DISTRIBUTION OF APPLIED ANHYDROUS AMMONIA IN SOILS, GERMINATION HAZARD, AND UREA-N FERTILIZATION IN TILLAGE SYSTEMS FOR WINTER WHEAT

By

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INTRODUCTION

There are two parts to this dissertation which involve three separate studies. The first study combines field and laboratory research dealing with the distribution of applied anhydrous ammonia in soils and its potential germination hazard to winter wheat. The movement of anhydrous ammonia was studied at two moisture contents, two N rates, and after three time intervals in three soils.

Nitrogen fertilization in winter wheat residue management systems comprises the second part of this research project. Field studies were conducted at Stillwater and Lahoma over a three-year period with grain yield, leaf tissue NO_3-N, and grain N concentrations used to determine residue system and fertilizer effects. Following the second cropping season, soil samples were taken to determine the effect of surface applications of N fertilizer on the distribution of soil acidity and residual soil NO_3-N within the profile.

Part I is presented in a format suitable for publication in the Soil Science Society of America Journal. Part II will be divided into two articles following completion of crop and soil analysis for the 1985 season. The crop analysis portion will be submitted to the Agronomy Journal with the soil analysis portion suitable for a soils journal.

PART I

DISTRIBUTION OF APPLIED ANHYDROUS AMMONIA IN SOILS AND GERMINATION HAZARD TO WINTER WHEAT

ABSTRACT

Current changes in residue management systems for winter wheat (Triticum aestivum L.) include anhydrous NH_3 injection combined with herbicide application, planting, and other field operations. The feasibility of NH_3 application during planting is dependent upon potential NH_3 toxicity to germinating seeds. A laboratory experiment was conducted to study anhydrous NH_3 movement in soils by injecting 124 and 180 mg N as NH_3 into a Hollister clay (fine, mixed, thermic Pachic Paleustoll), Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll), and Norge clay loam (fine-silty, mixed, thermic Udic Paleustoll) at 12.4 and 18.1 water (g g^{-1}) contents, with soil samples taken 1, 7, and 14 d after N application. Soil NH_4-N and calculated $NH_{3(aq)}$ concentrations following NH_3 injection generated a normal distribution curve with N concentration highest near the injection point, decreasing with distance. Calculated NH_4^+ diffusion coefficients decreased with time and water content and were soil dependent. Field studies conducted in 1983 determined the potential germination hazard from NH_3 applied at 0, 56, 112, 168, 224, and 280 kg N ha^{-1} while planting and in 1984, to winter wheat planted 0, 1, 3, 5, 6, and 7 d after applications of 0, 100, and 200 kg N ha^{-1}.

Stand counts, leaf tissue NO_3-N concentration, and yield were not influenced by NH_3 applications during planting in 1983, but grain N concentration increased linearly up to 24.1 mg g^{-1} with 280 kg N ha^{-1}. In the 1984 experiment, NH_3 rates did not decrease seedling stand, even though analysis of soil samples reflected increased soil pH and soil NH_4-N concentration. Anhydrous NH_3 placement at a sufficient distance from newly seeded rows will ensure the success of systems which include NH_3 injection in conjunction with other field operations in residue management systems.

Additional Index Words: NH_3 toxicity, NH_4-N and NO_3-N concentrations, soil moisture, soil type.

INTRODUCTION

Anhydrous NH_3, applied two to four weeks before planting, is the most common N source for continuous hard red winter wheat (Triticum aestivum L.) in the southern Great Plains. It accounts for 42 to 56% of all Oklahoma N (actual) fertilizer tonnage from 1975 through 1984 (Oklahoma State Department of Agriculture, 1975 to 1984). Winter wheat production systems are currently undergoing an evolution in residue management which must include the adaptation of suitable N fertilization practices. Anhydrous NH_3 injection in conjunction with herbicide application and planting offers potential in these conservation systems. Aqueous NH_3 ($NH_{3(aq)}$), identified as the toxic compound (Bennett and Adams, 1970; Bezdicek et al., 1971; DuPleissis and Kroontje, 1964; Warren, 1962), in close proximity to germinating seeds and its detrimental effect on plant growth are potentially the most limiting factors in this type of system.

The toxicity of $NH_{3(aq)}$ to germinating seeds is dependent upon characteristics such as plant species, N rate, application time, moisture level, seed placement, and soil properties. The potential toxicity hazard increases with an increase in pH, changing the equilibrium, and increasing the $NH_{3(aq)}$ concentration. The critical soil solution concentration for incipient toxicity for sudangrass was 0.13 and 0.17 mM $NH_{3(aq)}$ and for cotton was 0.17 to 0.22 mM $NH_{3(aq)}$ (Bennett and Adams, 1970). Ten days after anhydrous NH_3 injection in a sandy loam soil, 540, 600, and 1000 mg N kg^{-1} reduced barley germination by 40, 70, and 100%, respectively (Duisberg and Buehrer, 1954), with a similar reduction noted with 45 kg N ha^{-1} as urea placed near the seed (Brage et al., 1960). Fertilizer N placed near the seed under low moisture conditions reduced germination (Smika and Smith, 1957) with even 11.2 kg N ha^{-1} (Olson and Drier, 1956). Corn planted directly after NH_3 application at a 10 cm depth, had reduced stands with 224, 448, and 672 kg N ha^{-1} and when applied at the 17.5 cm depth, 448 and 672 kg N ha^{-1} reduced stands. After one week at the 448 and 672 rates and after two weeks with the highest rate at the 10 cm depth, crop stands were still reduced (Colliver and Welch, 1970). Seedling stands of spring wheat planted perpendicular to the direction of anhydrous NH_3 application were not affected by time of seeding or N rate, but barley stands were reduced in some instances (Varvel, 1982). The movement of NH_3 in the soil after N application will also determine caustic effects. Nommik and Nilsson (1963) found 1100 to 1700 mg NH_4-N kg^{-1} in a zone 0 to 1.5 cm from the injection line with applications of 86 to 270 kg N ha^{-1}.

Aqueous NH_3 (28-0-0) injected under grass sod at 126 and 502 kg N ha^{-1} resulted in soil NH_4-N concentrations of 900 to 1440 and 2360 to 3340 mg N kg^{-1}, respectively, decreasing to 100 mg N kg^{-1} at distances 2.5 and 5 cm for each rate (Gasser and Ross, 1975). Detailed studies following the movement of applied N should help evaluate the viability of simultaneous anhydrous NH_3 applications in combination with other farming operations in residue management systems.

The objectives of this research were to characterize the distribution patterns of inorganic N species under different soil moisture conditions and N rates with time following anhydrous NH_3 injection to soils in the laboratory and to determine the effects of anhydrous NH_3 rate and planting date on the germination and growth of winter wheat in the field.

MATERIALS AND METHODS

Laboratory Experiment

Two kg of oven-dry equivalent from three soils (Table 1) were premoistened to 12.4 and 18.1 water contents (g g^{-1}) designated M_1 and M_2, respectively, and uniformly packed (1.1 Mg m^{-3}) into wax-lined pots. After equilibration for 48 h, liquid anhydrous NH_3 was applied at 124 and 180 mg N (field equivalent of 138 and 206 kg N ha^{-1}) to a depth of 5.5 cm in the center of each pot (Papendick and Parr, 1965, 1966). The injection channel was immediately filled with moist soil, lightly packed, and the top of each pot was secured with polyethylene film. Moisture levels were maintained by surface water additions. All treatments were incubated at 25 C, replicated three times, and arranged into randomized complete blocks. One replication of check treatments including water content, soil, and sampling date were also included in the experiment. Pots were sampled 1, 7, and 14 d after NH_3 application by vertically slicing through the injection site, yielding two hemicylinders. Each hemicylinder was further sampled by removing successive subhemispherical regions of 0 to 2, 2 to 4, 4 to 6, and 6 to 8 cm from the injection point (Stevens and Reuss, 1975). Subsamples were immediately

Table 1. Classification and selected properties of soils used in the laboratory study[1].

Soil series (Classification)	CEC	pH	Clay	Organic matter	NH_4-N
	cmol(+) kg^{-1}		----g	kg^{-1}----	mg kg^{-1}
Hollister c (fine mixed thermic Pachic Paleustoll)	21	6.5	420	7	11
Grant sil (fine-silty mixed thermic Udic Argiustoll)	19	6.4	280	13	161
Norge cl (fine-silty mixed thermic Udic Paleustoll)	21	6.2	360	9	55

[1] Chemical analysis for soil pH by 1:1 H_2O, clay by hydrometer, and organic matter by $Cr_2O_7^{-2}$ oxidation.

taken for water calculations, with the remaining samples being frozen prior to chemical analysis of soil pH using 1:1 H_2O (McLean, 1982), NH_4-N, NO_2-N, and NO_3-N following extraction in 2 M KCl by Technicon Autoanalyzer methodologies (Henriksen and Selmer-Olsen, 1970; Selmer-Olsen, 1971). Aqueous NH_3 concentrations were estimated from techniques reported by Bezdicek et al. (1971). A general form of the normal distribution function is given by:

$$Y = a * e^{-b^2X^2} \qquad (1)$$

with a linear transformation of:

$$\ln Y = \ln a - b^2 * X^2 \qquad (2)$$

where Y = soil NH_4-N (mg N g^{-1}) or calculated $NH_{3(aq)}$ (mM) concentration, X = distance (cm), while a and b are constants. Full (FM) and reduced (RM) models were used to describe significant main effects of water, soil, and time. The significance of reduced models were determined from:

$$F_{df_{FM} - df_{RM},\ df\ MSE_{FM}} = \frac{(SS_{FM} - SS_{RM})/df_{FM} - df_{RM}}{MSE_{FM}} \qquad (3)$$

where df = degrees of freedom for full (FM) and reduced (RM) models, MSE = mean square error for the full model, and SS = sum of squares for each of the respective models. The distribution curves for the NH_4^+ ion were used to calculate NH_4^+ diffusion coefficients (Khengre and Savant, 1977; Pang et. al., 1973).

1983 Field Experiment

A field study was initiated in the fall of 1982 at the Perkins Agronomy Research Station on a Zaneis loam (fine-loamy, mixed, thermic, Udic Arguistoll). Coarse-textured soils accentuate anhydrous NH_3 damage which provides a further means of critically evaluating this method. Initial soil pH, NO_3-N, P, and K indices were 6.8, 75, 52, and 557 kg ha^{-1}, respectively, using a 1:1 H_2O, specific ion electrode, Bray and Kurtz no.1 (1:20 dilution), and 1 M NH_4OAc. According to Oklahoma State University soil test calibrations (Johnson and Tucker, 1982), a yield possibility of 2520 kg ha^{-1} could be expected from the soil NO_3-N test based upon sufficient levels of P and K. The experimental design was a randomized complete block with four replications. The six treatments included a check plot and five rates of anhydrous NH_3 (56, 112, 168, 224, and 280 kg N ha^{-1}) applied simultaneously during planting. A Tye-drill Pasturepleaser was modified to simultaneously inject anhydrous NH_3 to an average depth of 12.7 cm while seeding. Winter wheat (<u>Triticum aestivum</u> L. 'Tam W 105') was seeded on 24 Nov 1982 at a rate of 100 kg ha^{-1} with rows spaced 25.4 cm apart. Anhydrous NH_3 knives were mounted on a spring-tooth shank attached to the Tye-drill, equidistant (12.7 cm) from wheat rows.

Stand counts were made on 22 Dec 1982 and 7 Jan 1983 from four randomly selected 1 m row sections from the center of each experimental unit. Tissue samples from the above ground portions of 30 plants per plot were obtained on 8 March 1983 at Feekes Stage four (Large, 1954). Plant samples were dried at 65 C for 48 h, ground to pass a 0.85 mm sieve, and following an $Al_2(SO_4)_3$-Ag_2SO_4 extraction, were chemically analyzed for NO_3-N using a specific ion electrode. Grain yields were determined from a 3.0 by 15.2 m swathe from the center of each plot with a self-propelled combine on 23 June 1983. Grain subsamples were taken at harvest, dried, ground as previously described, and analyzed in duplicate for total N, P, and K. Nitrogen was determined by micro-Kjeldahl (Bremner and Mulvaney, 1982), and P and K were determined in a HNO_3-$HClO_4$ digest colorimetrically (Murphy and Riley, 1962), and by atomic absorption (Isaac and Kerber, 1972), respectively.

1984 Field Experiment

Fall 1983 planting operations with the Tye-drill were unsuccessful and a new study with an objective of determining the optimum buffer period from anhydrous NH3 injection and planting in separate field operations was initiated on 24 Feb 1984. Anhydrous NH_3 was applied to the 1983 experimental area in 3.6 by 12.2 m plots at 100 and 200 kg N ha^{-1} under a V-blade. Check plots were included by inserting the V-blade without applied N. Following N application, winter wheat (cv. 'Vona') was planted in 25.4 cm rows at a 100 kg ha^{-1} seeding rate at 0, 1, 3, 5, and 7 d intervals. Due to a significant rain (2 cm) between the first and third planting dates, only the first two replications of day three were planted. The remaining replications were seeded on a new day six. This randomized complete block design with two replications of 3 and 6 d and four replications on 0, 1, 5, and 7 d, had a total of 18 treatment combinations.

Ten soil samples from each plot were taken directly in the newly seeded wheat row after each planting date. The samples were divided into 0 to 7.6 and 7.6 to 15 cm depth increments, composited, air-dried, and ground. Chemical analyses included soil pH, NH_4-N, NO_2-N, and NO_3-N by previously described methods. Stand counts were made 30 d from each planting date.

Statistical Analysis

Data from the field and laboratory experiments were subjected to analysis of variance and general linear model procedures provided by the SAS Institute (Statistical

Analysis System Staff, 1982). The presence of a significant F test suggested treatment differences which were identified with Fisher's protected LSD.

RESULTS AND DISCUSSION

Laboratory Experiment

The movement of anhydrous NH_3 following injection at two N rates, into three soils, at two water contents, over three sampling dates, was investigated. The N rates employed in this study had no effect on N distribution and data presented (Tables and Figures) represents averages across N applications. Although NO_3-N was determined on all samples and NO_2-N on selected samples, no evidence of nitrification was found, possibly due to the short duration of the study. All Figures of main effects and interactions are significant at the 0.001 probability level.

Ammoniacal-N distributions following anhydrous NH_3 injection, as influenced by water content, soils, and time, are presented in Fig. 1. Movement of NH_4-N was greatest near the injection point at M_1, with differences decreasing with increasing distance. Total N (NH_4-N + NO_3-N) increased for the Hollister and Norge soils at M_2 while no differences were obtained at either M_1 or M_2 for the Grant soil. The difference between total N for M_1 (1.76 mg N g^{-1}) relative to M_2 (2.42 mg N g^{-1}) 1 cm from the injection point 1 d after N application decreased with time so that after 14 d

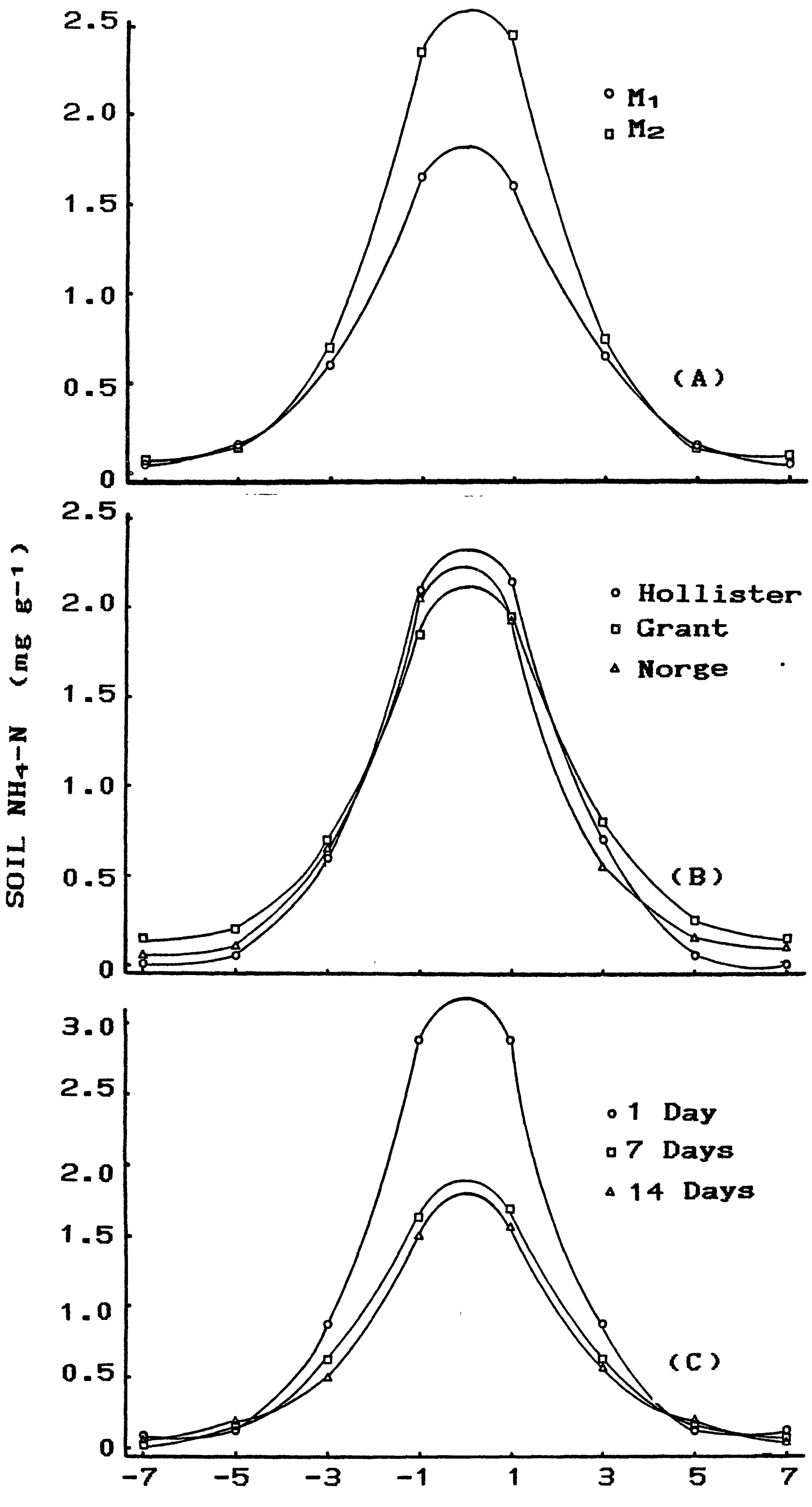

Fig. 1. Distribution of NH_4-N following anhydrous NH_3 injection for (A) two water contents, (B) three soils, and (C) three sampling dates.

no differences were present. Total N recovered was higher 1 d after NH_3 application 1 and 3 cm from the injection point compared to dates 7 and 14 with differences decreasing with distance. Differences among main effects for total N suggests the presence of fixed NH_4-N not extractable by 2 M KCl with the processes of immobilization, denitrification, and volatilization exerting some influence. The increase in water-free pore space at M_1 facilitated initial movement of NH_4-N relative to M_2, while the solvent action of water at M_2 retained anhydrous NH_3 (Parr and Papendick, 1966). The NH_3-retention capacity averaged across water contents, N rates, and time was in the order of Hollister> Norge>Grant near the injection point, with the order reversing at 7 cm. The ability of a soil to retain anhydrous NH_3, represented by the soil NH_4-N concentration, in a localized area away from germinating seeds would decrease the germination hazard. With time, nitrification would begin on the outer perimeter, further reducing this hazard. The level of soil NH_4-N was significantly higher 1 and 3 cm from the injection point 1 d after fertilizer application compared to N concentrations found after 7 and 14 d. At lateral distances of 5 and 7 cm, no differences between sampling dates were observed. Between 7 and 14 d after anhydrous NH_3 application, no differences were found between NH_4-N distribution, indicating that a relative equilibrium had been established and further N movement would be minimal.

The relationships between three soils and sampling date with water content are given in Fig. 2. At M_1, the Grant soil retained more NH_4-N at 1 cm followed by the Hollister and Norge soils, with differences diminishing with distance. With an increase in water content (M_2), the initial soil retention order changes. The Hollister soil retained more NH_4-N, followed by Norge, then Grant. But at 3 cm, NH_4-N concentration for the Hollister soil decreased below the levels of the other two soils. Apparently, the difference in retention behavior related to the clay content for the Grant soil at M_1 and M_2 was small relative to the response of the Hollister and Norge soils. Ammoniacal-N at M_2 1 cm from the injection point was greater than at M_1 1 d after N application, with M_1 levels higher than those found after 7 and 14 d at either M_1 or M_2. Distribution of NH_4-N for M_2 at 3 cm decreased to levels found at M_1 7 and 14 d after N application. With time the effect of water content on NH_4-N distribution was minimized with distance.

Through the quantitative measurement of soil NH_4-N concentration and soil pH, an estimate of the $NH_{3(aq)}$ concentration for the treatments used in this investigation can be determined. The potential hazard to germinating seeds and subsequent plant growth can then be established. Ideally, all concentrations should be corrected to activities by the appropriate activity coefficient based upon the ionic strength of the soil solution, but this was not logistically feasible and only concentrations are reported.

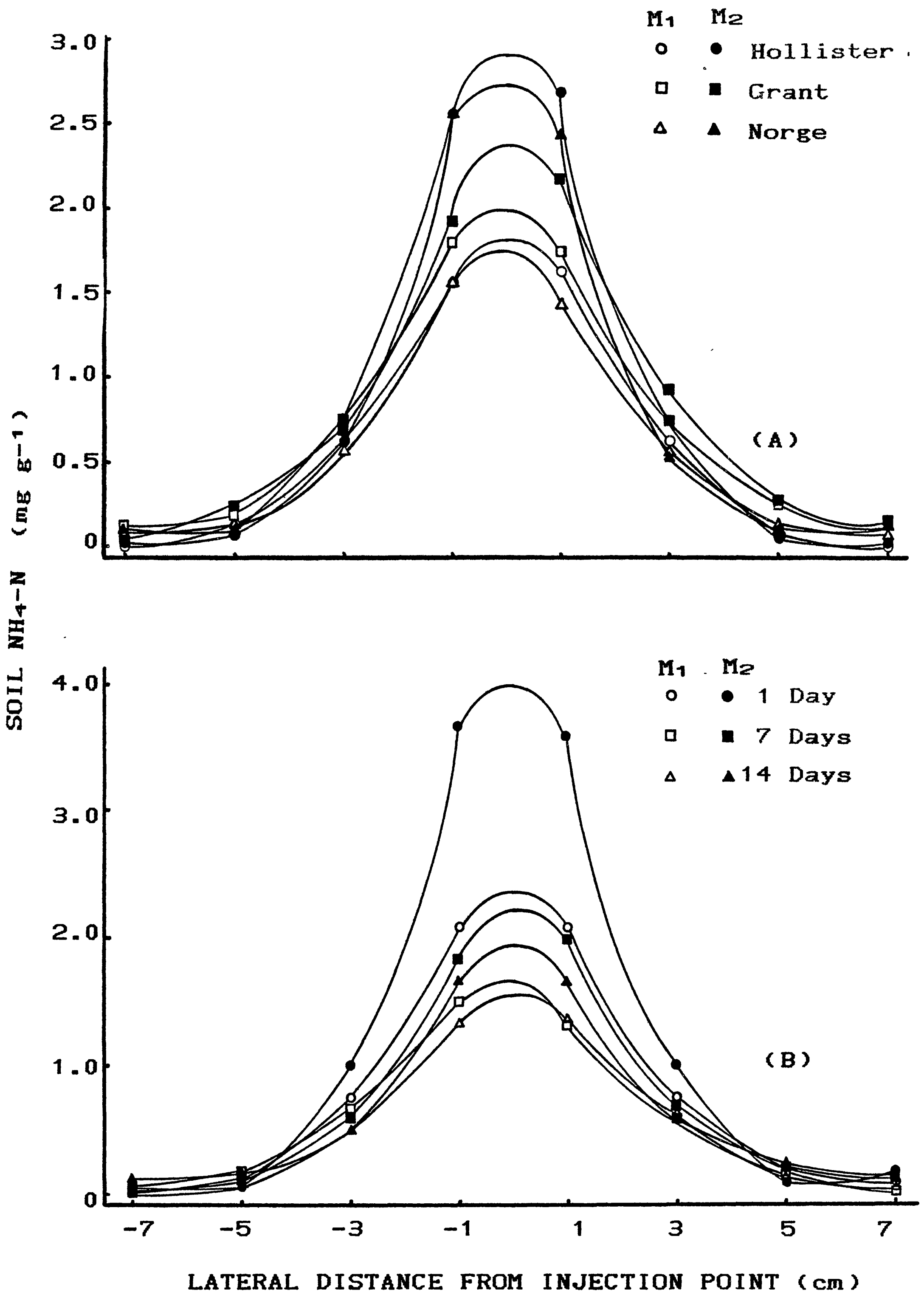

Fig. 2. Relationship between NH_4-N distribution for (A) three soils and (B) three sampling dates at two water contents.

Bennett (1974) stated that incipient toxicity levels of $NH_{3(aq)}$ occur at about 0.15 mM and lethal levels at about 6.0 mM.

Soil pH increased linearly ($Y = 7.67 + 0.44NH_4\text{-}N$; $r=0.73$) with soil NH_4-N concentrations (mg g^{-1}). Calculated $NH_{3(aq)}$ concentrations (mM) were primarily a function of soil NH_4-N concentrations (mg g^{-1}) and, to a lesser extent, soil pH ($Y = -5.74*10^{-4} + 3.38*10^{-5}pH + 1.98NH_4\text{-}N$; $R^2=0.89$), as indicated by the magnitude of each regression coefficient. Calculated $NH_{3(aq)}$ concentrations at 1 cm were 3.9 and 3.6 mM for M_2 and M_1, respectively, and decreased with distance, while levels at 3 cm and beyond for M_1 were higher than at M_2 (Fig. 3). Distribution of $NH_{3(aq)}$ decreased with time, specifically for the 1 to 7 d transition and was similar to the NH_4-N pattern. The highly significant interaction among soils, dates, and distance for calculated $NH_{3(aq)}$ concentrations is presented in Fig. 4. The steady decline in $NH_{3(aq)}$ concentrations from the Norge to the Hollister and, finally, to the Grant soil 1 d after anhydrous NH_3 indicates the difference in physical and chemical properties of these soils which influences the chemical behavior of added fertilizer. Additional changes were noted after 7 d with decreases in $NH_{3(aq)}$ concentration, but soil differences diminished. However, after 14 d, the concentration of $NH_{3(aq)}$ decreased at different rates, suggesting a dissimilar state of equilibrium for each soil, with the Hollister soil being most dynamic, followed by the

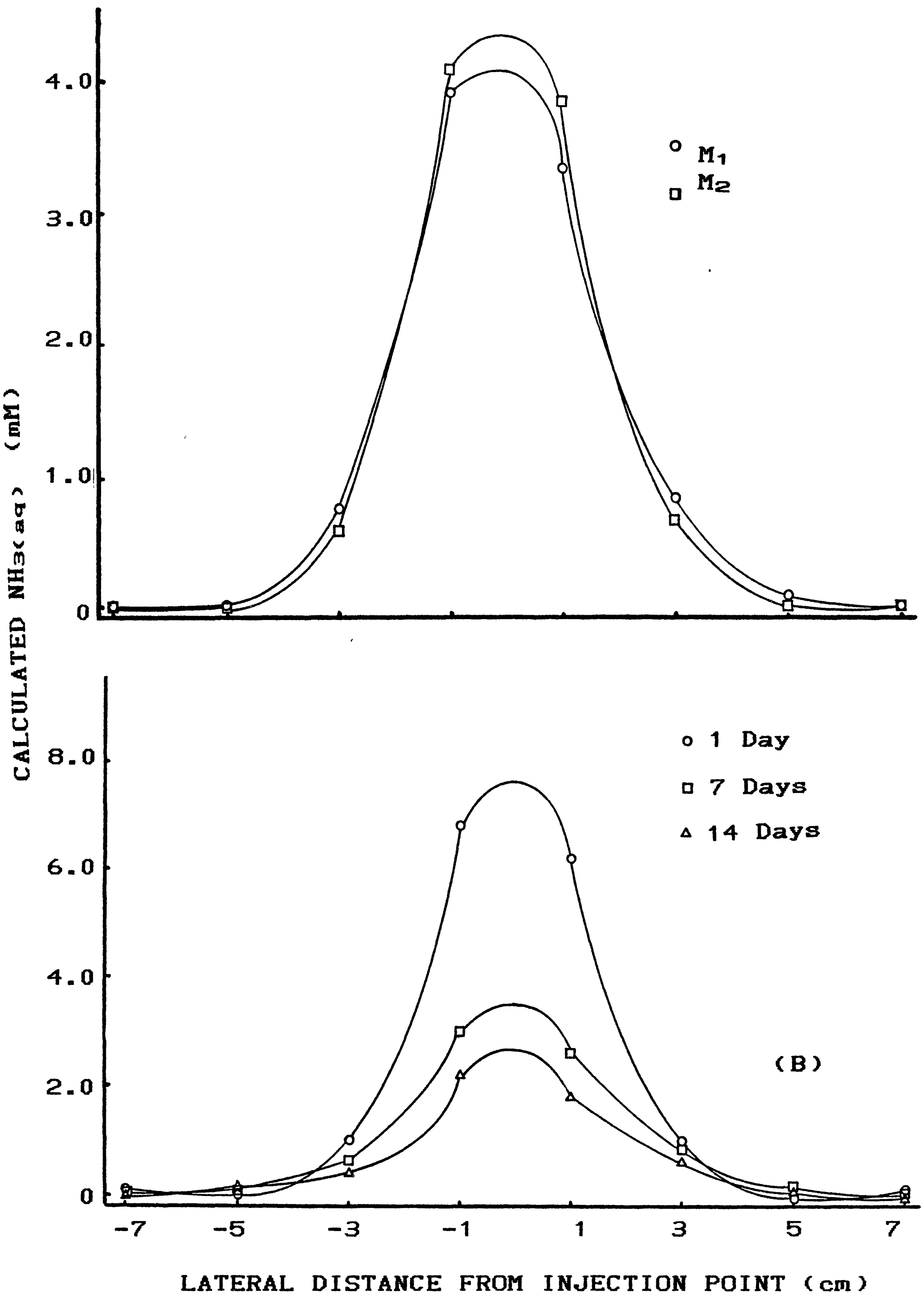

Fig. 3. Distribution of calculated $NH_{3(aq)}$ following anhydrous NH_3 injection for (A) two water contents and (B) three sampling dates.

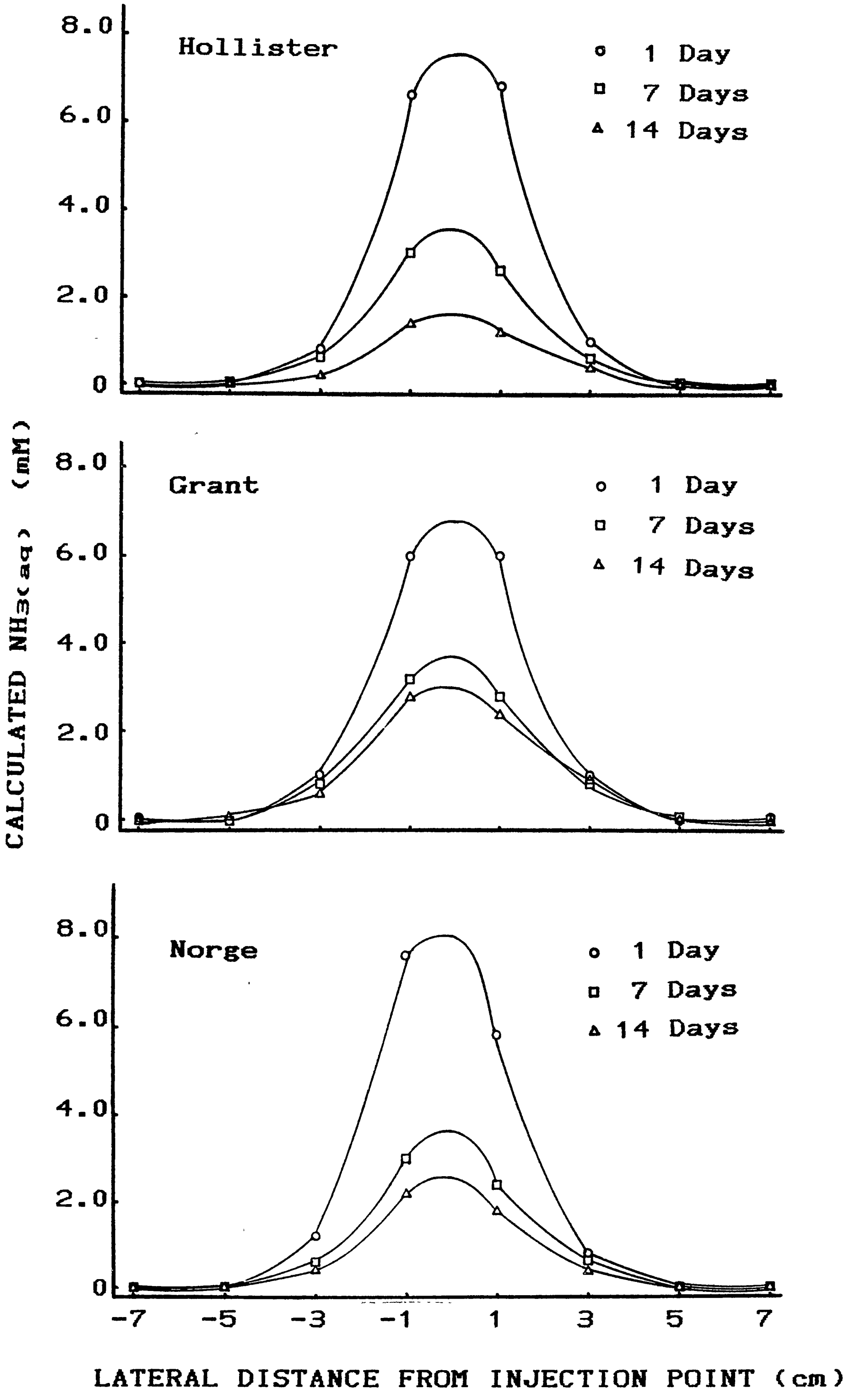

Fig. 4. Relationship between calculated $NH_{3(aq)}$ for each of the three soils on three sampling dates.

Norge soil, and nearing steady state conditions, the Grant soil. Calculated $NH_{3(aq)}$ concentrations were in the lethal to incipient toxicity range of Bennett (1974) for all three soils on all sampling dates up to a distance of 3 cm from the injection point. The rapid decline in $NH_{3(aq)}$ 7 d after N application and continuing to 14 d implies a decreased risk to germinating seeds after one week following injection of anhydrous NH_3.

Equations depicting the distribution of soil NH_4-N and calculated $NH_{3(aq)}$ concentrations for significant main effects of water content, soil, and sampling date were determined (Table 2). To further delineate the N distribution pattern, reduced models (RM) for each level of a factor were tested against a full model (FM) of averages across all levels of a factor. With the exception of the soil NH_4-N concentration distribution at M_1 and on sampling date one, all reduced models significantly described the response of N distribution better than one full model for each factor. Calculated $NH_{3(aq)}$ distribution at M_1 and M_2 was best described by the full model while reduced models were used for sampling date.

Ammonium diffusion coefficients (D_{NH4+}) characterize NH_4^+ diffusion in soil, which estimates the degree of spreading and indicates potential hazard from applied anhydrous NH_3 to germinating seeds. Based upon the conditions employed in this study, the D_{NH4+} is a function of soil characteristics, water content, and time (Table

Table 2. Reduced and full distribution models for soil NH_4-N and calculated $NH_{3(aq)}$ concentrations (graphs given in Fig. 1 and 3).

	Soil NH_4-N (mg g^{-1})		Calculated $NH_{3(aq)}$ (mM)	
Model name	Prediction equation	r^2 [1]	Prediction equation	r^2 [1]
Water content[2]				
M_1	$\ln Y=1.2361-0.0715X^2$	0.75NS	$\ln Y=2.2330-0.1318X^2$	0.85***
M_2	$\ln Y=1.3351-0.0731X^2$	0.75**		
Soil series				
Hollister c	$\ln Y=1.4506-0.0996X^2$	0.84***	NS	
Grant sil	$\ln Y=1.3615-0.0536X^2$	0.81***		
Norge cl	$\ln Y=1.3350-0.0732X^2$	0.75***		
Sampling date				
Date 1	$\ln Y=1.6721-0.0765X^2$	0.75NS	$\ln Y=2.9890-0.1338X^2$	0.86**
Date 7	$\ln Y=1.2010-0.0715X^2$	0.75***	$\ln Y=1.8876-0.1317X^2$	0.85***
Date 14	$\ln Y=1.3351-0.0731X^2$	0.75***	$\ln Y=1.9650-0.1316X^2$	0.85***

[1] **, *** Significant at the 0.01 and 0.001 levels, respectively.

[2] M_1 = 12.4, M_2 = 18.1 (g g^{-1}).

3). One d following NH_3 application, $D_{NH_4^+}$ for the Hollister, Grant, and Norge soils were significantly different ($P<0.05$). After 7 d, only the Hollister soil had slower NH_4-N movement, with all soil differences disappearing at 14 d. The Hollister had the lowest $D_{NH_4^+}$ (7.71 $cm^2\ s^{-1}*10^{-6}$) attributed to the higher clay content and CEC, which retain NH_4-N, and the higher pH, decreasing the fraction of N in the NH_4^+ form, resulting in restricted movement. Lower clay content, CEC, and soil pH decreased NH_4^+ retention for the Grant soil and resulted in the highest diffusion coefficient. The Norge soil was intermediate in NH_4^+ movement. Based on the $D_{NH_4^+}$, the potential germination hazard from applied NH_3 decreased in the order of Grant, Norge, and Hollister.

With increasing water content, the volume of air-filled pores decreases restricting N movement and the dissolution of applied N in water increases initial NH_4^+ retention, thereby decreasing $D_{NH_4^+}$, which conflicts with the data of Khengre and Savant (1977). Conditions encountered in the tests could account for these differences. This inverse relationship diminishes with time as applied N is desorbed. Low soil water levels during application of anhydrous NH_3 enhance NH_4^+ movement and increase the hazard to germinating seeds. Diffusion coefficients of NH_4^+ decreased with time.

Table 3. Effect of soil, water, and date on calculated NH_4^+ diffusion coefficients[1].

Variable	Sampling date 1	 7	 14	Mean
	--------$cm^2\ s^{-1}*10^{-6}$---------			
Soil series				
Hollister c	18.80	2.90	1.43	7.71
Grant sil	23.84	3.53	1.82	9.73
Norge cl	22.01	3.35	1.67	9.01
Water content[2]				
M_1	21.82	3.36	1.67	8.95
M_2	21.27	3.16	1.61	8.68
Mean	21.55	3.26	1.64	8.82

[1] F LSD (0.05) for comparing means of: soil series = 0.20, sampling date = 0.20, moisture content = 0.17, soil series X sampling date = 0.40, and moisture content X sampling date = 0.30 $cm^2\ s^{-1}*10^{-6}$.

[2] $M_1 = 12.4$, $M_2 = 18.1$ ($g\ g^{-1}$).

Field Experiments

The results of anhydrous NH_3 application during planting are illustrated in Table 4. Seedling stand counts 30 and 45 d after seeding and leaf NO_3-N concentrations were not affected by applied N. The placement of anhydrous NH_3 16 cm between newly seeded wheat rows and the injection center effectively eliminated potential NH_3 toxicity effects. Although a yield response to applied N was not observed due to the high levels of residual soil NO_3-N, the quality of grain reflected by grain N concentration (mg g^{-1}) increased linearly ($Y = 20.62 + 0.013Nrate$; $r=0.88$) with increased rates of fertilizer N (kg ha^{-1}). Numerous unsuccessful attempts were made to duplicate this study in time, resulting in a revised 1983 experiment being executed in the winter of 1984.

Winter wheat germination and pertinent soil chemical characteristics following planting on six dates after anhydrous NH_3 injection are reported in Table 5. Several least significant difference t-tests were used to determine seeding date differences due to the fractional replication on dates three and six. Fertilizer N applications up to 200 kg N ha^{-1} did not reduce seedling stand. The undercutting action of the V-blade facilitated horizontal movement of fertilizer N, effectively diluting the NH_3, and negating potential caustic effects across N rates. The diffusion of anhydrous NH_3 with time decreased germination of wheat

Table 4. Effect of anhydrous NH_3 on seedling stand counts, leaf tissue NO_3-N concentration, grain yield, and grain N concentration at Perkins, 1982-1983[1].

	Seedling stand		Leaf tissue		
N rate	22Dec	7Jan	NO_3-N	Yield	Grain N
kg N ha^{-1}	plants m^{-2}		g kg^{-1}	Mg ha^{-1}	mg g^{-1}
0	318	340	5.0	2.23	20.1
56	324	340	5.1	2.22	21.6
112	316	334	5.0	2.18	22.7
168	302	325	4.4	2.29	22.8
224	296	329	4.6	2.39	23.7
280	328	326	4.6	2.29	24.1

[1] Fisher's LSD (0.05) for comparing means of: seedling stand, leaf tissue NO_3-N, yield = NS, and grain N = 0.1 mg g^{-1}.

Table 5. Effect of anhydrous NH_3 and planting date on seedling stand count, soil pH, and soil NH_4-N and soil NO_3-N concentration at Perkins, 1984[1].

		Soil		
Variable	Seedling stand	pH	NH_4-N	NO_3-N
	plants m^{-2}		----kg ha^{-1}----	
N rate kg N ha^{-1}				
0	352	5.82	366	7.1
100	345	5.96	472	9.0
200	353	6.15	519	7.4
Seeding date[2] d				
0	357b	6.01a	430a	6.8a
1	330a	6.00a	503b	7.9ab
3	351ab	5.94a	389a	7.7ab
5	359b	5.96a	394a	6.9a
6	360b	5.98a	467ab	10.3b
7	347ab	5.95a	505b	8.7b

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[1] Fisher's LSD (0.05) for comparing N rate means for: seedling stand = NS, soil pH = 0.10, soil NH_4-N = 52 kg ha^{-1}, and soil NO_3-N = 1.8 kg ha^{-1}.

[2] With unequal replication for seeding date, standard deviations become date dependent, therefore column means followed by the same letter are not significantly ($P<0.05$) different comparisons according to least significant difference t-tests.

planted 1 d after N application. A gradual increase in germination was noted for subsequent planting dates, except for date seven. This seesaw effect was due to the 2 cm rainfall 2 d after fertilizer application, causing a downward movement of N away from germinating seeds. As the surface dried out, $NH_{3(aq)}$ moved upward, detrimentally affecting germination beginning at 7 d and at future dates not included in the study. Grain was not used to evaluate anhydrous NH_3 rate and planting date effects due to the late sowing date. No N rate X seeding date interaction was observed with any variable.

Soil chemical characteristics were averaged over depth, since there were no significant interactions of depth with N rate and planting date. Soil pH increased with increased N rates and was not influenced by seeding date. Ammoniacal-N increased with applied N and inversely followed the pattern observed with seedling stand. Nitrification was evident at the 100 kg N ha^{-1} rate, generally increased with seeding date except for date five, increasing the soil NO_3-N concentration. No detectable levels of NO_2-N were found in any soil sample.

SUMMARY

The movement of anhydrous NH_3 injected into soils in the laboratory increased at lower water contents and the extent of diffusion was further dependent upon the properties of the Hollister, Grant, and Norge soils. The distribution of soil NH_4-N and calculated $NH_{3(aq)}$ followed a normal distribution curve, with concentrations higher near the injection point, decreasing with distance, and in overall magnitude with time. Lower concentrations of $NH_{3(aq)}$ after 7 d suggest this buffer period in which some damage to germinating seeds and growing roots may occur, but if not lethal, complete plant recovery should be possible. Calculated NH_4^+ diffusion coefficients decreased with time and higher water content and were soil specific.

The 1983 field experiment demonstrated the feasibility of combining planting and anhydrous NH_3 injection into one simultaneous operation. This placement of anhydrous NH_3, accounting for N movement and subsequent root growth, eliminated any reduction in wheat germination. Further modifications of field equipment will be required to ensure the widespread adaptability of anhydrous NH_3 injection during planting operations in conservation tillage systems. The detrimental effect of anhydrous NH_3 on

germinating seeds were shown in the 1984 experiment 1 d after NH_3 injection and after a rainfall, returning on date seven.

The soil water content during anhydrous NH_3 injection appears to be the critical component in determining the degree of movement of applied N and future toxic effects. In addition to this restriction of N movement associated with increased water content, seed germination will be accelerated with more soil moisture, and higher levels of $NH_{3(aq)}$ can then be tolerated. Ideally, the timing of anhydrous NH_3 injection to minimize $NH_{3(aq)}$ damage should coincide with soil moisture levels adequate for seed germination, which results in restricted N movement, minimum gaseous N loss, and decreased toxicity hazard.

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PART II

UREA-N FERTILIZATION IN TILLAGE SYSTEMS FOR WINTER WHEAT

ABSTRACT

Field studies were initiated at two locations to determine the influence of residue management on N requirements for continuous winter wheat (Triticum aestivum L.) production. Variables measured included grain yield and both N concentrations in grain and forage over a three-year period. Soil acidity and residual soil NO_3-N concentrations and distribution were determined after two cropping seasons from depths of 0 to 2.5, 2.5 to 7.5, 7.5 to 15, 15 to 30, and 30 to 60 cm in profiles of a Grant silt loam (Udic Argiustoll) and a Norge clay loam (Udic Paleustoll). Nitrogen applications of 0, 56, 112, 168, 224, and 280 kg N ha^{-1} were applied to clean-(CT), reduced-(RT), and no-till (NT) residue management systems each location and year. Grain yields averaged over locations, years, and N rates were 2.10, 1.94, and 2.00 Mg ha^{-1}, respectively for CT, RT, and NT systems. Leaf NO_3-N and grain N concentrations were generally higher under CT compared to RT and NT. Nitrogen fertilization increased grain yields, leaf NO_3-N, and grain N concentrations. Averaged over locations and years, the N requirement for maximum grain production was 157 kg ha^{-1} for CT, 169 kg ha^{-1} for RT, and 192 kg ha^{-1} for NT. Soil pH was decreased in RT and NT systems at Stillwater and at both

Stillwater and Lahoma, soil acidity increased linearly with N fertilization. Soil pH increased with depth, with the exception of the 2.5 to 7.5 cm depth. Residual soil NO_3-N increased with N fertilization under the CT system and decreased with depth. The new environment associated with residue management systems for winter wheat changed the N requirement for grain production and N uptake in both forage and grain. Soil changes include a stratification of soil acidity and residual soil NO_3-N from applied N. The dynamic nature of residue systems requires long-term study until an equilibrium is attained.

Additional Index Words: Maximum yield, N response, N requirement, Leaf NO_3-N, Grain N, *Triticum aestivum* L., Soil Acidity, Residual Soil NO_3-N, Profile Distribution.

INTRODUCTION

Soil erosion has been identified as a major constraint for sustained productivity with winter wheat (*Triticum aestivum* L.) cropping systems in the Great Plains. Residue management has evolved as a viable management practice in conservation tillage systems (Magleby et al., 1985) by counteracting the forces of wind and water erosion, maintaining or possibly improving soil productivity, and ultimately, yields. The adaptation of residue management systems changes the physical, chemical, and biological nature of a soil (Doran, 1982). Consequently, nutrient recycling from the layer of crop residues (Holt, 1979) in this new environment modifies the availability of plant nutrients, specifically N (House et al., 1984; Stanford et al., 1973), thereby altering current N recommendations for winter wheat.

Ellis et al. (1983) found no difference in grain yield of winter wheat due to tillage system (clean-(CT), minimum-(MT), and no-till (NT)), but did observe a yield response to applied N. Average maximum grain yield for the CT, MT, and NT systems occurred with 158, 174, and 194 kg N ha^{-1}, respectively. Although visual N deficiency symptoms with corn in MT were apparent with additions of 45 and 90 kg N

ha^{-1} compared to conventional tillage, the N requirement for maximum grain yield was similar (Bandel et al., 1975). The authors postulated that the future reservoir of N in NT soils would be gradually increasing while declining in CT soils. Corn grown under MT required an additional 68 kg N ha^{-1} more than under plow tillage due to a greater crop N requirement and lower uptake of soil N (Meisinger et al., 1985). Although past research for winter wheat cropping systems in Oklahoma has shown no yield advantage with conservation tillage systems such as MT and NT (Davidson and Santelmann, 1973; Tucker et al., 1971), the advent of new herbicides, cultivars, and equipment could lead to greater yields.

The profile stratification that develops with MT and NT systems combined with surface applications of ammoniacal-N fertilizers has led to an acidification of the soil surface (Dick, 1983; Fox and Hoffman, 1981; Mahler and Harder, 1984). The degree and depth of acidification is dependent upon the N source and rate, with acidity increasing as applied N increases. With increased acidity, the effectiveness of some herbicides will diminish (Fox and Hoffman, 1981), weed competition will increase, and yields may eventually decline as Al^{3+} and Mn^{2+} toxicities develop (Blevins et al., 1977, 1983).

Jolley and Pierre (1977) have shown that residual soil NO_3-N closely correlates with soil acidity by representing applied N that has been nitrified, thus generating potential acidity. Applications of N fertilizer in excess (residual NO_3-N) of crop requirements further aggravates the potential acidity, as plant uptake of applied N reduces soil acidity. Measured residual NO_3-N in the top 15 cm of soil sufficiently influenced irrigated corn yields and was correlated with grain yield and applied N (Onken et al., 1985). In addition to pH relationships, residual soil NO_3-N indicates the overall soil N status with respect to plant uptake, immobilization, denitrification, and mineralization processes in residue management systems.

The objective of this study was to determine the influence of residue management for continuous winter wheat cropping systems on the N requirement for grain production, N concentrations in grain and wheat forage, and after two cropping seasons, on the profile distribution of residual soil NO_3-N and soil acidity.

MATERIALS AND METHODS

Field experiments were initiated in the fall of 1982 at the North Central Research Station at Lahoma and the Agronomy Research Station at Stillwater on a Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll) and a Norge clay loam (fine-silty, mixed, thermic Udic Paleustoll), respectively. Initial soil pH, NO_3-N, P, and K indices were 5.8, 20, 60, and 658 kg ha^{-1} at Lahoma and 5.6, 30, 81, and 545 kg ha^{-1} at Stillwater, respectively, using 1:1 H_2O, specific ion electrode, Bray and Kurtz (1945) no. 1 extract (1:20 dilution), and 1 M neutral NH_4OAc (Knudsen et al, 1982). Soils at each location contained sufficient P and K based on Oklahoma State University soil test calibrations (Johnson and Tucker, 1982) and application of P and K was not necessary.

Current treatments at each location were arranged in a split-plot experimental design with four replications. Clean-(CT), reduced-(RT), and no-till(NT) residue management systems were the main plots and urea-N rates were the subplots. Main plots were 29.3 m by 15.2 m and subplots within main plots were 4.9 by 15.2 m, respectively. The CT plots were disked twice, while RT plots were V-bladed twice to a depth of 12 cm to partially incorporate crop residues and control weeds. Paraquat (1,1'-dimethyl-4,4'bipyridinium ion), bromoxynil plus (3,5-dibromo-4-hydroxybenzonitrile and [(4-chloro-otolyl)oxy]acetic acid), and glyphosate [N-(phosphonomethyl) glycine] were applied to the experimental area as needed to control weeds at recommended rates. Prior to the initiation of the study at Lahoma, the entire experimental area was disked twice following the 1981 harvest. The fertilizer N treatments applied as urea were surface applied at rates of 0, 56, 112, 168, 224, and 280 kg N ha^{-1}. Winter wheat (cv. Tam W-101) was planted in 25.4 cm rows at a rate of 100 kg ha^{-1} each year, with a Tye-drill Pasturepleaser adapted with rolling coulters and double disk openers for seeding in residue management systems. Fertilization, seeding, tissue sampling, and harvest dates for each location are reported in Table 1.

Tissue samples from the above ground portion of thirty plants at Feekes stage four (Large, 1954) per subplot were taken at both locations each year. Plant samples were dried at 65 C for 48 h and ground to pass through a 0.85 mm sieve. The NO_3-N concentration was determined following $Al_2(SO_4)_3$-Ag_2SO_4 extraction using a specific ion electrode. Grain yields were determined from a 3.0 by 15.2 m swathe from the center of each subplot with a self-propelled combine. A subsample from each plot at harvest was dried and ground as previously described. Grain N concentration was determined in duplicate for individual samples by

Table 1. Experiment locations, fertilization, seeding, tissue sampling, and harvest dates.

	Date			
Location	Fertilization	Seeding	Tissue Sampling	Harvest
Lahoma	30 Oct 1982	31 Oct 1982	10 March 1983	5 July 1983
Stillwater	11 Nov 1982	8 Oct 1982	11 March 1983	22 June 1983
Lahoma	15 Oct 1983	3 Nov 1983	22 March 1984	29 June 1984
Stillwater	29 Sept 1983	30 Sept 1983	16 March 1984	18 June 1984
Lahoma	25 Sept 1984	23 Oct 1984	14 March 1985	1 July 1985
Stillwater	19 Sept 1984	8 Nov 1984	12 March 1985	2 July 1985

micro-Kjeldahl (Bremner and Mulvaney, 1982). Grain P and K concentrations were determined in duplicate after a HNO_3-$HClO_4$ digestion by colorimetry (Murphy and Riley, 1962) and atomic absorption (Isaac and Kerber, 1972), respectively. Following the 1984 harvest at each location, three soil samples were taken from all subplots at depths of 0 to 2.5, 2.5 to 7.5, 7.5 to 15, 15 to 30, and 30 to 60 cm. Composited soil samples were dried, crushed, and analyzed for pH with 1:1 H_2O (McLean, 1982) and NO_3-N (Henriksen and Selmer-Olsen, 1970).

Second-order polynomial regression models (1) described the yield response to N fertilization within each residue management system.

$$\text{Yield} = B_0 + B_1N + B_2N^2 \qquad (1)$$

This function was maximized and the N rate associated with maximum grain production was determined from:

$$N = -B_1/2B_2 \qquad (2)$$

Data for the experiments were analyzed statistically using procedures outlined by the SAS Institute (Statistical Analysis System Staff, 1982).

RESULTS AND DISCUSSION

Grain yield, leaf NO_3-N, and grain N concentrations for individual years at Stillwater and Lahoma are reported in Tables 2 and 3. The variability between location and year is apparent with average yields at Stillwater of 2.42, 3.42, and 0.26 Mg ha^{-1} and 2.03, 2.43, and 1.50 Mg ha^{-1} at Lahoma in 1983, 1984, and 1985, respectively. Although grain yields were depressed in 1985 due to late planting and extremely dry weather, resulting in poor germination, specially at Stillwater, conclusions from ANOVA procedures without these data did not change. Consequently, these were included in all subsequent year analysis. Environmental conditions characterized statewide were as follows: the 1982-1983 season was initially dry, delaying germination, but ideal for wheat growth and development thereafter; the 1983-1984 season began dry, but late fall moisture with a cool wet spring made wheat growing conditions good; and finally, the 1984-1985 season was initially dry which delayed planting and reduced fall growth, with a cool wet spring providing an ideal environment for diseases, resulting in below average yields.

Table 2. Effect of tillage system and N fertilization on grain yield, leaf NO_3-N, and grain N concentrations at Stillwater.

	1983			1984			1985	
Variable	Yield	Leaf NO_3-N	Grain N	Yield	Leaf NO_3-N	Grain N	Yield	Leaf NO_3-N
	Mg ha^{-1}	---g kg^{-1}---		Mg ha^{-1}	---g kg^{-1}---		Mg ha^{-1}	g kg^{-1}
<u>Tillage</u>								
CT	2.67	1.86	20.8	3.31	0.61	20.2	0.45	1.85
RT	2.08	1.71	21.1	3.60	0.40	19.7	0.19	1.93
NT	2.52	2.00	20.6	3.36	0.25	18.7	0.15	1.52
<u>N rate</u> kg ha^{-1}								
0	2.14	0.38	18.8	1.84	0.12	17.8	0.24	1.26
56	3.04	1.07	18.7	3.07	0.13	17.1	0.20	1.35
112	2.73	1.98	20.4	3.78	0.26	19.2	0.19	1.60
168	2.56	2.30	21.4	4.20	0.39	19.5	0.25	1.86
224	2.15	2.66	22.3	4.02	0.59	21.0	0.39	2.26
280	1.91	2.74	23.5	3.63	1.02	22.8	0.30	2.28
<u>Statistics</u>[1]								
CT vs RT and NT	***	NS[2]	NS	#	***	*	**	NS
RT vs NT	***	NS[2]	NS	#	**	*	NS[2]	*
N lin	***	***	***	***	***	***	***	***
N quad	***	***	NS	***	***	**	NS	NS
T x N	**	**	NS	NS	***	NS	#	NS

[1] #,*,**,*** Significant at the 0.15, 0.05, 0.01, and 0.001 levels, respectively.

[2] Significant tillage system responses were dependent upon the N rate.

Table 3. Effect of tillage system and N fertilization on grain yield, leaf NO_3-N, and grain N concentrations at Lahoma.

	1983			1984			1985	
Variable	Yield	Leaf NO_3-N	Grain N	Yield	Leaf NO_3-N	Grain N	Yield	Leaf NO_3-N
	Mg ha^{-1}	---g kg^{-1}---		Mg ha^{-1}	---g kg^{-1}---		Mg ha^{-1}	g kg^{-1}
Tillage								
CT	2.04	2.61	21.6	2.47	1.88	24.1	1.66	1.55
RT	1.92	2.25	22.0	2.28	1.36	23.4	1.56	1.28
NT	2.12	2.34	22.2	2.54	1.15	23.3	1.28	1.27
N rate kg ha^{-1}								
0	1.87	1.64	20.8	1.69	0.57	18.9	0.87	0.18
56	2.02	2.24	21.4	2.32	1.19	20.7	1.65	0.98
112	2.02	2.33	21.8	2.50	1.40	23.3	1.82	1.61
168	2.11	2.77	22.2	2.71	1.76	25.4	1.58	1.54
224	2.07	2.78	22.5	2.66	1.84	26.2	1.63	1.91
280	2.06	2.64	22.8	2.71	2.04	27.0	1.45	1.98
Statistics[1]								
CT vs RT and NT	NS	NS	#	NS	**	#	**	NS
RT vs NT	#	NS	NS	#	#	NS	**	NS
N lin	**	***	***	***	***	***	**	***
N quad	*	***	NS	***	**	**	***	***
T x N	NS	NS	NS	NS	NS	NS	NS	NS

---

[1] #,*,**,*** Significant at the 0.15, 0.05, 0.01, and 0.001 levels, respectively.

Crop Analysis

Grain yield in the conventional CT system compared to RT and NT systems was higher in three cropping-years out of six with one year favoring RT and NT. No grain yield differences were observed between tillage systems in two cropping-years. In a comparison of RT versus NT, yields in NT were higher in three cropping-years, while higher under RT for only two seasons. The highly significant tillage X N interaction at Stillwater in 1983 was due to the rapid decline in yield after 56 kg N ha^{-1} with CT and specially RT, attributed to the timing of the tillage operations in the initial year of the investigation which dried the soil (Fig. 1). Averaging over years and locations, grain yields under CT were significantly ($P<0.0002$) greater than RT and NT, with no difference found between RT and NT. The lack of yield advantage for RT and NT systems relative to CT further substantiates past research results with tillage systems for winter wheat in Oklahoma (Davidson and Santelmann, 1973; Tucker et al., 1971). The Lahoma site generally had lower grain yields compared to Stillwater except in 1985, when poor environmental conditions coupled with the later planting date depressed yields. No significant tillage X N interactions at Lahoma were found for grain yield, leaf tissue NO_3-N, and grain N concentrations.

The NO_3-N concentration of forage samples collected in early spring at Feekes stage four reflected the N status in

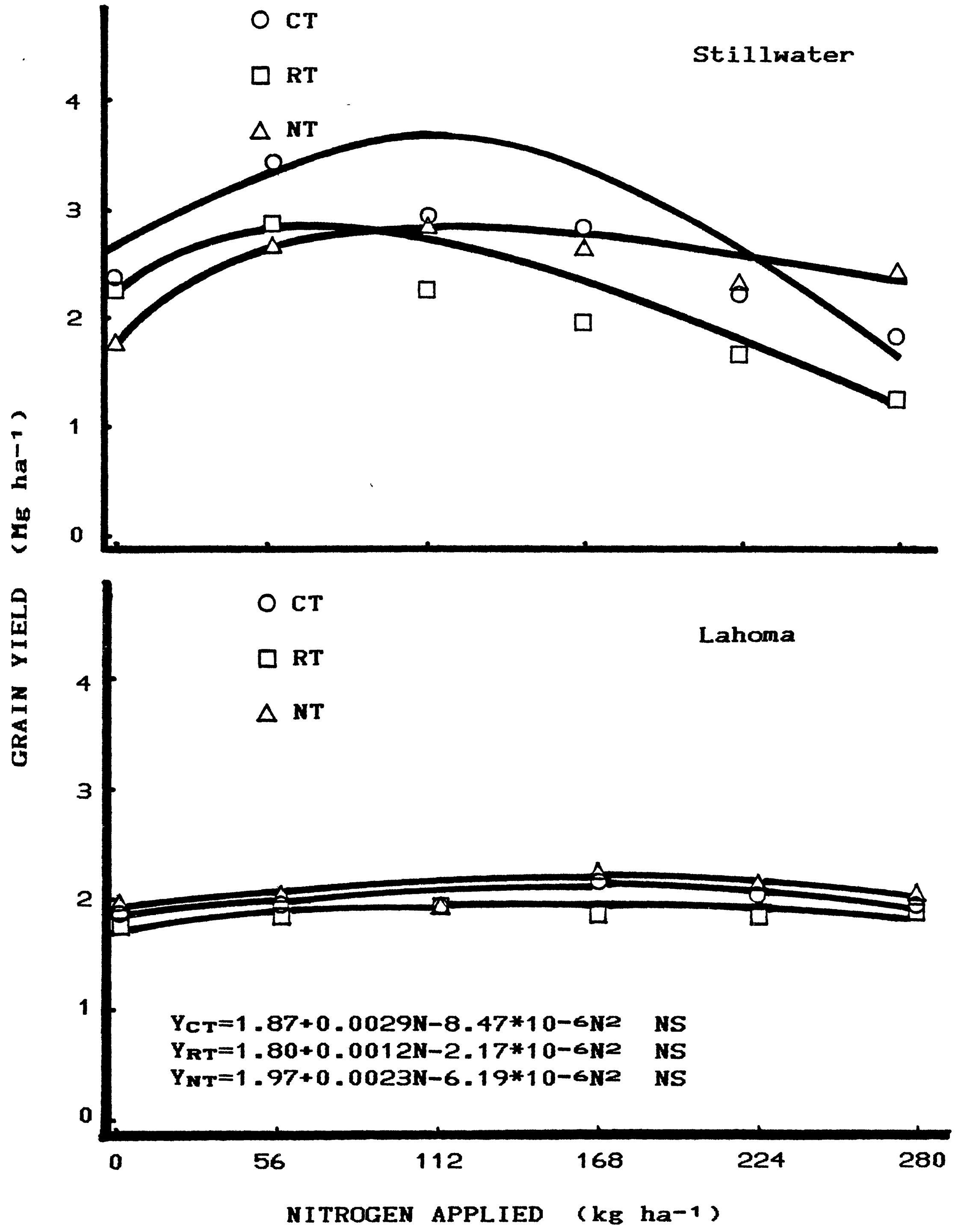

Fig. 1. Grain yield response to N fertilization in CT, RT, and NT residue management systems at Stillwater and Lahoma, 1983. (*, *** denotes significance at the 0.05 and 0.0001 levels, respectively)

each residue management system. The significant tillage X N interaction at Stillwater in 1983 was due to the higher leaf NO_3-N concentration for NT with N rates up to 168 kg N ha^{-1} relative to CT and RT, with differences diminishing at higher N rates. At Stillwater in 1984, leaf NO_3-N concentration in CT systems rapidly increased with rates of 168 kg N ha^{-1} and greater, while an increase of less magnitude occurred with RT, followed by NT. In the initial year of the investigation (1983), no differences between CT, RT, and NT were observed for leaf tissue NO_3-N concentration. The equilibrium between N cycling processes under each residue system had not yet been established. In the following year, leaf NO_3-N concentrations at both locations reflected the degree of residue management, with tissue concentrations decreasing with increasing amounts of residue remaining on the soil surface. The immobilization of applied N with RT and NT systems appears to be the major cause of decreased N availability and lower plant uptake at this growth stage. Poor growing conditions during the 1984-1985 season suppressed any tillage differences except at Stillwater where forage NO_3-N concentrations in RT were 1.93 g kg^{-1} compared to 1.52 g kg^{-1} under NT. Leaf NO_3-N concentration under CT was higher ($P<0.0001$) relative to RT and NT, with RT greater ($P<0.05$) compared to NT when averaged over the Stillwater and Lahoma locations from 1983 to 1985.

Grain N concentrations were not influenced by N fertilization in tillage systems at Stillwater or Lahoma in 1983 or 1984. Nitrogen concentration in the grain was significantly lower for CT compared to RT and NT at Lahoma in 1983, with no differences being found at Stillwater. The second year at both locations, grain N concentration for CT was higher than that of RT and NT. Further division between RT and NT occurred at Stillwater with grain N concentrations of 19.7 and 18.7 g kg^{-1}, respectively. After two cropping seasons at two locations, grain N concentration for CT was higher ($P<0.05$) than RT and NT, with RT greater ($P<0.10$) than NT. This parallels the effect of leaf tissue NO_3-N concentration reported earlier. Grain P and K concentrations were not influenced by tillage system or N fertilization.

Nitrogen fertilization increased grain yield, leaf NO_3-N, and grain N concentrations at each location each year measured (Tables 2 and 3). A highly significant N_{linear} component was observed throughout with the $N_{quadratic}$ contrast significant for most parameters. A good response curve to applied N was found with grain yield initially increasing at low rates, tapering off to a maximum, and finally decreasing at higher rates (Fig. 1, 2, 3, and 4). Fertilizer N effects averaged over locations and years for yield produced highly significant linear and quadratic responses. The N response varied with location and year. Nitrogen rates averaged across residue systems associated with maximum grain production at Lahoma were 193, 215, and

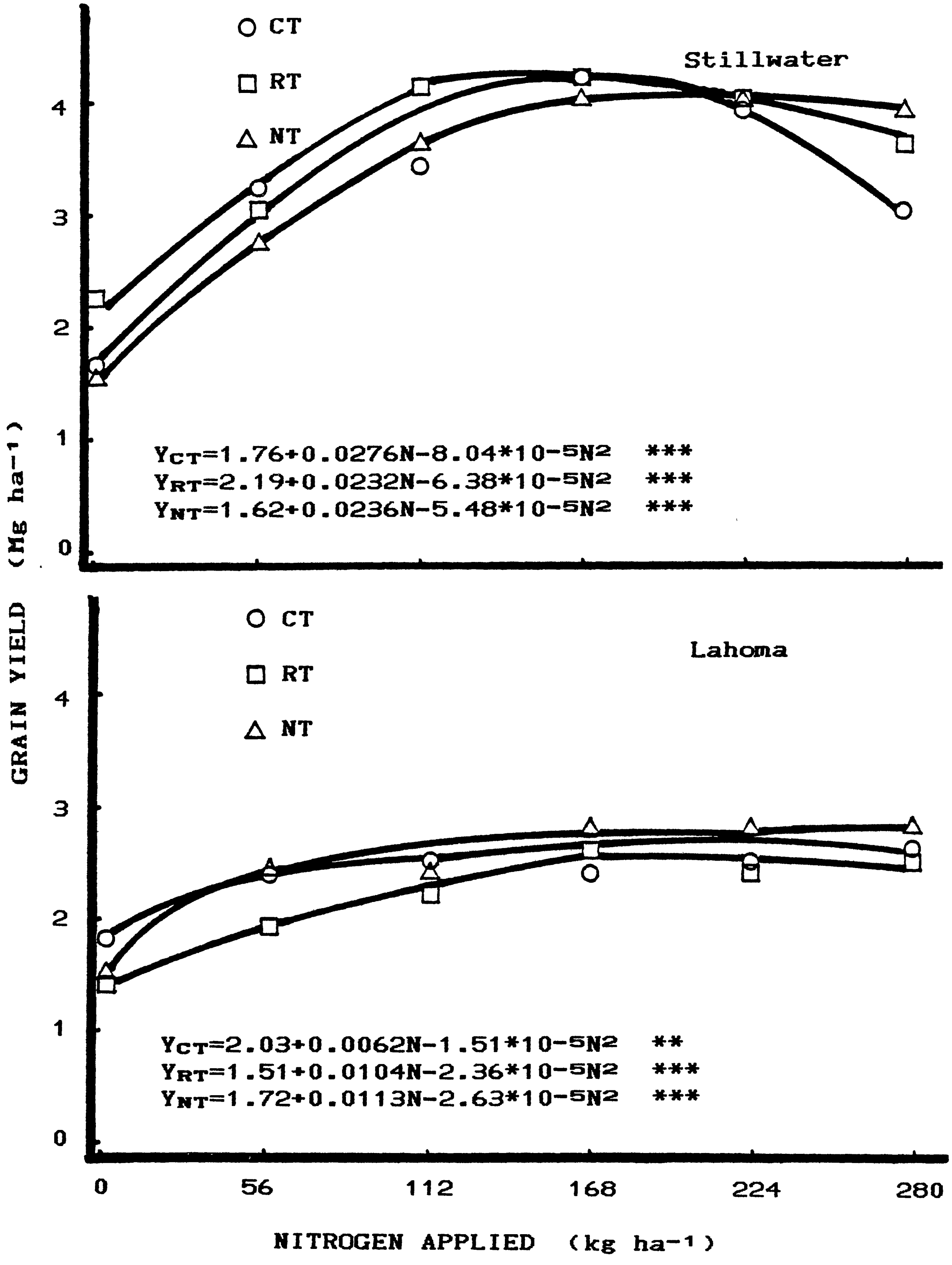

Fig. 2. Grain yield response to N fertilization in CT, RT, and NT residue management systems at Stillwater and Lahoma, 1984. (**, *** denotes significance at the 0.01 and 0.0001 levels, respectively)

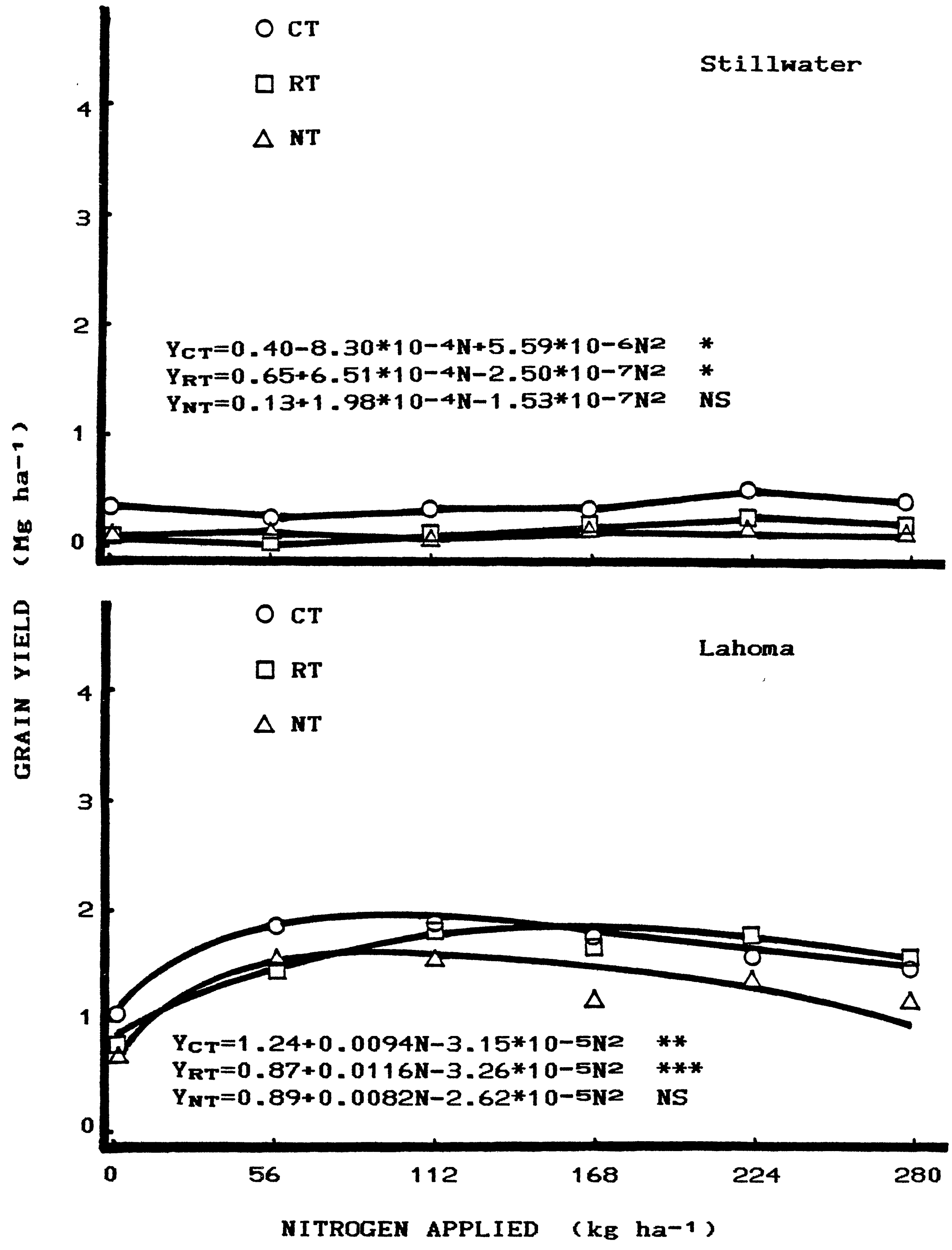

Fig. 3. Grain yield response to N fertilization in CT, RT, and NT residue management systems at Stillwater and Lahoma, 1985. (*, **, *** denotes significance at the 0.05, 0.01, and 0.0001 levels, respectively)

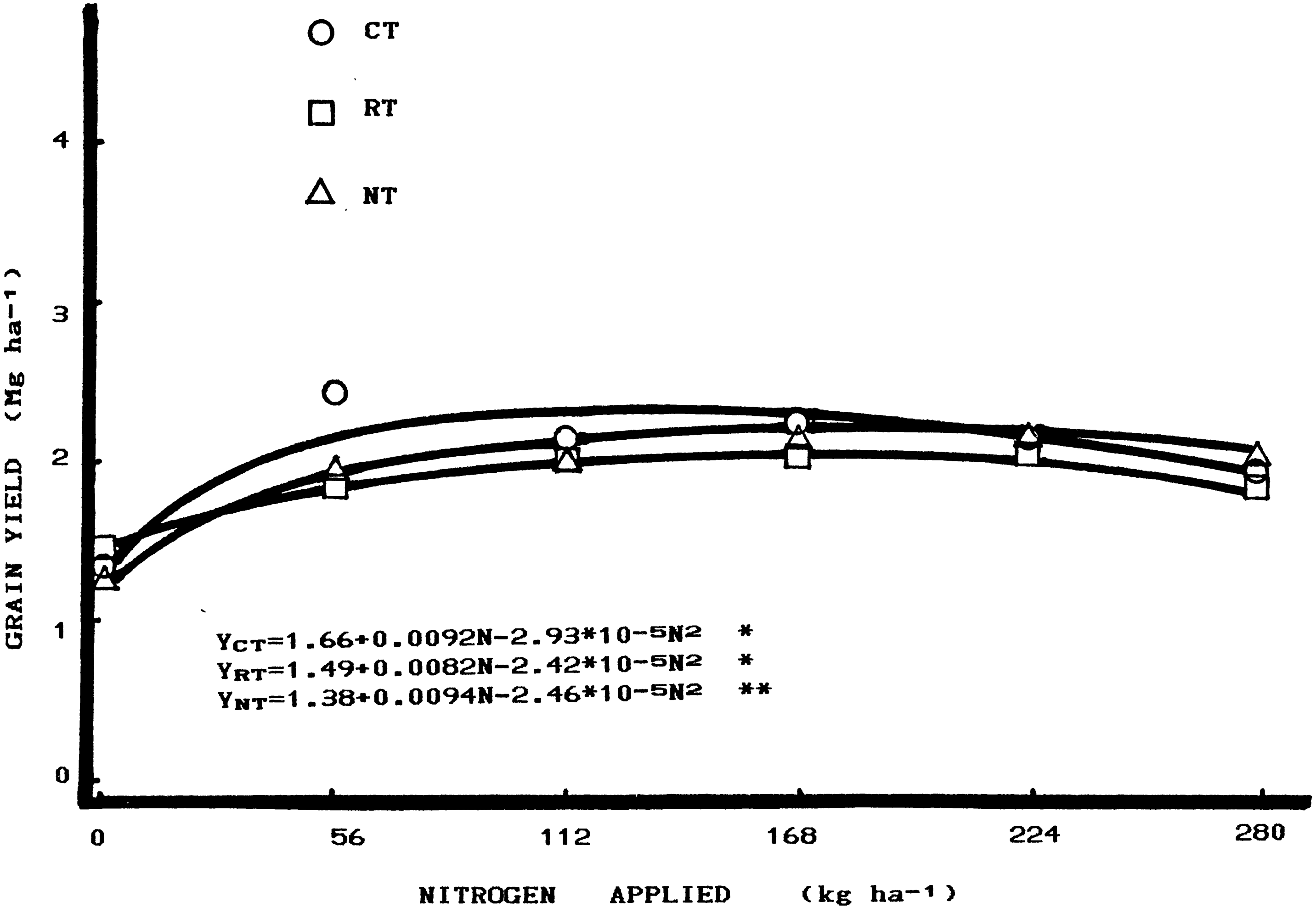

Fig. 4. Grain yield response to N fertilization in CT, RT, and NT residue management systems at Stillwater and Lahoma, 1983 - 1985. (*, ** denotes significance at the 0.05 and 0.01 levels, respectively)

162 kg N ha^{-1} for the 1983, 1984, and 1985 seasons, and at Stillwater were 110 and 187 for the 1983 and 1984 seasons, respectively. Yields for Stillwater in 1985 were not included due to the low yields.

With the exception of Lahoma in 1983, leaf NO_3-N concentration (g kg^{-1}) continued to increase ($P<0.0001$) with N (kg ha^{-1}) fertilization ($NO_3\text{-}N=0.838+0.0051N$; $r=0.52$). A similar increase was observed at the end of the season with N concentration in the grain for each location in the first two years. Applied N progressively increased ($P<0.0001$) grain N concentration (Grain $N=18.88+ 0.0186N$; $r=0.64$) up to 27.0 g N kg^{-1} with 280 kg N ha^{-1} at Lahoma in 1984. Averaging the 1983 and 1984 seasons for both locations, leaf tissue NO_3-N (g kg^{-1}) predicted ($P<0.0001$) final grain N (g kg^{-1}) concentration (Grain $N=18.99+1.62NO_3\text{-}N$; $r=0.59$). The low correlations were attributed to the variability with the unique environments encountered at each location over years.

The N fertilization rate associated with maximum grain production was determined from maximizing polynomial models for CT, RT, and NT systems. Due to the drastic differences between years, N requirements for maximum grain production were averaged over locations within a given year. For the 1983 season, application of 116, 66, and 164 kg N ha^{-1} produced maximum yields for CT, RT, and NT residue management systems, respectively (Fig. 1). The substantially lower N requirement for RT was due to soil dessication following the action of the V-blade, thus limiting yields and the N response. With the residue management systems more established in the second year, the N requirements became more refined with 177, 192, and 216 kg N ha^{-1} required for maximum yields in CT, RT, and NT systems, respectively (Fig. 2). Poor yields and the lack of N response in 1985 for the CT, RT, and NT systems led to N requirements of 166, 187, and 159 kg N ha^{-1}, respectively (Fig. 3). The yield response to applied N in each residue management system was different ($P<0.05$) after three years over both locations with N requirements of 157 kg N ha^{-1} for CT, 169 kg N ha^{-1} for RT, and 192 kg N ha^{-1} for NT (Fig. 4).

Soil Analysis

Soil samples taken at the end of the second cropping season and analyzed for soil pH and residual soil NO_3-N exhibited some interesting changes (Table 4). Significant interactions are illustrated in Fig. 5, 6, and 7. Soil pH under CT was higher than RT and NT at Stillwater with no differences found between tillage systems at Lahoma. Residual soil NO_3-N concentrations under the CT residue system relative to RT and NT were higher at both locations, with levels found at Lahoma approximately twice those of Stillwater. Grain yields at Stillwater were generally higher resulting in greater N uptake and consequently more

Table 4. Effect of tillage system and N fertilization on soil pH and residual NO_3-N at Stillwater and Lahoma.

	Stillwater		Lahoma	
Variable	Soil pH	Soil NO_3-N	Soil pH	Soil NO_3-N
		kg ha^{-1}		kg ha^{-1}
Tillage				
CT	6.26	6.8	6.25	16.4
RT	6.15	5.6	6.33	12.0
NT	6.18	5.9	6.34	10.3
N rate kg ha^{-1}				
0	6.39	5.0	6.45	4.4
56	6.26	4.2	6.38	5.5
112	6.15	5.8	6.28	7.4
168	6.12	5.5	6.33	9.7
224	6.14	7.7	6.29	16.4
280	6.13	8.5	6.10	34.0
Statistics[1]				
CT vs RT and NT	#	#	NS	*
RT vs NT	NS	NS	NS	NS
N lin	***	**	***	***
N quad	**	NS	NS	***
T X N	NS	NS	NS	NS

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[1] #,*,**,*** Significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively.

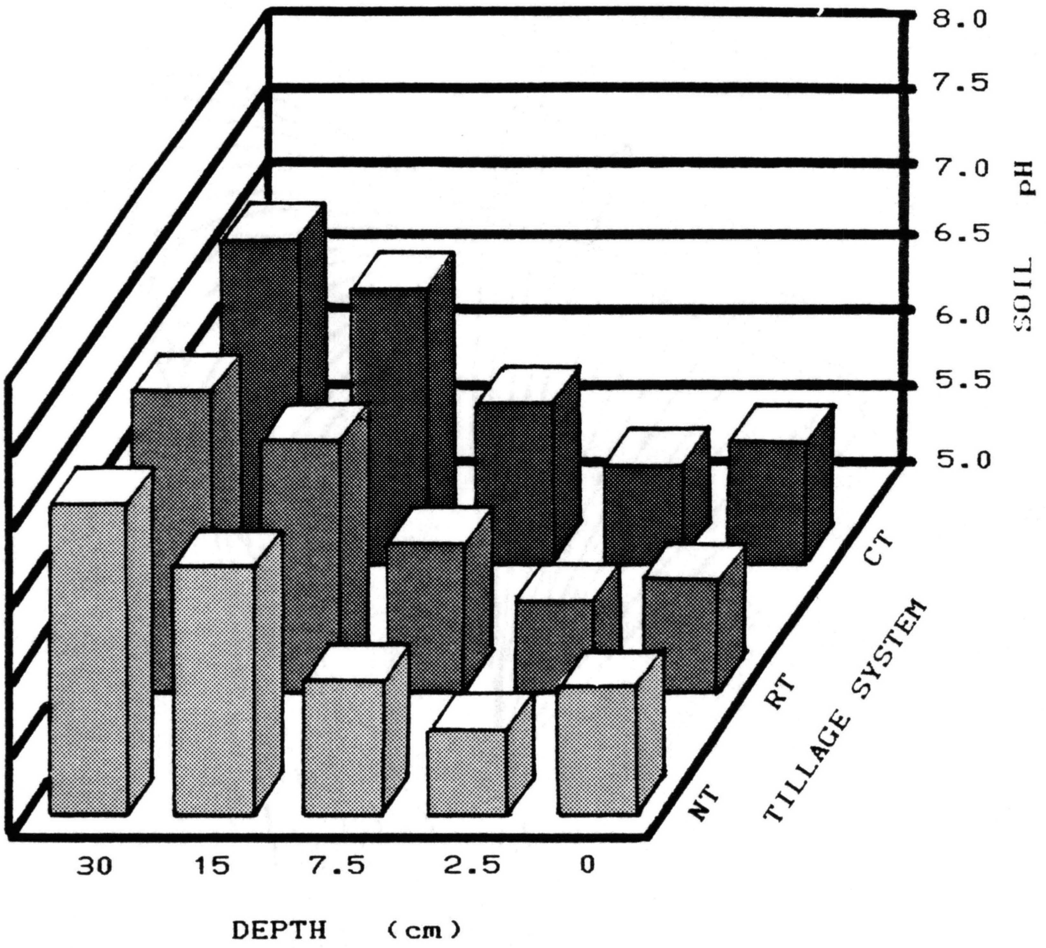

Fig. 5. Distribution within the soil profile of soil acidity in CT, RT, and NT residue management systems at Stillwater, 1984.

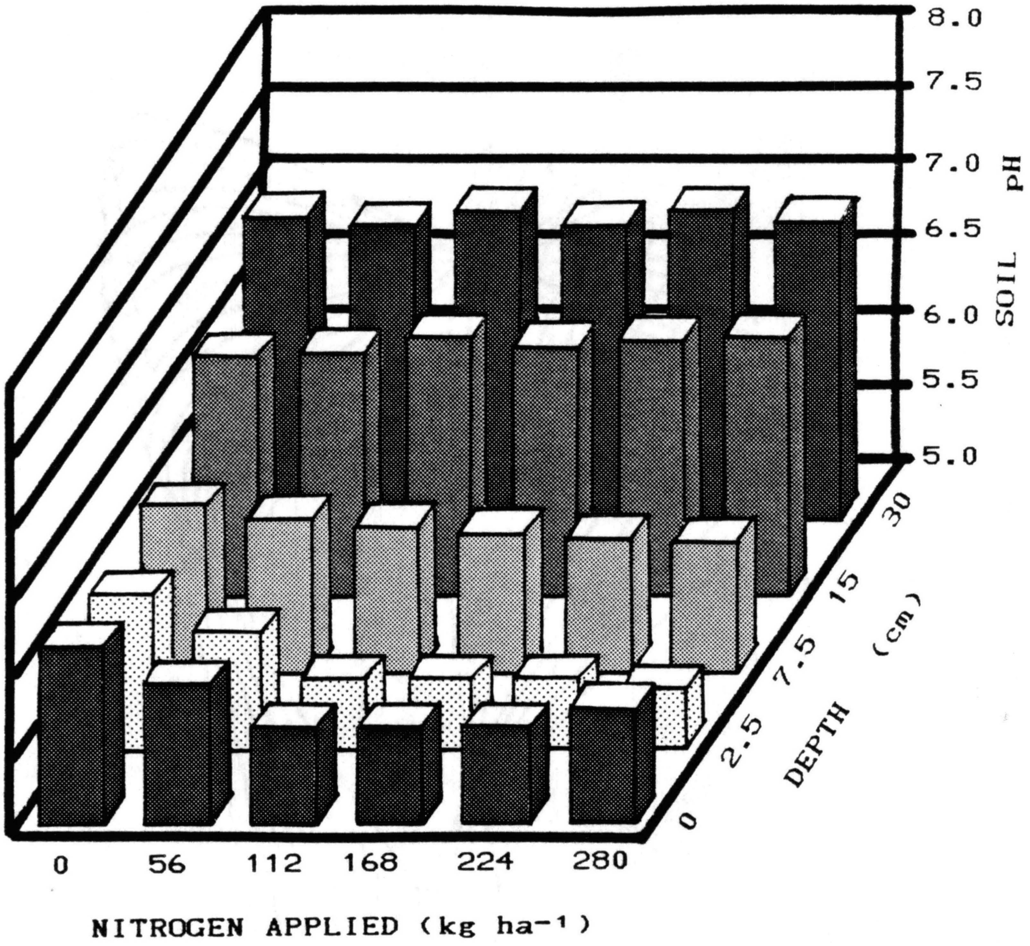

Fig. 6. Distribution within the soil profile of soil acidity in CT, RT, and NT residue management systems at Stillwater, 1984.

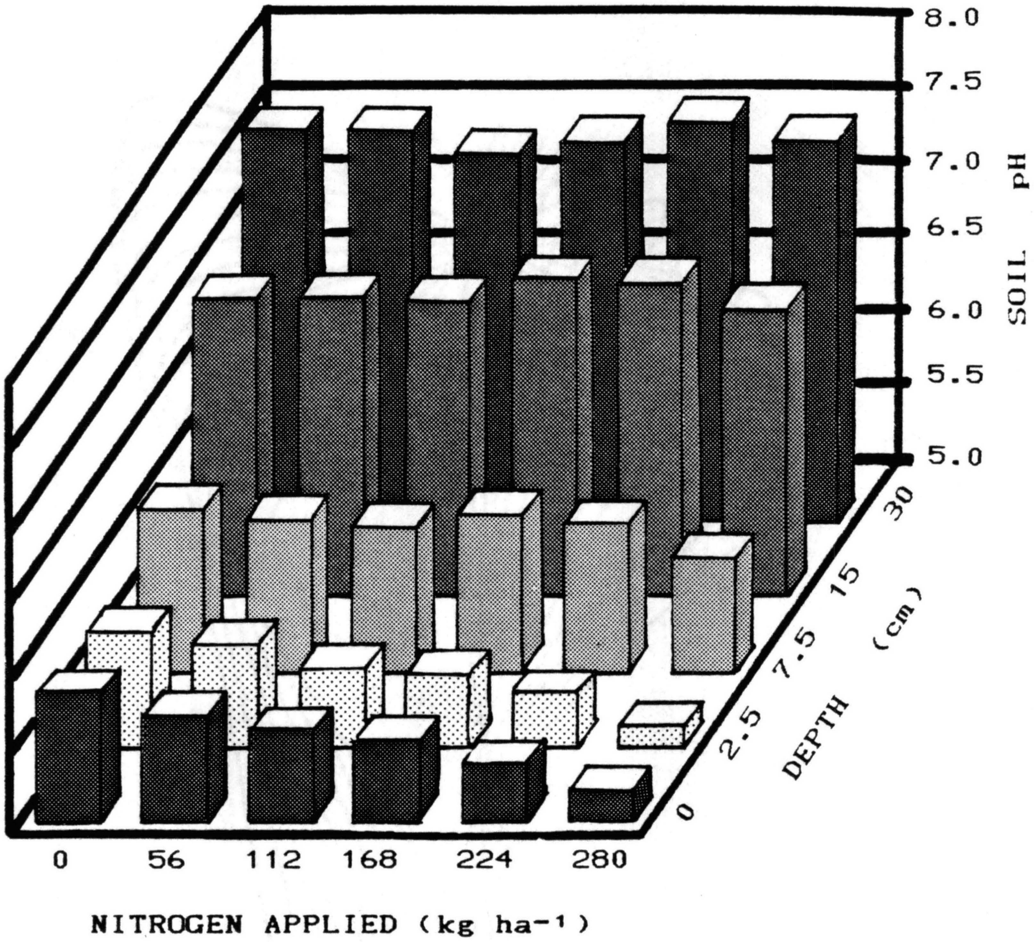

Fig. 7. Distribution within the soil profile of soil acidity in CT, RT, and NT residue management systems at Lahoma, 1984

straw production; this immobilized more N and lowered residual soil NO_3-N levels.

Nitrogen fertilization had a marked effect on soil acidity and residual soil NO_3-N concentrations. Compared to the check, soil pH decreased linearly up to a maximum difference of 0.26 pH units at Stillwater and 0.35 pH units at Lahoma with N applications of 280 kg N ha^{-1}. A similar trend was observed with residual NO_3-N at each location; an increase in N concentration occurred with increased N fertilization. The increase at Lahoma was particularly striking with N applications of 224 and 280 kg ha^{-1} resulting in residual soil NO_3-N concentrations of 16.4 and 34.0 kg ha^{-1}, respectively. These high residual NO_3-N levels account for the two-fold increase in residual NO_3-N found at Lahoma compared to Stillwater.

Linear, quadratic, cubic, and quartic polynomial equations were used to describe significant tillage X depth using the midpoints of each interval (Fig. 5), and N X depth (Fig. 6 and 7) interactions for soil pH at the specified location. At Stillwater, the tillage X depth interaction followed quartic responses for CT, RT, and NT systems. Due to the overall similarity between responses, treatment differences were identified with LSD determinations. The pH decrease under NT between the 0 to 2.5 cm and 2.5 to 7.5 cm increments was more rapid than the decline associated with RT and CT. Except for NT at the surface 2.5 cm, NT and RT had more acidity at each depth compared to CT. Residual soil NO_3-N levels were higher in the top 15 cm of soil relative to the lower depths at Stillwater with levels of 8.9, 7.8, 7.5, 2.9, and 3.5 kg N ha^{-1} for each depth interval, respectively. At Lahoma, residual soil NO_3-N accumulated in the top 2.5 cm of soil (19.2, 13.9, 11.3, 11.4, and 8.8 kg N ha^{-1}) and gradually declined with depth.

A cubic function described the soil pH response with depth at Stillwater for N rates of 0 and 56 kg N ha^{-1} while a quartic response described the acidification of soil with depth at rates of 112 kg N ha^{-1} and greater (Fig. 6). Application of N up to 280 kg ha^{-1} did not decrease the pH of the 15 to 30 or 30 to 60 cm intervals. Soil pH changes in the top 15 cm of soil were similar, but location specific. At Stillwater, the pH of the 2.5 to 7.5 cm depth was significantly lower at all rates of applied N compared to the 0 to 2.5 and 7.5 to 15 cm depths. With N applications at and exceeding 112 kg ha^{-1}, soil pH in the surface 2.5 cm decreased below values found at 7.5 to 15 cm. Compared to the check at each depth, acidification from N fertilization significantly decreased soil pH for the 7.5 to 15 cm depth with rates of 112 kg N ha^{-1} and higher while decreases in the top two intervals occurred with 56 kg N ha^{-1} and higher. With N rates of 0, 56, and 112 kg N ha^{-1} at Lahoma, a cubic function described the acidification process with depth, while with N rates of 168 kg N ha^{-1} and greater, a quartic response was obtained. The soil pH of the 0 to 2.5 and 2.5 to 7.5 cm depths were significantly lower than the

7.5 to 15 cm depth at applied N rates of 56 kg ha^{-1} and higher. Acidification from N fertilization relative to the check at each depth was observed with only 280 kg ha^{-1} for the 7.5 to 15 cm depth and at 168 kg ha^{-1} for the 0 to 2.5 and 2.5 to 7.5 cm increments.

The similar response of soil pH for each N rate with depth suggests statistically valid comparisons for each depth interval averaged over tillage system and N rate. Soil pH was 5.78, 5.58, 5.95, 6.68, and 7.01 at Stillwater and 5.54, 5.48, 5.96, 6.99, and 7.56 at Lahoma for each increasing interval of depth. The distribution within the soil profile of soil pH generally increased down to the 30 to 60 cm depth. With the exception at Lahoma in the 2.5 to 7.5 cm inteval relative to the surface 2.5 cm, all depth increments showed soil pH differences. The decrease in soil pH at Lahoma and significant decrease at Stillwater at the 2.5 to 7.5 cm depth suggest a movement of broadcast urea into the soil profile while hydrolysis occurs, followed by the acidifying process of nitrification.

SUMMARY

Nitrogen fertilizer effects on grain yield, forage, and grain nutrient concentrations in CT, RT, and NT residue management systems for winter wheat were investigated at two locations over a three-year period. Grain yields were generally higher at Stillwater and for the CT system when averaged over locations and years. The NO_3-N concentration of forage samples collected in early spring indicated a progressive increase in available soil N as tillage intensity increased with leaf tissue levels lowest under NT, moderate with RT, and highest in CT. Grain N concentration was higher in CT systems compared to RT and NT in two years out of three when significant differences existed. Nitrogen fertilization increased grain yields, leaf tissue NO_3-N, and grain N concentrations. The overall yield response to applied N for the Stillwater and Lahoma locations from 1983 to 1985 was dependent upon the residue management system. The N requirement for maximum grain production was 157 kg ha^{-1} for CT, 169 kg ha^{-1} for RT, and 192 kg ha^{-1} for NT. The dynamic status between the N cycling processes of immobilization, nitrification, and denitrification in each residue system accounts for N requirement differences. The change in N requirement with time from these winter wheat

residue management systems will be determined from future results. From an economic standpoint after three years, grain yields from RT and NT were not competitive. Future changes such as decreased use of fertilizer N with time and increased soil productivity with erosion control in these conservation tillage systems could offset the initial disadvantages, if yields become competitive.

Soil samples were taken after harvest in 1984 from five depths following the second cropping season to determine the effects of N fertilization in tillage systems on the distribution of soil acidity and residual soil NO_3-N. The mixing of the top 15 cm of soil with the CT system at Stillwater resulted in a higher pH compared to RT and NT, each with a tillage imposed profile stratification, with no differences observed at Lahoma. Evidence of stratification after only two seasons is shown by the rapid decline in soil pH from the surface 2.5 cm to the 2.5 to 7.5 cm depth in NT relative to the CT and RT systems. The decomposition of surface crop residues will promote acidic conditions and contribute to the acidification of the soil surface in RT and specially NT systems. Nitrogen fertilization increased soil acidity with N rates of 56 kg ha^{-1} and higher at Stillwater and with 112 kg ha^{-1} and higher at Lahoma. A direct relationship was found between N fertilization and the distribution of soil acidity within the profile with N fertilization increasing the depth and magnitude of soil acidification. Residual soil NO_3-N was higher under CT relative to RT and NT systems indicating a greater immobilization of applied N in the surface crop residues. There was an increase in residual NO_3-N with N fertilization. Residual soil NO_3-N tended to accumulate in the top 15 cm of soil at Stillwater and in the top 2.5 cm at Lahoma. No differences in residual NO_3-N concentrations between CT, RT, and NT systems with N fertilization were found after two cropping seasons.

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