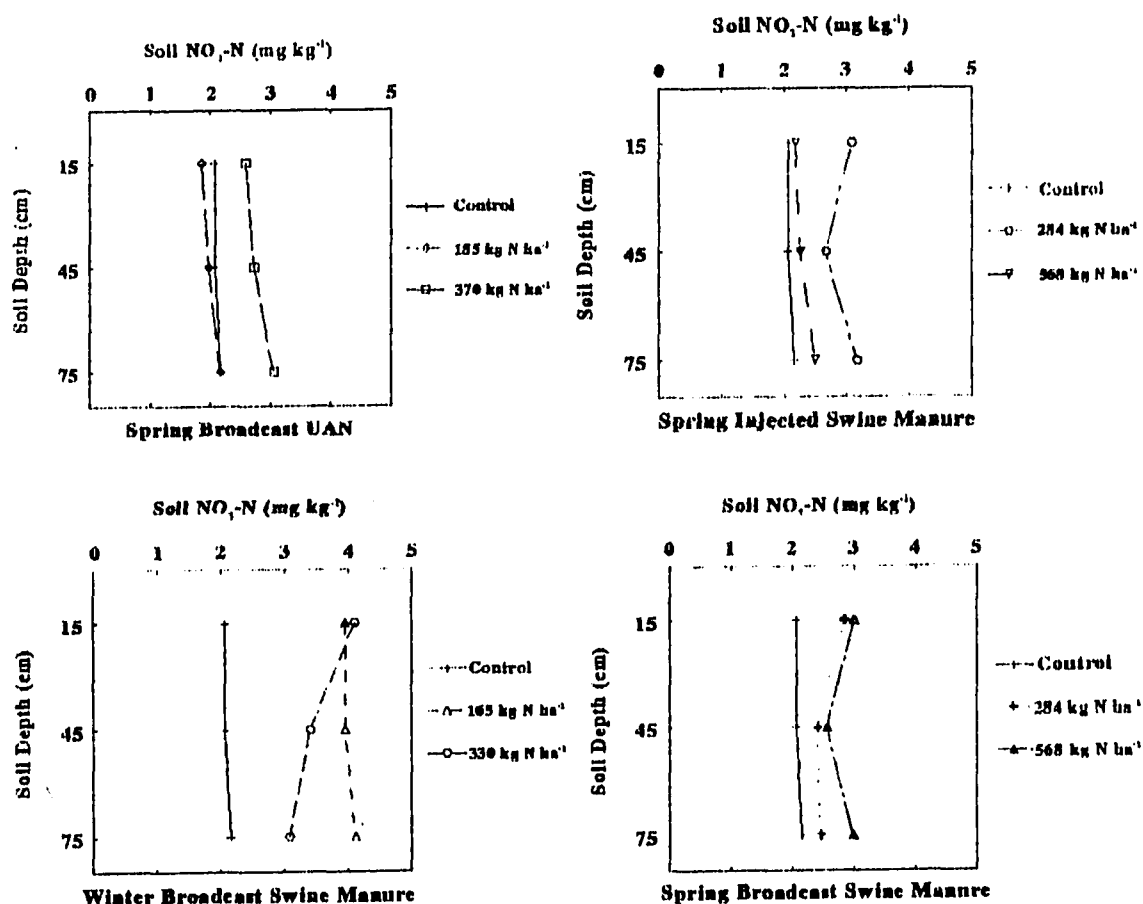


Figure 15. Soil profile $\text{NO}_3\text{-N}$ concentrations for each manure and application rate at the Curtiss Farm on 1 May 1991 before spring-manure application.

Table 19. Mean squares for main effects and interactions from 1991 Curtiss Farm soil data.

	df	Mean squares	
		NH ₄ -N	NO ₃ -N
N application method (M)	3	85.9**	97.93
Rep*M (error a) [†]	9	12.08	83.73
N-rate (NR)	2	104.38**	846.25**
M*NR	6	17.61	133.15*
Rep*M*NR (error b)	24	11.57	85.57*
Sample depth (D)	2	1116.5**	232.08*
D*M	6	54.40**	38.13
D*NR	4	35.16**	113.39
D*M*NR	12	23.07*	43.52
Sample date (T)	6	140.87**	457.23**
M*T	18	49.77**	88.87*
NR*T	12	21.65*	103.38*
M*NR*T	36	21.67**	65.79
D*T	12	49.92**	22.05
NR*D*T	24	10.89	21.21
NR*M*D*T	108	21.84**	46.90

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

[†] Error a was used to test the significance of M and error b was used to test the significance of NR and M*NR.

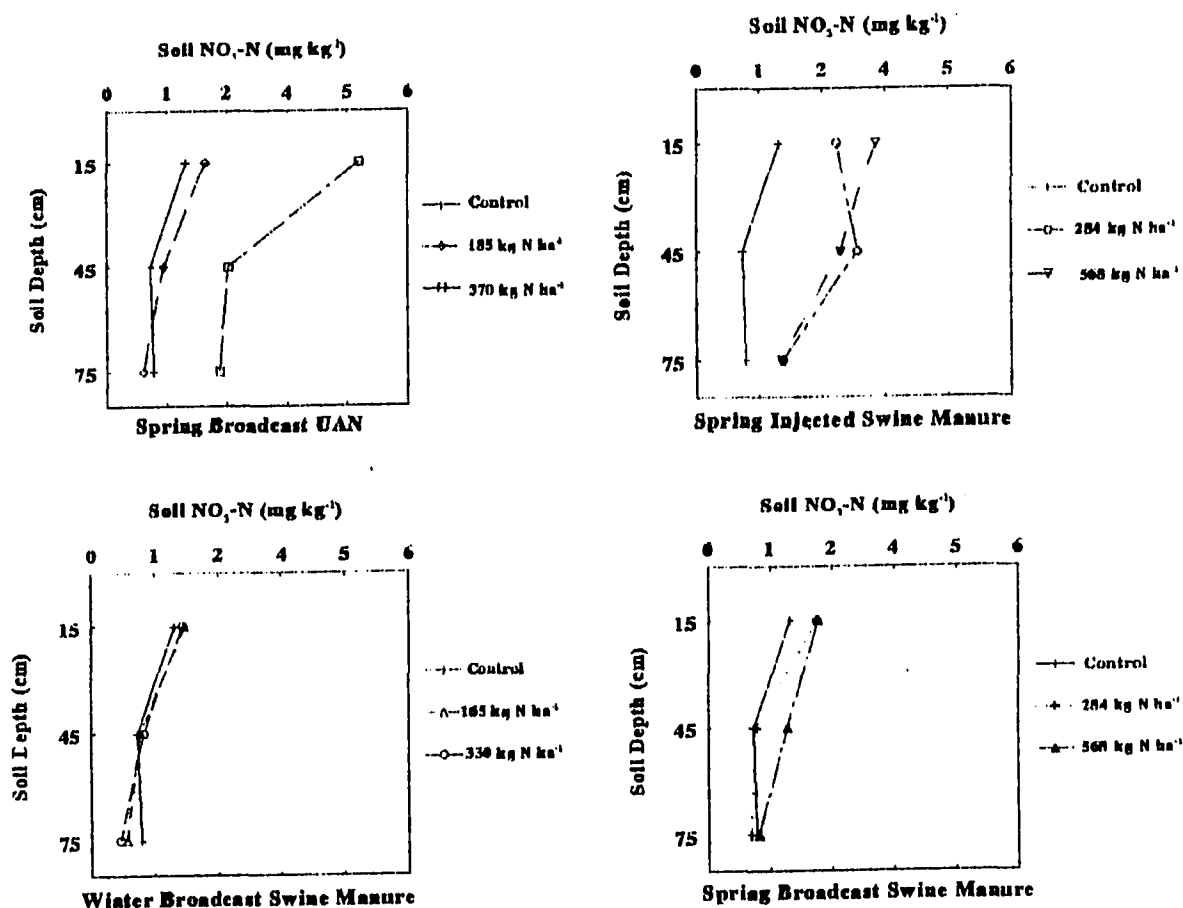


Figure 16. Soil $\text{NO}_3\text{-N}$ concentrations in a 91-cm profile for each manure and application rate after harvest at the Curtiss Farm on 5 Nov. 1991.

all other treatments was not significantly different from $\text{NO}_3\text{-N}$ concentrations under control plots.

Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for spring-applied treatments are shown in Fig. 17. In general, higher N application rates produced lower $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios. The notable exception is the high rate of SIS. Early in the season there was a large jump in the ratio. A similar increase, but with a much smaller magnitude, was seen with the low rate of SIS. Both rates of UAN produced the lowest ratios about one month after application. Ratios for WBS were similar the ratios from control plots (Fig. 18).

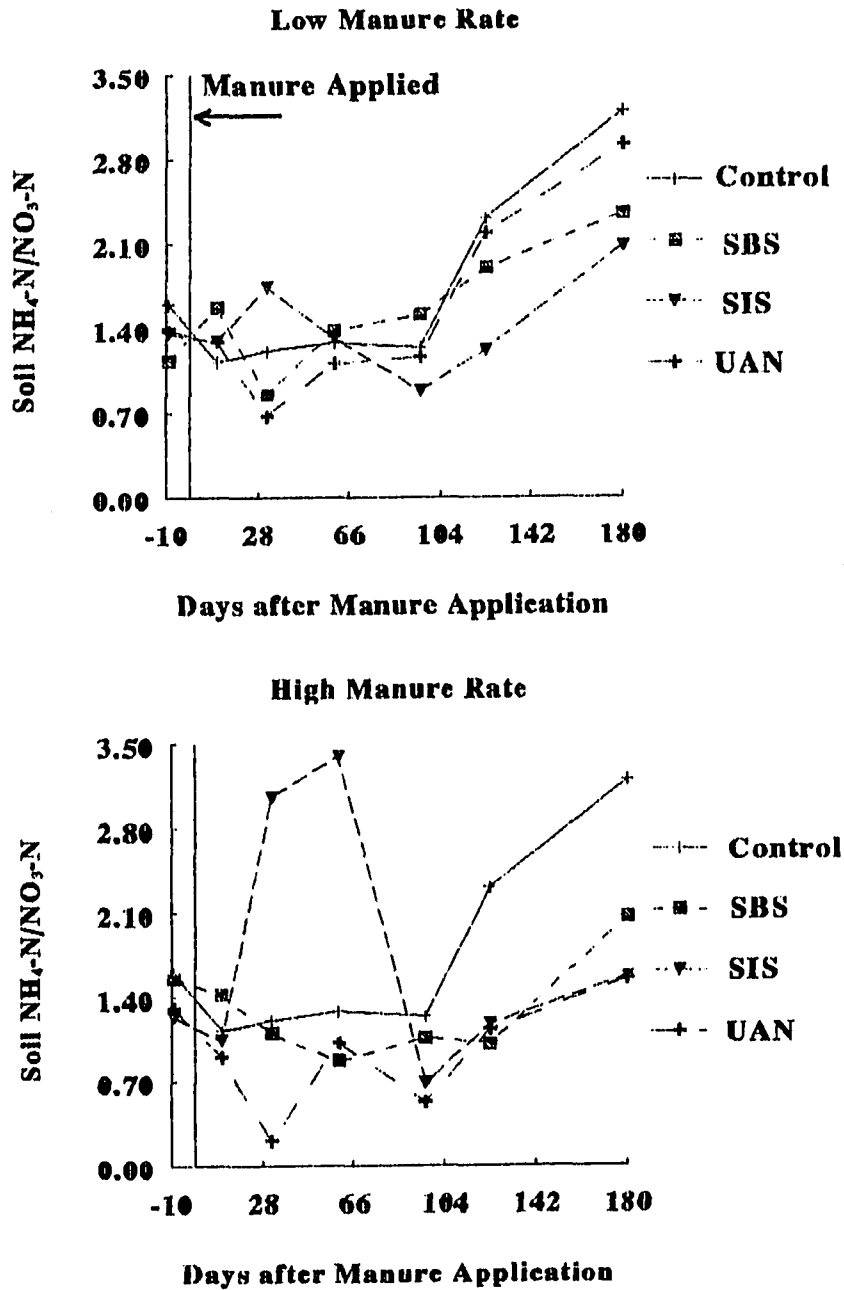


Figure 17. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for spring-applied treatments (SBS, spring broadcast swine; SIS, spring injected swine; UAN, urea-ammonium nitrate) in a 91-cm profile for 1991 at the Curtiss Farm site.

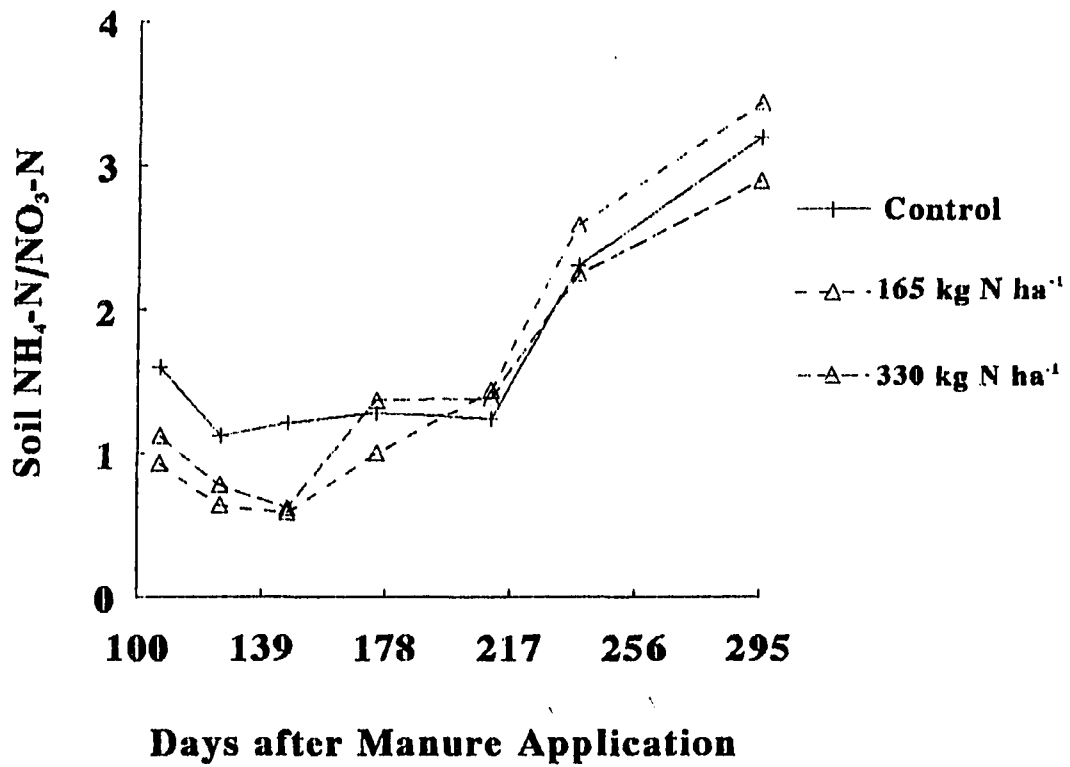


Figure 18. Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios for a 91-cm profile under two rates of winter-broadcast swine manure at the Curtiss Farm in 1991.

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_1 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. ANE's and ANR's were consistently higher with UAN than with the manures. High values indicated more of the applied N was used by the corn. SIP-treated plots had ANE and ANR values similar to UAN. SID and SIS treatments tended to have higher ANE's and ANR's than the corresponding broadcast treatments. In other words, UAN was the most efficiently used N-source of all the treatments studied. Of the manure treatments, injected manure-N was more efficiently used than broadcast manure-N.

The concentration of N_i in the soil profile was low. Specifically, NO_3-N was on the order of 5 mg kg^{-1} . 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 not suggest 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 . Soil NH_4-N/NO_3-N ratios showed that the greatest potential for NO_3-N leaching was in soil amended with SIP. 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.

REFERENCES CITED

- Bitzer, C.C., and J.T. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. *J. Environ. Qual.* 17:47-54.
- Comfort, S.D., K.A. Kelling, D.R. Keeney, and J.C. Converse. 1988. The fate of nitrogen from injected liquid manure in a silt loam soil. *J. Environ. Qual.* 17:317-322.
- Council for Agricultural Sciences and Technology. 1985. Agricultural and groundwater quality. Rep. 103. CAST, Ames, IA.
- Evans, S.D., P.R. Goodrich, R.C. Munter, and R.E. Smith. 1977. Effects of solid and liquid beef manure and liquid hog manure on soil characteristics on the growth, yield, and composition of corn. *J. Environ. Qual.* 6:361-368.
- Fletcher, D.A. 1987. A national perspective. p. 9-17. *In* R.F. Follett, D.R. Keeney, and R.M. Cruse (eds.). *Managing nitrogen for groundwater quality and farm profitability.* SSSA, Madison, WI.
- Fratric, I., and E. Parraková. 1977. Waste management problems and their impact on the environment. p. 797-806. *In* R.C. Loehr (ed.) *Land as a waste management alternative.* Proc. of the 1976 Cornell agricultural waste management conference. Ann Arbor Sci. Pub. Ann Arbor, MI
- Hallberg, G.R. 1986. From hoes to herbicides: Agriculture and groundwater quality. *J. Soil Water Conserv.* 41:357-364.
- Jokela, W.E. 1992. Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. *Soil Sci. Soc. Am. J.* 56:148-154.
- Keeney, D.R. 1982. Nitrogen management for maximum efficiency and minimum pollution. p. 605-649. *In* F.J. Stevenson (ed.) *Nitrogen in agricultural soils.* Agron. Monogr. 22. ASA, CSSA, SSSA, Madison, WI.
- Keeney, D.R., and R.F. Follett. 1991. Managing nitrogen for groundwater quality and farm profitability: Overview and introduction. p. 1-7. *In* R.F. Follett, D.R. Keeney, and R.M. Cruse (eds.) *Managing nitrogen for groundwater quality and farm profitability.* SSSA, Madison, WI.
- Keeney, D.R., and D.W. Nelson. 1982. Nitrogen--Inorganic forms. *In* A.L. Page (ed.) *Methods of soil analysis.* Part 2. 2nd. ed. *Agronomy* 9:643-698.
- Killorn, R.J., D. Wetterauer, and A. Britten. 1990. Animal manure management project. p. 53-56. *In* *Integrated farm management demonstration program, 1990 progress report.* Iowa State Univ. Extension Pub. Pm-1417. Ames, IA.

- Kimble, J.M., R.J. Bartlett, J.L. McIntosh, and K.E. Varney. 1972. Fate of nitrate from manure and inorganic nitrogen in a clay soil cropped to continuous corn. *J. Environ. Qual.* 4:413-415.
- Liebhardt, W.C., C. Golt, and J. Tupin. 1979. Nitrate and ammonium concentrations of ground water resulting from manure applications. *J. Environ. Qual.* 8:211-215.
- Martin, W.P., W.E. Fenster, and L.D. Hanson. 1970. Fertilizer management for pollution control. p. 142-158. *In* T.L. Willrich and G.E. Smith (eds.) *Agricultural practices and water quality*. Iowa State Univ. Press. Ames, IA.
- Meer H.G. van der, R.B. Thompson, P.J.M. Snijders, and J.H. Geurink. 1987. Utilization of nitrogen from injected and surface-spread cattle slurry applied to grassland. p.47-71. *In* H.G. v.d. Meer et al. (eds.) *Animal manure on grassland and fodder crops*. Martinus Nijhoff Pub. Dordrecht, The Netherlands.
- Miner, J.R., and T.L. Willrich. 1970. Livestock operations and field-spread manure as sources of pollutants. p. 231-240. *In* T.L. Willrich and G.E. Smith (eds.) *Agricultural practices and water quality*. Iowa State Univ. Press. Ames, IA.
- N'Dayegamiye, A., and D. Côté. 1989. Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological properties. *Can. J. Soil Sci.* 69:39-47.
- Parr, J.F. 1973. Chemical and biological considerations for maximizing the efficiency of fertilizer nitrogen. *J. Environ. Qual.* 2:75-84.
- SAS Institute. 1982. *SAS user's guide: Statistics*. SAS Institute, Inc. Cary, NC.
- Shortall, J.G., and W.C. Liebhardt. 1975. Yield and growth of corn as affected by poultry manure. *J. Environ. Qual.* 4:186-191.
- Sims, J.T. 1986. Nitrogen transformations in a poultry manure amended soil: Temperature and moisture effects. *J. Environ. Qual.* 15:59-63.
- Sims, J.T. 1987. Agronomic evaluation of poultry manure as a nitrogen source for conventional and no-tillage corn. *Agron. J.* 79:563-570.
- Smith, J.J. 1989. Stacking the odds in favor of the plant. *Dealer Progress*. May/June 1989, p.33.
- Sommers, L.E. 1986. Use of sewage sludge in corn production. Purdue Univ. Extension Pub. NCH-27. West Lafayette, IN.

- Sutton, A.L., D.W. Nelson, V.B. Mayrose, and J.C.Nye. 1978. Effects of liquid swine waste applications on corn yield and soil chemical composition. *J. Environ. Qual.* 7:325-333.
- Sweeten, J.M., and A.C. Mathers. 1985. Improving soils with livestock manure. *J. Soil Water Conser.* 40:206-210.
- Tiarks, A.E., A.P. Mazurak, and L. Chesnin. 1974. Physical and chemical properties of soil associated with heavy applications of manure from cattle feedlots. *Soil Sci. Soc. Amer. Proc.* 38:826-830.
- van Faassen, and H. van Dijk. 1987. Manure as a source of nitrogen and phosphorus. p.27-46. *In* H.G. v.d. Meer et al. (eds.) *Animal manure on grassland and fodder crops*. Martinus Nijhoff Pub. Dordrecht, The Netherlands.
- Wadman, W.P., C.M.J. Slijmans, and L.C.N. de la Lande Cremer. 1987. Value of animal manures: Changes in perception. p. 1-16. *In* H.G. v.d. Meer et al. (eds.) *Animal manure on grassland and fodder crops*. Martinus Nijhoff Pub. Dordrecht, The Netherlands.
- Walters, D.T., and G.L. Malzer. 1990. Nitrogen management and nitrification inhibitor effects on nitrogen-15 urea: I. Yield and fertilizer use efficiency. *Soil Sci. Soc. Am. J.* 54:115-122.

PAPER II. SOIL pH AND EC FOLLOWING APPLICATIONS OF LIQUID ANIMAL
MANURE

INTRODUCTION

In areas where livestock confinement facilities operate there is concern over using the soil as a disposal medium for animal wastes. The benefits of using animal manure as a source of nutrients for crop production are well known (Jokela, 1992; N'Dayegamiye and Côté, 1989; Shortall and Liebhardt, 1975; Sims, 1987; Sutton et al., 1978; Sweeten and Mathers, 1985; Tiarks et al., 1974). Over-application of manure may cause crop production problems.

Manure has variable concentrations of mineral salts that can contribute to soil salinity. Major cations in salt-affected soils are Na^+ , Ca^{2+} , Mg^{2+} , and K^+ . In manure-amended soil, K^+ may be the most important source of salinity (Liebhardt, 1976). Applying excessive amounts of manure can increase the salt content of the soil, causing crop yield reductions and in severe cases no plant growth at all. In the laboratory, columns of Kansas soil were saturated with lagoon water from a beef feedlot and salt levels increased 200% (Travis et al., 1971). The measured electrical conductivities (EC) were as high as 13.4 dS m^{-1} . Wallingford et al. (1974) irrigated corn in Kansas with beef-feedlot-lagoon water and found soil EC increasing with amount of lagoon water applied. They also found that corn forage yield increased from improved fertility with lagoon water but noted relative yield decreases as soil EC increased. At an EC value of around 1.2 dS m^{-1} forage yields began decreasing in the second year of the experiment. Adriano et al. (1971) found a potential salinity hazard from dairy-manure disposal.

Concern over soil salinity occurs mainly in arid and semi-arid areas where limited water movement through the soil profile controls the

concentrations of soluble salts. In subhumid and humid regions, greater precipitation may control the concentration of salts in the profile. Salinity problems in these areas can occur as the result of agricultural activities such as crop fertilization and waste-spreading operations. Concentrations of salts added with animal manure may temporarily affect the salinity of the soil and increase the EC of the soil solution. In Minnesota Evans et al. (1977) found that high applications of beef and hog manure raised soil EC enough that corn wilting was observed in some areas.

Many environmental factors determine a plant's capacity to tolerate the effects of excess salt. Biologically, seedling emergence and early seedling growth can be the most sensitive stages of development (Maas, 1990). Corn has also been shown to be more sensitive during vegetative and early reproductive stages than during the grain-filling stage (Maas et al., 1983).

A threshold EC value of 1.7 dS m^{-1} for corn (*Zea mays* L.) has been reported (Maas, 1990; Maas and Hoffman, 1977). Above the threshold level yield decreases can be expected. Other work shows that corn yield reductions of 10% may occur if soil EC values reach 5 dS m^{-1} and at EC values of 7 dS m^{-1} yield reductions of 50% may occur (Bernstein, 1964).

Soil pH may also be affected by applications of manure. Soil pH in turn can determine the rate of various reactions in the soil solution. In incubation studies using activated sludge Fine et al. (1989) found that increases in soil pH from applications of sludge increased the $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios of the soil. The adsorption of $\text{NH}_4\text{-N}$ and the reduction of pH from volatilization and carbonate precipitation were responsible for slowing the loss of mineral N.

The objectives of the current work were to evaluate the risk of salinity damage to corn grain yield from repeated applications of liquid animal manure at normal rates and to determine the potential for long-term changes in soil EC and pH. Corn grain yield is reported in the first part of this dissertation. This section will report on the relative differences in EC and pH values of soil treated with the different manures.

MATERIALS AND METHODS

The two study areas for this experiment were located in central Iowa. The Answer Farm site was located about 16 km east of Fort Dodge, IA. Soil at the site was Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls) on a 2% slope. The Curtiss Farm site was located about 1.6 km southwest of Ames, IA. Soil at the Curtiss Farm plot was Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludolls) on a 1% slope. Manure had not been applied at either site within 10 y of the start of this experiment. Initial pH and EC values for the two sites are shown in Table 1.

Table 1. Initial EC and pH values for soils used in this study.

Depth (cm)	Nicollet l			Webster sicl		
	0-30	30-61	61-91	0-30	30-61	61-91
pH	6.1	6.8	7.5	6.8	7.2	7.2
EC, dS m ⁻¹	0.4	0.5	0.5	0.6	0.5	0.7

Liquid dairy manure obtained on site and poultry manure from a commercial egg producer were applied at the Answer Farm site. Liquid hog manure from a commercial confinement facility and an inorganic fertilizer, urea-ammonium nitrate (UAN) were applied at the Curtiss Farm site. Manure and UAN were applied based on total N content. The low and high rates supplied 185 and 370 kg N ha⁻¹, respectively. Control plots were also included for each treatment. Dairy-manure plots received 34 000 L ha⁻¹ and 68 000 L ha⁻¹, poultry manure was applied at 20 500 L ha⁻¹ and 41 000 L ha⁻¹, and hog manure was applied at 28 000 L ha⁻¹ and 56 000 L ha⁻¹. The manure was

broadcast on some of the plots and injected on others in the spring before planting corn (*Zea mays* L.). During the winter, dairy manure was broadcast at the Answer Farm site and hog manure was broadcast at the Curtiss Farm site.

The manure was applied by using a standard 11 250 L pressure/vacuum manure tank equipped with two knives spaced about 127 cm apart. The equipment was calibrated by measuring flow from the knives and adjusting tractor speed to apply the desired quantity of manure. The knives were in an upright position for broadcast treatments and set to a depth of about 15 cm for injected treatments. Tillage of the plots consisted of disking within 2 d of manure application 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 4°C until analysis by the Analytical Services Laboratory at Iowa State University (Table 2). Samples were generally stored for about one week before analysis. In 1989 the poultry manure was diluted with water to thin it enough so it could be applied with the manure tank. A sample 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 determined from the difference in N concentration between the two samples. The dilution factor was then used to estimate the solid content of the diluted sample.

Corn was planted in six-row plots (4.5 by 12 m) that were arranged as a split-plot with four replications. The main-plot was the method of manure application and the sub-plots were the application rates. The first

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

Manure	Date	Total-N	Total-P	Total-K	Solids
		----- mg kg ⁻¹ -----			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.

treatments were applied in the spring of 1989.

Soil samples were collected before manure application and then periodically until harvest. Soil samples were collected a total of 4, 8, and 7 times in 1989, 1990, and 1991, respectively. Three soil cores, 2.5 cm in diameter and 91 cm deep, were collected in 30.5-cm sections from each plot. Core positions were located diagonally across the center of each plot. The soil was dried and ground to pass a 2-mm sieve. A water-saturated paste was made of each composite sample by using standard procedures (Rhodes, 1982) and was analyzed for pH by using a standard combination pH electrode. The saturated paste was vacuum filtered and the extract was analyzed for soluble salts by resistance measurements.

The effect of manure treatment on soil EC and pH were statistically analyzed by using the GLM (General Linear Models) procedure (SAS Institute, 1982). The independent parameters for 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 pH and EC values for each year of the experiment. The analysis was completed for each year of the experiment independently of the other years.

RESULTS AND DISCUSSION

Soil Electrical Conductivity

The effect of manure treatment on soil EC for both sites and each year is shown in Table 3. The application of poultry manure by spring injection (SIP) to the soil caused significant changes in soil EC (Fig. 1a). Soil EC increased to 0.87 dS m^{-1} 12 d after manure was applied. After 55 d, EC had reached 1.2 dS m^{-1} . When the last soil samples were collected after harvest in 1989, EC in plots that received SIP was higher than control plots but had fallen to around 1 dS m^{-1} . These values are below the reported threshold levels for corn. Analysis of corn grain yield did not indicate any EC effects on yield. Plots treated with SIP were the second highest yielding plots at this site. In 1989, however, only the low rate of SIP was applied. Application of the high rate of SIP could have resulted in considerably higher EC values.

At the time of the second manure application, EC of treated plots had returned to a level similar to the level found in control plots (Fig. 1b). In 1990, two rates of SIP were applied. Six days after manure was applied, EC in treated soil was around 0.7 dS m^{-1} for both application rates. The high rate of SIP resulted in a slightly higher EC than the lower rate. It has been suggested that K added with manure may be a significant factor contributing to increased salinity. According to the manure analysis, almost twice the amount of K was added in 1990 and the resulting EC values were lower than from the first manure application. In fact, all measured SIP-manure characteristics were higher in 1990 than in 1989 except for solid

Table 3. Effect of manure treatment on soil EC.

Source	1989		1990		1991	
	df	MS	df	MS	df	MS
Answer Farm Site						
Manure (M)	2	0.01	3	0.01	3	0.01
Rate (R)	3	0.52**	6	0.13**	6	0.05**
M*R	2	0.02	2	0.03*	2	0.002
Sample depth (D)	2	0.14**	2	0.003	2	0.003
D*M	4	0.003	6	0.01	6	0.01
D*R	6	0.05*	12	0.02**	12	0.01
D*M*R	4	0.002	4	0.005	4	0.002
Sample time (T)	3	0.19**	7	0.34**	5	0.19**
D*T	6	0.01	14	0.02**	10	0.02
T*M	6	0.01	21	0.009	15	0.01
T*R	9	0.03	42	0.01*	30	0.02
T*M*R	18	0.03	14	0.01	10	0.01
Curtiss Farm Site						
N-Source (M)			3	0.19**	3	0.08**
Rate (R)			2	0.56**	2	0.79**
M*R			6	0.15**	6	0.11**
Sample depth (D)			2	0.02	2	0.12**
D*M			6	0.03	6	0.01
D*R			4	0.02	4	0.06**
D*M*R			12	0.01	12	0.02
Sample time (T)			7	0.81**	6	0.34**
T*D			14	0.03*	12	0.02
T*M			20	0.06**	18	0.04**
T*R			14	0.09**	12	0.03*
T*M*R			40	0.04**	36	0.03**

*,** Significant at the 0.05 and 0.01 probability levels, respectively.

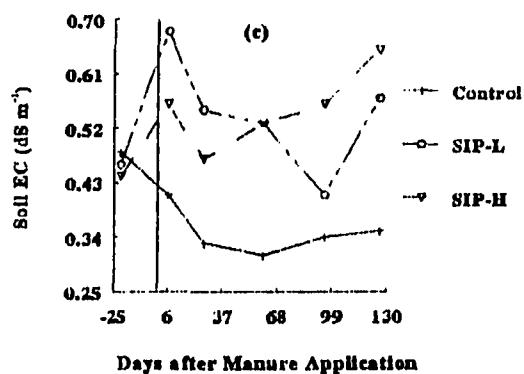
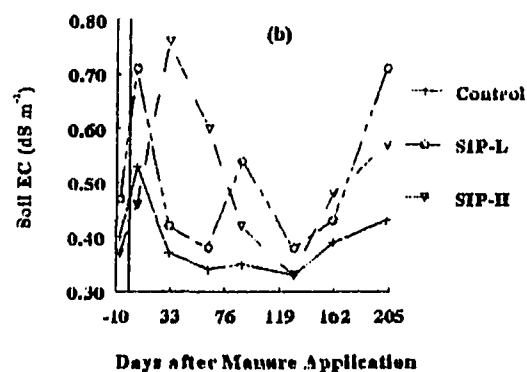
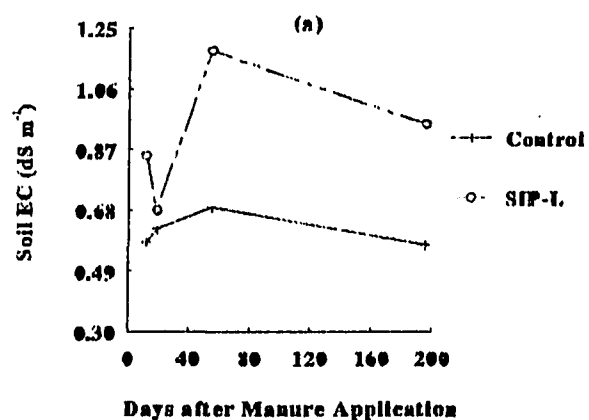


Figure 1. EC of the surface 30 cm of soil treated with poultry manure for (a) 1989, (b) 1990, and (c) 1991 at the Answer Farm site. Two rates of manure (L and H, 20 500 and 41 000 L ha⁻¹, respectively) were injected in the spring of each year before planting.

content. In 1989, solid content of SIP was so high it created difficulties in applying the manure and was estimated at about 15%. The highest soil EC was measured in 1989. The high solid content of applied SIP seemed to have an affect on manure produced salinity.

During the 1990 growing season, EC values of SIP-treated soil slowly dropped to near the level of control plots. The last soil samples were collected at harvest time and EC in SIP-treated soils had increased.

Before manure was applied in 1991 EC had again returned to the level of control plots (Fig. 1c). Soil EC showed basically the same response as the two previous years. EC increased and 6 d after manure was applied was about 0.7 dS m^{-1} . Solid content of SIP in 1991 was lower than the two previous years and EC of the soil showed a smaller increase.

Dairy manure was applied at the Answer Farm site by broadcasting over the surface in the spring (SBD) and injecting (SID). The same manure was used and applied at the same rates for both methods of application. Dairy manure was also applied in the winter (WBD). There were some interesting differences in how the method of application affected soil EC.

Dairy manure used for the first application was very low in K and solid content. Initially, after manure application, soil EC increased to about 0.8 dS m^{-1} then decreased to the level of control plots for the rest of the season (Fig. 2a). During the second year of the experiment, the high rate of SBD increased EC to levels similar to SIP (Fig. 2b). The dairy manure had a lower K concentration and lower solid content. About 30 d after manure application, EC levels had dropped to near the level of control plots and remained there through harvest. The final year of the experiment showed no

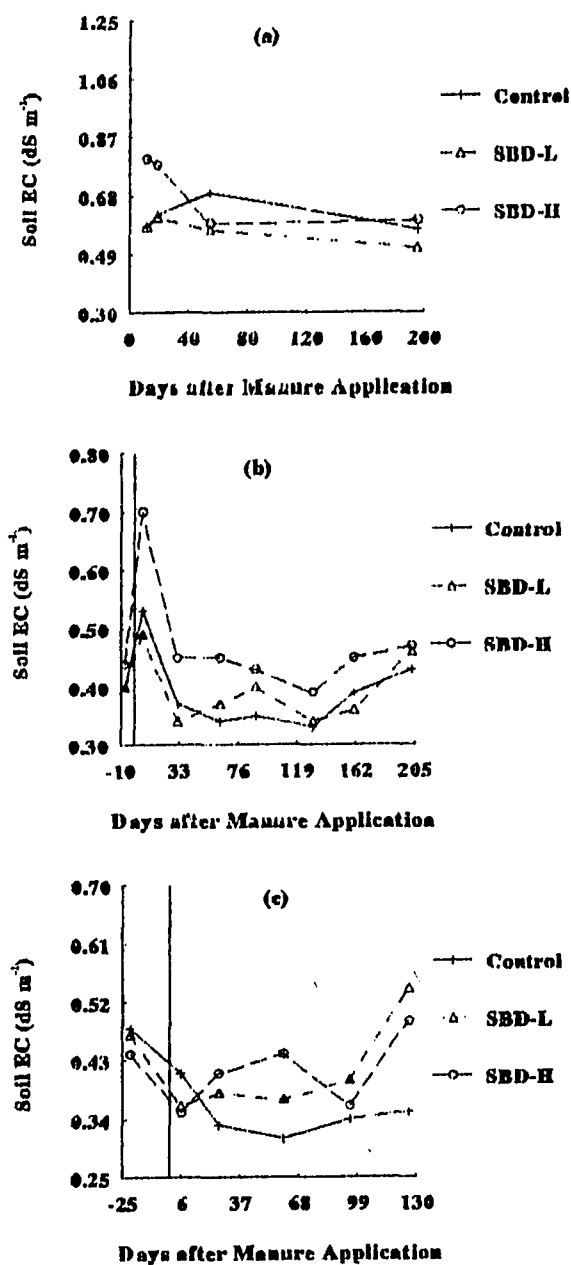


Figure 2. EC to a depth of 30 cm of soil treated with dairy manure for (a) 1989, (b) 1990, and (c) 1991 at the Answer Farm site. Two rates of manure (L and H, 34 000 and 68 000 L ha⁻¹, respectively) were broadcast in the spring before planting.

initial increase in soil EC from manure application (Fig. 2c). Solid content of spring 1991 dairy manure was the lowest of any manure used in the experiment.

When dairy manure was injected, the sharp increases in soil EC were not observed (Fig. 3). EC response to injected manure in the first year was almost identical to the response with broadcast manure (Fig. 3a). The second manure application showed increases in soil EC with the high rate of manure but the increase occurred through the middle of the growing season (Fig. 3b). This may be because the injection bands concentrate the manure in isolated areas across the plot. The effects observed could occur as salt from the manure dissipates away from the band into the plot. Higher EC values may have been measured if soil samples had been collected directly from the injection band. Fall soil samples collected after harvest in 1990 showed EC of soil treated with the high rate of SID was slightly higher than EC of soil treated with the same rate of SBD.

A similar pattern was repeated in the third year of SID manure application (Fig. 3c). Before manure application soil EC values were near the values of the fall before. After manure application soil EC values fluctuated but generally remained at approximately the same level throughout the growing season.

The first soil samples from plots treated with WBD showed only small variations from control-plot EC values (Fig. 4a). The second year of WBD also showed little effect of manure on soil EC values (Fig. 4b).

Swine manure broadcast in the spring (SBS) did not change soil EC after the first application (Fig. 5a). The EC of treated soil followed closely

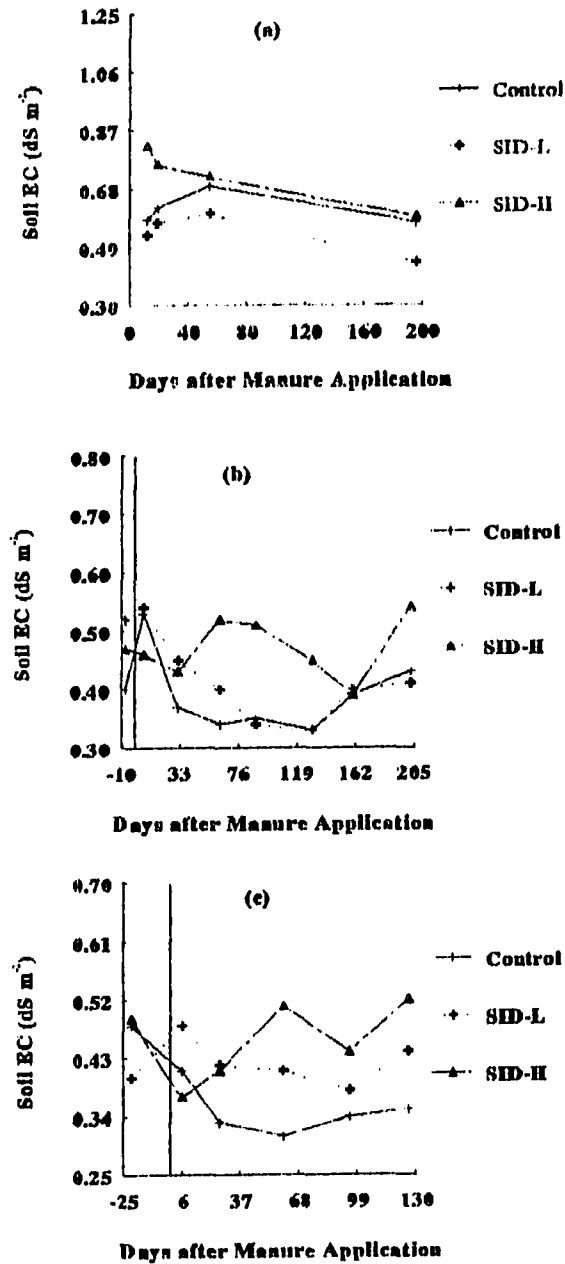


Figure 3. EC of the surface 30 cm of soil in plots treated with injected dairy manure (SID) for (a) 1989, (b) 1990, and (c) 1991. Manure was applied at two rates (L and H, 34 000 and 68 000 L ha⁻¹, respectively) in the spring before planting.

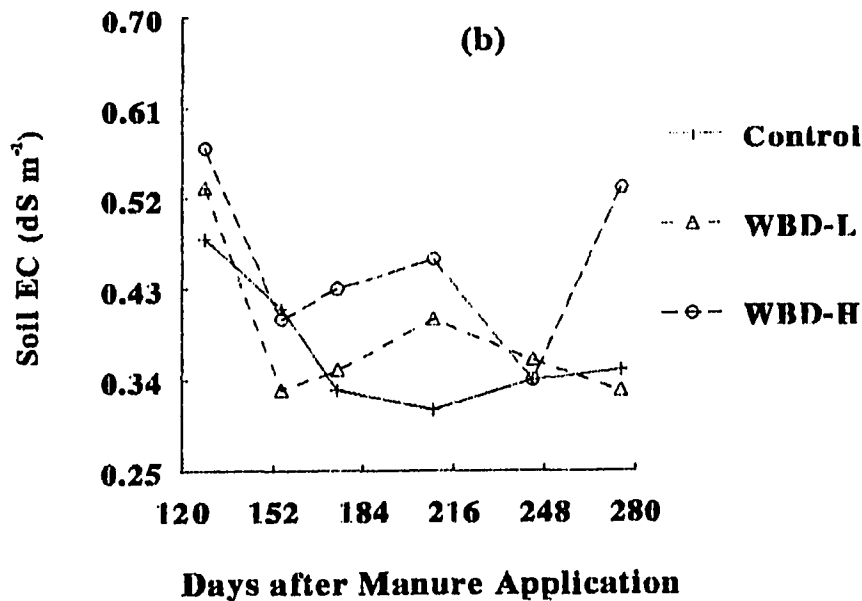
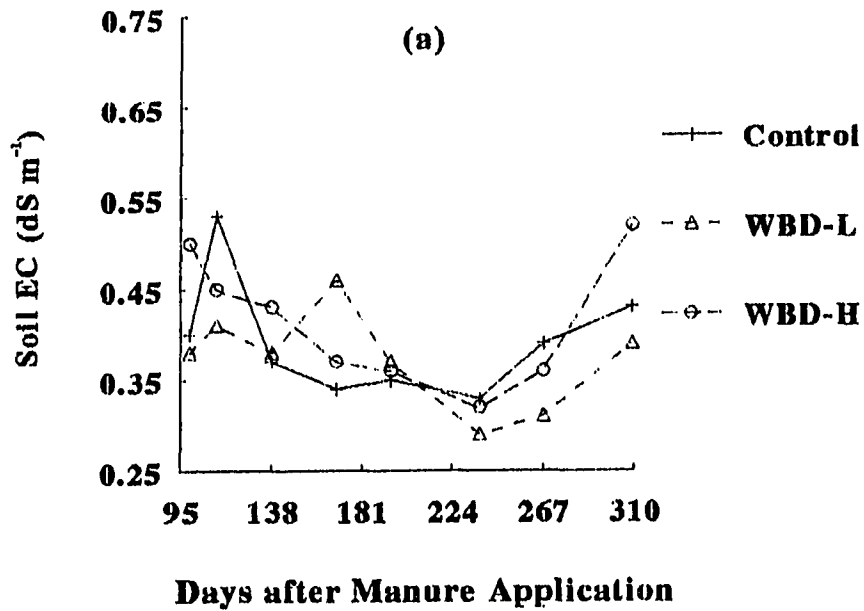


Figure 4. EC in the surface 30 cm of soil that received dairy manure broadcast during the winter (WBD) of (a) 1990 and (b) 1991 at two rates (L and H, 34 000 and 68 000 L ha^{-1} , respectively) at the Answer Farm site.

with EC of control plots. The second application of SBS (in 1991) increased soil EC to 0.9 dS m^{-1} in the soil samples collected after manure was applied (Fig. 5b). Thirty days after manure was applied, soil EC in SBD-treated plots had returned to initial values.

Soil EC from plots treated with injected swine manure (SIS) was similar to EC of plots treated with SID (Fig. 6a). Soil EC generally increased but without the sharp peaks seen with broadcast manure. One notable exception occurred during the first year with SIS. About two months after manure was applied, an average EC of almost 1.2 dS m^{-1} was measured in SIS plots. The EC values for each plot receiving SID were 1.67, 2.12, 0.32, and 0.59 dS m^{-1} on that sampling date. This is an example of the high variability that occurs when sampling plots that received injected-manure treatments. It also shows that when manure is concentrated EC values above the threshold level for corn can occur and there may be some effect on yield. The second year of SIS showed relatively moderate increases in soil EC (Fig. 6b).

Winter broadcasted swine manure (WBS) showed small relative increases in soil EC over control plots in both years (Fig. 7a and b).

Finally, urea-ammonium nitrate (UAN) treated soil had generally higher EC values than manure treated soil during the first year (Fig. 8a). The response during the second year was similar to the response to SBS manure (Fig. 8b).

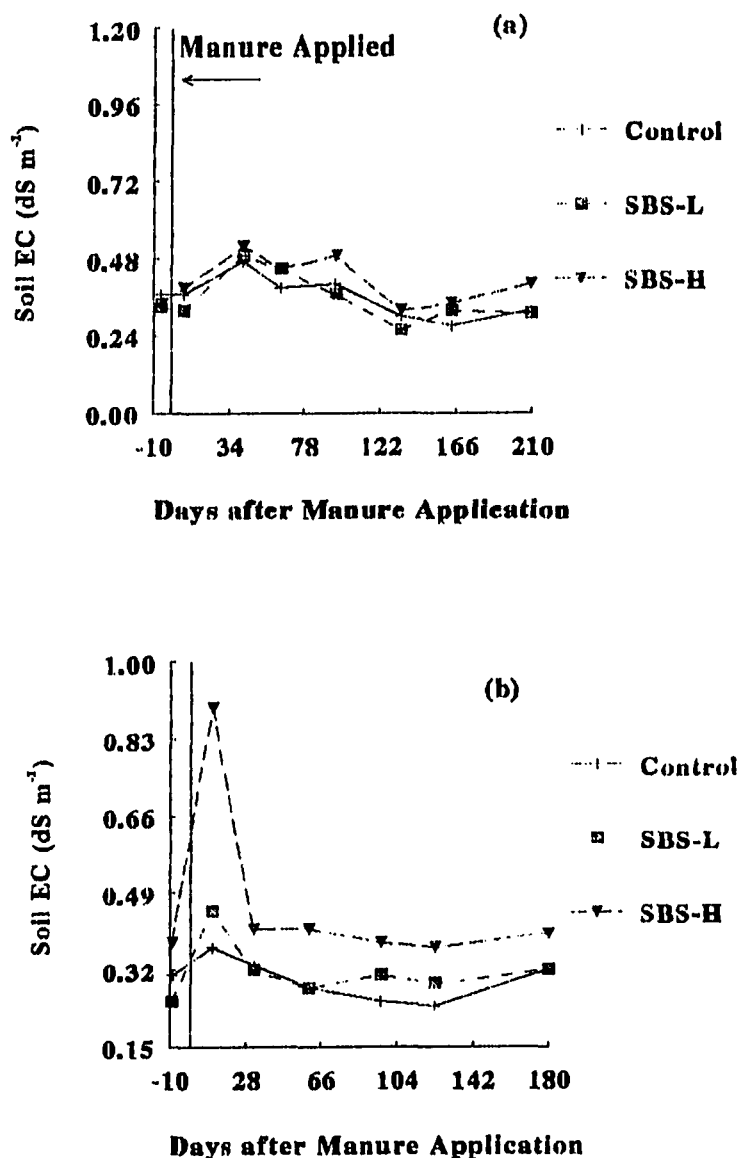


Figure 5. EC of the surface 30 cm of soil treated with swine manure (SBS) for (a) 1990 and (b) 1991 at the Curtiss Farm site. Manure was broadcast at two rates (L and H, 28 000 and 56 000 L ha⁻¹, respectively) in the spring before planting.

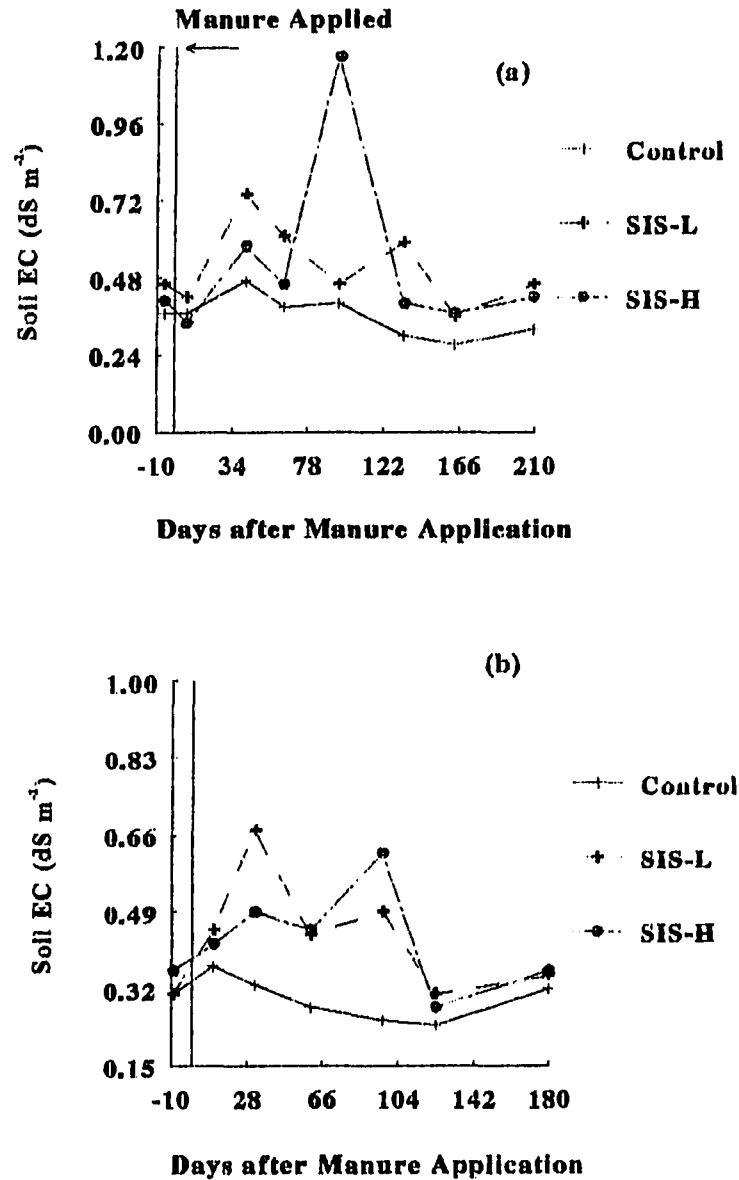


Figure 6. EC of the surface 30 cm of soil treated with injected swine manure (SIS) for (a) 1990 and (b) 1991 at the Curtiss Farm site. Manure was applied at two rates (L and H, 28 000 and 56 000 L ha⁻¹, respectively) in the spring before planting.

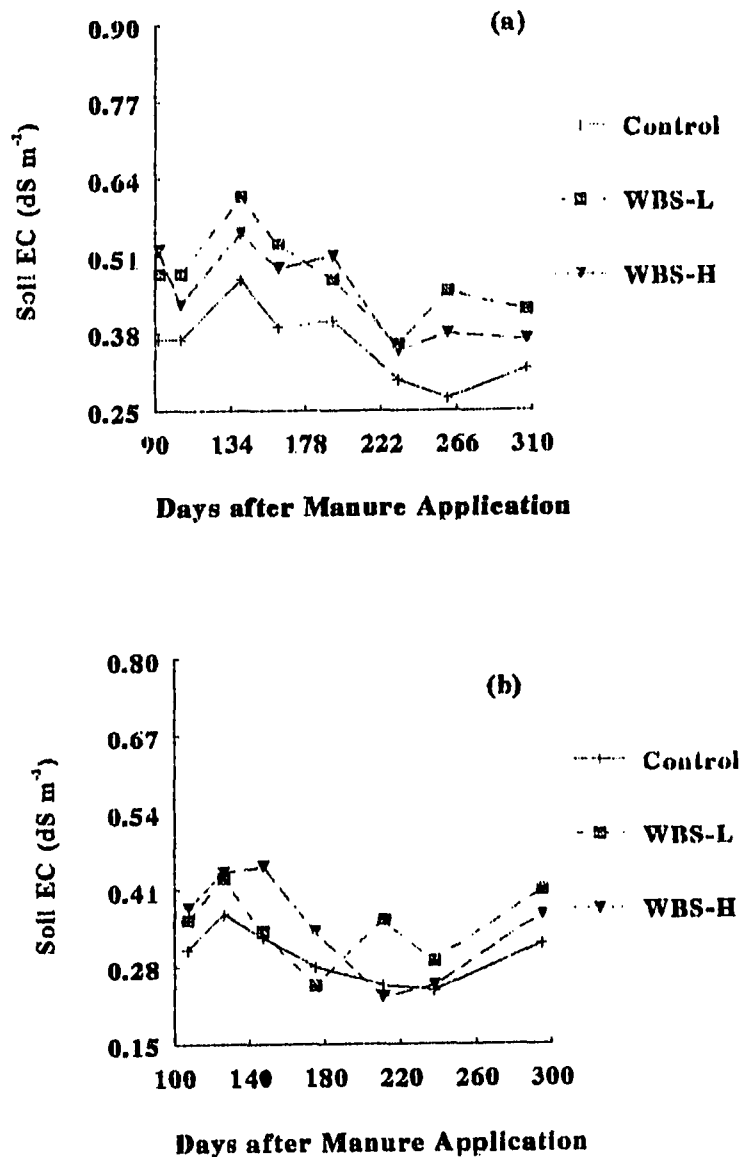


Figure 7. EC of the surface 30 cm of soil treated with winter applied swine manure for (a) 1990 and (b) 1991 at the Curtiss Farm site. Manure was applied at two rates (L and H, 28 000 and 56 000 L ha⁻¹, respectively) during January of each year.

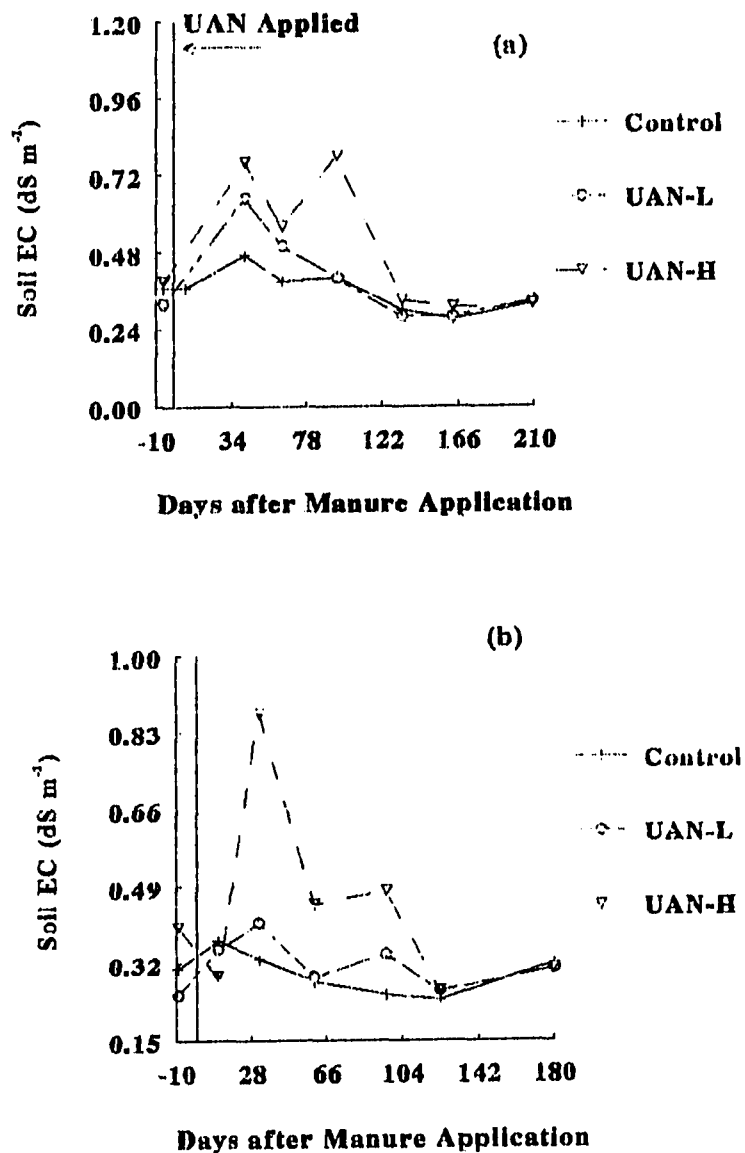


Figure 8. EC of the surface 30 cm of soil treated with urea-ammonium nitrate (UAN) for (a) 1990 and (b) 1991 at the Curtiss Farm site. UAN was broadcast at two rates (L and H, 165 and 330 kg N ha^{-1} , respectively) in the spring before planting.

Soil pH

Relative changes in soil pH from the application of manure at the two sites were small. The experiment was conducted for a total of 5 site-years, 3 yr at the Answer Farm site and 2 yr at the Curtiss Farm site. During that time, soil pH varied less than 1 unit from initial values (Table 4). 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 SBD and SID. High rates of SIP produced slightly lower soil pH values. Higher soil pH values from plots that received broadcast manure may be due to volatilization. Applying manure during the winter produced pH values that were similar to values from control plots. When swine manure was applied (SBS and SIS) soil pH generally was slightly lower than control plot pH values.

Table 4. Soil pH of the surface 30 cm in samples collected at both sites under each treatment.

Source	Application	Rate	Spring pH [†]	Fall pH [†]
Answer Farm Site				
	Control		6.76	6.48
Dairy	Winter Broadcast (WBD)	L	6.76	6.61
		H	6.76	6.61
	Spring Broadcast (SBD)	L	6.87	6.84
		H	6.94	6.46
	Spring Inject (SID)	L	6.39	6.45
		H	7.10	6.74
Poultry	Spring Inject (SIP)	L	6.73	6.56
		H	6.76	6.11
Curtiss Farm Site				
	Control		6.26	6.19
Swine	Winter Broadcast (WBS)	L	6.58	6.50
		H	6.22	6.28
	Spring Broadcast (SBS)	L	6.01	6.13
		H	6.16	6.34
	Spring Inject (SIS)	L	6.13	6.09
		H	6.44	6.35
UAN	Spring Broadcast (UAN)	L	6.25	6.26
		H	6.24	6.08

[†] Spring sampling dates are 6 May 1989 and 12 April 1990, and fall sample dates are 17 Oct. 1991 and 5 Nov. 1991 for the Answer Farm site and Curtiss Farm site, respectively.

SUMMARY

Liquid manure from three different sources was applied at commonly used rates in central Iowa. Manure was broadcast on some of the plots in the winter. Other plots received broadcast and injected manure in the spring before planting. Urea-ammonium nitrate (UAN, 28% N w/w) was also broadcast in the spring at one site. No other sources of plant nutrients were provided. Soil samples were collected from the plots throughout each growing season to measure the effect of manure on soil electrical conductivity (EC) and pH.

Poultry manure (SIP) produced the highest average EC value during the first year of the experiment, 1.2 dS m^{-1} . This was below the threshold level of 1.7 dS m^{-1} reported for corn, therefore, EC was not considered to be a major factor affecting grain yield. Each application of SIP 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 (SBD) 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 (SID and SIS) 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.

REFERENCES CITED

- Adriano, D.C., P.F. Pratt, and S.E. Bishop. 1971. Nitrate and salts in soils and ground waters from land disposal of dairy manure. *Soil Sci. Soc. Amer. Proc.* 35:759-762.
- Bernstein, L. 1964. Salt tolerance of plants. U.S.D.A. Information Bull. 283.
- Evans, S.D., P.R. Goodrich, R.C. Munter, and R.E. Smith. 1977. Effects of solid and liquid beef manure and liquid hog manure on soil characteristics and on growth, yield, and composition of corn. *J. Environ. Qual.* 6:361-368.
- Fine, P., U. Mingelgrin, and A. Feigin. 1989. Incubation studies of the fate of organic nitrogen in soils amended with activated sludge. *Soil Sci. Soc. Am. J.* 53:444-450.
- Jokela, W.E. 1992. Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. *Soil Sci. Soc. Am. J.* 56:148-154.
- Liebhardt, W.C. 1976. Soil characteristics and corn yield as affected by previous applications of poultry manure. *J. Environ. Qual.* 5(4):459-462.
- Mass, E.V. 1990. Crop salt tolerance. p. 262-304. *In* K.K. Tanji (ed.) *Agricultural salinity assessment and management*. Am. Soc. Civil Eng. Manuals and reports on engineering practices no. 71.
- Maas, E.V., and G.J. Hoffman. 1977. Crop salt tolerance -- current assessment. *J. Irrig. and Drainage Div. ASCE* 103(IR2):115-134.
- Maas, E.V., G.J. Hoffman, G.D. Chaba, J.A. Poss, and M.C. Shannon. 1983. Salt sensitivity of corn at various growth stages. *Irrig. Sci.* 4:45-57.
- N'Dayegamiye, A., and D. Côté. 1989. Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological properties. *Can. J. Soil Sci.* 69:39-47.
- Rhodes, J.D. 1982. Soluble salts. *In* A.L. Page, R.H. Miller, and D.R. Keeney (eds.) *Methods of soil analysis*. Part 2. 2nd. ed. *Agronomy* 9:167-179.
- SAS Institute. 1982. *SAS user's guide: Statistics*. SAS Institute, Inc. Cary, NC.
- Shortall, J.G., and W.C. Liebhardt. 1975. Yield and growth of corn as affected by poultry manure. *J. Environ. Qual.* 4:186-191.

- Sims, J.T. 1987. Agronomic evaluation of poultry manure as a nitrogen source for conventional and no-tillage corn. *Agron. J.* 79:563-570.
- Sutton, A.L., D.W. Nelson, V.B. Mayrose, and J.C.Nye. 1978. Effects of liquid swine waste applications on corn yield and soil chemical composition. *J. Environ. Qual.* 7:325-333.
- Sweeten, J.M., and A.C. Mathers. 1985. Improving soils with livestock manure. *J. Soil Water Conser.* 40:206-210.
- Tiarks, A.E., A.P. Mazurak, and L. Chesnin. 1974. Physical and chemical properties of soil associated with heavy applications of manure from cattle feedlots. *Soil Sci. Soc. Amer. Proc.* 38:826-830.
- Travis, D.O., W.L. Powers, L.S. Murphy, and R.I. Lipper. 1971. Effect of feedlot lagoon water on some physical and chemical properties of soils. *Soil Sci. Soc. Amer. Proc.* 35:122-126.
- Wallingford, G.W., L.S. Murphy, W.L. Powers, and H.L. Manges. 1975. Disposal of beef-feedlot manure: Effects of residual and yearly applications on corn and soil chemical properties. *J. Environ. Qual.* 4:526-531.

GENERAL SUMMARY

Studies were conducted at two sites in central Iowa to determine the effects of different animal manures and application methods on soil $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ and corn grain yield. Additionally, soil samples were analyzed for changes in electrical conductivity (EC) and pH. The objectives of the experiment were (i) to evaluate changes in soil inorganic N (N_i) to determine the potential for $\text{NO}_3\text{-N}$ contamination of surface and groundwater from different manure systems, (ii) to measure the effect of different types of manure application on corn grain yield, and (iii) to estimate the salinity hazard to corn grain yield from repeated application of moderate amounts of manure.

Paper I reports on the concentrations of N_i found in soil samples collected from manure-treated soils. After the first year of the experiment soil N_i concentrations were low. Observed N deficiencies in corn growing on plots treated with dairy manure indicate N from the manure was unable to supply the crop's needs. Soil at the Answer Farm site varied in degree of wetness from planting to harvest each year. At different sampling times free water was encountered in the 60-91 cm segment of the sampled profile in some plots producing conditions favorable for denitrification. There were no attempts made to determine the extent of denitrification under these conditions; however, it is possible that denitrification could be responsible for the loss of some N from the soil profile. Movement of $\text{NO}_3\text{-N}$ through the profile may also be responsible for N losses from the system. The low $\text{NO}_3\text{-N}$ concentrations in the profile present little threat to the quality of groundwater at the site.

Soil $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios showed that greater concentrations of the soil N_i fraction were $\text{NO}_3\text{-N}$ and therefore a greater potential for $\text{NO}_3\text{-N}$ leaching existed in poultry manure systems. When higher rates of poultry manure are applied the $\text{NO}_3\text{-N}$ leaching potential can increase.

The Curtiss Farm site plots that received the high rate of UAN produced the highest corn grain yield. The lowest $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios were from plots that received high rates of UAN, suggesting a greater potential for $\text{NO}_3\text{-N}$ leaching. Soil treated with high rates of injected swine manure also had low $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratios. The broadcast treatments of swine manure had the lowest potential for $\text{NO}_3\text{-N}$ leaching.

Paper II showed that the application of animal manure significantly increased soil EC at both sites. Increases in soil EC occurred early in the season at a time when corn plants are reported to be sensitive to salinity. The measured EC values were lower than reported threshold values for corn but suggest that with higher applications of manure, salinity problems may develop. Where manure was injected high EC values were measured near the bands. The EC values measured were high enough to affect corn plants growing near the bands. The soil EC values in all plots returned to initial levels before the next growing season, suggesting that there was some water movement through the soil profile after harvest.

The application of manure had no significant effects on soil pH in these experiments.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation and thanks to my wife Letitia for her support and encouragement through these difficult years of graduate school. I would also like to thank the rest of my family for indulging me while I did this Ph.D. thing.

I would like to express my appreciation to Dr. Randy Killorn for serving as my advisor for my Ph.D. and for the time spent reviewing and editing my work and encouragement along the way. I would like to thank Dr. Tom Loynachan for serving as a co-advisor on my committee and offering his assistance in completing this dissertation. I am also thankful to Dr. Rick Cruse, Dr. Michael Duffey, Dr. Doug Karlen, and Dr. Stu Melvin for serving on my committee.

I could not have completed all the work without the help of a number of friends and co-workers. Jaime Daza got me started in the lab and Joyce Hornstein put up with a graduate student messing up the work schedule all the time. John Ferrari provided valuable assistance in applying manure and collecting soil samples. Jeff Carr, Cindy Deppe, Boyd Derr, Lisa Hingtgen, Lori Nelson, Cheryl Ness, Kevin Roose, Lisa Schultz, Chris Sharp, and Jonathan Teske all provided help in the lab and put up with those nasty black flies while taking soil sample and I can never repay them for that misery. I would also like express my appreciation to Angela Reick for her help during this project.

Finally, I want to thank Paul Clayton at the Land O' Lakes Answer Farm and John and Bill for their help with tillage, planting, etc. and manure application during the course of the experiment.

APPENDIX TABLES

Appendix Table 1. Bray-1 extractable P and organic carbon to a depth of 91 cm in 1989 soil samples from the Answer Farm site.

		P			Organic carbon		
Depth (cm)		0-30	31-61	61-91	0-30	30-61	61-91
Manure Application		-----mg kg ⁻¹ -----			-----g kg ⁻¹ -----		
Control		30.14	8.36	4.31	57.6	26.9	14.7
SBD	L	31.58	8.27	3.29	55.0	25.0	15.7
	H	31.15	7.85	2.80	54.4	26.1	13.8
SID	L	31.20	9.10	2.95	50.8	25.2	14.2
	H	30.77	7.96	2.71	58.4	25.4	19.0
SIP	L	49.50	10.43	3.40	52.5	19.8	12.1

Appendix Table 2. Bray-1 extractable P and organic carbon to a depth of 91 cm in 1990 soil samples from the Answer Farm site.

Site 1							
		P			Organic carbon		
Depth (cm)		0-30	31-61	61-91	0-30	30-61	61-91
Manure Application		-----mg kg ⁻¹ -----			-----g kg ⁻¹ -----		
Control		24.22	6.43	4.11	56.4	25.2	14.9
SBD	L	27.44	6.31	5.50	54.8	26.1	15.4
	H	27.74	7.78	4.84	55.3	22.8	14.0
SID	L	29.72	6.56	2.70	53.7	26.3	15.8
	H	28.73	7.35	2.05	59.5	29.4	16.7
WBD	L	24.15	6.74	6.38	55.8	25.2	15.6
	H	25.72	5.82	2.99	57.2	23.9	13.6
SIP	L	40.33	10.03	3.08	54.7	29.2	16.8
	H	38.43	14.68	5.34	57.6	27.6	14.7

Appendix Table 3. Bray-1 extractable P and organic carbon to a depth of 91 cm in 1991 soil samples from the Answer Farm site.

Depth (cm)	P			Organic carbon		
	0-30	31-61	61-91	0-30	30-61	61-91
Manure Application	-----mg kg ⁻¹ -----			-----g kg ⁻¹ -----		
Control	24.41	4.48	2.02	52.5	24.0	13.3
SBD	L 25.38	6.37	1.27	52.5	23.1	13.7
	H 29.63	7.52	1.56	51.7	23.8	12.1
SID	L 27.75	4.47	1.64	47.5	24.2	13.0
	H 29.46	5.60	0.50	54.5	25.3	14.6
WBD	L 24.86	6.39	3.78	52.0	21.1	13.9
	H 29.94	7.68	1.85	52.3	23.8	13.6
SIP	L 47.32	6.53	4.40	49.8	23.5	15.6
	H 55.61	13.75	6.47	51.4	25.5	13.6

Appendix Table 4. Bray-1 extractable P and organic carbon to a depth of 91 cm in 1990 soil samples from the Curtiss Farm site.

Depth (cm)	P			Organic carbon		
	0-30	31-61	61-91	0-30	30-61	61-91
Manure Application	-----mg kg ⁻¹ -----			-----g kg ⁻¹ -----		
Control	17.09	5.18	2.97	45.2	22.5	14.1
SBS	L 21.25	6.84	4.06	49.2	26.1	15.7
	H 20.08	6.91	3.87	46.4	21.7	14.3
SIS	L 21.26	4.67	2.67	42.8	19.9	11.0
	H 18.66	4.62	1.88	41.6	19.8	12.0
WBS	L 16.14	5.70	2.95	44.7	21.9	13.6
	H 16.99	5.02	2.55	44.5	21.0	12.6
UAN	L 19.57	4.56	3.18	46.5	21.5	13.0
	H 12.90	3.38	1.69	43.9	22.2	11.6

Appendix Table 5. Bray-1 extractable P and organic carbon to a depth of 91 cm in 1991 soil samples from the Curtiss Farm site.

Depth (cm)	P			Organic carbon		
	0-30	31-61	61-91	0-30	30-61	61-91
Manure Application	-----mg kg ⁻¹ -----			-----g kg ⁻¹ -----		
Control	16.82	6.50	3.08	43.2	22.5	14.0
SBS	L 23.29	10.40	4.98	44.7	25.0	13.5
	H 34.46	16.26	4.65	40.2	19.1	11.7
SIS	L 29.71	8.22	4.64	41.3	20.8	13.1
	H 25.12	7.21	2.26	39.8	20.0	12.0
WBS	L 18.54	5.91	2.87	42.6	20.8	11.8
	H 18.77	6.85	6.24	41.9	20.5	12.7
UAN	L 16.47	5.37	2.88	42.5	21.4	12.8
	H 10.52	3.70	1.51	41.0	19.6	12.8

Appendix Table 6. Total-N and N-uptake from grain samples harvested in 1989 at the Answer Farm site.

Manure Application	Rate	Total-N	N-uptake
		g kg ⁻¹	kg ha ⁻¹
Control		12.1	101.5
SBD	L	12.4	103.7
	H	12.1	121.0
SID	L	12.7	102.1
	H	12.6	120.2
SIP	L	13.5	131.5

Appendix Table 7. Total-N and N-uptake from grain samples harvested in 1990 at the Answer Farm site.

Manure Application	Rate	Total-N	N-uptake
		g kg ⁻¹	kg ha ⁻¹
Control		10.7	27.3
SBD	L	11.0	30.6
	H	10.8	31.8
SID	L	11.2	37.3
	H	11.8	47.2
WBD	L	10.6	27.8
	H	10.9	28.1
SIP	L	12.1	54.4
	H	12.6	60.4

Appendix Table 8. Total-N and N-uptake from grain samples harvested in 1991 at the Answer Farm site.

Manure Application	Rate	Total-N	N-uptake
		g kg ⁻¹	kg ha ⁻¹
Control		9.9	32.0
SBD	L	10.3	37.0
	H	11.0	41.0
SID	L	11.0	45.7
	H	12.4	50.9
WBD	L	10.1	41.4
	H	11.4	54.6
SIP	L	14.1	62.9
	H	14.1	61.9

Appendix Table 9. Total-N and N-uptake from grain samples harvested in 1990 at the Curtiss Farm site.

Manure Application	Rate	Total-N	N-uptake
		g kg ⁻¹	kg ha ⁻¹
Control		10.4	35.9
SDS	L	10.4	39.6
	H	10.9	40.3
SIS	L	10.9	56.5
	H	10.7	48.7
WBS	L	9.8	37.1
	H	11.2	61.0
UAN	L	10.4	49.1
	H	11.5	70.0

Appendix Table 10. Total-N and N-uptake from grain samples harvested in 1990 at the Curtiss Farm site.

Manure Application	Rate	Total-N	N-uptake
		g kg ⁻¹	kg ha ⁻¹
Control		9.7	25.9
SDS	L	10.8	43.4
	H	10.8	52.8
SIS	L	11.9	71.1
	H	11.3	54.2
WBS	L	9.7	38.7
	H	10.1	33.2
UAN	L	10.0	37.1
	H	12.1	79.3

Appendix Table 11. 1989 average air temperature and precipitation for Webster City, IA near the Answer Farm site.

Month	Air Temp.	Deviation from normal	Preip.	Deviation from normal
	(⁰ C)	(⁰ C)	(mm)	(mm)
March	3.6	0.3	88.1	--
April	9.2	0.1	52.8	-19.0
May	13.8	-2.0	149.6	55.1
June	21.3	0.8	284.5	171.4
July	21.9	-2.0	144.3	38.1
Aug.	21.9	0.1	55.1	-50.8
Sept.	18.9	1.8	35.3	-35.0
Oct.	10.2	-0.9	35.8	-16.8
Nov.	4.8	2.7	21.8	-9.9

Appendix Table 12. 1990 average air temperature and precipitation for Webster City, IA near the Answer Farm site.

Month	Air Temp.	Deviation from normal	Preip.	Deviation from normal
	(⁰ C)	(⁰ C)	(mm)	(mm)
March	0.1	-0.3	17.3	-30.5
April	9.6	0.4	54.1	-17.8
May	15.0	-0.8	42.7	-51.8
June	20.0	-0.8	133.1	19.6
July	23.3	0.2	115.1	8.9
Aug.	21.3	-0.5	66.8	-39.1
Sept.	15.5	-1.6	100.8	30.5
Oct.	11.3	0.2	122.9	70.4
Nov.	0.3	-1.8	9.9	-21.6

Appendix Table 13. 1991 average air temperature and precipitation for Webster City, IA near the Answer Farm site.

Month	Air Temp.	Deviation from normal	Preip.	Deviation from normal
	(⁰ C)	(⁰ C)	(mm)	(mm)
March	3.6	3.2	94.7	47.0
April	10.3	1.2	179.6	107.7
May	17.7	1.8	217.9	123.4
June	23.1	2.3	116.3	2.79
July	23.2	0.1	57.4	-48.8
Aug.	21.7	-0.1	99.1	-6.9
Sept.	16.3	-0.8	113.8	43.4
Oct.	9.7	-1.3	102.9	50.3
Nov.	-2.6	-4.8	90.7	59.2

Appendix Table 14. 1990 average air temperature and precipitation for Ames, IA near the Curtiss Farm site.

Month	Air Temp.	Deviation from normal	Preip.	Deviation from normal
	(⁰ C)	(⁰ C)	(mm)	(mm)
March	4.7	3.6	127.2	74.7
April	9.9	0.2	50.8	35.6
May	14.3	-1.8	217.4	106.4
June	21.7	0.6	210.1	80.3
July	22.6	-0.7	195.6	107.9
Aug.	22.4	0.3	109.0	10.2
Sept.	19.9	2.5	57.1	24.4
Oct.	11.6	0.0	41.7	-17.0
Nov.	5.6	2.8	39.4	5.6

Appendix Table 15. 1991 average air temperature and precipitation for Ames, IA near the Curtiss Farm site.

Month	Air Temp.	Deviation from normal	Preip.	Deviation from normal
	(°C)	(°C)	(mm)	(mm)
March	4.6	3.5	123.9	71.4
April	11.3	1.6	232.9	146.6
May	18.3	2.2	131.8	20.8
June	23.3	2.2	106.2	-23.6
July	23.3	-0.1	44.4	-43.2
Aug.	21.9	-0.2	93.2	-5.6
Sept.	17.5	0.0	59.9	-21.6
Oct.	10.6	-0.9	84.6	25.9
Nov.	-2.0	-4.8	69.6	--

Appendix Table 16. Average soil temperature at 3 depths in 1989 at Ames, IA.

Depth (cm)	Soil temperature (°C)		
	5	10	20
March	6.8	4.3	1.8
April	21.5	18.2	12.4
May	30.2	27.2	20.2
June	33.4	30.9	25.2
July	39.3	36.9	30.0
Aug.	36.8	34.8	28.0
Sept.	29.4	27.4	22.0
Oct.	21.6	19.4	16.1
Nov.	6.6	5.3	6.3

Appendix Table 17. Average soil temperature at 3 depths in 1990 at Ames, IA.

Depth (cm)	Soil temperature ($^{\circ}\text{C}$)		
	5	10	20
March	11.7	8.7	5.5
April	21.1	17.4	12.3
May	24.8	21.8	16.7
June	29.9	27.2	22.1
July	31.8	29.3	24.4
Aug.	31.1	29.0	24.4
Sept.	28.7	26.8	22.7
Oct.	18.4	16.3	14.0
Nov.	9.6	8.4	8.4

Appendix Table 18. Average soil temperature at 3 depths in 1991 at Ames, IA.

Depth (cm)	Soil temperature ($^{\circ}\text{C}$)		
	5	10	20
March	9.2	6.8	4.5
April	17.7	15.5	11.8
May	24.6	22.6	18.5
June	32.3	29.7	24.4
July	3.1	2.2	3.4
Aug.	36.0	33.5	27.7
Sept.	27.4	25.7	22.0
Oct.	17.9	16.1	14.2
Nov.	3.1	2.2	3.4

Appendix Table 19. Corn hybrids used in these experiments.

Site	Year	Corn hybrid
Answer Farm	1989	Pioneer 3475
	1990	Pioneer 3475
	1991	Cenex 432
Curtiss Farm	1990	Pioneer 3343
	1991	Pioneer 3362