NITROGEN FERTILIZER MANAGEMENT EXPERIMENTS: RATES, APPLICATION TIMES, SOURCES, AND RESIDUAL NITRATE IN SOILS CROPPED TO WINTER WHEAT AND RATES VERSUS MEPIQUAT CHLORIDE IN SHORT-SEASON COTTON

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INTRODUCTION

This dissertation consists of three chapters, each summarizing research problems conducted separately during my doctoral degree program. The first and second chapters are presented in formats suitable for publication in professional journals. The third chapter has already been accepted for publication in the Journal of Production Agriculture and, as such, utilizes English units of measurement for most reported response variables.

CHAPTER I

NITROGEN RATE AND TIME OF APPLICATION EFFECTS ON WINTER WHEAT AND RESIDUAL SOIL NITRATE

ABSTRACT

Timing of N fertilization for winter wheat (Triticum aestivum L.) forage and grain production is important to overall N management. Objectives of this experiment were to determine the effects of N fertilizer rate and time of application on grain and forage yields, N uptake, and distribution of residual soil NO_3-N. Field experiments were conducted for 4 years near Perkins, OK, and for 3 years near Hennessey, OK; both Udic Argiustolls cropped to winter wheat under conventional tillage. Urea ammonium nitrate (UAN) was applied broadcast preplant incorporated (PPI) and topdressed in December, January, February, and March at rates of 34, 67, 101, and 134 kg N ha^{-1}. An unfertilized check was included. Forage dry matter yield (late March to mid-April) and grain yield were determined each year. Soil samples were taken from each plot after grain harvest to 1.2 m and analyzed by depth to assess soil residual NH_4-N and NO_3-N. Grain and forage dry matter yields and N uptake values were significantly increased by N application at Perkins. Grain yield response to applied N was quadratic while forage yield response was generally linear. Optimum timing of N application for grain and forage yields was early January and mid-November, respectively. Grain N uptake was generally unaffected by date of N application, however, forage N uptake values were reduced by March application in 2 years. At Hennessey, environmental problems (hail damage, drought, and freeze damage in 1990, 1991, and 1992, respectively) reduced grain yields, and limited interpretation of grain and soil data. At both sites, March application resulted in lower forage yields compared to earlier dates as tissue damage was noted at high N rates. No significant differences in soil residual NH_4-N were observed at either site. Linear increases in NO_3-N were detected in soil profiles in some years at Perkins, however, low residual NO_3-N was generally observed. Nitrogen application timing was important for forage dry matter production at Perkins, but less critical for grain production. If adequate precipitation was received after December and January application, total forage yields (measured in late-March to mid-April) were comparable to PPI levels. Delayed application until January or February did not significantly affect grain yield response. Mid-March applications were effective, but resulted in lower grain yields when compared to December, January, or February treatment.

INTRODUCTION

Rate and timing of N fertilization in winter wheat forage and grain production is important to nitrogen management. Grazing of winter wheat forage by cattle can increase income for many wheat producers. Forage dry matter production generally requires N to be present in the fall to enhance growth. Grain production is less dependent on early vegetative growth for optimum yield, and N may be applied later in the season. Various researchers have examined the efficiency of spring-versus winter-applied N fertilizers in winter wheat production. Literature supports the concept that when spring and fall applications are compared, equal or superior grain yields for spring application are generally observed (Welch et al., 1966; Hunter and Stanford, 1973; Fowler and Brydon, 1989). Some researchers report results from various ^{15}N experiments relative to N use efficiency in winter wheat (Olson et al., 1979; Olson and Swallow, 1984; Riga et al., 1980; Christensen and Meints, 1982; Harper et al., 1987). Christensen and Meints (1982) found that fall topdressed urea on winter wheat was only 69% as effective as fall topdressed ammonium nitrate which was considered to be a function of increased NH_3 volatilization from applied urea. However, fall topdressed ammonium nitrate, spring topdressed ammonium nitrate, and spring topdressed urea were equally effective for N sources for winter wheat grain yield. Harper et al. (1987) concluded that spring fertilization is important for winter wheat, as isotope analysis in their work indicated about one-third of the total N in the grain was derived from fertilizer N when 112 kg N ha^{-1} was applied (39.2 kg in November plus 72.8 kg applied in March). Olson and Swallow (1984) observed that approximately 30% of applied N fertilizer was removed by the grain, with spring application resulting in higher N efficiency in 4 of 5 years, the differential likely due to immobilization of fall treatments. Residual soil N in the 1.8 m profile accounted for approximately 50% of applied fertilizer N at the end of the trial, with approximately 70% of the residual fertilizer located in the upper 0.1 m of soil. When working with a crop rotation, Riga et al. (1980) reported increased uptake of fertilizer N was related to splitting of applications and determined the bulk of residual fertilizer N following winter wheat was in the upper 70 cm of a well-drained silt loam soil. They also concluded that NH_3 volatilization losses from ammonium sulfate and fertilizer residual N below 70 cm were about 5% and 2% of that applied, respectively.

Timing of N fertilizer application on sandy soils is important from the environmental perspective, as N present as NO_3-N can be leached below the root zone of the crop if soil profiles are saturated and precipitation exceeds evapotranspiration for extended periods. When considering increasing trends toward regulation of fertilizer usage, the fate of fertilizer N must be investigated. Some researchers have reported residual aspects of N fertilization, but few relate effects of various dates of N application on profile NO_3-N distribution. The objectives of this study were to determine the effects of N rate and time of application on grain and forage yields, N uptake and distribution of residual soil NO_3-N in winter wheat production systems.

MATERIALS AND METHODS

Field experiments were conducted for four consecutive years (1990 to

1993) near Perkins, OK, and three cropping seasons (1990 to 1992) near Hennessey, OK, (Teller sandy loam, Udic Argiustoll; Shellabarger loam, Udic Argiustoll; respectively). Continuous wheat had been produced previously at both locations under conventional tillage conditions. Soil profile characterization is provided in Table 1. Nitrogen fertilizer application dates were preplant incorporated (PPI), and as mid-month topdress applications in December (DEC), January (JAN), February (FEB), and March (MAR). All N fertilizer was applied for each rate on the respective date (no split-applications). The preplant application was incorporated by a spring-tooth chisel plow, whereas later applications were topdressed. Rates of N fertilizer were 34, 67, 101, and 134 kg N ha^{-1}. An unfertilized check was included. Urea ammonium nitrate (UAN, 28-0-0) was used as the N source. All treatments were broadcast applied. Plot size was 5 m wide by 12 m and 15 m lengths for the Perkins and Hennessey sites, respectively, with treatments applied to the same plots each year. A randomized complete block experimental design with a factorial arrangement of treatments with three replications was used. The experimental area was drilled in 25 cm rows to winter wheat at a 67 kg ha^{-1} seeding rate each year. Cultivars planted included 'Chisholm' at Perkins and Hennessey in all years, except for the 1993 crop year, when 'Karl' was planted at Perkins. Field activities are provided in Table 2. Diammonium phosphate, (18-20-0) was banded with the seed at planting at a rate of 15 kg P ha^{-1} at both sites in all years, based on OSU soil test recommendations (Allen and Johnson, 1993; Johnson et al., 1991). About 7 to 14 days after an incorporating rainfall event for March fertilizer treatments, forage was harvested. One row 1 m long was hand clipped from each plot and the entire biomass was dried in a forced air oven at 65°C for 48 hours to determine forage dry matter yield. Wheat plant growth on this date generally corresponded to Feekes growth stage 6 to 8 (Large, 1954). Measurement of biomass at this time evaluated total forage production. This method is not an assessment of early-season forage growth which can be more important to Oklahoma wheat producers. Grain yields were determined by harvesting 3 m by 12 m or by 15 m for the Perkins and Hennessey experiments, respectively, with a small conventional combine. Grain and forage samples were analyzed for total N using a Carlo Erba CNS 1500 dry combustion analyzer. Grain N uptake (GNUP) and forage N uptake (FNUP) were calculated by multiplying yield and total N analyses. Based on N removal in forage, the difference method was used to estimate N fertilizer recovery. Nitrogen uptake in the unfertilized check was subtracted from N uptake by treatments and divided by the respective N rate to provide an estimate of fertilizer N recovery. When using this technique, problems of overestimating N fertilizer recovery are often encountered (Hauck and Bremner, 1976; Westerman and Kurtz, 1974). Errors can be somewhat large, and a priming effect of N fertilizer application on indigenous soil N has been observed (Westerman and Kurtz, 1973; Hauck and Bremner, 1976; Riga et al., 1980; Jansson and Persson, 1982). However, Westerman and Kurtz (1974) state that the difference and isotopic methods are more likely to agree when only one crop harvest is obtained and when soil mineralizable N is low. Plots were sampled to a depth of 1.2 m immediately after each grain harvest using a hydraulic soil probe. One core, 4.4 cm in diameter, was taken from near the center of each plot. Cores were partitioned into six increments including 0-15, 15-30, 30-45, 45-60, 60-90, and 90-120 cm depths. Soil samples were air dried at ambient temperature, processed to pass a 2 mm sieve, extracted using 2M KCl (Bremner, 1965) and analyzed for NO_3-N and NH_4-N using the Lachat-Quikchem automated flow injection analysis system. Nitrite plus nitrate-N was determined using a cadmium reduction method. Ammonium-N was determined using the same KCl extract, and the phenolate method.

Statistical analysis of data was performed using appropriate procedures given by the SAS Institute (SAS, 1988). Interpretations of data are based on non-orthogonal single degree of freedom contrasts. Since long-term effects of N fertilization were important, grain and forage yields were combined over 3 years and 4 years, respectively, for the Perkins site, using a split-plot in-time analysis of variance (Steel and Torrie, 1980). Quadratic response surface models were fit to grain and forage data using PROC RSREG. The model included linear, quadratic, and a linear interaction term for N fertilizer rate and date of application (Pesek and Heady, 1961; Heady et al., 1961). The quadratic model used was

$$Y = \beta_0 + \beta_1 \text{ DAP} + \beta_2 \text{ DAP}^2 + \beta_3 \text{ NRATE} + \beta_4 \text{ NRATE}^2 + \beta_5 \text{ DAP*NRATE}$$

where Y = percent relative maximum yield of grain or forage; β_0 = intercept; β_1, β_2, β_3, β_4, β_5 are regression coefficients for DAP (fertilizer application date expressed as days after planting), DAP^2, NRATE (N fertilizer rate, kg ha^{-1}), $NRATE^2$ and the linear by linear interaction term DAP*NRATE, respectively. Lower and upper boundaries for NRATE were 34 and 134 kg N ha^{-1}, respectively, (check treatments were deleted from dataset) while lower and upper boundaries for DAP were 0 and 180, respectively. For response surface modeling, grain and forage yields per plot were expressed as percent relative maximum yield, using the highest yielding individual plot from each year as 100 percent. This minimized effects of fluctuations in actual yield over years. Maximizing the function indicates optimum date of application and N rate for both grain and forage yields. Absolute maxima were used to determine optimum fertilization date and rate for grain yields. Since forage yield response was linear for some dates of application, the absolute maximum of the model was found to be slightly above N rates used in the experiment (149 kg ha^{-1}). As a result the partial maximum of the forage yield function was set equal to zero and solved at the highest utilized N rate of 134 kg ha^{-1} to determine optimum date of fertilization at that rate. The partial derivative of forage yield with respect to date of application is

$$\partial Y/\partial DAP = \beta_1 + 2\beta_2\, DAP + \beta_5\, NRATE.$$

Where appropriate, linear and quadratic regression models for grain and forage yields were fit to the data.

RESULTS AND DISCUSSION

Seasonal Overviews

Precipitation for each growing season is presented in Table 3. At the Perkins site, total rainfall over the 4 year period varied considerably (see Appendix A). Above average seasonal precipitation was encountered in 3 of 4 years. The 1993 growing season had above average rainfall in 6 of 9 months. At Hennessey, total precipitation did not deviate significantly from the long-term average in 2 of 3 years. In late April, 1990, a hailstorm damaged the Hennessey experiment reducing grain yields. In 1991, precipitation was extremely low, and significantly affected crop response to applied N. The 1992 crop year was near long-term average for precipitation at both sites during the seeding period, with higher than average rainfall occurring in December. Forage growth was enhanced by mild weather and excellent moisture conditions. Beginning on March 10, 1992, a series of late freezes were encountered which substantially reduced grain yields at Hennessey by damaging the embryonic inflorescence in some advanced tillers. Dense, succulent forage growth appeared to accentuate the amount of grain yield reduction associated with the late freezes at Hennessey. The Perkins experiment was affected by these freezes, but to a lesser degree. Because environmental extremes at Hennessey reduced grain yields in all 3 years, interpretation of grain and soil data from that site was complex and limited, therefore, those data are presented in Appendix A.

Perkins Experiment

Grain. Significant grain yield responses to N fertilization were observed in all years (Tables 4-7 and Fig.1). No significant date by N rate interaction for grain yield was detected in any year. Responses to N fertilization were generally quadratic, with the exception of the 1992 year which was linear. Significant differences due to date of application were observed only in 1990, with PPI treatment resulting in lower grain yields than other dates. Increased immobilization of fall applied N may account for this difference (Olson and Swallow, 1984), as early season rainfall was not excessive. Due to freeze damage in 1992, data for grain yield from that year were deleted from the combined analysis, thus 1990, 1991, and 1993 were used. Main effect of date was not significant over years (Table 8), however PPI and March application dates were somewhat lower in yield than December, January, and February. This trend was present in 2 of 3 years that were used in the combined analysis. Results from quadratic response surface modeling suggest the optimum N fertilization date for grain yield is about 81 days after planting at 103 kg N ha^{-1} (Table 9, Fig. 2). This date coincides with early January application. Grain yield response to applied N combined over date of application and three years was significant for quadratic fit, and the regression equation is presented in Table 10. Maximization of the quadratic N response function is obtained at 94 kg N ha^{-1}, which reasonably coincided with the quadratic response surface model.

Grain N was significantly increased by N fertilization in 3 of 4 years (Tables 4-7, Fig.3). Date of application was significant in 1990 and 1993, with higher grain N for March application than other dates. Nitrogen rate response was linear in both years. Date by rate interactions were highly significant in 1991 and 1992. At higher N rates in 1991, December and March applications appeared to increase grain N more than other application dates. This may be due to lower rainfall than normal during January and February of 1991. Grain N in 1992 was the lowest of the 4 year period, and may have been affected by the late freezes. March treatments in 1992 were actually applied after the initial freeze which occurred on March 10. Rate responses to applied N were extremely variable across dates of application, but March application resulted in higher grain N concentrations at the two high N rates in 1992.

Grain N uptake was significantly increased in all years of the experiment (Fig. 4). Significant date by rate interactions were not detected in any year except at the 0.10 level in 1990. Date of application was not significant in any year except for 1990, when PPI application resulted in lower uptake values than other dates. Nitrogen rate responses were quadratic in 1990 and 1991, and linear in the other two years.

Forage. Forage yields were increased by N fertilization in all years of the experiment (Tables 4-7, Fig. 5). Date of application by N rate interaction was not significant in any year. Nitrogen rate responses were quadratic in 1990 and 1993, and linear in 1991 and 1992. Significant differences due to date of application were observed in 3 of 4 years of the trial. Although total forage growth by mid-April was good, lack of adequate rainfall in January, February, and March of 1991 resulted in relatively poor early forage growth conditions, therefore, date of application differences were not detected in that year. February N application produced significantly less forage yield than PPI treatment in all years with responses to date of application. In those same years, March fertilization resulted in significantly less forage yield than other application dates. In the 1990 season, PPI application resulted in greater forage production than December which was likely due to low precipitation in December. December application produced more forage than PPI in 1992. This may be due to greater immobilization of PPI applied N. Although excessive rainfall was encountered in the 1993 season, no differences among PPI, December, and January fertilization dates for forage yield were observed.

When forage yields were analyzed over the 4 year period, a significant (0.05 level) N rate by year interaction was detected. Forage yield response in 1990 and 1993 was quadratic (0.01 level), and linear in the 1991 and 1992 seasons. Main effect of date of application was significant, with February and March application dates resulting in lower forage yields than other dates over the 4 year period. Preplant incorporated, December, and January dates were not significantly different for forage production. Response to PPI, February, and March dates of application were linear with a nonsignificant (0.05 level) model and poor R^2 value for March observed (Table 10). Severe tissue burn due to high N application rates is probably responsible for considerable variation in plot forage yields and poor correlation for the March application date. December and January regression models for forage were quadratic with maxima at 116, and 136 kg N ha^{-1}. Results show N rates used in the experiment were insufficient to achieve full expression of the forage yield response curve. For the highest N rate used in the experiment (134 kg ha^{-1}), the quadratic response surface model estimates the optimum date of application for forage yield to be 38 days after planting (Table 9, Fig. 6). If early fall forage growth is not important, these results suggest N fertilization can be delayed until after stand establishment of winter wheat in order to maximize total forage yields measured in late-March to mid-April. Nitrogen application after stand establishment could result in less fertilizer N immobilization and reduced leaching potential of N from PPI application.

Forage N concentrations were significantly increased in all years of the trial (Fig.7). Significant date by rate interactions were observed in 1990 and 1992. Forage tissue burn for N rates above 34 kg ha^{-1} in the February treatments in 1990 damaged wheat plants and resulted in reduced vigor and may account for lower forage N for those rates. March application in that year resulted in tissue damage at all N rates. Excessive rainfall (greater than 270 mm) during February and March may have contributed to lower forage N for those application dates. Grain N for February and March applications were not significantly lower than other dates, so the ultimate effect on total plant N by grain filling time was minimal. Wheat forage N in 1992 was generally lower for PPI than other dates, with a much less pronounced N rate response. Increases in forage N concentration for February and March application were dramatic, especially at the higher N rates. Wheat forage growth in 1992 was the lowest of the 4 year period, but was also harvested 11 to 27 days earlier than in other years. Higher forage N concentrations for February and March applications may be attributed to higher forage yields for other dates, more readily available N during rapid growth, or less immobilization. Forage N concentrations for PPI application were lower than December, February and March in 1991 and 1993. Response to N rate was quadratic and linear in 1991 and 1993, respectively.

Forage N uptake was linearly increased by N fertilization in all years (Fig. 8). No date by rate interactions for forage N uptake were detected in any year, and date of application was significant in 1990 and 1992. In 1990, March application resulted in lower forage N uptake than all dates except February. March application produced lower forage N uptake than other dates in 1992. February forage N uptake compared to PPI was lower and higher in 1990 and 1992, respectively. This differential was attributed to lower and higher forage N concentrations for February application date in those years, respectively.

The difference method was used to estimate fertilizer N recovery in forage. The 4 year mean value of forage N uptake from the check plot (by replication) was subtracted from each 4 year mean value for N treatments (by replication). This difference is an estimate of the amount of fertilizer taken up in the forage and was divided by the N rate applied and estimates of N recovery were made. Analysis of variance on 4 year means of estimated N recoveries (averaged over N rates) indicated 0.49, 0.51, 0.53, 0.42, 0.34 kg kg^{-1} applied N fertilizer was recovered in forage growth; for PPI, December, January, February, and March application dates, respectively. March application resulted in lower N recovery than other dates of application, which were not significantly different. No rate differences were noted for N recovery, although a trend for lower recovery was observed at the highest N rate (0.48, 0.47, 0.47, 0.42 kg kg^{-1} applied N fertilizer for 34, 67, 101, and 134 kg N ha^{-1} applications, respectively).

Plant N losses between forage harvest and grain harvest can be estimated if some assumptions are made. If grain N uptake values plus estimates of N remaining in straw are subtracted from forage N uptake, then plant N losses from forage harvest date through grain harvest can be evaluated. No straw yields were measured during the study, however, working back from an estimated harvest index of 0.4 (ratio of grain yield to grain yield + straw yield) and 4 mg g^{-1} N concentration in straw (Unruh, 1981), a grain yield of 2250 kg ha^{-1} would result in about 13.5 kg N ha^{-1} remaining in straw. Olson and Swallow, 1984, measured somewhat less than that value (9.1 kg N ha^{-1} remaining in wheat straw and large root residue at 100 kg N ha^{-1} rate applied in fall). According to these estimates, plant N losses that occurred from forage harvest date to grain harvest ranged between 20 and 30 kg N ha^{-1} for the 134 kg N rate (15 to 22 percent of that applied) averaged over all dates of application for the 4 year period.

Soil Analyses. Results from deep soil sampling show no significant differences in soil residual NH_4-N in any year (data not shown). Low soil residual NO_3-N values were observed in the experiment (Tables 11 and 12). Slight linear increases in soil residual NO_3-N values were observed in some soil depths in 1990 and 1992 in the rep by date by rate complete factorial analysis, but the check vs others contrast was seldom significant in the rep by treatment model (data not shown). Consequently, observations from each year for the highest N rate (134 kg N ha^{-1}) from each application date and the check plot were analyzed as a subset of the data. Significant differences (check vs others at the 134 kg N ha^{-1} rate) in soil residual NO_3-N were only found in the 1991 year in the 15-30, 30-45, 45-60, and 60-90 cm depths, with response generally linear across application dates (data not shown). The 1991 year had the lowest precipitation of the 4 year study and exhibited the highest amount of soil residual NO_3-N (up to 8 mg NO_3-N kg^{-1} in the 45-60 cm increment). March application generally resulted in higher soil residual NO_3-N than other dates in soil increments where responses were noted. Soil residual NO_3-N values of < 2 and < 3 mg NO_3-N kg^{-1} soil were found in 1990, and 1993, respectively. Both years experienced above average rainfall. The 1992 year had higher than normal rainfall and somewhat higher residual NO_3-N values than the 1990 and 1993 seasons (up to 7 mg NO_3-N kg^{-1} soil in the surface increment to 3 mg NO_3-N kg^{-1} soil or less in other depths).

Low soil residual NO_3-N can be attributed to immobilization (Westerman et al., 1972; Westerman and Kurtz, 1972; Olson et al., 1979; Olson and Swallow, 1984;), denitrification (Riga et al., 1980), volatilization of NH_3 from topdressed treatments, plant N uptake, subsequent plant N loss (Daigger et al., 1976;

Hooker et al., 1980; Harper et al., 1987; Parton et al., 1988), or leaching below sampling depth.

CONCLUSIONS

Grain and forage yields, N concentrations, and N uptake values were significantly increased as a result of N fertilization during a 4 year experiment near Perkins. Data from 3 of 4 years which had near long-term average to high rainfall, indicated date of N fertilizer application was generally not significant for grain yields, although PPI and March applications had trends for lower yields as compared to December, January, and February applications. A quadratic response surface model predicted grain yields were maximized with 103 kg N ha^{-1} applied in early January. Total forage yield as measured in late-March to mid-April was significantly affected by date of N application in 3 of 4 years. Averaged over 4 years and N rates, February and March application resulted in lower forage yields than PPI, December, or January which were not significantly different. March treatment resulted in poor forage yields due to lateness of application and tissue damage from high N rates. Response surface model prediction indicated forage yields were not maximized by N rates used, but at the highest N rate (134 kg N ha^{-1}), mid-November application maximized yields. This resulted from slightly lower forage yields for PPI application compared to December and January in 1992 and 1993, attributed to immobilization of PPI applied N. Grain N uptake was generally unaffected by date of N application.

Forage N uptake (probably a better estimate of total plant N uptake than grain N uptake) for March application was lower than other application dates in 2 years where differences were observed.

No significant differences in soil NH_4-N were observed at either site. Data from Perkins indicate linear increases in NO_3-N were detected in soil profiles in some years. Low soil residual NO_3-N was generally encountered. Small linear increases in soil NO_3-N were found at the high N rate in some soil increments in one year, with March application resulting in higher residual than other application dates. It is unclear whether March treatment exhibited higher soil NO_3-N as a result of NO_3-N mobility due to later application (with reduced N uptake ability due to poor rooting in mid to lower profile depths), or if greater immobilization or soil profile N losses from other application dates are responsible.

These results generally support findings of other researchers (Hunter and Stanford, 1973; Olson et al., 1979; Olson and Swallow, 1984; Christensen and Meints, 1982; Harper et al., 1987; Fowler and Brydon, 1989). Results from these experiments show N fertilization timing was important for forage dry matter production on N deficient soils, but was less critical for grain production. If adequate precipitation was received after December and January N application, total forage yields (as measured in late-March to early-April) were comparable to PPI levels on a N deficient soil. If decreasing immobilization and NO_3-N leaching potential of PPI applications are important, then delaying total N application until January or February can be considered without significantly affecting grain yield response. This strategy is not without risk, because delaying application may affect N fertilizer responses by reducing plant availability (low precipitation) or by resulting in application problems (excessive precipitation causing wet fields). Mid-March N applications were still effective, but generally resulted in lower grain yields when compared to December, January, or February N applications. From the environmental perspective, slightly higher soil residual NO_3-N arising from March application was sometimes encountered, but large differences in NO_3-N concentrations and distribution due to date of N application were generally not detected.

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Table 1. Soil physical and chemical characteristics and classification at experimental sites.

				Mehlich III							Bulk
Soil depth	pH	NH_4-N	NO_3-N	P	K	Total N	Organic C	Sand	Silt	Clay	density
— cm —		— mg kg^{-1} —				— g kg^{-1} —		— % —			Mg m^{-3}
Perkins											
0-15	6.1	9.0	1.3	15	167	0.55	6.4	60	20	20	1.81
15-30		7.6	1.2			0.58	6.5	57	18	25	1.69
30-45		8.0	1.2			0.51	5.8	52	23	25	1.62
45-60		7.3	1.0			0.42	4.5	54	22	24	1.69
60-90		8.0	0.8			0.30	3.1	62	18	20	1.72
90-120		7.8	0.7			0.24	2.4	70	13	17	1.76
Hennessey											
0-15	5.0	13.6	6.9	28	233	0.61	7.7	48	33	19	1.51
15-30		8.0	12.5			0.71	8.9	45	29	26	1.52
30-45		8.4	11.3			0.67	7.9	31	34	35	1.55
45-60		10.3	7.5			0.43	4.3	40	27	33	1.64
60-90		9.7	8.3			0.39	4.5	32	32	36	1.75
90-120		9.4	6.0			0.21	1.7	40	29	31	1.79

Classification:

Perkins - Teller sandy loam (fine-loamy, mixed, thermic Udic Argiustoll)
Hennessey - Shellabarger loam (fine-loamy, mixed, thermic Udic Argiustoll)

Table 2. Field activities for N experiments.

	Year						
	1990		1991		1992		1993
Location	Perkins	Hennessey	Perkins	Hennessey	Perkins	Hennessey	Perkins
Planted	11 Oct	28 Sept	13 Oct	12 Oct	27 Sept	8 Oct	9 Oct
Harvest date							
Forage	3 Apr	5 Apr	16 Apr	9 Apr	23 Mar	25 Mar	19 Apr
Grain	11 June	19 June	14 June	11 June	13 June	23 June	18 June
Fertilization date[†]							
Preplant	10 Oct	25 Sept	24 Sept	26 Sept	27 Sept	26 Sept	25 Sept
Dec	18 Dec	20 Dec	11 Dec	11 Dec	18 Dec	18 Dec	22 Dec
Jan	15 Jan	15 Jan	18 Jan	17 Jan	17 Jan	17 Jan	19 Jan
Feb	19 Feb	19 Feb	13 Feb	15 Feb	18 Feb	18 Feb	23 Feb
Mar	21 Mar	20 Mar	14 Mar	14 Mar	13 Mar	13 Mar	16 Mar
Soil sampled	28 June	20 June	14 June	11 June	13 June	7 July	18 June

[†] - Except for the preplant incorporated treatment, N fertilizer was applied as topdress applications.

Table 3. Seasonal precipitation (mm) at experimental sites.

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
Perkins										
1990	70	1	14	36	104	169	207	95	46	742
1991	8	42	30	20	2	29	60	166	89	486
1992	107	67	127	23	37	37	129	101	208	836
1993	45	171	89	60	74	53	179	271	94	1036
LTA[†]	80	52	34	28	32	61	67	132	106	592
Hennessey										
1990	69	2	4	NR[‡]	93	121	104	104	33	530
1991	25	39	14	6	1	32	27	80	72	296
1992	60	60	105	11	10	51	75	79	166	617
LTA[†]	51	41	25	18	29	47	60	135	99	505

[†] - Long term average for location as reported by nearest official recording station.

[‡] - Data not reported.

Table 4. Rep-treatment and factorial arrangement of treatment analyses of variance on grain and forage yield, N concentration, and N uptake at Perkins, OK, 1990.

	df	Grain yield	Forage yield	Grain N conc.	Forage N conc.	GNUP	FNUP
Treatment	20	**	**	**	**	**	**
Error	40						
Contrast							
Check vs others	1	**	*	*	**	**	**
Date	4	**	**	**	**	**	**
Rate	3	**	**	**	**	**	**
Date*Rate	12	NS	NS	NS	***	†	NS
Error	38						
Contrasts							
PPI vs Dec	1	**	**	NS	NS	**	**
PPI vs Jan	1	**	NS	†	NS	**	NS
PPI vs Feb	1	**	**	NS	**	**	**
Mar vs others	1	NS	**	**	**	NS	**
N rate linear	1	**	**	**	**	**	**
N rate quadratic	1	**	**	NS	*	**	NS
CV, %		8	11	5	6	8	13

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS - Not significant.
CV - coefficient of variation.

Table 5. Rep-treatment and factorial arrangement of treatment analyses of variance on grain and forage yield, N concentration, and N uptake at Perkins, OK, 1991.

	df	Grain yield	Forage yield	Grain N conc.	Forage N conc.	GNUP	FNUP
Treatment	20	**	*	**	**	**	**
Error	40						
Contrast							
Check vs others	1	**	**	**	**	**	**
Date	4	NS	NS	**	**	NS	NS
Rate	3	**	**	**	**	**	**
Date*Rate	12	NS	NS	**	NS	NS	NS
Error	38						
Contrasts							
PPI vs Dec	1	NS	NS	*	**	NS	NS
PPI vs Jan	1	NS	NS	NS	NS	NS	NS
PPI vs Feb	1	NS	NS	NS	**	NS	NS
Mar vs others	1	NS	NS	**	**	NS	NS
N rate linear	1	**	**	**	**	**	**
N rate quadratic	1	**	NS	*	*	*	NS
CV, %		10	19	3	9	24	20

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS - Not significant.
CV - coefficient of variation.

Table 6. Rep-treatment and factorial arrangement of treatment analyses of variance on grain and forage yield, N concentration, and N uptake at Perkins, OK, 1992.

	df	Grain yield	Forage yield	Grain N conc.	Forage N conc.	GNUP	FNUP
Treatment	20	*	**	**	**	**	**
Error	40						
Contrast							
Check vs others	1	*	**	NS	**	*	**
Date	4	NS	**	**	**	NS	**
Rate	3	**	**	**	**	**	**
Date*Rate	12	NS	NS	**	**	NS	NS
Error	38						
Contrasts							
PPI vs Dec	1	NS	*	NS	**	NS	**
PPI vs Jan	1	NS	NS	NS	**	NS	†
PPI vs Feb	1	NS	*	NS	**	NS	**
Mar vs others	1	NS	**	**	**	NS	**
N rate linear	1	**	**	**	**	**	**
N rate quadratic	1	NS	NS	**	NS	†	NS
CV, %		31	20	4	7	30	23

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS - Not significant.
CV - coefficient of variation.

Table 7. Rep-treatment and factorial arrangement of treatment analyses of variance on grain and forage yield, N concentration, and N uptake at Perkins, OK, 1993.

	df	Grain yield	Forage yield	Grain N conc.	Forage N conc.	GNUP	FNUP
Treatment	20	*	**	**	**	**	**
Error	40						
Contrast							
Check vs others	1	**	**	**	**	**	**
Date	4	NS	**	**	**	NS	NS
Rate	3	**	**	**	**	**	**
Date*Rate	12	NS	NS	NS	†	NS	NS
Error	38						
Contrasts							
PPI vs Dec	1	NS	NS	NS	*	NS	NS
PPI vs Jan	1	NS	NS	†	†	NS	NS
PPI vs Feb	1	NS	†	NS	**	NS	NS
Mar vs others	1	NS	**	**	**	NS	NS
N rate linear	1	**	**	**	**	**	**
N rate quadratic	1	*	**	NS	NS	NS	NS
CV, %		13	13	7	9	12	16

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS - Not significant.
CV - coefficient of variation.

Table 8. Split-plot in-time analyses of variance on grain and forage yields at Perkins, OK.

Source	df	Grain yield	df	Forage yield
		Mean squares		Mean squares
All treatments				
Rep	2	73864.9	2	3992329.1**
Trt	20	399643.7**	20	4234459.6**
Rep*Trt (Error a)	40	89550.5	40	270957.1
Yr	2	1629167.5**	3	78708833.1**
Trt*Yr	40	47348.1	60	418993.4
Error b	84	41913.2	126	343416.6
Contrast				
Check vs others	1	2251363.5**	1	13095774.9**
Date x Rate Factorial				
Rep	2	108879.1	2	3753490.8**
Date	4	163055.9	4	6231256.0**
Rate	3	1369459.1**	3	13777560.9**
Date*Rate	12	81742.4	12	444642.5
Rep*Date*Rate (Error a)	38	89167.6	38	284315.9
Yr	2	1694712.2**	3	76176685.6**
Yr*Date	8	70710.7	12	569963.2†
Yr*Rate	6	26106.4	9	723472.1*
Yr*Date*Rate	24	37348.3	36	276150.4
Error b	80	43228.6	120	352803.1
Contrasts				
PPI vs Dec	1	356698.6	1	8680.5
PPI vs Jan	1	340238.5	1	6977.5
PPI vs Feb	1	490225.1	1	3891233.4**
Mar vs others	1	46421.1	1	19075917.0**
N rate linear	1	2356623.8**	1	37801106.1**
N rate quadratic	1	1732113.9**	1	3524962.2**

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively.

Table 9. Quadratic response surface regression models of relative maximum grain and forage yields at Perkins, OK.

Parameter	Model	Significance (Prob > F)	R^2	Critical values	Predicted yield at critical value (% relative maximum)	Data range DAP (MIN) (MAX)	Data range NRATE (MIN) (MAX)
Relative maximum grain yield combined over 3 years (179 total df in model)							
	$Y = 45.76^{**} + 0.177\ DAP^{**} - 0.000718\ DAP^{2**}$	0.0001	0.31	DAP=81	86.4	0	34
	$+ 0.653\ NRATE^{**} - 0.002949\ NRATE^{2**}$			NRATE=103		180	134
	$- 0.000595\ DAP{*}NRATE^{*}$						
Relative maximum forage yield combined over 4 years (239 total df in model)							
	$Y = 30.32^{**} + 0.271\ DAP^{**} - 0.001859\ DAP^{2**}$	0.0001	0.43	DAP=34	82.9	0	34
	$+ 0.645\ NRATE^{**} - 0.002056\ NRATE^{2**}$			NRATE=149†		180	134
	$- 0.000971\ DAP{*}NRATE^{*}$			DAP=38	82.5		
				NRATE=134			

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

† - N rate for predicted maximum forage yield is greater than rates used in experiment, so partial maximum solution for DAP at highest N rate utilized is reported.

Y - respective yield as a percent of relative maximum in dataset.

DAP - days after planting.

NRATE - N fertilizer rate, kg ha^{-1}.

Table 10. Regression equations, significance of model, and R^2 values for grain and forage yields at Perkins, OK.

Parameter	Model	Significance (Prob > F)	R^2
Grain yield, kg ha^{-1} combined over 3 years and dates of application (188 total df in model)			
	$Y = 1721.9 + 15.6\ NRATE - 0.083\ NRATE^2$	0.0001	0.30
Forage yield, kg ha^{-1} combined over 4 years for date of application (59 total df in model)			
PPI	$Y = 2262.6 + 17.0\ NRATE$	0.0001	0.28
Dec	$Y = 2132.2 + 31.0\ NRATE - 0.134\ NRATE^2$	0.0001	0.30
Jan	$Y = 2211.7 + 27.2\ NRATE - 0.100\ NRATE^2$	0.0002	0.25
Feb	$Y = 2250.6 + 11.8\ NRATE$	0.0004	0.19
Mar	$Y = 2267.0 + 6.2\ NRATE$	0.0993	0.05

Table 11. Treatment means for 134 kg N ha^{-1} rate for soil NO_3-N at Perkins, OK, 1990, 1992, and 1993.[†]

	Depth, cm					
	0-15	15-30	30-45	45-60	60-90	90-120
	mg NO_3-N kg^{-1} soil					
	1990					
Treatment means						
Check	0.9	0.8	0.9	0.8	0.9	0.9
PPI	1.0	0.9	0.8	1.0	1.1	1.0
Dec	1.1	1.0	1.0	0.9	1.0	1.0
Jan	1.1	0.9	0.8	0.8	0.9	0.9
Feb	1.2	1.0	1.0	1.0	1.0	1.0
Mar	1.2	1.4	1.6	1.2	1.0	0.9
	1992					
Treatment means						
Check	4.8	2.9	2.6	2.4	2.3	2.2
PPI	5.9	3.1	2.7	2.5	2.4	2.2
Dec	6.0	3.3	2.8	2.7	2.6	2.4
Jan	5.0	3.0	2.6	2.4	2.3	2.3
Feb	6.5	3.3	3.1	3.0	2.6	2.3
Mar	7.0	3.0	2.9	3.1	3.0	2.4
	1993					
Treatment means						
Check	2.4	1.8	1.6	1.6	1.6	1.6
PPI	2.6	1.8	1.7	1.7	2.0	1.9
Dec	2.7	1.9	1.7	1.7	1.7	1.7
Jan	2.5	1.7	1.6	1.6	1.7	1.9
Feb	2.4	1.6	1.5	1.6	1.8	1.9
Mar	2.6	2.0	2.0	1.6	1.7	1.7

[†] - No significant differences found among treatment means.

Table 12. Treatment means for 134 kg N ha^{-1} rate and analyses of variance on soil NO_3-N at Perkins, OK, 1991.

		Depth, cm					
		0-15	15-30	30-45	45-60	60-90	90-120
		mg NO_3-N kg^{-1} soil					
Treatment means							
Check		1.9	0.9	0.8	0.7	0.5	0.7
PPI		3.3	3.9	3.1	5.3	5.3	2.9
Dec		2.8	3.7	5.3	5.6	4.2	2.3
Jan		3.2	3.6	4.1	4.5	2.6	2.4
Feb		3.3	2.7	2.9	3.2	2.6	2.5
Mar		3.1	3.4	5.7	8.6	6.4	3.8
SED		0.5	0.7	1.1	2.4	1.1	1.3
CV, %		22	31	38	63	40	66
Analysis of variance							
	df	Mean squares					
Rep	2	0.14	0.87	3.13	13.96	5.25	0.72
Trt	5	0.84	3.66*	9.72*	20.90†	13.56**	3.08
Error	10	0.42	0.90	2.02	8.88	2.10	2.65
Contrast							
Check vs others	1	3.68	15.70**	29.24**	57.12*	34.22**	11.09
PPI vs Dec	1	0.37	0.04	7.26†	0.20	1.81	0.54
PPI vs Jan	1	0.01	0.10	1.30	0.88	10.66	0.32
PPI vs Feb	1	0.00	2.16	0.10	6.20	10.93	0.28
Mar vs other dates	1	0.00	0.20	8.21†	37.28†	18.15*	3.70

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

†, *, ** - Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

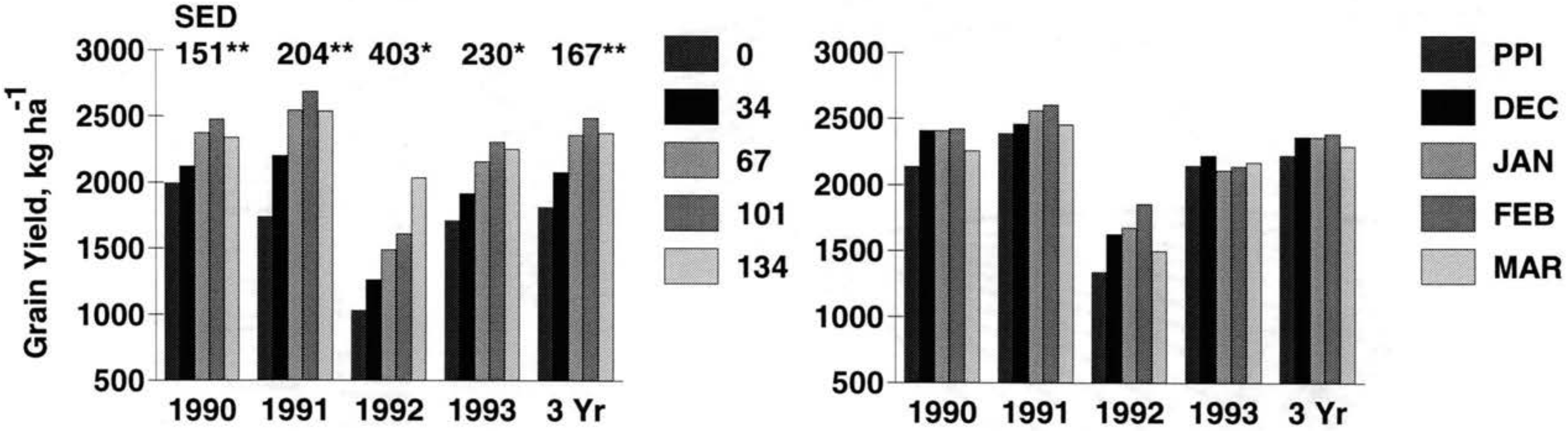

Figure 1. Wheat grain yield as affected by N fertilizer rates and dates of application, Perkins, OK , 1990-1993.

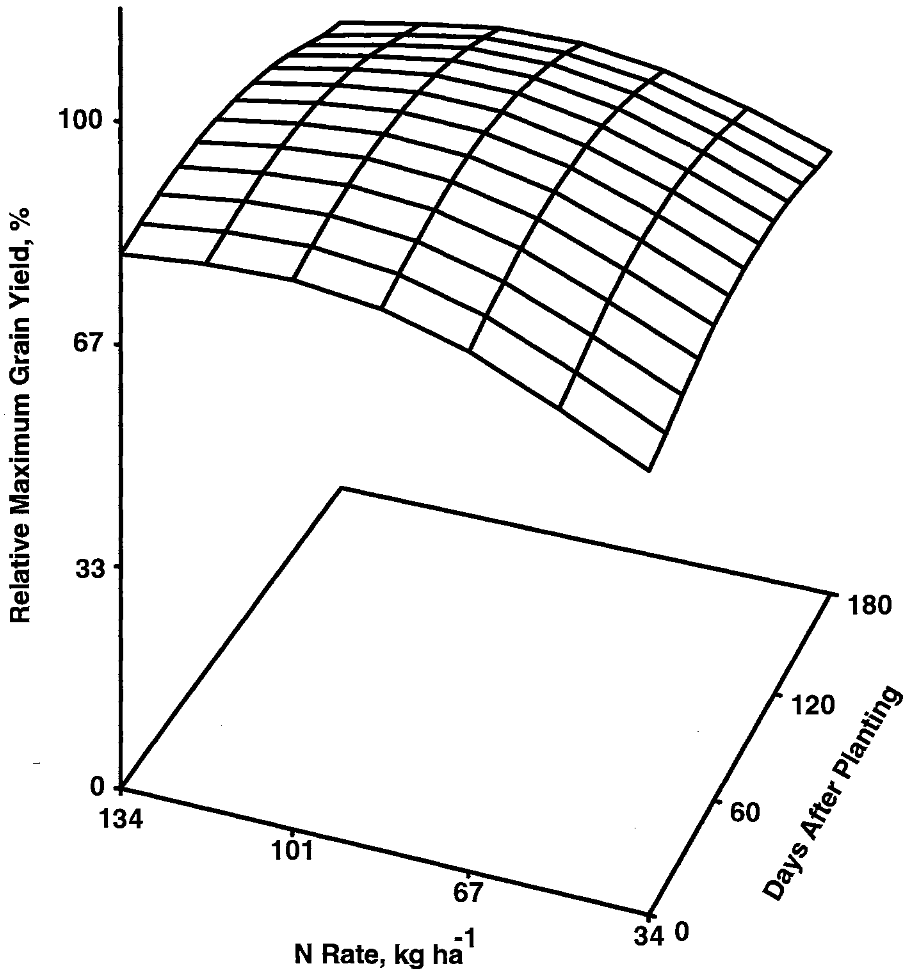

Figure 2. Quadratic response surface model of relative maximum wheat grain yield versus N fertilizer rates and dates of application (expressed as days after planting), Perkins, OK.

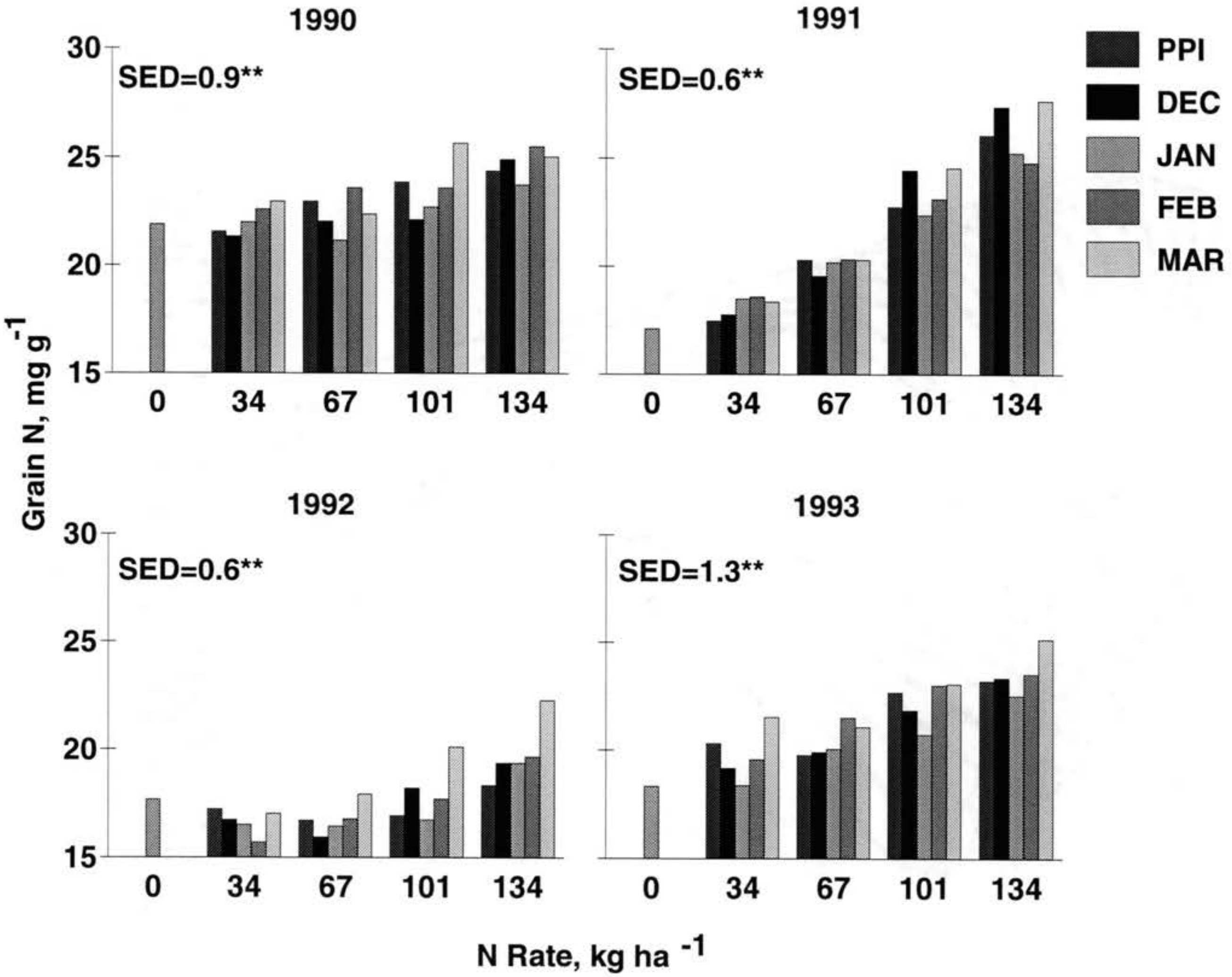

Figure 3. Wheat grain N concentration as affected by N fertilizer rates and dates of application, Perkins, OK, 1990-1993.

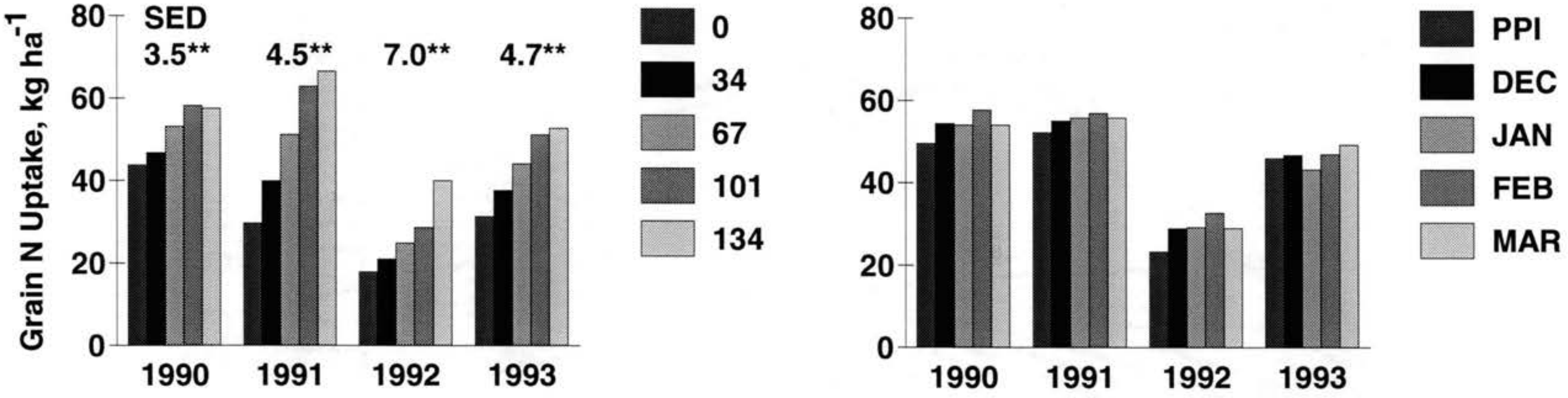

Figure 4. Wheat grain N uptake as affected by N fertilizer rates and dates of application, Perkins, OK, 1990-1993.

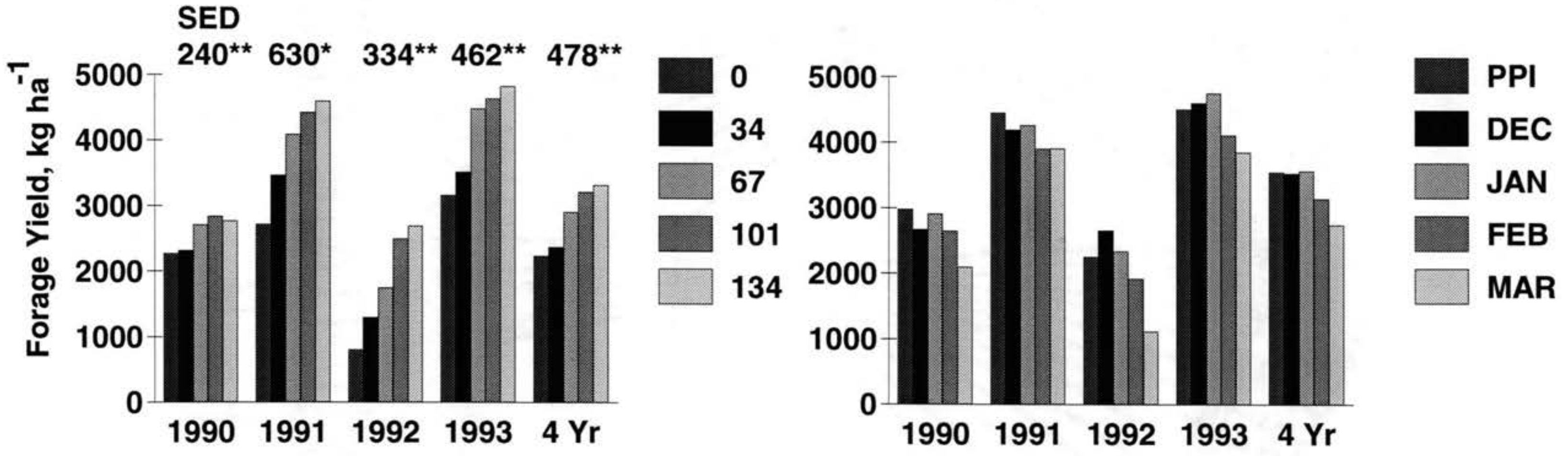

Figure 5. Wheat forage yield as affected by N fertilizer rates and dates of application, Perkins, OK, 1990-1993.

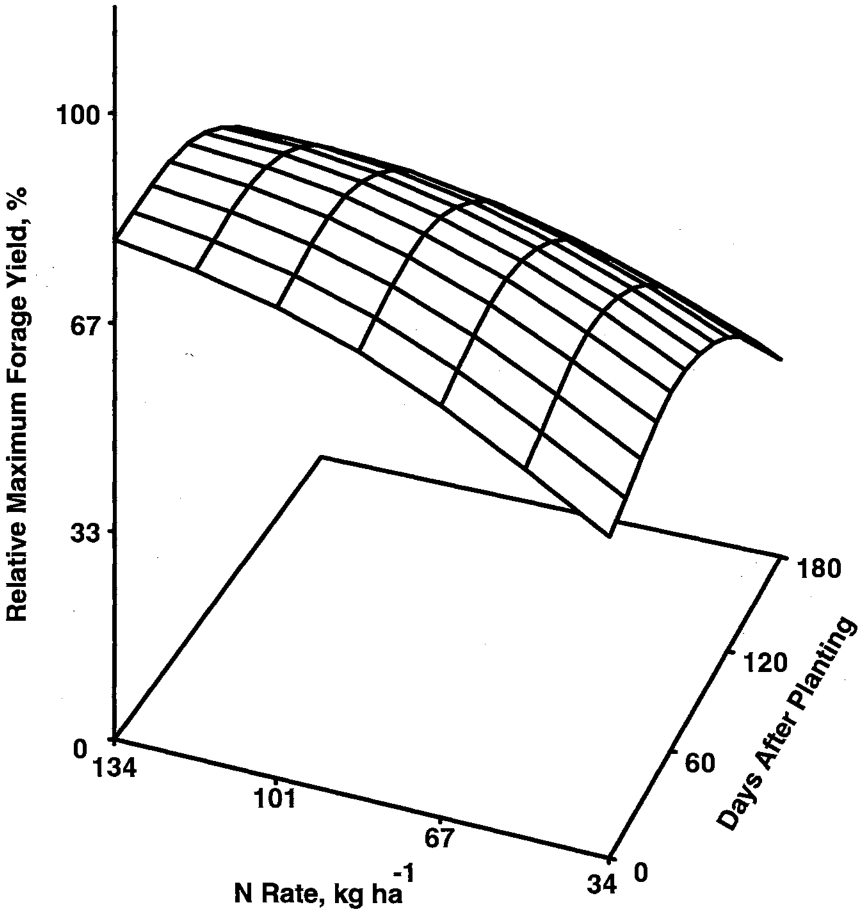

Figure 6. Quadratic response surface model of relative maximum wheat forage yield versus N fertilizer rates and dates of application (expressed as days after planting), Perkins, OK.

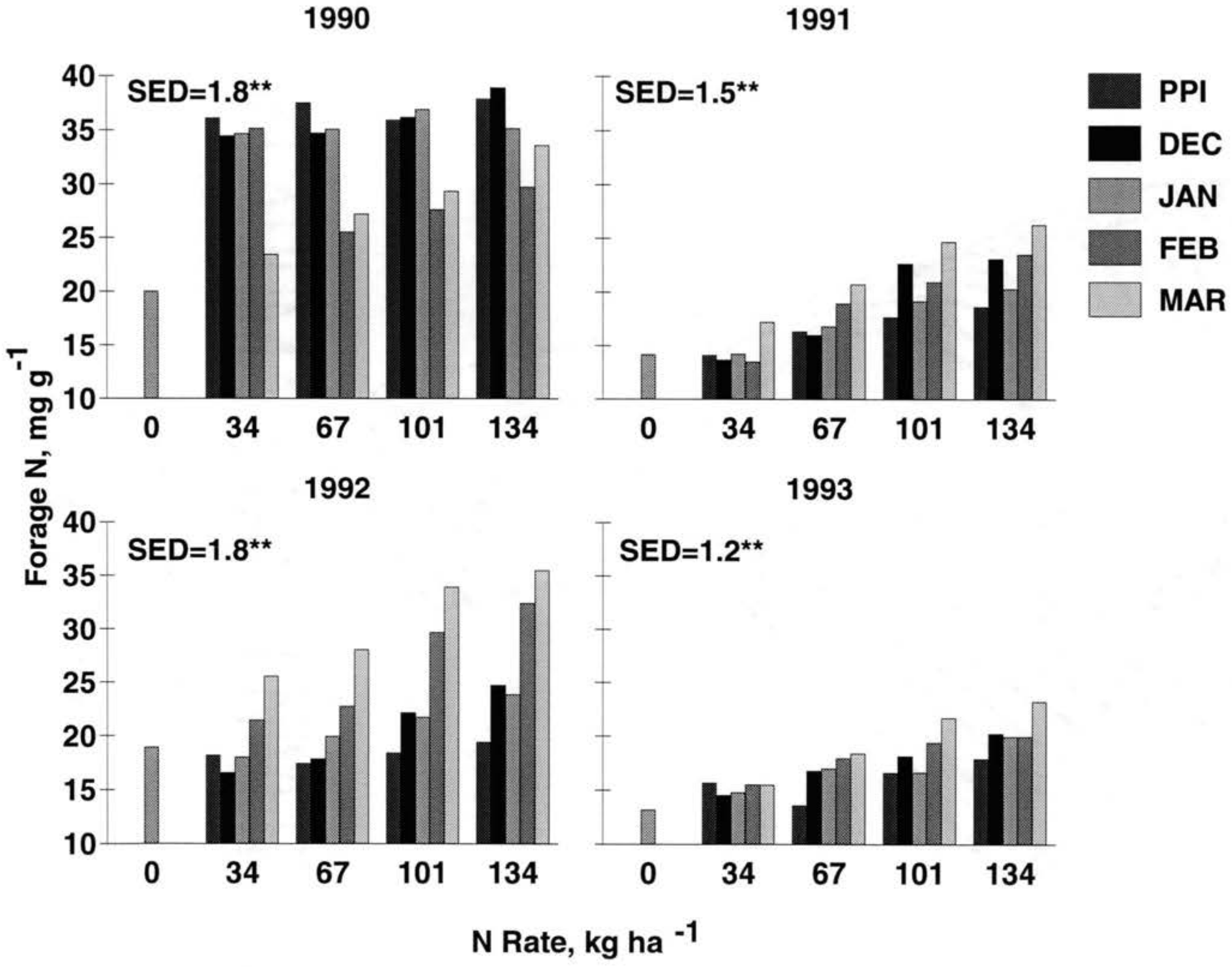

Figure 7. Wheat forage N concentration as affected by N fertilizer rates and dates of application, Perkins, OK, 1990-1993.

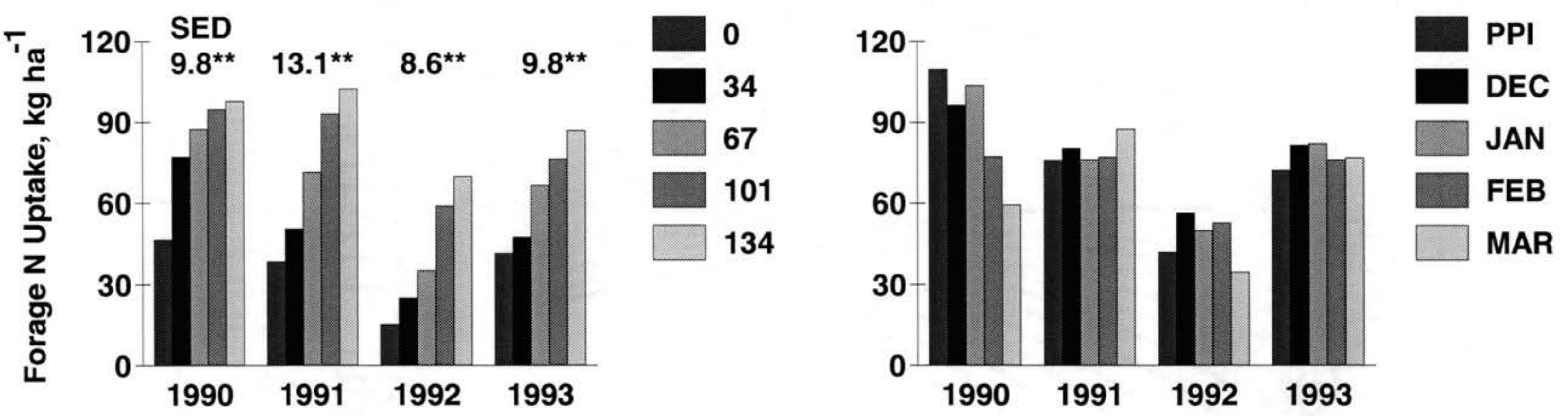

Figure 8. Wheat forage N uptake as affected by N fertilizer rates and dates of application, Perkins, OK, 1990-1993.

CHAPTER II

SPRING-APPLIED NITROGEN SOURCE AND RATE INFLUENCES ON WINTER WHEAT AND RESIDUAL SOIL NITRATE

ABSTRACT

Spring fertilization in winter wheat (Triticum aestivum L.) grain production systems can be a strategy to reduce NO_3-N leaching potential on soils that are susceptible to that N loss mechanism. The objectives of this experiment were to determine the effects of spring applications of three N fertilizer sources and rates on grain yield and N concentration, and residual soil profile NH_4-N and NO_3-N. Anhydrous ammonia (AA), urea ammonium nitrate (UAN), and UAN + dicyandiamide (1 kg DCD 100 kg^{-1} total N) were applied for three consecutive years on a Teller sandy loam soil (Udic Argiustoll) near Perkins, OK, and a Pond Creek silt loam soil (Pachic Argiustoll) near Carrier, OK, with low and high residual soil N, respectively. Nitrogen was applied at 34, 67, and 101 kg N ha^{-1}, and an unfertilized check was included. Anhydrous ammonia was applied using a colter applicator and knifed in 45 cm bands. The UAN and UAN+DCD mixture were broadcast applied. Soil cores were taken to 1.2 m from each plot after

harvest. Core samples were partitioned by depth and analyzed to determine NH_4-N and NO_3-N. Grain yield responses to applied N were observed at Perkins in all 3 years. No grain yield reduction was measured due to stand disturbance by the AA applicator, except in 1993 at Perkins. Grain N uptake and fertilizer N recovery were superior for knifed AA as compared to UAN at the Perkins site. It is unclear whether this was due to method of placement or enhanced ammonium nutrition. No differences in soil NH_4-N were detected at either site or in soil NO_3-N at Carrier. Anhydrous ammonia use resulted in slightly higher soil NO_3-N than either UAN or UAN+DCD in 2 of 3 years at Perkins. Knifing AA was an effective method for applying N when compared to broadcast UAN. Addition of DCD to UAN did not alter measured plant or soil parameters, however, low concentration of DCD in the mixture may have contributed to lack of response.

INTRODUCTION

Nitrogen fertilizer management is important to winter wheat production. Excess fertilization can result in accumulation of residual NO_3-N in the profile and contribute to possible environmental degradation. On sandy soils, if N fertilizer is applied preplant and subsequent high rainfall occurs prior to plant uptake, N loss due to leaching is possible. A management strategy to prevent leaching loss would be to apply enough fertilizer N in the fall to establish the crop and topdress the remaining N requirement in the late winter or early spring before rapid growth occurs. Warm soil temperatures subsequent to this time would coincide with rapid wheat growth and thus increased nutrient demand. For Oklahoma wheat producers to maintain or increase current levels of production on sandy soils, the fate of fertilizer N must be determined. The greatest portion of the total wheat production within Oklahoma is from an area where annual rainfall ranges from 250 to 1000 mm year^{-1}, and as a result little NO_3-N leaching is anticipated. Occasionally, however, major rainfall events may result in movement of NO_3-N through profiles of environmentally at-risk soils (Nofziger and Hornsby, 1989).

Use of UAN (28-0-0) as a spring topdress material is common. Nitrification inhibitors have been used to enhance yield and prevent N losses by leaching. Dicyandiamide (DCD) is a nitrogen source (65% N) with nitrification inhibitor properties and can be mixed with fluid UAN to reduce N mobility. Numerous experiments have been performed with DCD concerning its effectiveness as a nitrification inhibitor (Vilsmeier, 1981; Touchton, 1981; Amberger, 1989; Frye et al., 1989; Malzer et al., 1989; Bronson et al., 1991; Sawyer and Carter, 1993). It is relatively nontoxic to mammals, (LD_{50} of 10,000 mg kg^{-1}) and, in contrast to nitrapyrin (also a nitrification inhibitor), is classified as bacteriostatic rather than bacteriocidal. The ultimate products of DCD degradation in soil are CO_2, NH_4^+, and H_2O (Amberger, 1989). He states that in an incubation trial using ^{15}N labeled ammonium fertilizer at 14° C, DCD inhibited nitrification for 63 days. Vilsmeier (1981) reported that soil temperature, rather than soil moisture, is primarily responsible for DCD degradation; at lower temperatures, the degradation rate of DCD is considerably reduced. In a soft red winter wheat field experiment where DCD treated urea was used as a broadcast surface topdress application on the Coastal Plains of Alabama, Touchton (1981) found that DCD treatment resulted in significantly higher NH_4-N content in the surface soil 33 and 47 days after treatment. The DCD-treated fertilizers resulted in 39 and 26% more NH_4-N on days 33 and 47, respectively, compared to the normal urea. The DCD treatment did not result in increased grain yield. Touchton (1981) concluded that DCD-treated urea was not likely to be used as an N source in wheat production, although the data were collected in a somewhat dry production year. Bronson et al. (1991) concluded that the use of DCD in an ^{15}N experiment (10 kg N as DCD 100 kg^{-1} total N applied as fall broadcast and incorporated) on winter wheat in Alabama apparently conserved fertilizer N. The addition of DCD to N fertilizer did not result in significant increases in grain yields. Frye et al. (1989) summarized several location-years of experimental data collected on various crops produced in the southeastern United States and concluded that DCD did inhibit nitrification, but results generally were not manifested in increased crop yields. They found that corn yields were not significantly increased, but trends toward increased yields were observed. Malzer et al. (1989) concluded that in the North Central states response to DCD was best when applied on coarse textured soils in the early spring, prior to rainfall events. More recently, Sawyer and Carter (1993) reported winter wheat data from Illinois collected during 2 years with low leaching potential indicated that UAN broadcast applied at 101 kg total N ha^{-1} in the spring with DCD added at various rates resulted in decreased grain yields compared to fall treatments. Fall application with DCD addition did not result in large increases in grain yields, but the authors recommended nitrification inhibitor use as a precaution against N loss if all N was fall applied.

Primarily due to fertilizer economics, a practice gaining in popularity with producers in north central Oklahoma is knifing of AA into existing wheat stands in February and March. Equipment consisting of a smooth, rolling colter with a thin (1 cm) applicator knife following directly behind it has been successfully used to apply AA without significant damage to wheat stands. This strategy has potential due to reduced expense of AA fertilizer when compared to other N sources. In combination with the application of ammoniacal forms of N, cooler soil temperatures in the spring could result in reduced nitrification rates allowing the N fertilizer to remain as NH_4^+ for longer periods of time. This would theoretically enable N to be held on the soil exchange complex, resulting in reduced N mobility. Little information concerning the feasibility of AA as a spring-applied N source in winter wheat is available, particularly concerning the environmental aspects of residual soil NO_3-N compared to currently used sources.

The objectives of this experiment were to determine the effects of spring applications of three N sources on grain yield, grain N concentration, subsequent N fertilizer recovery based on the difference method, and residual NH_4-N and NO_3-N distribution in the soil profile in winter wheat production systems.

MATERIALS AND METHODS

Experiments were conducted under conventional tillage conditions at two locations 1) Teller sandy loam (Udic Argiustoll) on the Perkins Research Station and 2) Pond Creek silt loam (Pachic Argiustoll) near Carrier. The Perkins site had been in continuous wheat without fertilization for several years, and its soil profile (0-1.2 m) NO_3-N was very low (Table 1). The Carrier site contained more residual profile N. Although in continuous wheat for many years, this location has a history of high N fertilization. Soil profile total N and organic C indicated the N pool at Carrier was much greater than at Perkins. These properties ultimately reduced the ability to obtain grain yield response to spring-applied N fertilizer and to accurately determine residual mineral N at the Carrier site. No preplant N fertilizer was applied in any year at Perkins. The Carrier experiment received 90 kg ha^{-1} as anhydrous ammonia applied in September of each year. The Perkins experimental area was drilled in 25-cm rows on Oct. 13, Sept. 27, and Oct. 9 of 1990, 1991, and 1992, respectively. Winter wheat cultivars at Perkins were seeded at a 67 kg ha^{-1} seeding rate and included 'Chisholm' in crop years 1991 and 1992, and 'Karl' in 1993. The Carrier experiment was planted to the '2163' cultivar in 18-cm rows at 67, 84, and 84 kg ha^{-1} seeding rates on Oct. 5, Nov. 13, and Oct. 12 of 1990, 1991, and 1992, respectively. Each year, diammonium phosphate, (DAP, 18-20-0) was band applied with the seed at planting at a rate of 15 kg P ha^{-1}. Plots were 5 m by 12 m and by 15 m at Perkins and Carrier, respectively. Sources of N fertilizer included AA, UAN, and UAN + Dicyandiamide (1 kg DCD 100 kg^{-1} total mixture, 28-0-0). Nitrogen rates were 34, 67, and 101 kg N ha^{-1}. An unfertilized check and an unfertilized AA applicator check were included to help assess potential stand damage and associated yield reduction due to the AA knifing operation. Anhydrous ammonia was applied using a rolling colter applicator and knifed approximately 15 cm deep in 45 cm bands perpendicular to the drill rows. A Continental B6000 series Metermatic flow regulator was used to meter the AA. The UAN and UAN+DCD mixture were broadcast applied using a power take-off pump and spray boom calibrated to deliver the chosen rates. Treatments were applied at both locations on Feb. 20 and 18, in 1991 and 1992, respectively. Wheat was in the Feekes physiological growth stage 3 (Large, 1954) in those years. In 1993, N fertilizer application was intentionally delayed to Feekes growth stage 5 in order to assess wheat stand damage from the AA applicator and possible grain yield reduction from late application. Treatments were applied on Mar. 16 and 17, 1993, at Perkins and Carrier, respectively. Treatments were replicated four times in a randomized complete block design and were applied on the same experimental units each year. Harvest areas were 3 m by 12 m and by 15 m at Perkins and Carrier, respectively. Plots were harvested using a small conventional combine. Harvest dates at Perkins were June 14, June 13, and June 21 in 1991, 1992, and 1993, respectively. The Carrier site harvest dates were June 13, June 24, and June 24 in 1991, 1992, and 1993, respectively. Late freezes occurred in March and April of 1992 which reduced grain yields at Carrier. A hail storm slightly damaged the Carrier experiment on June 18, 1993.

Wheat was at physiological maturity, and some grain was lost due to shattering. Grain samples were analyzed for total N using a Carlo Erba CNS 1500 dry combustion analyzer. Apparent nitrogen fertilizer recovery in grain has been estimated using the difference method (Jansson and Persson, 1982; Bock, 1984; Olson and Swallow, 1984). When using this technique, overestimating N fertilizer recovery can occur (Hauck and Bremner, 1976; Westerman and Kurtz, 1974). Errors can be somewhat large, and a priming effect of N fertilizer application on indigenous soil N has been observed (Westerman and Kurtz, 1973; Hauck and Bremner, 1976; Riga et al., 1980; Jansson and Persson, 1982). However, Westerman and Kurtz (1974) state that the difference and isotopic methods are more likely to agree when only one crop harvest is obtained and when soil mineralizable N is low. Grain N uptake in the unfertilized check was subtracted from grain N uptake by N treatments and estimated the amount of N fertilizer taken up by the grain. The difference was then divided by the N application rate to obtain an estimate of percent fertilizer N recovery. Each plot was sampled using a hydraulic soil probe to a depth of 1.2 m immediately following grain harvest. An attempt was made to conduct deep soil sampling between AA injection zones, recognizing that fertilizer N distribution in the soil can be affected by injection location (Jacobson et al., 1986; Bezdicek et al., 1971). Cores were partitioned into six increments representing the 0-15, 15-30, 30-45, 45-60, 60-90, and 90-120 cm depths. Soil samples were air dried at ambient temperature and processed to pass a 2 mm sieve. Soil samples were extracted using 2M KCl (Bremner, 1965) and analyzed for NO_3-N and NH_4-N using the Lachat-Quikchem automated flow injection analysis system. Nitrite plus nitrate-N was determined using a cadmium reduction procedure. Ammonium-N was determined from the same extract, using the phenolate method.

Statistical analysis of data was performed by year using appropriate GLM procedures outlined by the SAS Institute (SAS, 1988). Statistical differences between treatments were determined using non-orthogonal single degree of freedom contrasts.

RESULTS AND DISCUSSION

Perkins Experiments

Grain Yield. Significant seasonal differences were encountered over the 3 year duration of the experiment, with rainfall amount and distribution varying considerably at this site (Table 2 and Appendix A). In all years, moderate grain yields were obtained and highly significant grain yield responses to N fertilizer were observed (Tables 3-8). No significant differences among fertilizer sources were found. Grain yield responses were quadratic for anhydrous ammonia and linear for UAN and UAN+DCD in all years. A significant source by rate interaction was observed in 1992 for grain yield where the highest rate of AA decreased grain yield compared to the other N sources (Table 5). Grain yields did not increase when N was applied at the 101 kg N ha^{-1} rate (compared to 67 kg N ha^{-1}). It was interesting to note a trend for yields to decrease at the high AA N rate in all 3 years. This yield reduction could have been due to root phytotoxicity from excessive NH_4^+ in the rhizosphere during rapid vegetative and reproductive growth phases. No significant reduction in grain yield was observed as a result of AA knifing operations (0 N applied), except when performed at the later Feekes growth stage 5 in 1993. In the first two years soil moisture conditions were considered ideal for AA application (i.e. moist soil, low compaction which facilitated applicator shank penetration, allowing for adequate seal). In 1993 soil conditions were wet, but still facilitated good AA application.

<u>Grain N Uptake and Fertilizer N Recovery.</u> Grain N concentration was increased by N fertilization in all years (see appendix). Grain N uptake (GNUP) values were calculated by multiplying grain yield by grain N concentration. This results in an estimate of total N removal. Source and rate of N were both highly significant for GNUP in all years (Tables 3-8). Grain N uptake was significantly higher for AA when compared to other sources. The GNUP response to N rates was linear in all years. Fertilizer N recovery (kg of estimated fertilizer in the grain per kg fertilizer applied) was significantly higher for AA than the other two sources. A significant source by rate interaction was detected in all years. Response to UAN and UAN+DCD across N rates was fairly constant. The AA source at the 34 kg N ha^{-1} rate resulted in up to two-fold increases in percent fertilizer N recovery when compared to other N sources in all years. At the 67

kg N ha^{-1} rate, fertilizer N recovery for AA was generally superior to other sources. The effect was diminished at the 101 kg N rate partially due to the quadratic nature of the AA grain yield response. It is unclear whether this difference is attributable to N source, or method of fertilizer placement (AA - knifed, UAN - broadcast). Because AA was knifed 15 cm deep and was positionally available to rapidly growing roots, initial availability may have been improved compared to other N sources. Lower availability of surface applied UAN may have been due to immobilization (Jansson and Persson, 1982; Olson and Swallow, 1984). Bypassing the surface portion of the microbial and organic pool by deep knifing of AA may also have had an effect by reducing N immobilization. Sharpe et al. (1988) reported that for wheat produced under conservation tillage conditions, placement of N below the surface layer may improve availability by decreasing immobilization. Varvel et al. (1989), reported that results from ^{15}N labeled fertilizer applied in April to wheat in Nebraska indicated no differences in uptake of labeled fertilizer N for method of placement (broadcast vs. injected). However, differences were found when comparing no-till, stubble mulch, and plow fallow tillage methods. They also stated that cool soil temperatures in that region may not be conducive to N immobilization until late spring.

<u>Split-Plot in-Time and Regression Analyses for Grain Yield.</u> Split-plot in-time analysis of variance indicated significant year by treatment interaction for grain yield, therefore, yield data were not combined over years (Table 9). The factorial

model demonstrated significant year by N rate interaction was encountered, which was probably due to variability in precipitation in the three environments encountered at this site. The resultant model significance and regression equations for grain yield prediction are provided in Table 10.

Soil Analyses. No significant differences in soil NH_4-N were observed in any year (data not shown). No significant differences in soil NO_3-N were observed in any year when comparing the check to the AA applicator check (Tables 11-16). Increasing N rates generally resulted in small increases in residual NO_3-N concentrations in most profile increments in 1991 (Table 11). When averaged over sources, the 1991 data show the 67 and 101 kg N ha^{-1} rates resulted in significantly higher NO_3-N concentrations than the unfertilized check in the mid to lower portions of the soil profile, while the 90 to 120 cm depth was unaffected. Application of AA resulted in higher residual NO_3-N than either UAN or UAN+DCD. When averaged over rates, no differences in residual NO_3-N concentrations were found between UAN and the UAN+DCD. Residual soil NO_3-N in 1992 was generally higher than 1991 in all increments of the soil profile (Table 13). No significant source differences were found for soil NO_3-N. When averaged over sources, the 101 kg N ha^{-1} rate resulted in significantly higher soil NO_3-N compared to the unfertilized check (0-15 cm). When compared to other years, rainfall in 1993 (after fertilizer N was applied) was excessive at this site (Table 2), however, grain N uptake was also the highest during the 3 year period. When averaged over rates, significant differences in soil NO_3-N were noted in 1993 in upper to mid-profile soil increments. The AA source resulted in slight, but significantly higher residual NO_3-N than other sources. It is unclear why AA use would result in higher residual soil NO_3-N in two of three years of this experiment. It is possible that N volatilization losses from surface applied UAN and UAN+DCD could have been encountered. Microbial immobilization of fertilizer N prior to plant uptake (after incorporation by rainfall into the soil), or loss through surface runoff and leaching may also have occurred.

Carrier Experiments

No significant differences in grain yields or N uptake were observed in any year at the Carrier site (Table 17), however, grain N concentration was slightly increased by N fertilization in all years (see appendix). This was a result of the high soil residual N and indicated that spring application of N fertilizer was not necessary to achieve optimum grain yields when 90 kg N ha^{-1} was fall applied and the wheat forage was not grazed by cattle. It is common for producers in this area to topdress both grazed and ungrazed wheat fields with N in the spring, and according to these data, no significant grain yield increases should be expected on this soil when adequate fall N fertilization is practiced. No significant reductions in grain yield could be attributed to knifing operations as a result of wheat stand disturbance in any year, including the delayed application in 1993. A hail storm damaged the experiment just prior to harvest in 1993, therefore, grain yield and N uptake values were not reliable for that year. No significant differences were measured for soil NH_4-N or NO_3-N in any year (see appendix), due to the low fertilizer rates used relative to the high inorganic N status and considerable variability in concentrations of those N forms in the soil at this site.

CONCLUSIONS

Spring fertilization with N rates up to 101 kg N ha^{-1} resulted in substantial grain yield increases at Perkins over a 3 year period. Knifing of AA using a rolling colter applicator with a 45 cm shank spacing was as effective as broadcast UAN for spring applied N. No significant yield reduction was observed from disturbance by AA application except for the Feekes 5 growth stage application at Perkins in 1993. Grain N concentration was increased by N fertilization in all years at both sites. At Perkins, grain N uptake and fertilizer N recovery were superior for knifed AA as compared to broadcast UAN. It is unclear whether this was due to method of placement, or enhanced ammonium nutrition. No significant differences were detected in soil NH_4-N at either site in any year. At Perkins, AA resulted in significantly higher soil residual NO_3-N concentrations than either UAN or UAN+DCD in 1991 and 1993. Residual soil NO_3-N was small from all treatments (< 5 mg N kg^{-1} soil) but significantly higher in the subsoil for AA than UAN. No differences in residual soil NO_3-N concentrations were found between UAN and UAN+DCD. Soil data from 1992 indicated slightly higher residual NO_3-N than in 1991 and 1993, with minimal treatment effect observed. These data indicate that spring application of N fertilizers can be an effective strategy for increasing grain yields and minimizing potential for N loss. Knifing of AA into winter wheat stands in the spring can be an effective method of applying N. Residual soil NO_3-N and fertilizer N recovery were higher for AA than UAN. Addition of DCD (1 kg DCD 100 kg^{-1} total mixture, as presently marketed in Oklahoma) to UAN did not significantly alter soil N or plant responses. The low concentration of DCD in the mixture may have contributed to lack of response.

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Table 1. Soil physical and chemical characteristics and classification for N experiments.

Soil depth	pH	NH_4-N	NO_3-N	Mehlich III P	Mehlich III K	Total N	Organic C	Sand	Silt	Clay	Bulk density
— cm —		——— mg kg^{-1} ———				—— g kg^{-1} ——		——— % ———			Mg m^{-3}
Perkins											
0-15	6.1	8.0	0.4	11	148	0.52	6.8	65	18	17	1.79
15-30		6.9	0.4			0.46	5.8	71	14	15	1.75
30-45		7.7	0.4			0.52	6.5	60	20	20	1.63
45-60		7.3	0.5			0.48	5.8	54	20	26	1.77
60-90		6.8	0.6			0.34	4.1	62	15	23	1.67
90-120		6.5	0.6			0.21	2.2	68	16	16	1.74
Carrier											
0-15	4.8	13.6	6.8	50	308	0.73	9.1	33	46	21	1.53
15-30		8.0	12.4			0.65	7.8	15	54	31	1.44
30-45		8.4	11.2			0.62	7.2	15	54	31	1.45
45-60		10.3	7.4			0.54	6.3	13	50	37	1.51
60-90		9.6	8.3			0.57	6.1	11	44	45	1.61
90-120		9.4	6.0			0.55	5.4	15	38	47	1.65

Classification:

Perkins - Teller sandy loam (fine-loamy, mixed, thermic Udic Argiustoll)
Carrier - Pond Creek silt loam (fine-silty, mixed, thermic Pachic Argiustoll)

Table 2. Total and monthly precipitation following fertilizer application at Perkins, OK, 1991-1993.

	Year		
Month	1991	1992	1993
	mm		
Feb	0	10	--
Mar	28	37	43
Apr	6	130	178
May	166	127	272
June	81	77	69
Total	281	381	562

Table 3. Treatment and main effect means for grain yield, N uptake (GNUP), and fertilizer N recovery at Perkins, OK, 1991.

	Grain yield	GNUP	Fertilizer N recovery
	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}
Treatment means			
Check	1794	26.7	--
AA Check	1913	29.9	--
AA 34	2501	47.3	0.675
AA 67	2716	56.5	0.474
AA 101	2714	57.5	0.326
UAN 34	2220	36.0	0.339
UAN 67	2605	44.2	0.290
UAN 101	2753	53.2	0.283
UAN+DCD 34	2180	33.5	0.263
UAN+DCD 67	2718	46.1	0.320
UAN+DCD 101	3067	56.3	0.314
SED	183	3.6	0.063
CV, %	10	11	23
Source means			
AA	2644	53.7	0.492
UAN	2526	44.4	0.304
UAN+DCD	2655	45.3	0.299
N Rate means			
34	2301	38.9	0.426
67	2680	48.9	0.361
101	2845	55.6	0.307
SED	174	3.5	0.063
CV, %	9	10	23

GNUP - grain nitrogen uptake.
SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 4. Analyses of variance for grain yield, N uptake (GNUP), and fertilizer N recovery at Perkins, OK, 1991.

Source	df	Grain yield	GNUP	Fertilizer N recovery
		Mean squares		
All treatments				
Rep	3	193837.3*	99.365*	0.035
Trt	10	620573.0***	504.629***	0.068
Error	30	67232.7	25.593	0.007
Contrast				
AA Linear	1	1371957.9***	1696.187***	0.244***
AA Quadratic	1	347722.5*	271.986**	0.001
UAN Linear	1	2128859.5***	1529.290***	0.006
UAN Quadratic	1	77774.0	0.063	0.001
UAN+DCD Linear	1	3798293.3***	2054.769***	0.005
UAN+DCD Quadratic	1	1366.0	12.054	0.002
Check vs AA check	1	28455.4	19.319	--
Source x N Rate				
Rep	3	203406.8*	105.181*	0.035**
Source	2	61089.2	318.956***	0.144***
N Rate	2	934614.5***	849.881***	0.041**
Source*N Rate	4	113764.6	47.384	0.044**
Error	24	60538.8	25.874	0.007
Contrast				
AA vs UAN	1	82978.5	521.621***	0.211***
UAN vs UAN+DCD	1	99536.6	4.328	0.000
N Rate Linear	1	1777705.5***	1678.420***	0.083**
N Rate Quadratic	1	91523.5	21.342	0.000
AA vs UAN*N Linear	1	101888.6	49.000	0.086**
AA vs UAN+DCD*N Linear	1	453844.7*	160.883*	0.160***
UAN vs UAN+DCD*N Linear	1	125656.0	32.307	0.011

GNUP - grain nitrogen uptake.

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 5. Treatment and main effect means for grain yield, N uptake (GNUP), and fertilizer N recovery at Perkins, OK, 1992.

	Grain yield	GNUP	Fertilizer N recovery
	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}
Treatment means			
Check	932	14.9	--
AA Check	848	14.2	--
AA 34	1816	30.1	0.521
AA 67	2071	35.1	0.336
AA 101	2153	37.2	0.244
UAN 34	1332	20.3	0.232
UAN 67	1982	29.0	0.244
UAN 101	2489	38.3	0.255
UAN+DCD 34	1485	21.8	0.277
UAN+DCD 67	2086	33.6	0.313
UAN+DCD 101	2570	40.6	0.278
SED	151	2.8	0.049
CV, %	11	14	23
Source means			
AA	2013	34.1	0.367
UAN	1934	29.2	0.244
UAN+DCD	2047	32.0	0.289
N Rate means			
34	1544	24.1	0.343
67	2046	32.6	0.298
101	2404	38.7	0.259
SED	154	2.9	0.049
CV, %	10	13	23

GNUP - grain nitrogen uptake.
SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 6. Analyses of variance for grain yield, grain N uptake (GNUP), and fertilizer N recovery at Perkins, OK, 1992.

Source	df	Grain yield	GNUP	Fertilizer N recovery
		Mean Squares		
All treatments				
Rep	3	152737.6*	48.091*	0.003
Trt	10	1343954.8***	356.000***	0.032
Error	30	45755.9	16.754	0.004
Contrast				
AA Linear	1	3480182.3***	1096.976***	0.153***
AA Quadratic	1	783862.3***	190.550**	0.005
UAN Linear	1	5665247.7***	1240.753***	0.001
UAN Quadratic	1	11560.5	15.147	0.000
UAN+DCD Linear	1	6084015.6***	1576.661***	0.000
UAN+DCD Quadratic	1	4744.4	0.000	0.003
Check vs AA check	1	14112.0	0.980	--
Source x N Rate				
Rep	3	135737.3	37.913	0.003
Source	2	40066.7	73.621*	0.046***
N Rate	2	2240500.1***	645.728***	0.021*
Source*N Rate	4	206300.5**	44.589	0.030***
Error	24	47335.0	17.714	0.004
Contrast				
AA vs UAN	1	37408.0	146.263**	0.091***
UAN vs UAN+DCD	1	76018.5	47.669	0.012
N Rate Linear	1	4439251.3***	1280.128***	0.042**
N Rate Quadratic	1	41748.9	11.328	0.000
AA vs UAN*N Linear	1	672137.6***	116.812*	0.090***
AA vs UAN+DCD*N Linear	1	558905.7**	134.374*	0.077***
UAN vs UAN+DCD*N Linear	1	5218.6	0.614	0.000

GNUP - grain nitrogen uptake.

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 7. Treatment and main effect means for grain yield, grain N uptake (GNUP), and fertilizer N recovery, at Perkins, OK, 1993.

	Grain yield	GNUP	Fertilizer N recovery
	kg ha^{-1}	kg ha^{-1}	kg kg^{-1}
Treatment means			
Check	1937	36.1	--
AA Check	1676	31.2	--
AA 34	2326	52.3	0.483
AA 67	2538	62.6	0.394
AA 101	2503	63.0	0.266
UAN 34	2242	40.9	0.145
UAN 67	2444	46.9	0.160
UAN 101	2501	53.1	0.169
UAN+DCD 34	2167	39.8	0.111
UAN+DCD 67	2404	48.5	0.185
UAN+DCD 101	2442	57.6	0.213
SED	105	2.2	0.041
CV, %	6	7	24
Source means			
AA	2456	59.3	0.381
UAN	2396	47.0	0.158
UAN+DCD	2338	48.7	0.170
N Rate means			
34	2245	44.4	0.246
67	2462	52.7	0.246
101	2482	57.9	0.216
SED	105	2.5	0.041
CV, %	6	6	24

GNUP - grain nitrogen uptake.

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

Table 8. Analyses of variance for grain yield, grain N uptake (GNUP), and fertilizer N recovery at Perkins, OK, 1993.

Source	df	Grain yield	GNUP	Fertilizer N recovery
		Mean Squares		
All treatments				
Rep	3	118305.0**	233.513***	0.025
Trt	10	292626.0***	446.071***	0.062
Error	30	22100.3	12.084	0.003
Contrast				
AA Linear	1	1448683.7***	2227.400***	0.093***
AA Quadratic	1	469827.9***	430.479***	0.001
UAN Linear	1	718235.3***	651.899***	0.001
UAN Quadratic	1	61821.8	1.882	0.000
UAN+DCD Linear	1	615247.0***	1076.337***	0.020*
UAN+DCD Quadratic	1	36679.9	28.901	0.001
Check vs AA check	1	135616.3*	47.472*	--
Source x N Rate				
Rep	3	104335.9**	186.274***	0.025***
Source	2	41888.1	534.250***	0.189***
N Rate	2	206972.2***	559.526***	0.003
Source*N Rate	4	3689.8	26.004	0.027***
Error	24	21962.3	12.542	0.003
Contrast				
AA vs UAN	1	21542.4	907.936***	0.298***
UAN vs UAN+DCD	1	20351.3	16.746	0.000
N Rate Linear	1	336672.8***	1100.422***	0.005
N Rate Quadratic	1	77271.6	18.629	0.001
AA vs UAN*N Linear	1	6776.5	2.371	0.058***
AA vs UAN+DCD*N Linear	1	9824.7	51.380	0.101***
UAN vs UAN+DCD*N Linear	1	282.2	31.674	0.006

GNUP - grain nitrogen uptake.

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 9. Split-plot in-time analysis of variance on grain yield at Perkins, OK, combined over years 1991-1993.

Source	df	Grain yield
		Mean squares
All treatments		
Rep	3	384834.7**
Trt	10	1976447.0***
Rep*Trt (Error a)	30	70144.1**
Yr	2	5356760.5***
Trt*Yr	20	140353.4***
Error b	66	33158.8
Contrast		
AA Linear	1	5993787.1***
AA Quadratic	1	1555891.2***
UAN Linear	1	7321803.0***
UAN Quadratic	1	58800.0
UAN+DCD Linear	1	9012909.3***
UAN+DCD Quadratic	1	29474.3
Check vs AA check	1	33786.0
Source x Rate Factorial		
Rep	3	351534.5**
Source	2	69797.7
Rate	2	2796722.8***
Source*Rate	4	216832.8*
Rep*Source*Rate (Error a)	24	59037.0
Yr	2	3455149.8***
Yr*Source	4	36623.2
Yr*Rate	4	292682.0***
Yr*Source*Rate	8	53461.0
Error b	54	36574.4
Contrast		
AA vs UAN	1	131563.9
UAN vs UAN+DCD	1	67065.8
N Rate Linear	1	5388125.2***
N Rate Quadratic	1	205320.4
AA vs UAN*N Rate Linear	1	497240.0**
AA vs UAN+DCD*N Rate Linear	1	770538.7**
UAN vs UAN+DCD*N Rate Linear	1	29808.3
Yr 1 vs Yr 2	1	6702485.6***
Yr 2 vs Yr 3	1	2853564.9***
Yr 1 vs Yr 2*N Rate Linear	1	299264.7**
Yr 1 vs Yr 3*N Rate Linear	1	283558.0**
Yr 2 vs Yr 3*N Rate Linear	1	1165433.8***
Yr 1,2 vs Yr 3*N Rate Linear	1	866239.7***

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 10. Regression equations, significance of model, and R^2 values for grain yield at Perkins, OK, 1991-1993.

Source	Model	Significance (Prob > F)	R^2
Grain yield, kg ha^{-1}			
1991			
AA	$Y = 1921.3 + 23.4 X - 0.163 X^2$	0.0002	0.73
UAN	$Y = 1854.2 + 10.8 X$	0.0002	0.64
UAN+DCD	$Y = 1786.5 + 14.5 X$	0.0001	0.76
1992			
AA	$Y = 875.3 + 36.0 X - 0.245 X^2$	0.0001	0.86
UAN	$Y = 885.8 + 17.7 X$	0.0001	0.88
UAN+DCD	$Y = 941.3 + 12.9 X$	0.0001	0.90
1993			
AA	$Y = 1686.2 + 26.1 X - 0.190 X^2$	0.0001	0.80
UAN	$Y = 1997.1 + 6.31 X$	0.0004	0.60
UAN+DCD	$Y = 1974.6 + 5.84 X$	0.0001	0.67

Table 11. Treatment and main effect means for soil NO_3-N at Perkins, OK, 1991.

Treatment	Depth, cm 0-15	15-30	30-45	45-60	60-90	90-120
	mg NO_3-N kg^{-1} soil					
Check	1.8	1.6	1.2	0.9	0.7	0.6
AA Check	2.0	1.3	1.0	0.8	0.7	1.2
AA 34	2.3	1.9	1.8	1.6	1.1	1.1
AA 67	2.1	2.0	2.3	2.8	2.4	2.3
AA 101	2.4	3.7	4.6	3.8	1.7	0.8
UAN 34	1.6	1.1	1.0	0.8	0.7	0.8
UAN 67	2.6	2.3	2.0	1.2	0.7	0.6
UAN 101	3.5	2.9	2.4	2.2	1.4	1.0
UAN+DCD 34	1.5	1.1	1.1	1.2	0.6	0.6
UAN+DCD 67	2.9	2.6	2.2	1.7	0.9	0.7
UAN+DCD 101	2.8	3.6	2.8	1.3	0.7	0.6
SED	0.8	0.7	0.6	0.6	0.3	0.4
CV, %	47	46	40	50	42	59
Source						
AA	2.3	2.6	2.9	2.8	1.7	1.4
UAN	2.5	2.1	1.8	1.4	0.9	0.8
UAN+DCD	2.4	2.4	2.0	1.4	0.7	0.6
N Rate						
34	1.7	1.4	1.3	1.2	0.8	0.8
67	2.5	2.3	2.2	1.9	1.3	1.2
101	2.9	3.4	3.2	2.5	1.3	0.8
SED	0.8	0.7	0.4	0.7	0.3	0.4
CV, %	65	45	38	48	42	58

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 12. Analyses of variance for soil NO_3-N at Perkins, OK, 1991.

Source	df	Depth, cm					
		0-15	15-30	30-45	45-60	60-90	90-120
		Mean squares					
All treatments							
Rep	3	5.651**	7.960***	5.208***	1.973	0.338	1.247*
Trt	10	1.566	3.536**	4.525***	3.708***	1.316***	1.015**
Error	30	1.218	1.060	0.688	0.742	0.214	0.337
Contrast							
AA Linear	1	0.259	11.347**	25.946***	21.903***	3.561***	0.001
AA Quadratic	1	0.000	1.107	2.002	0.025	1.232*	2.109*
UAN Linear	1	7.982*	5.559*	4.436*	4.072*	1.180*	0.199
UAN Quadratic	1	1.171	0.945	0.324	1.282	0.455	0.018
UAN+DCD Linear	1	4.651	11.689**	7.140**	0.780	0.040	0.001
UAN+DCD Quadratic	1	0.039	2.088	0.442	0.442	0.029	0.015
Check vs AA check	1	0.137	0.156	0.094	0.023	0.015	0.696
Source x N Rate							
Rep	3	5.786*	7.974**	5.709***	2.313	0.409	0.782
Source	2	0.210	0.673	4.108**	7.403**	3.235***	1.965**
N Rate	2	4.150	12.408***	11.650***	5.077**	1.049*	0.636
Source*N Rate	4	1.203	0.741	1.144	1.261	0.801*	1.056*
Error	24	1.421	1.200	0.758	0.850	0.249	0.325
Contrast							
AA vs UAN	1	0.421	1.278	7.425**	11.206**	3.720***	2.220*
UAN vs UAN+DCD	1	0.109	0.624	0.350	0.000	0.222	0.150
N Rate Linear	1	7.992*	24.786***	23.246***	10.075**	1.349*	0.016
N Rate Quadratic	1	0.308	0.030	0.055	0.080	0.750	1.256
AA vs UAN*N Linear	1	3.231	0.000	1.809	0.585	0.024	0.240
AA vs UAN+DCD*N Linear	1	1.568	0.469	1.155	4.212*	0.299	0.071
UAN vs UAN+DCD*N Linear	1	0.297	0.493	0.072	1.657	0.493	0.049

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 13. Treatment and main effect means for soil NO_3-N at Perkins, OK, 1992.

	Depth, cm					
Treatment	0-15	15-30	30-45	45-60	60-90	90-120
	mg NO_3-N kg^{-1} soil					
Check	3.5	2.3	2.1	2.0	2.0	1.8
AA Check	4.4	2.1	2.0	1.9	2.0	1.9
AA 34	4.2	2.2	2.1	2.7	1.7	1.8
AA 67	4.1	2.8	2.6	2.5	2.6	1.9
AA 101	5.3	2.9	2.2	2.0	1.9	1.9
UAN 34	3.9	2.2	1.9	1.9	2.2	2.3
UAN 67	4.4	2.6	2.2	2.2	1.9	1.8
UAN 101	5.6	3.2	2.3	2.2	2.2	2.0
UAN+DCD 34	4.3	2.4	2.8	2.1	1.9	1.8
UAN+DCD 67	4.1	2.6	2.3	2.1	1.6	1.8
UAN+DCD 101	4.4	2.2	2.0	2.1	1.9	1.7
SED	0.7	0.3	0.3	0.4	0.3	0.3
CV, %	22	18	19	24	18	18
Source						
AA	4.5	2.6	2.3	2.4	2.1	1.9
UAN	4.6	2.7	2.1	2.1	2.1	2.0
UAN+DCD	4.2	2.4	2.3	2.1	1.8	1.8
N Rate						
34	4.1	2.3	2.3	2.2	1.9	2.0
67	4.2	2.7	2.3	2.3	2.1	1.8
101	5.1	2.8	2.2	2.1	2.0	1.8
SED	0.7	0.3	0.3	0.4	0.3	0.3
CV, %	45	18	20	25	20	19

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 14. Analyses of variance for soil NO_3-N at Perkins, OK, 1992.

Source	df	Depth, cm					
		0-15	15-30	30-45	45-60	60-90	90-120
		Mean squares					
All treatments							
Rep	3	5.702**	1.162**	1.197**	0.902*	0.417	0.254
Trt	10	1.438	0.470*	0.255	0.247	0.302	0.106
Error	30	0.974	0.221	0.196	0.278	0.144	0.121
Contrast							
AA Linear	1	1.540	1.687**	0.177	0.006	0.105	0.001
AA Quadratic	1	2.030	0.000	0.200	1.664*	0.252	0.000
UAN Linear	1	9.031**	1.888**	0.209	0.147	0.014	0.005
UAN Quadratic	1	0.616	0.351	0.063	0.011	0.001	0.081
UAN+DCD Linear	1	1.217	0.000	0.080	0.011	0.035	0.039
UAN+DCD Quadratic	1	0.195	0.286	0.916	0.024	0.115	0.012
Check vs AA check	1	1.505	0.043	0.000	0.002	0.000	0.019
Source x N Rate							
Rep	3	3.873*	1.433**	1.417**	1.105*	0.443	0.257
Source	2	0.484	0.254	0.130	0.384	0.357	0.247
N Rate	2	3.626*	0.799*	0.077	0.123	0.040	0.079
Source*N Rate	4	0.697	0.420	0.457	0.286	0.554*	0.095
Error	24	0.968	0.227	0.214	0.320	0.173	0.148
Contrast							
AA vs UAN	1	0.037	0.005	0.123	0.576	0.001	0.220
UAN vs UAN+DCD	1	0.870	0.424	0.248	0.000	0.567	0.473
N Rate Linear	1	5.703*	1.363*	0.057	0.166	0.007	0.102
N Rate Quadratic	1	1.548	0.235	0.097	0.080	0.074	0.056
AA vs UAN*N Linear	1	0.305	0.067	0.081	1.076	0.071	0.099
AA vs UAN+DCD*N Linear	1	1.005	0.810	0.718	0.529	0.022	0.039
UAN vs UAN+DCD*N Linear	1	2.418	1.345	1.282	0.096	0.013	0.013

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 15. Treatment and main effect means for soil NO_3-N at Perkins, OK, 1993.

Treatment	Depth, cm 0-15	15-30	30-45	45-60	60-90	90-120
	mg NO_3-N kg^{-1} soil					
Check	3.1	1.1	0.7	0.6	0.6	0.6
AA Check	1.8	0.9	0.6	0.6	0.6	0.6
AA 34	3.9	2.6	0.7	0.5	0.6	0.6
AA 67	4.7	4.9	1.5	0.7	0.9	0.8
AA 101	5.1	4.4	1.4	0.8	0.7	0.7
UAN 34	2.5	0.7	0.6	0.6	0.6	0.8
UAN 67	2.7	1.2	0.7	0.7	0.7	0.7
UAN 101	3.6	1.6	0.8	0.7	0.8	1.0
UAN+DCD 34	2.4	0.9	0.6	0.6	0.6	0.6
UAN+DCD 67	3.0	1.0	0.6	0.6	0.6	0.5
UAN+DCD 101	3.0	1.1	0.6	0.6	0.6	0.6
SED	0.8	0.8	0.2	0.1	0.1	0.1
CV, %	35	59	28	16	19	24
Source						
AA	4.6	3.9	1.2	0.7	0.7	0.7
UAN	2.9	1.1	0.7	0.6	0.7	0.8
UAN+DCD	2.8	1.0	0.6	0.6	0.6	0.6
N Rate						
34	2.9	1.4	0.6	0.6	0.6	0.7
67	3.5	2.4	0.9	0.6	0.7	0.7
101	3.9	2.3	0.9	0.7	0.7	0.7
SED	0.9	0.9	0.2	0.1	0.1	0.1
CV, %	35	59	30	17	21	25

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 16. Analyses of variance for soil NO_3-N at Perkins, OK, 1993.

Source	df	Depth, cm					
		0-15	15-30	30-45	45-60	60-90	90-120
		Mean squares					
All treatments							
Rep	3	1.428	1.440	0.058	0.073**	0.147***	0.241***
Trt	10	4.008**	8.629***	0.460***	0.021	0.056**	0.073*
Error	30	1.361	1.290	0.058	0.012	0.019	0.032
Contrast							
AA Linear	1	22.578***	33.269***	2.128***	0.130**	0.117**	0.074
AA Quadratic	1	3.385	4.526	0.029	0.017	0.045	0.050
UAN Linear	1	0.524	0.628	0.020	0.027	0.080*	0.224*
UAN Quadratic	1	2.673	0.628	0.058	0.003	0.028	0.007
UAN+DCD Linear	1	0.001	0.002	0.020	0.000	0.000	0.006
UAN+DCD Quadratic	1	0.483	0.046	0.000	0.003	0.001	0.000
Check vs AA check	1	3.685	0.127	0.012	0.000	0.002	0.003
Source x N Rate							
Rep	3	1.997	1.952	0.065	0.049*	0.135**	0.268**
Source	2	11.877**	32.895***	1.320***	0.012	0.061	0.189**
N Rate	2	2.649	3.724	0.371*	0.019	0.085*	0.013
Source*N Rate	4	0.295	1.503	0.251*	0.027	0.058	0.054
Error	24	1.479	1.532	0.071	0.014	0.022	0.036
Contrast							
AA vs UAN	1	16.716**	47.012***	1.804***	0.002	0.023	0.056
UAN vs UAN+DCD	1	0.064	0.105	0.014	0.011	0.039	0.372**
N Rate Linear	1	5.282	5.405	0.543**	0.039	0.097*	0.024
N Rate Quadratic	1	0.016	2.043	0.199	0.000	0.072	0.002
AA vs UAN*N Linear	1	0.001	0.970	0.278	0.029	0.005	0.019
AA vs UAN+DCD*N Linear	1	0.330	2.975	0.600**	0.088*	0.020	0.011
UAN vs UAN+DCD*N Linear	1	0.375	0.547	0.061	0.015	0.047	0.061

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 17. Treatment and main effect means for grain yield, and N uptake (GNUP) at Carrier, OK, 1991-1993.

	1991		1992		1993	
	Grain					
	Yield	GNUP	Yield	GNUP	Yield	GNUP[†]
	kg ha^{-1}					
Treatment means						
Check	3198	97.6	1428	42.2	2493	--
AA Check	3311	98.7	1560	44.7	2541	--
AA 34	3260	102.6	1396	42.0	2224	--
AA 67	3161	99.1	1414	43.1	2108	--
AA 101	3202	101.4	1429	44.6	2251	--
UAN 34	3250	97.4	1441	42.9	2523	--
UAN 67	3316	103.1	1480	45.0	2427	--
UAN 101	3378	108.0	1456	44.0	2105	--
UAN+DCD 34	3497	95.6	1446	42.2	2447	--
UAN+DCD 67	3252	100.9	1434	42.9	2246	--
UAN+DCD 101	3302	103.8	1580	47.5	2293	--
SED	180	6.3	123	3.4	110	--
CV, %	7	8	11	11	6	--
Source means						
AA	3208	101.0	1413	43.2	2194	--
UAN	3315	102.8	1459	44.0	2352	--
UAN+DCD	3351	100.1	1487	44.2	2329	--
N Rate means						
34	3336	98.5	1428	42.3	2398	--
67	3243	101.0	1443	43.7	2260	--
101	3294	104.4	1489	45.4	2216	--
SED	190	6.9	127	3.5	108	--
CV, %	8	9	12	11	6	--

[†] - Grain N uptake values not useful due to hail damage.
SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

CHAPTER III

NITROGEN AND MEPIQUAT CHLORIDE EFFECTS ON THE PRODUCTION OF NONRANK, IRRIGATED, SHORT-SEASON COTTON

ABSTRACT

Nitrogen fertility is an important component of irrigated, short-season cotton (Gossypium hirsutum L.) production and is necessary to achieve optimum yield. However, excessive N almost invariably results in decreased yield and quality of cotton lint and seed. Utilization of mepiquat chloride (MC) (N,N-dimethylpiperidinium chloride) for remediation of the detrimental effects of excessive N in cotton has been suggested. A field experiment was conducted for 3 years to determine if MC applied at selected rates on traditionally nonrank, irrigated, short-season cotton could influence cotton yield, related agronomic characteristics, and fiber properties at different N fertilizer rates. The experiment was conducted near Altus, OK, on a Tillman-Hollister clay loam (fine, mixed, thermic Pachic Paleustoll). Cotton lint and seed yield responded positively to the Oklahoma State University recommended rate of 50 lb/acre of fertilizer N in all 3 years, but negatively at the higher rates in the second and third years.

Application of MC did not affect lint yield, seed yield, or lint/seed ratio in any year. Higher N fertilizer rates generally produced taller plants (by as much as 3.2 in.) while MC significantly reduced plant height (by as much as 5.7 in.) during this 3 year period. Percent first harvest was increased (up to 5.5%) by MC in 1 year, but was reduced (by as much as 17.4%) by higher N rates. Lint percentages were generally reduced by N fertilizer in all years, but were not affected by MC in any year. Excessive N increased fiber grayness in 1 year and fiber yellowness in another, but did not affect micronaire, length, uniformity, strength, elongation, or leaf index in any of the 3 years. Applications of MC increased fiber strength in 1 of 3 years (by 3.8%). They also affected elongation, fiber grayness, and leaf index in 1 year apiece, but not in the other two. Data from this study indicate that for measured parameters, the only consistent positive effect of MC use under any N fertilization regime was reduced plant height. No significant N by MC rate interactions were noted.

INTRODUCTION

Nitrogen fertility is an important component of irrigated, short-season cotton production and is necessary to achieve optimum yield. It is also important on the northern edge of the Cotton Belt to emphasize management practices that enhance early fruit set, fruit retention and maturation of early set bolls, and early harvest (Tucker and Thomas, 1985). However, the latter management goals are often in opposition to the realities of N fertilization because seasonal fluctuations in rainfall amount/distribution and heat unit accumulation often result in undesirable effects on lint and seed yield and quality if an improper amount of N is present during the fruiting cycle. In short-season cotton production environments, substantially reduced soil N availability should generally coincide with physiological "cutout". However, the timing of the cutout phenomenon in the Rolling Plains area is extremely seasonally dependent. Nitrogen management is particularly important when short-season cotton is stripper-harvested. In addition to seedcotton, considerable plant debris (including burs, residual leaves, branches, and in some cases stalks) are taken into the basket at harvest. Such trash increases ginning costs and contributes to lower lint grades in general (Verhalen and Banks, 1989) and to "barky" lint in particular (Metzer, 1984). Excessive N results in larger plants, delayed maturity, and a more dense canopy, particularly under high moisture regimes. This increases the mass of plant debris at harvest. These effects can be a result of factors such as over-fertilization, last minute crop species changes after preplant fertilization and subsequent stand loss, or planting cotton following alfalfa. Nitrogen fertilizer recommendations for cotton in Oklahoma are based on the philosophy of realistic long-term yield goals and soil testing for residual soil NO_3-N to a depth of 24 inches. The decision process for establishing a yield goal is based on various site specific factors including management level, soil productivity, available moisture, growing season potential, and past recorded yields. The N requirement of the crop is based on the assumption that 60 lb N/acre is needed for each bale of lint. The NO_3-N available in the 0-24 in. soil profile is subtracted from the crop N requirement for the respective yield goal. Any N available from high NO_3-N concentrations in irrigation water would also be subtracted [N required for the crop - (residual soil NO_3-N + NO_3-N in irrigation water)]. The resultant value is the N fertilizer requirement to produce the yield goal.

Mepiquat chloride is a growth regulator which has been used in full-season, picker-type cotton production systems to aid in control of excess vegetative growth and to induce earliness. Morphological effects of MC on such cultivars are well documented (Kerby, 1985; Kerby et al., 1986). Applications of MC have in some cases shown little yield response in full-season cultivars (York, 1983a). Other researchers (Niles and Bader, 1986) compared a full-season cultivar, 'Stoneville 213', to a short-season one, 'Tamcot CAMD-E', and reported that MC may not induce as much early maturity into the short-season cotton as it does into the full-season type. A 3 year experiment was conducted to determine if interactions between N fertilization and MC could be detected using full-season, Delta-type cottons under high N and moisture (Heilman, 1981). No interactions were found, but MC did not significantly affect yield and did reduce plant size. York (1983b) in an experiment involving two full-season cultivars observed that N rates and plant populations which resulted in the highest yield without MC were also the highest when MC was applied. Recently, Tracy and Sappenfield (1992) reported that cotton lint yield response in Missouri to MC and increased N management was greater in narrow-row cotton (30 in.) than in wider rows (38 in.).

Nitrogen fertilization practices should be examined for short-season cultivars combined with the growth regulator MC for the potential remediation of overfertilization in irrigated cotton production. Perhaps, MC could offset, in whole or in part, yield decreases and/or delays in maturity caused by excessive N. If MC reduces plant size and thus reduces the amount of plant debris in harvested cotton, a reassessment of N fertilization rates might be profitable. The objective of this study was to determine if MC applied at selected rates on traditionally nonrank, irrigated, short-season cotton could influence cotton yield, related agronomic characteristics, and fiber properties at different N fertilizer rates.

MATERIALS AND METHODS

A field experiment was initiated in the spring of 1984 and continued through 1986 on the Irrigation Research Station near Altus, OK, on a Tillman-Hollister clay loam. Initial soil samples were analyzed using standard Oklahoma State University soil testing procedures. Soil test values are provided in Table 1. The site would have a realistic long term yield goal of 1.75 bales/acre. The N fertilizer requirement would then be 1.75 times 60 minus 53 lb of residual soil NO_3-N as measured by soil testing. This results in a 50 lb/acre fertilizer N requirement. The soil contained sufficient P and K based on soil test calibrations (Johnson and Tucker, 1988); thus, P and K were not applied.

The experiment was established in a randomized complete block design with a factorial arrangement of treatments and four replications. Plot size was 13.3 ft wide (four 40-in. rows) by 50 ft long. The area had been in continuous cotton production for several years prior to establishing this experiment. Nitrogen rates of 0, 50, 100, and 200 lb of actual N/acre were applied broadcast preplant and disk incorporated. Ammonium nitrate was used as the N source. The area was then bedded, and trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine] was applied at 1 lb a.i./acre and incorporated using a rolling cultivator. Rates of 0, 0.022, and 0.044 lb MC a.i./acre (1/2 pint and 1 pint/acre of 0.35 lb/gallon material, respectively) were foliar applied at early bloom. Early bloom was considered to be when approximately 5 white blooms/25 row-feet were observed. In Oklahoma, MC applications are recommended when plants are in early bloom and at least 24 inches tall. An attempt was made to follow the supplemental labeling for MC as it related to traditionally nonrank cotton in Oklahoma and Texas (BASF Wyandotte Corporation, 1984), yet also include a wider range of application rates. Spray volume for MC was 30 gallons/acre at 35 lbs/in^2.

'Paymaster 404' cotton was planted each year at a 21 lb/acre seeding rate. The cultivar used was considered a short-season stripper type, but in this production area is somewhat less determinate than a number of other short-season cultivars. The less determinate cultivar was used to allow seasonal effects on N and/or MC response to be more fully expressed. The cultivar also has good tolerance to verticillium wilt (causal agent: Verticillium dahliae Kleb.)

which was important at this location. The experimental site was located in the W.C. Austin Irrigation District and was furrow irrigated as judged necessary with available water. The irrigation water available in any particular year is a function of runoff that previously occurred in the watershed, and it is allocated by the Irrigation District. Insecticides were applied as needed. Harvest aids were not used during these experiments to more fully allow measurement of the direct effects of N and MC. Long-term (i.e., 1948-1988 inclusive) rainfall and temperature data for the station were acquired, and seasonal heat unit accumulations were calculated using the average daily temperature minus base temperature (DD60) procedure (Supak, 1984). Experimental conditions and procedures are summarized in Table 1.

Cotton yield/plot was determined each year by harvesting one of the center two rows in each plot with a self-propelled cotton stripper equipped with a brush-roll header. The other row was hand harvested twice to estimate earliness by the percent first harvest method (based on lint yield). In 1986 excessive rainfall prevented early hand harvest; therefore, earliness data were not available for that year. The area remained saturated due to excessive rainfall, and machine harvest of the plots was delayed until the following April. Burs were extracted from samples of the stripper-harvested cotton on a stationary extractor, and seedcotton was ginned on a laboratory 10-saw gin and used to estimate stripper lint percent and to convert plot weights of lint and seed to an acre basis. Plant height was determined by measuring stalk height from the soil surface in four locations/plot. Picked and pulled lint percents were determined for each plot by ginning hand-pulled samples using the same ginning procedures as for the stripped plots. Boll samples were also taken from each plot prior to harvest, deburred by hand, and seedcotton were ginned on the laboratory 10-saw gin. Lint samples were sent to Texas Tech University Textile Research Center for High Volume Instrument (HVI) determinations of fiber properties. Properties included micronaire, length, uniformity, strength, elongation, leaf index, Rd, and +b. However, only those fiber properties significantly affected by treatment are reported.

An estimate of residual fertilizer N accumulation was made by multiplying the actual yield (expressed as number of 480-lb bales of lint/acre) times 37 lbs N/bale removed in seed, lint, and burs. This constant was chosen after checking removal estimates in several sources (Waddle, 1984; Martin et al., 1976; Christidis and Harrison, 1955). Those estimates ranged from 35 to 40 lbs of N. The estimated amount of N removed was subtracted from the amount of loading for each N rate by year and is presented in Table 2.

Data were analyzed using procedures outlined by the SAS Institute (1988). Years were analyzed separately due to the increasing estimated residual soil N especially at the two high application rates.

RESULTS AND DISCUSSION

Environmental conditions for 1984 could be characterized as very dry with available heat units being somewhat higher than average for June, but near the long-term average for the remainder of the season (Table 1). The 1985 crop year was considerably above long-term seasonal rainfall averages, with May having substantially less and June having much more. The seasonal total heat units was near the long-term average. Rainfall in 1986 was excessive during late summer and fall with over 11 inches during August and September. Those are critical months for maturation of bolls in OK, and heat unit accumulation was lower than the long-term average for August.

For the variables reported, no significant N rate by MC rate interactions were observed, and are not discussed.

Lint and Seed Yield

In 1984 and 1986, N fertilization resulted in a significant quadratic response in lint yield; while in 1985, the response was linear (Tables 3, 4, and 5). A lint yield reduction was noted at the higher N rates in 1985 and 1986 (Tables 4 and 5). A very wet fall in both years coupled with estimated excess accumulation of residual fertilizer N apparently delayed maturity at those higher N rates, and thereby decreased yields due to lack of boll maturity. Estimated residual accumulation of fertilizer N was substantial by the second and third years of this experiment at the higher rates (Table 2). Within N treatments, as expected, the 50 lb/acre rate had the least accumulation. Over the 3 year period, the 50 lb/acre rate consistently produced the most lint.

Applications of MC did not significantly affect lint yield in any of the 3 years. Yield response to MC in other experiments has been extremely variable across environments. Work conducted by Kerby (1985) in California indicated that unless heat units are less than 2600 or plant size is greater than 43 inches, positive yield response to MC is unlikely. In the Altus production area, plant size is traditionally nonrank; and although total heat unit accumulation may be adequate, daily distribution is not always optimum. Some researchers have reported increased yield when plants were rank (Gordon et al., 1986; York, 1983b). Cathey and Meredith (1988) found that cotton yield from full-season cultivars, produced under short-season conditions, responded to MC. However, a short-season production study detected no increase in yield on short-season cultivars (Stuart et al., 1984) as did another experiment using a determinate cultivar (Niles and Bader, 1986).

Seed yield was affected by N fertilization all 3 years of the experiment (Tables 3, 4, and 5). Seed yield response largely mirrored lint yield though the ratio of lint to seed (pounds of lint/pounds of seed) was significantly reduced by N fertilization. This was a consequence of seed weight increasing faster than lint weight at the higher N rates. Christidis and Harrison (1955) reported that N fertilization increased seed weight and reduced lint percentage. Mepiquat chloride had no effect on seed yield or on lint/seed ratio in any year.

Plant Height

Plant height was affected by N fertilization and MC application in all 3 years (Tables 3, 4, and 5). Nitrogen fertilization resulted in a significant linear increase of up to 3.2 in. in plant height in 1984. Response in the latter 2 years was quadratic with initial increases in plant height, followed by a decline at the highest N rate. It is unclear why the 200 lb N rate resulted in shorter plants than lower N rates in 1985 and 1986. It is possible the additional excess N resulted in greater overall vegetative growth, with much of that growth found in increased leaf area rather than plant height.

In all 3 years, MC applications resulted in a highly significant quadratic reduction in plant height. Plant size was reduced by 0.8 to 4.3 inches at the low MC rate and by 1.3 to 5.7 inches at the high rate. As a percentage of the check, those reductions corresponded to 3.1 to 15.1% and 5.0 to 20.0%, respectively.

Percent First Harvest

In 1984, N fertilization resulted in a significant linear decline in percent first harvest, a commonly used measure of earliness (Table 3). Percent first harvest was reduced by 3.9, 9.0, and 17.4% at the 50, 100, and 200 lb/acre N fertilization rates, respectively. Nitrogen fertilization resulted in a significant quadratic effect on percent first harvest in 1985 (Table 4). At the 200-lb rate, a higher percentage of the residual bolls which remained after the first harvest did not produce harvestable lint. The rainfall during this period was extremely high and probably exaggerated the plants response to excess N. Application of MC significantly increased percent first harvest by 2.6 to 5.5% in 1985, but was ineffective in 1984. Earliness data for the 1986 season were unavailable because excessive rainfall prevented multiple harvests.

Lint Percentage

In 1984, N fertilization resulted in a significant linear reduction in picked lint percentage; while in 1985 and 1986, the reductions were quadratic (Tables 3, 4, and 5). Pulled lint percentages were reduced linearly in 1984 and 1985, but quadratically in 1986. Stripper lint percentages were reduced linearly in 1984, not at all in 1985, and quadratically in 1986.

Application of MC did not affect any of the measures of lint percentage during the 3 year experiment. Plant height was expected to influence stripper lint percentages to some extent since larger stalk size should result in potentially more loose material to be gathered during the harvest process. However, regression analyses of plant height vs. stripper lint percentage resulted in poor correlation coefficients (0.29, 0.04, and 0.33 for 1984, 1985, and 1986, respectively). This suggests that plant height measurements alone are poor indicators of relative stripper lint percentage. A number of other plant characters, individually or combined, could also have an influence including width or shape of the plant, total amount and/or size of residual leaves, stalk and branch diameter, degree of deterioration of stalk and branches, and stalk moisture content.

HVI Fiber Properties

Fiber property results are presented in Table 6. No fiber properties were influenced by N or MC rates in 1984. The Rd (or reflectance) value was linearly reduced by N fertilization in 1985 but had no effect in other years of the study. This component of color measures grayness of the fiber (Verhalen and Banks, 1989), and a reduction in Rd indicates an increase in grayness which is undesirable. Nitrogen fertilization linearly increased the Hunter's +b (or yellowness) value only in 1986. An increase in +b indicates an increase in yellowness which is also undesirable. Rates of N did not significantly influence micronaire, length, uniformity, strength, elongation, or leaf index in any of the 3 years.

Application of MC linearly increased fiber strength by up to 3.8% in 1985. Elongation was also increased quadratically in 1985. The Rd value was linearly reduced in 1985. Leaf index was significantly increased quadratically by MC in 1986. Rates of MC did not significantly influence micronaire, length, uniformity, or +b. Some effects of MC on fiber properties have been previously noted (Kerby, 1985; York, 1983a), but those were observed in full-season cultivars. Others reported finding differences in full-season cultivars, but not in more determinate types (Niles and Bader, 1986).

CONCLUSIONS

Results from this 3 year experiment conducted on nonrank, irrigated, short-season cotton indicate that application of MC under any N fertilizer management regime had minimal direct benefit on measured parameters. One consistent significant response to MC was reduction in plant height which resulted in a more open canopy than untreated plants. Although not directly measured, a more open crop canopy could enhance pesticide and harvest aid efficacy by facilitating better penetration of the foliage during application. Oklahoma State University soil test recommendations for N fertilizer management were appropriate for maximizing lint yields over the 3 year period.

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Table 1. Experimental conditions and procedures.

Variable		Year 1984	1985	1986
Initial soil test values				
NO_3-N (0-2 ft), lb/acre		53	--	--
pH		6.8	--	--
P index		111	--	--
K index		845	--	--
Planting date		June 5	May 17	May 23
Plant population/acre		58,000	51,000	56,000
Heat units by months				
May	(360)†	404	408	349
June	(595)	682	579	547
July	(725)	772	742	760
Aug	(675)	768	769	649
Sept	(470)	454	512	453
Heat units available to crop		2675	2828	2409
First freeze date (<32°F)		Sept 30	Nov 7	Nov 11
Precipitation by months, in.				
May	(4.7)†	0.3	1.9	5.4
June	(3.4)	2.5	8.3	3.8
July	(1.9)	0.9	1.2	1.6
Aug	(2.0)	0.7	1.5	5.9
Sept	(3.0)	0.3	4.7	6.0
Number of irrigations		6	4	3
Estimated irrigation, acre-in.		17	12	12
MC application date		July 31	July 24	July 26
Harvest dates				
First		Oct 15	Sept 23	Dec 31
Second		Nov 9	Dec 17	--
Stripper		Nov 14	Dec 23	Apr 3, 1987

† Long-term averages (1948-1988) shown in parentheses.

Table 2. Nitrogen loading rates, estimated N removal, and estimated residual fertilizer N.

	Actual N loading				Estimated N removal[†]				Estimated residual fertilizer N			
	Year				Year				Year			
N rate	1984	1985	1986	Total	1984	1985	1986	Total	1985	1986	1987	Total
	lb/acre											
0	0	0	0	0	45	55	50	150	-45	-55	-50	-150
50	50	50	50	150	55	60	55	170	-5	-10	-5	-20
100	100	100	100	300	60	50	50	160	40	50	50	140
200	200	200	200	600	65	50	40	155	135	150	160	445

[†] Estimated by multiplying lint yield in bales/acre times 37 lb N/bale.

Table 3. Nitrogen and mepiquat chloride effects on yield and other agronomic characteristics of cotton, 1984.

Comparison	Yield Lint	 Seed	Lint/seed ratio	Plant height	Percent first harvest	Lint percent Picked	 Pulled	 Stripper
	lb/acre			in.	%			
N rate (lb/acre)								
0	615	870	0.71	23.6	76.0	43.2	29.9	28.9
50	740	1075	0.69	24.6	72.1	41.7	29.0	28.6
100	805	1285	0.63	25.6	67.0	40.9	28.3	26.7
200	850	1370	0.62	26.8	58.6	39.5	26.9	26.3
F test								
Rate	****	****	****	***	***	****	***	****
Linear	****	****	****	****	****	****	****	****
Quadratic	**	**	NS	NS	NS	NS	NS	NS
MC rate (lb a.i./acre)								
0	760	1145	0.67	28.5	66.4	41.6	28.7	27.6
0.022	740	1130	0.66	24.2	68.6	41.0	28.5	27.6
0.044	760	1180	0.65	22.8	70.2	41.4	28.3	27.6
F test								
Rate	NS	NS	NS	****	NS	NS	NS	NS
Linear	NS	NS	NS	****	NS	NS	NS	NS
Quadratic	NS	NS	NS	****	NS	NS	NS	NS
N x MC	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	10	12	6	7	13	4	5	4
SED	55	95	0.03	1.3	6.4	1.1	1.0	0.8

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

,*,**** Significant at the 0.01, 0.001, and 0.0001 probability levels, respectively. NS = not significant.

Table 4. Nitrogen and mepiquat chloride effects on yield and other agronomic characteristics of cotton, 1985.

Comparison	Yield		Lint/seed ratio	Plant height	Percent first harvest	Lint percent		
	Lint	Seed				Picked	Pulled	Stripper
	lb/acre			in.	%			
N rate (lb/acre)								
0	705	1135	0.62	24.5	61.8	37.5	27.4	26.1
50	780	1290	0.61	25.6	58.3	36.6	26.7	25.8
100	670	1120	0.60	26.0	59.3	36.3	26.4	25.7
200	645	1085	0.60	24.8	63.4	36.3	26.1	25.6
F test								
Rate	**	**	*	**	*	***	**	NS
Linear	**	*	*	NS	NS	***	***	NS
Quadratic	NS	NS	NS	***	*	**	NS	NS
MC rate (lb a.i./acre)								
0	700	1170	0.60	25.9	58.0	36.7	26.7	25.6
0.022	685	1125	0.61	25.1	63.5	36.6	26.5	25.8
0.044	720	1185	0.61	24.6	60.6	36.6	26.8	26.0
F test								
Rate	NS	NS	NS	**	**	NS	NS	NS
Linear	NS	NS	NS	*	**	NS	NS	NS
Quadratic	NS	NS	NS	**	NS	NS	NS	NS
N x MC	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	12	13	4	4	8	2	3	6
SED	61	109	0.02	0.8	3.3	0.5	0.6	1.1

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

*,**,***,**** Significant at the 0.05, 0.01, 0.001, and 0.0001 probability levels, respectively. NS = not significant.

Table 5. Nitrogen and mepiquat chloride effects on yield and other agronomic characteristics of cotton, 1986.

Comparison	Yield Lint	 Seed	Lint/seed ratio	Plant height	Percent first harvest[†]	Lint percent Picked	 Pulled	 Stripper
	lb/acre			in.	%			
N rate (lb/acre)								
0	640	1160	0.55	28.3	--	36.4	26.3	28.2
50	725	1425	0.51	30.3	--	34.4	25.0	26.0
100	630	1300	0.49	30.7	--	33.8	24.5	24.7
200	545	1080	0.51	29.7	--	33.8	23.8	25.7
F test								
Rate	****	****	****	*	--	****	****	****
Linear	***	*	***	NS	--	****	****	***
Quadratic	*	***	****	*	--	****	*	****
MC rate (lb a.i./acre)								
0	655	1275	0.51	32.3	--	34.5	24.9	26.2
0.022	630	1210	0.52	29.3	--	34.8	25.0	26.1
0.044	620	1235	0.51	27.6	--	34.5	24.7	26.2
F test								
Rate	NS	NS	NS	****	--	NS	NS	NS
Linear	NS	NS	NS	***	--	NS	NS	NS
Quadratic	NS	NS	NS	****	--	NS	NS	NS
N x MC	NS	NS	NS	NS	--	NS	NS	NS
CV, %	13	14	5	8	--	3	4	5
SED	59	120	0.02	1.7	--	0.7	0.6	0.9

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

*,***,**** Significant at the 0.05, 0.001, and 0.0001 probability levels, respectively. NS = not significant.

[†] Due to excessive rainfall, two harvests could not be performed in this year.

Table 6. Nitrogen and mepiquat chloride effects on HVI fiber properties of cotton, 1985 and 1986.

	1985			1986	
Comparison	Strength	Elongation	Rd	Leaf index	+b
	g/tex	%	grayness	%	yellowness
N rate (lb/acre)					
0	27	5.6	72	6.6	6.7
50	27	5.7	71	6.7	7.2
100	27	5.7	70	6.4	7.6
200	26	5.6	70	6.6	7.7
F test					
Rate	NS	NS	*	NS	*
Linear	NS	NS	**	NS	**
Quadratic	NS	NS	NS	NS	NS
MC rate (lb a.i./acre)					
0	26	5.6	72	6.3	7.3
0.022	27	5.6	70	6.4	7.7
0.044	27	5.8	71	7.1	7.0
F test					
Rate	*	*	*	*	NS
Linear	*	NS	**	NS	NS
Quadratic	NS	*	NS	*	NS
N x MC	NS	NS	NS	NS	NS
CV, %	6	3	2	13	12
SED	1	0.1	1	0.6	0.6

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

*,**,***,**** Significant at the 0.05, 0.01, 0.001, and 0.0001 probability levels, respectively. NS = not significant.

APPENDIX A

MATERIAL RELATED TO CHAPTER I

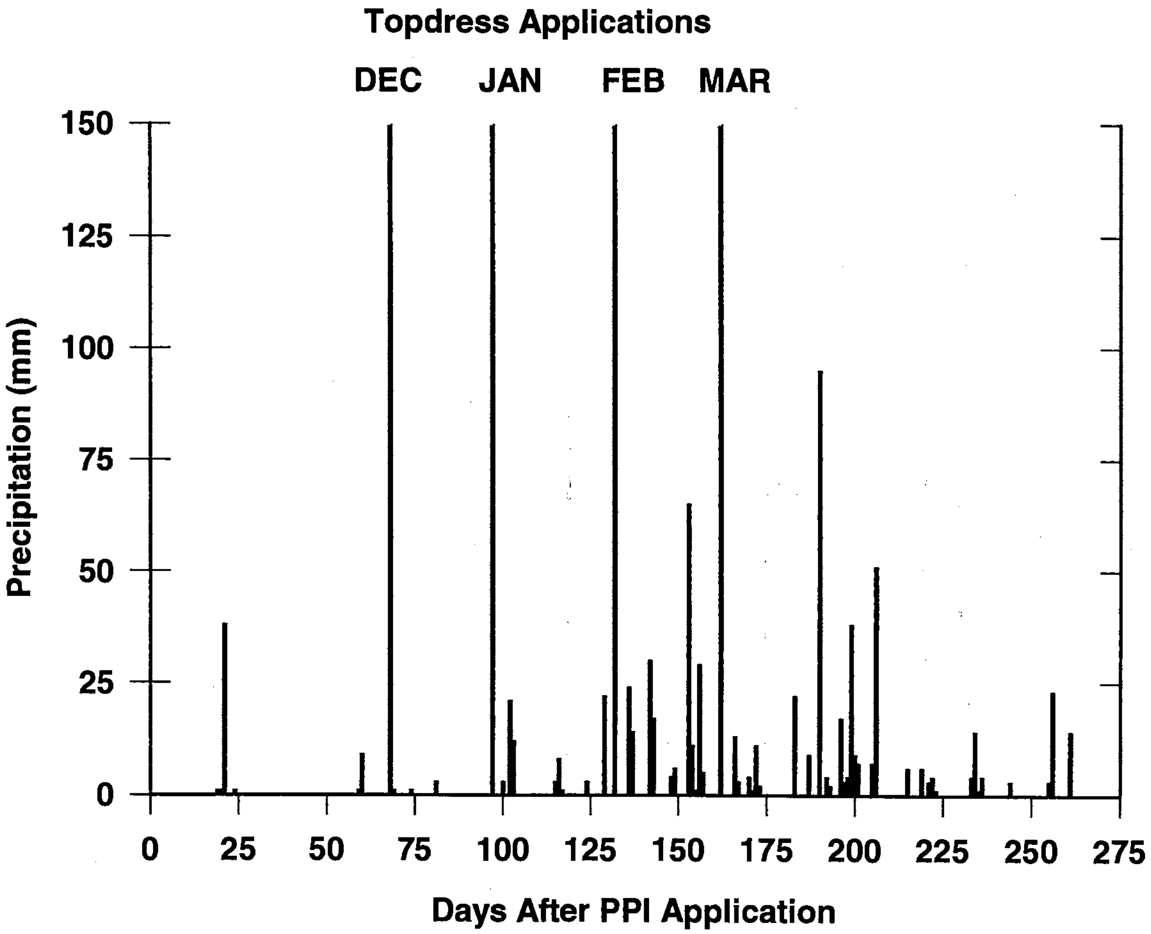

Figure 1. Precipitation amount and distribution at Perkins, OK, 1990 season.

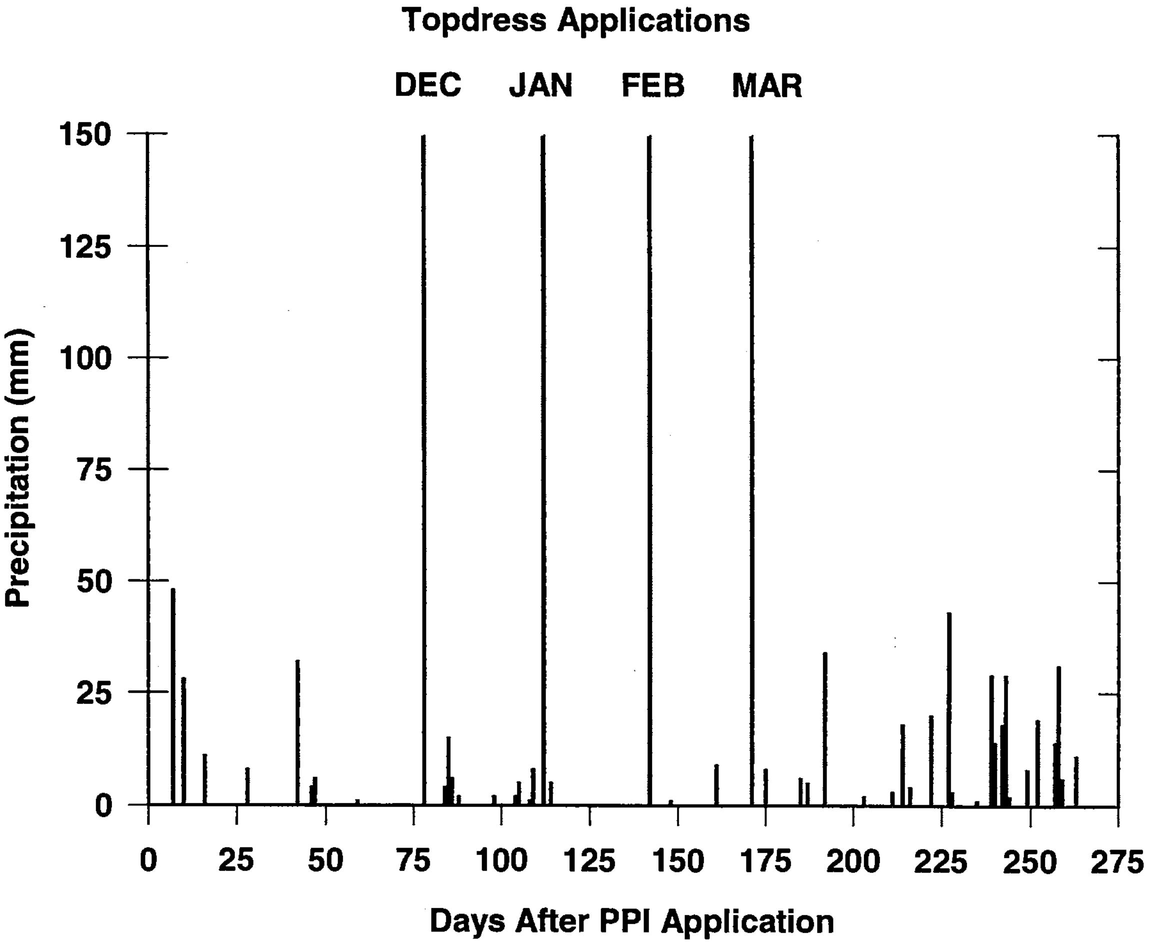

Figure 2. Precipitation amount and distribution at Perkins, OK, 1991 season.

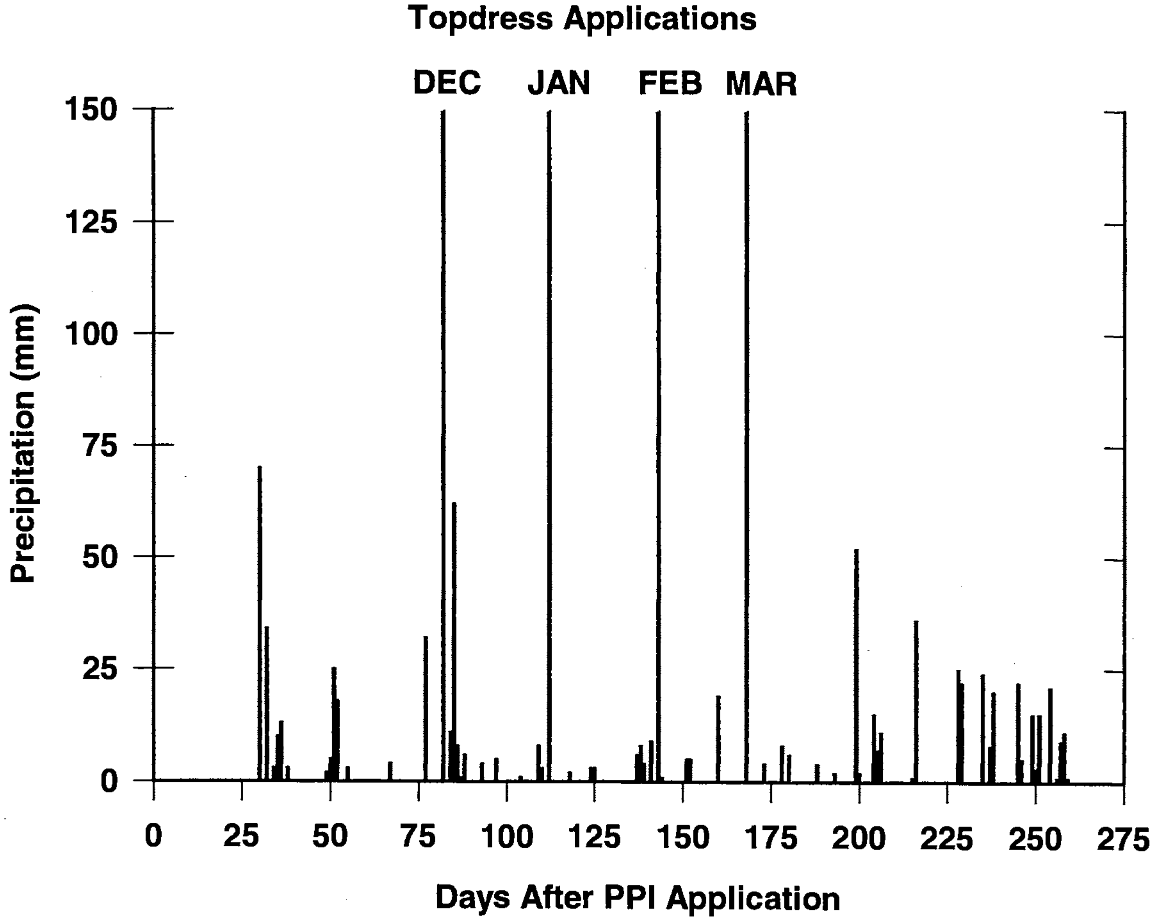

Figure 3. Precipitation amount and distribution at Perkins, OK, 1992 season.

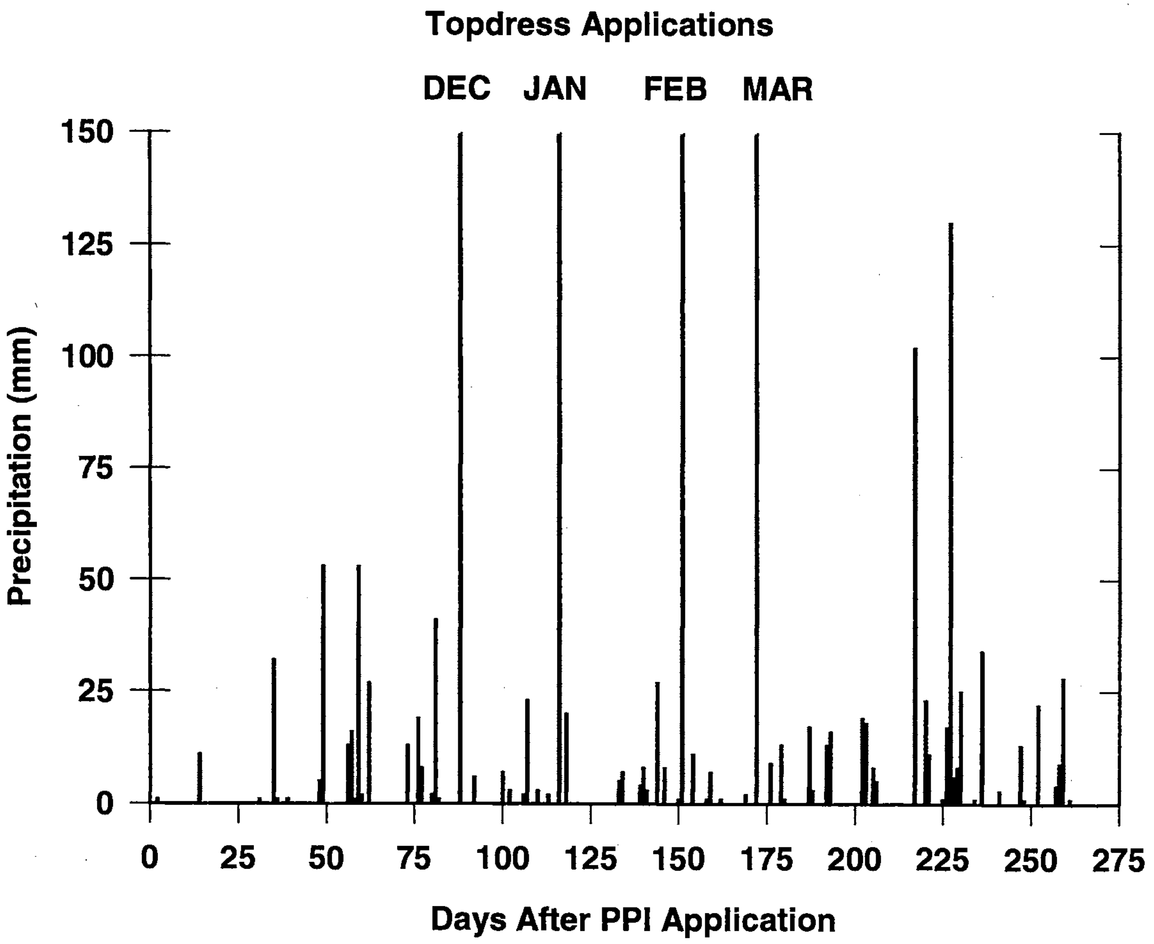

Figure 4. Precipitation amount and distribution at Perkins, OK, 1993 season.

Table 1. Rep-treatment and factorial arrangement of treatment analyses of variance on grain and forage yield, N concentration, and N uptake at Hennessey, OK, 1990.

	df	Grain yield	Forage yield	Grain N conc.	Forage N conc.	GNUP	FNUP
Treatment	20	*	*	*	**	†	**
Error	40						
Contrast							
Check vs others	1	*	*	NS	**	*	**
Date	4	*	**	**	**	**	**
Rate	3	NS	NS	**	**	NS	*
Date*Rate	12	†	NS	NS	NS	NS	NS
Error	38						
Contrasts							
PPI vs Dec	1	NS	NS	NS	*	NS	†
PPI vs Jan	1	NS	NS	†	*	NS	NS
PPI vs Feb	1	NS	NS	**	**	†	**
Mar vs others	1	**	**	NS	**	**	**
N rate linear	1	NS	NS	**	**	NS	**
N rate quadratic	1	NS	NS	NS	NS	NS	NS
CV, %		12	22	5	9	14	26

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS - Not significant.
CV - coefficient of variation.

Table 2. Rep-treatment and factorial arrangement of treatment analyses of variance on grain and forage yield, N concentration, and N uptake at Hennessey, OK, 1991.

	df	Grain yield	Forage yield	Grain N conc.	Forage N conc.	GNUP	FNUP
Treatment	20	NS	†	**	**	**	*
Error	40						
Contrast							
Check vs others	1	NS	**	**	**	**	**
Date	4	*	*	*	*	**	†
Rate	3	NS	NS	**	**	*	*
Date*Rate	12	NS	NS	NS	*	NS	NS
Error	38						
Contrasts							
PPI vs Dec	1	NS	NS	NS	NS	NS	NS
PPI vs Jan	1	NS	NS	NS	NS	NS	NS
PPI vs Feb	1	NS	NS	*	NS	*	NS
Mar vs others	1	**	*	NS	**	**	NS
N rate linear	1	NS	NS	**	**	**	**
N rate quadratic	1	NS	NS	NS	NS	NS	NS
CV, %		15	20	8	7	18	22

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS - Not significant.
CV - coefficient of variation.

Table 3. Rep-treatment and factorial arrangement of treatment analyses of variance on grain and forage yield, N concentration, and N uptake at Hennessey, OK, 1992.

	df	Grain yield	Forage yield	Grain N conc.	Forage N conc.	GNUP	FNUP
Treatment	20	**	NS	*	**	-	*
Error	40						
Contrast							
Check vs others	1	**	NS	**	**	-	†
Date	4	†	†	NS	**	-	*
Rate	3	**	NS	**	**	-	**
Date*Rate	12	NS	NS	NS	**	-	NS
Error	38						
Contrasts							
PPI vs Dec	1	NS	NS	NS	NS	-	NS
PPI vs Jan	1	NS	NS	NS	NS	-	NS
PPI vs Feb	1	NS	NS	NS	*	-	*
Mar vs others	1	**	†	NS	**	-	NS
N rate linear	1	**	NS	**	**	-	**
N rate quadratic	1	NS	NS	NS	NS	-	NS
CV, %		12	19	8	9	-	20

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively. NS - Not significant.
CV - coefficient of variation.

Table 4. Split-plot in-time analysis of variance for forage yield at Hennessey, OK.

Source	df	Forage Yield
All treatments		mean squares
Rep	2	2259129.8
Trt	20	1511495.9†
Rep*Trt (Error a)	40	871783.7
Yr	2	44902796.2**
Trt*Yr	40	384825.1
Error b	84	390909.2
Contrast		
Check vs others	1	4154979.3*
Date x Rate Factorial		
Rep	2	2031057.9
Date	4	4498017.6**
Rate	3	1282254.1
Date*Rate	12	566717.8
Rep*Date*Rate (Error a)	38	900960.3
Yr	2	40109605.9**
Yr*Date	8	574010.3
Yr*Rate	6	131168.5
Yr*Date*Rate	24	319646.8
Error b	80	409241.8
Contrasts		
PPI vs Dec	1	41630.8
PPI vs Jan	1	289351.2
PPI vs Feb	1	2755975.5†
Mar vs others	1	12697605.9**
N rate linear	1	438714.6
N rate quadratic	1	294383.0

†, *, ** - Significant at 0.10, 0.05, and 0.01 probability levels, respectively.
CV - coefficient of variation.

Table 5. Treatment means for 134 kg N ha^{-1} rate for soil NO_3-N at Hennessey, OK, 1990†.

	Depth, cm					
	0-15	15-30	30-45	45-60	60-90	90-120
	mg NO_3-N kg^{-1} soil					
Treatment means						
Check	9.8	6.5	6.3	6.5	8.1	6.4
PPI	8.3	6.1	5.8	5.3	7.2	5.0
Dec	10.4	7.3	8.3	5.8	6.3	7.5
Jan	12.6	7.0	8.0	10.2	7.2	6.8
Feb	13.4	7.6	6.6	5.9	6.3	6.9
Mar	12.4	6.7	5.9	6.0	5.5	6.2

† - No significant differences found among treatment means.

Table 6. Treatment means for 134 kg N ha^{-1} rate and analyses of variance on soil NO_3-N at Hennessey, OK, 1991.

		Depth, cm					
		0-15	15-30	30-45	45-60	60-90	90-120
		mg NO_3-N kg^{-1} soil					
Treatment means							
Check		4.1	3.1	1.9	1.3	1.3	1.3
PPI		32.2	22.8	6.2	2.1	1.6	2.6
Dec		20.3	17.6	8.0	3.0	1.5	1.8
Jan		7.8	9.0	4.9	2.5	1.7	2.0
Feb		17.1	15.4	9.0	2.5	2.0	3.1
Mar		9.5	10.6	5.1	2.2	1.9	1.6
SED		6.6	5.6	2.7	0.7	0.3	1.4
CV, %		53	52	58	39	28	84
Analysis of variance							
	df	Mean squares					
Rep	2	18.87	48.45	7.63	0.22	0.28	2.52
Trt	5	317.57*	146.39*	19.08	0.94	0.18	1.44
Error	10	66.98	48.14	11.71	0.83	0.22	3.14
Contrast							
Check vs others	1	442.66*	362.00*	56.96	3.36	0.41	2.27
PPI vs Dec	1	211.22†	41.08	4.68	1.12	0.01	1.04
PPI vs Jan	1	893.04**	287.04*	2.66	0.24	0.01	0.48
PPI vs Feb	1	339.00*	82.14	11.20	0.28	0.24	0.42
Mar vs other dates	1	232.46†	74.81	8.89	0.25	0.09	1.60

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

†, *, ** - Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

Table 7. Treatment means for 134 kg N ha^{-1} rate and analyses of variance on soil NO_3-N at Hennessey, OK, 1992.

		Depth, cm					
		0-15	15-30	30-45	45-60	60-90	90-120
		mg NO_3-N kg^{-1} soil					
Treatment means							
Check		7.8	5.8	4.0	3.8	3.4	3.1
PPI		8.8	7.2	5.8	6.4	7.5	7.8
Dec		8.4	6.5	6.4	8.6	12.1	9.1
Jan		8.3	5.8	5.0	6.1	7.1	9.4
Feb		13.8	8.8	8.4	9.9	14.0	15.6
Mar		7.4	5.4	6.4	6.5	6.8	6.1
SED		1.5	1.6	1.9	1.8	2.7	2.7
CV, %		20	31	40	32	39	38
Analysis of variance							
	df	Mean squares					
Rep	2	38.38**	4.69	4.54	20.30*	39.05†	28.02
Trt	5	16.64*	4.85	6.60	13.48†	45.39*	52.02*
Error	10	3.48	4.26	5.84	4.95	11.50	11.05
Contrast							
Check vs others	1	6.08	2.27	14.32	33.73*	94.45*	107.14**
PPI vs Dec	1	0.32	0.80	0.48	7.26	31.74	2.53
PPI vs Jan	1	0.48	3.22	1.12	0.20	0.24	3.68
PPI vs Feb	1	36.50**	3.84	9.62	18.02†	64.02*	89.70*
Mar vs other dates	1	13.92	6.53	0.00	3.80	26.93	45.41†

SED - standard error of the difference of two treatment means.

CV - coefficient of variation.

†, *, ** - Significant at the 0.10, 0.05, and 0.01 probability levels, respectively.

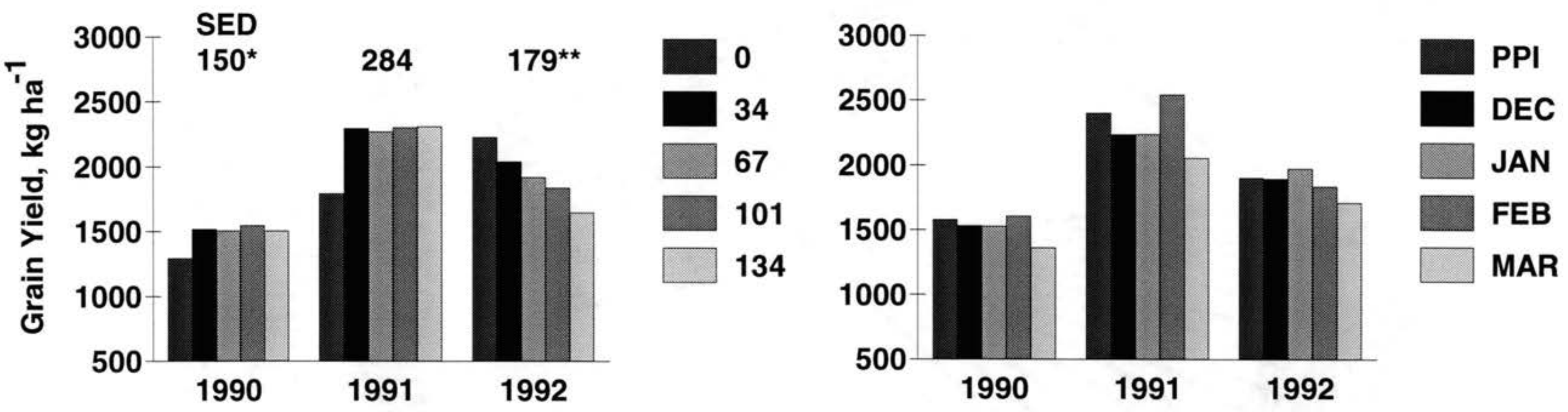

Figure 1. Wheat grain yield as affected by N fertilizer rates and dates of application, Hennessey, OK, 1990-1992.

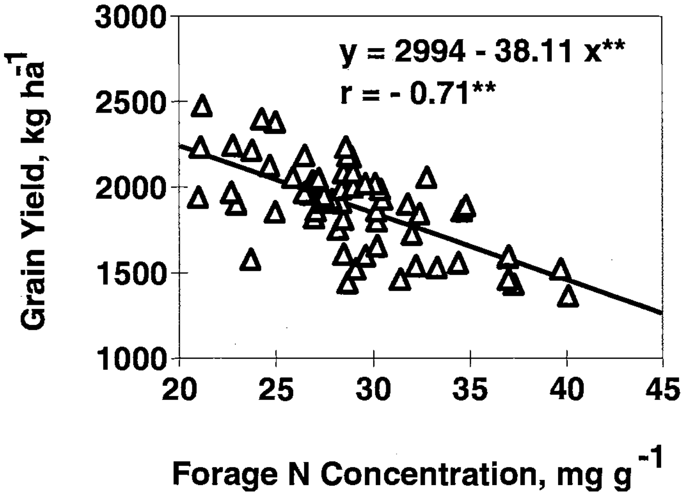

Figure 2. Relationship between wheat forage N concentration after late freeze and grain yield, Hennessey, OK, 1992.

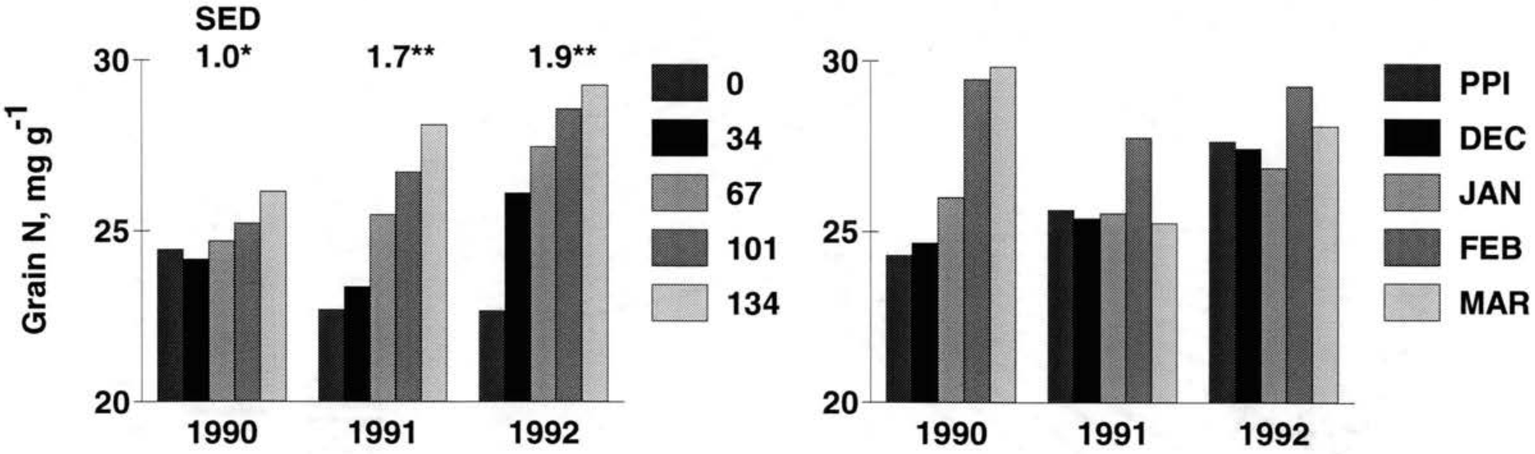

Figure 3. Wheat grain N concentration as affected by N fertilizer rates and dates of application, Hennessey, OK, 1990-1992.

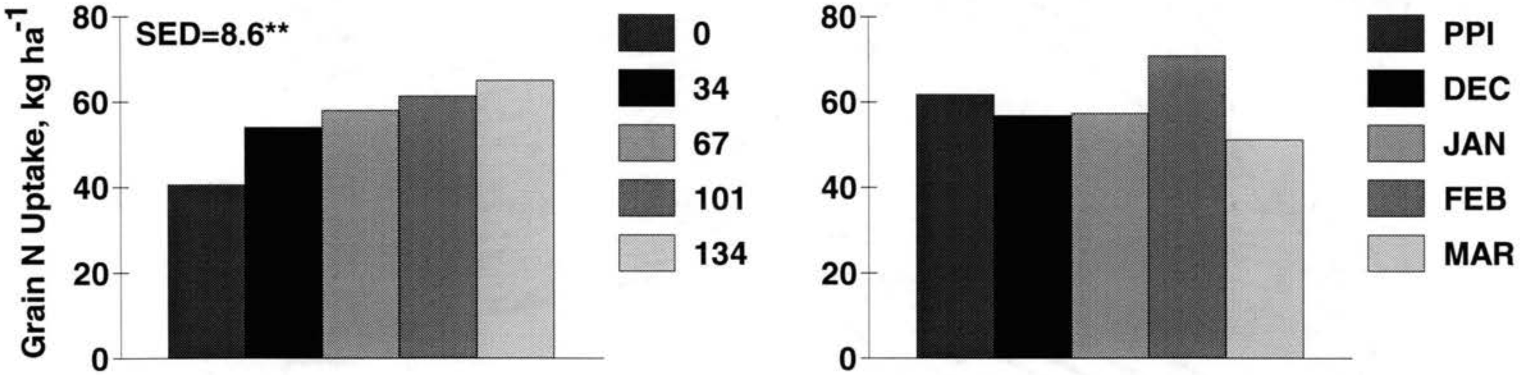

Figure 4. Wheat grain N uptake as affected by N fertilizer rates and dates of application, Hennessey, OK, 1991.

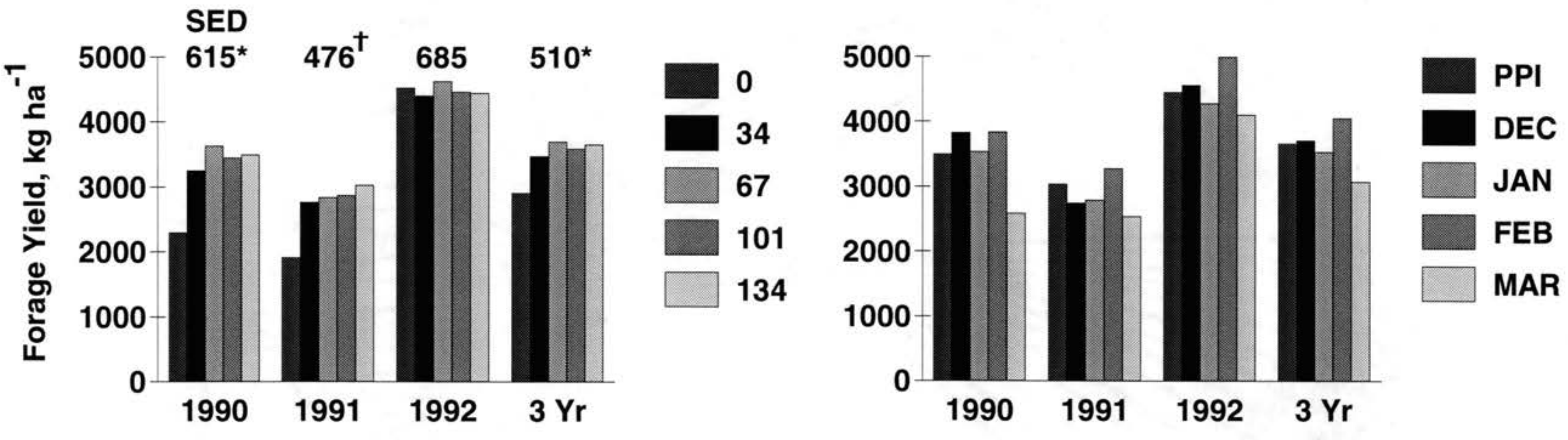

Figure 5. Wheat forage yield as affected by N fertilizer rates and dates of application, Hennessey, OK, 1990-1992.

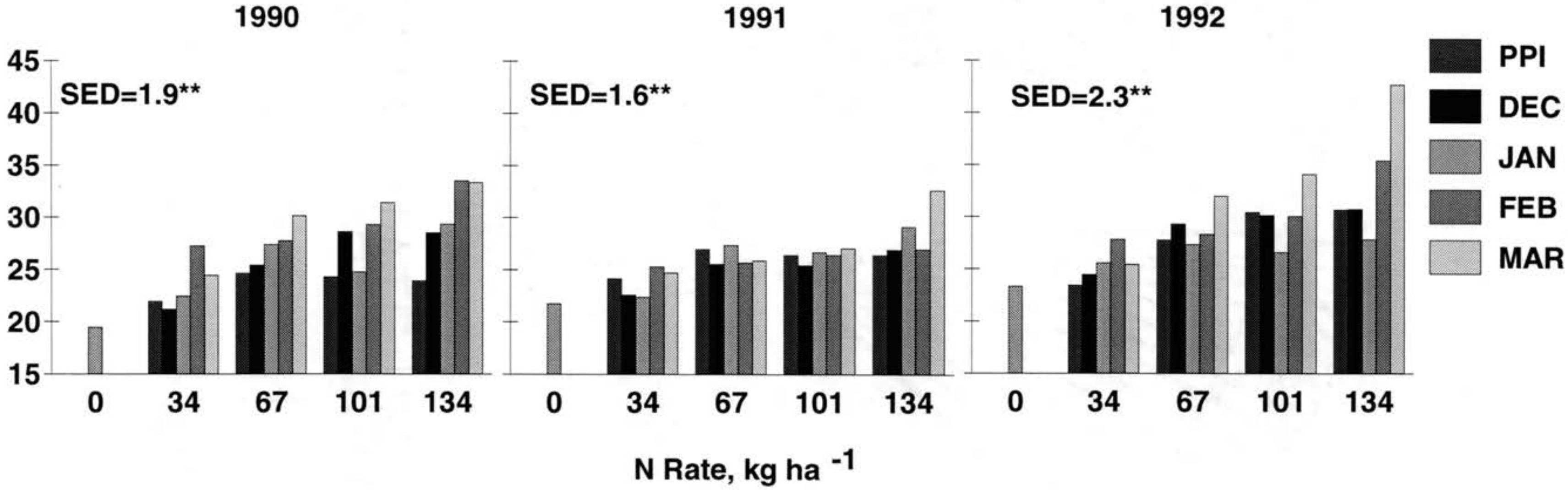

Figure 6. Wheat forage N concentration as affected by N fertilizer rates and dates of application, Hennessey, OK, 1990-1992.

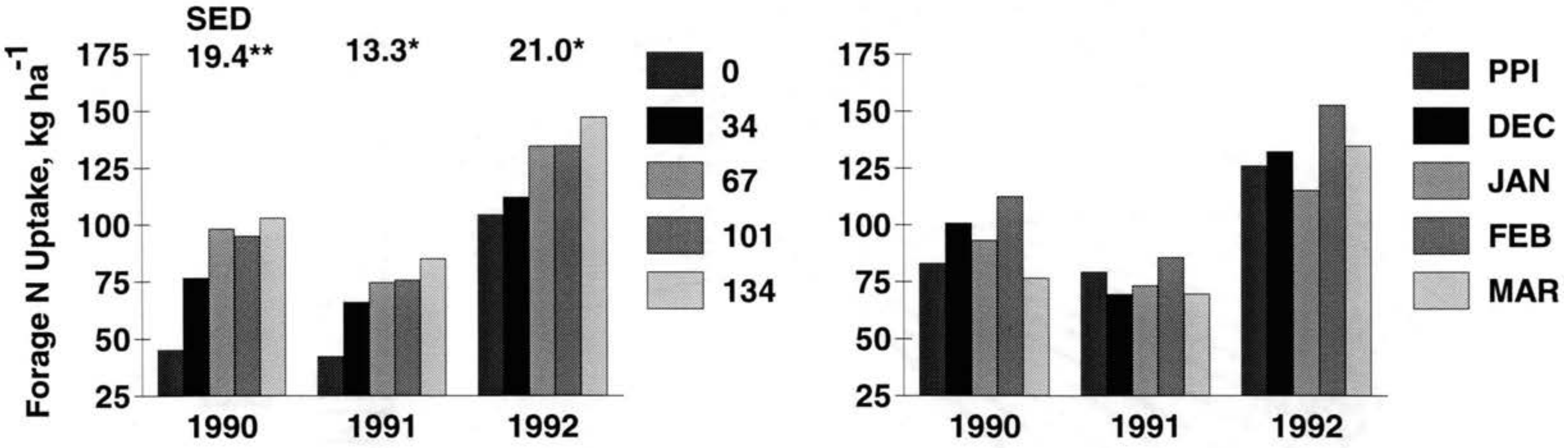

Figure 7. Wheat forage N uptake as affected by N fertilizer rates and dates of application, Hennessey, OK, 1990-1992.

APPENDIX B

MATERIAL RELATED TO CHAPTER II

Table 1. Treatment and main effect means for grain N concentration at Perkins, OK, 1991-1993.

	Grain N Year		
	1991	1992	1993
	mg g^{-1}		
Treatment means			
Check	14.8	15.8	18.6
AA Check	15.6	16.7	18.5
AA 34	18.9	16.6	22.5
AA 67	20.8	16.9	24.7
AA 101	21.2	17.3	25.1
UAN 34	16.2	15.3	18.2
UAN 67	16.9	14.6	19.1
UAN 101	19.2	15.3	21.2
UAN+DCD 34	15.3	14.7	18.4
UAN+DCD 67	16.9	16.0	20.2
UAN+DCD 101	18.3	15.8	23.8
SED	0.5	0.5	1.1
CV, %	3.8	4.7	7.5
Source means			
AA	20.3	16.9	24.1
UAN	17.4	15.1	19.5
UAN+DCD	16.8	15.5	20.8
N Rate means			
34	16.8	15.5	19.7
67	18.2	15.8	21.3
101	19.5	16.1	23.4
SED	0.5	0.5	1.2
CV, %	3.9	4.9	7.8

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 2. Analyses of variance for grain N concentration at Perkins, OK, 1991-1993.

		Grain N		
		Year		
Source	df	1991	1992	1993
		Mean squares		
All treatments				
Rep	3	0.918	1.532	20.682***
Trt	10	18.803***	3.250***	28.398***
Error	30	0.459	0.555	2.491
Contrast				
AA Linear	1	68.820***	0.882	97.461***
AA Quadratic	1	8.410***	0.360	12.425*
UAN Linear	1	37.675***	0.903	15.753*
UAN Quadratic	1	0.765	1.380	6.125
UAN+DCD Linear	1	28.800***	0.351	59.85***
UAN+DCD Quadratic	1	0.810	0.855	14.440*
Check vs AA check	1	1.201	1.805	0.020
Source x N Rate				
Rep	3	7.965	0.060	16.692**
Source	2	40.216***	11.480***	66.378***
N Rate	2	22.414***	1.171	40.874***
Source*N Rate	4	0.976	1.046	3.390
Error	24	0.499	0.601	2.801
Contrast				
AA vs UAN	1	48.166***	20.720***	124.215***
UAN vs UAN+DCD	1	2.100	0.960	9.250
N Rate Linear	1	44.826***	2.343*	81.401***
N Rate Quadratic	1	0.002	0.000	0.347
AA vs UAN*N Linear	1	0.455	0.562	0.140
AA vs UAN+DCD*N Linear	1	0.490	0.140	7.425
UAN vs UAN+DCD*N Linear	1	0.000	1.265	5.522

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 3. Treatment and main effect means for grain N concentration at Carrier, OK, 1991-1993.

	Grain N Year		
	1991	1992	1993
	mg g^{-1}		
Treatment means			
Check	30.5	29.6	24.9
AA Check	29.8	28.7	24.6
AA 34	31.5	30.1	25.3
AA 67	31.3	30.6	25.9
AA 101	31.8	31.2	26.3
UAN 34	30.0	29.8	24.9
UAN 67	31.2	30.5	26.5
UAN 101	31.9	30.3	26.6
UAN+DCD 34	27.4	29.2	24.7
UAN+DCD 67	31.1	29.9	25.3
UAN+DCD 101	31.5	30.1	26.2
SED	1.6	0.5	0.8
CV, %	7.3	2.4	4.6
Source means			
AA	31.5	30.6	25.8
UAN	31.0	30.2	26.0
UAN+DCD	30.0	29.7	25.4
N Rate means			
34	29.6	29.7	25.0
67	31.2	30.3	25.9
101	31.7	30.5	26.4
SED	1.8	0.5	0.8
CV, %	8.0	2.6	4.5

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 4. Analyses of variance for grain N concentration at Carrier, OK, 1991-1993.

		Grain N Year		
Source	df	1991	1992	1993
			Mean squares	
All treatments				
Rep	3	7.816	0.930	2.960
Trt	10	6.759	1.930**	2.306
Error	30	5.128	0.528	1.416
Contrast				
AA Linear	1	6.498	0.132***	6.612*
AA Quadratic	1	1.322	0.680	0.062
UAN Linear	1	6.328	1.404	8.911*
UAN Quadratic	1	1.500	0.160	0.005
UAN+DCD Linear	1	8.911	0.903	4.278
UAN+DCD Quadratic	1	12.075	0.330	1.380
Check vs AA check	1	0.781	1.805	0.151
Source x N Rate				
Rep	3	6.281	0.919	2.625
Source	2	7.547	2.520*	1.170
N Rate	2	14.508	2.267*	6.180*
Source*N Rate	4	4.889	0.205	0.430
Error	24	6.154	0.632	1.369
Contrast				
AA vs UAN	1	1.401	1.260	0.135
UAN vs UAN+DCD	1	6.826	1.260	2.160
N Rate Linear	1	26.881*	4.083*	12.041**
N Rate Quadratic	1	2.135	0.451	0.320
AA vs UAN*N Linear	1	2.640	0.390	0.422
AA vs UAN+DCD*N Linear	1	14.062	0.040	0.275
UAN vs UAN+DCD*N Linear	1	4.515	0.180	0.015

*, **, *** - Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 5. Treatment and main effect means for soil NO_3-N at Carrier, OK, 1991.

Treatment	Depth, cm					
	0-15	15-30	30-45	45-60	60-90	90-120
	mg NO_3-N kg^{-1} soil					
Check	5.5	15.8	23.7	8.6	6.4	4.7
AA Check	6.6	13.9	22.7	4.2	1.6	1.4
AA 34	17.7	31.1	30.1	8.9	2.0	1.3
AA 67	14.6	28.2	28.9	10.2	3.5	2.1
AA 101	12.3	34.2	23.6	6.0	5.2	5.7
UAN 34	9.3	21.9	33.5	5.6	4.7	4.1
UAN 67	8.3	11.8	22.3	12.0	3.9	1.8
UAN 101	7.7	16.8	21.9	6.2	4.9	4.6
UAN+DCD 34	6.7	7.8	14.0	4.1	0.9	0.7
UAN+DCD 67	9.0	25.1	37.2	8.3	4.2	2.4
UAN+DCD 101	14.1	24.6	23.1	11.0	6.2	3.2
SED	3.8	9.5	7.9	4.3	2.6	2.4
CV, %	52	64	43	78	93	118
Source						
AA	14.9	31.1	27.5	8.4	3.5	3.0
UAN	8.4	16.8	25.9	7.9	4.5	3.5
UAN+DCD	10.0	19.2	24.8	7.8	3.8	2.1
N Rate						
34	11.2	20.3	25.9	6.2	2.5	2.0
67	10.7	21.7	29.4	10.2	3.9	2.1
101	11.4	25.2	22.9	7.7	5.4	4.5
SED	4.2	9.8	8.1	3.9	2.2	2.3
CV, %	53	62	44	68	80	114

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 6. Treatment and main effect means for soil NO_3-N, Carrier, OK, 1992.

Treatment	Depth, cm 0-15	 15-30	 30-45	 45-60	 60-90	 90-120
	mg NO_3-N kg^{-1} soil					
Check	10.0	6.2	8.9	12.7	14.6	10.4
AA Check	7.5	4.8	5.3	9.5	13.3	7.1
AA 34	9.7	10.3	11.4	10.9	15.0	10.1
AA 67	9.4	9.7	13.2	16.8	18.6	9.8
AA 101	14.6	9.2	11.3	18.5	20.7	11.2
UAN 34	9.2	11.8	19.3	19.2	11.7	7.8
UAN 67	10.7	6.4	9.1	13.5	11.3	5.3
UAN 101	13.1	9.6	15.2	17.5	12.4	6.3
UAN+DCD 34	9.2	6.9	8.6	9.5	7.0	4.3
UAN+DCD 67	10.8	9.5	15.1	19.2	12.3	3.5
UAN+DCD 101	20.1	20.0	21.8	19.8	16.8	7.7
SED	4.8	6.3	8.0	6.7	4.3	3.6
CV, %	60	93	89	62	43	67
Source						
AA	11.2	9.7	12.0	15.4	18.1	10.4
UAN	11.0	9.3	14.6	16.7	11.8	6.5
UAN+DCD	13.4	12.1	15.1	16.2	12.0	5.2
N Rate						
34	9.4	9.6	13.1	13.2	11.2	7.4
67	10.3	8.6	12.5	16.5	14.1	6.2
101	15.9	12.9	16.1	18.6	16.6	8.4
SED	5.1	7.0	8.8	7.3	4.4	2.3
CV, %	61	94	89	64	45	45

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

Table 7. Treatment and main effect means for soil NO_3-N at Carrier, OK, 1993.

Treatment	Depth, cm					
	0-15	15-30	30-45	45-60	60-90	90-120
	mg NO_3-N kg^{-1} soil					
Check	6.9	3.7	2.2	1.6	2.2	5.8
AA Check	9.5	5.3	4.0	4.9	4.1	3.7
AA 34	7.7	5.0	4.0	4.7	8.4	12.6
AA 67	7.7	7.2	5.9	4.7	5.0	7.1
AA 101	6.1	6.4	5.8	3.2	5.2	9.8
UAN 34	7.1	4.1	2.1	2.0	4.2	4.3
UAN 67	9.1	6.4	6.7	7.5	7.8	8.8
UAN 101	8.1	4.6	2.8	2.5	5.5	8.0
UAN+DCD 34	6.7	4.5	2.7	2.2	2.0	3.0
UAN+DCD 67	6.7	3.9	3.4	4.0	5.9	5.6
UAN+DCD 101	8.3	5.2	3.7	4.5	6.6	9.2
SED	1.3	1.8	2.2	2.3	2.8	4.5
CV, %	25	49	79	84	77	90
Source						
AA	7.2	6.2	5.2	4.2	6.2	9.8
UAN	8.1	5.0	3.8	4.0	5.8	7.0
UAN+DCD	7.3	4.5	3.3	3.6	4.8	6.0
N Rate						
34	7.2	4.5	2.9	3.0	4.9	6.6
67	7.9	5.8	5.3	5.4	6.2	7.2
101	7.5	5.4	4.1	3.4	5.7	9.0
SED	1.4	1.7	2.2	2.4	2.8	4.6
CV, %	26	45	76	86	71	86

SED - standard error of the difference of two treatment means.
CV - coefficient of variation.

SAS PROGRAM FOR PERKINS N TOPDRESS EXPERIMENT
SINGLE DEGREE OF FREEDOM NON-ORTHOGONAL CONTRASTS USING PROC GLM
BY YEAR AND COMBINED ANALYSIS

```
OPTIONS LINESIZE=78;
DATA ONE; INFILE ’B:P919293P.TXT’;
INPUT YR REP TRT NSOURCE NRATE PLOTWT BUSHELS NPCT GNUP;
    KG_HA=BUSHELS*60*1.12;
    GNUP_KG=GNUP*1.12;
PROC SORT DATA=ONE; BY YR REP TRT;
DATA TWO; SET ONE;
    IF NRATE=0 THEN NRATE=1;
    IF YR = 1991 AND REP=1
          THEN PCTFNREC=((GNUP-21.7)/NRATE)*100;
    IF YR = 1991 AND REP=2
          THEN PCTFNREC=((GNUP-19.5)/NRATE)*100;
    IF YR = 1991 AND REP=3
          THEN PCTFNREC=((GNUP-24.8)/NRATE)*100;
    IF YR = 1991 AND REP=4
          THEN PCTFNREC=((GNUP-22.0)/NRATE)*100;
    IF YR = 1991 AND TRT=1 THEN PCTFNREC=0;
    IF YR = 1991 AND TRT=2 THEN PCTFNREC=0;
    IF YR = 1992 AND REP=1
          THEN PCTFNREC=((GNUP-11.3)/NRATE)*100;
    IF YR = 1992 AND REP=2
          THEN PCTFNREC=((GNUP-9.8)/NRATE)*100;
    IF YR = 1992 AND REP=3
          THEN PCTFNREC=((GNUP-12.6)/NRATE)*100;
    IF YR = 1992 AND REP=4
          THEN PCTFNREC=((GNUP-11.2)/NRATE)*100;
    IF YR = 1992 AND TRT=1 THEN PCTFNREC=0;
    IF YR = 1992 AND TRT=2 THEN PCTFNREC=0;
    IF YR = 1993 AND REP=1
          THEN PCTFNREC=((GNUP-38.4)/NRATE)*100;
    IF YR = 1993 AND REP=2
          THEN PCTFNREC=((GNUP-27.4)/NRATE)*100;
    IF YR = 1993 AND REP=3
          THEN PCTFNREC=((GNUP-31.0)/NRATE)*100;
    IF YR = 1993 AND REP=4
          THEN PCTFNREC=((GNUP-32.2)/NRATE)*100;
    IF YR = 1993 AND TRT=1 THEN PCTFNREC=0;
    IF YR = 1993 AND TRT=2 THEN PCTFNREC=0;
PROC SORT DATA=TWO; BY YR REP TRT;
DATA THREE; SET TWO;
KEEP YR REP TRT PCTFNREC;
DATA FOUR; MERGE ONE THREE; BY YR REP TRT;
PROC SORT DATA=FOUR; BY YR REP TRT;
PROC GLM DATA=FOUR; BY YR;
    CLASS REP TRT;
    MODEL BUSHELS KG_HA NPCT GNUP GNUP_KG PCTFNREC =REP TRT;
        CONTRAST ’AA LINEAR’ TRT 0 -3 -1 1 3;
        CONTRAST ’AA QUAD’ TRT 0 1 -1 -1 1;
        CONTRAST ’UAN LINEAR’ TRT -3 0 0 0 0 -1 1 3 ;
        CONTRAST ’UAN QUAD’ TRT 1 0 0 0 0 -1 -1 1 ;
        CONTRAST ’UAN+DCD LIN’ TRT -3 0 0 0 0 0 0 0 -1 1 3;
        CONTRAST ’UAN+DCD QUAD’ TRT 1 0 0 0 0 0 0 0 -1 -1 1;
        CONTRAST ’CHK VS AACHCK’ TRT -1 1;
        CONTRAST ’AA30 VS UAN30’ TRT 0 0 -1 0 0 1;
```

```
      CONTRAST ’AA60 VS UAN60’ TRT 0 0 0 -1 0 0 1;
      CONTRAST ’AA90 VS UAN90’ TRT 0 0 0 0 -1 0 0 1;
      CONTRAST ’UAN30 VS UAN+DCD30’ TRT 0 0 0 0 0 -1 0 0 1;
      CONTRAST ’UAN60 VS UAN+DCD60’ TRT 0 0 0 0 0 0 -1 0 0 1;
      CONTRAST ’UAN90 VS UAN+DCD90’ TRT 0 0 0 0 0 0 0 -1 0 0 1;
      CONTRAST ’AA VS UAN’ TRT 0 0 -1 -1 -1 1 1 1;
      CONTRAST ’AA VS UAN+DCD’ TRT 0 0 -1 -1 -1 0 0 0 1 1 1;
      CONTRAST ’UAN VS UAN+DCD’ TRT 0 0 0 0 0 -1 -1 -1 1 1 1;
   MEANS TRT;
PROC GLM DATA=FOUR;
   CLASSES REP TRT YR;
   MODEL BUSHELS KG_HA NPCT GNUP GNUP_KG PCTFNREC
   =REP TRT REP*TRT YR YR*TRT;
   TEST H = REP TRT
   E = REP*TRT;
   CONTRAST ’AA LINEAR’ TRT 0 -3 -1 1 3 /E=REP*TRT;
   CONTRAST ’AA QUAD’ TRT 0 1 -1 -1 1 /E=REP*TRT;
   CONTRAST ’UAN LINEAR’ TRT -3 0 0 0 0 -1 1 3/E=REP*TRT;
   CONTRAST ’UAN QUAD’ TRT 1 0 0 0 0 -1 -1 1/E=REP*TRT;
   CONTRAST ’UAN+DCD LIN’ TRT -3 0 0 0 0 0 0 0 -1 1 3/E=REP*TRT;
   CONTRAST ’UAN+DCD QUAD’ TRT 1 0 0 0 0 0 0 0 -1 -1 1/E=REP*TRT;
   CONTRAST ’CHK VS AACHCK’ TRT -1 1/E=REP*TRT;
   CONTRAST ’AA30 VS UAN30’ TRT 0 0 -1 0 0 1/E=REP*TRT;
   CONTRAST ’AA60 VS UAN60’ TRT 0 0 0 -1 0 0 1/E=REP*TRT;
   CONTRAST ’AA90 VS UAN90’ TRT 0 0 0 0 -1 0 0 1/E=REP*TRT;
   CONTRAST ’UAN30 VS UAN+DCD30’ TRT 0 0 0 0 0 -1 0 0 1/E=REP*TRT;
   CONTRAST ’UAN60 VS UAN+DCD60’ TRT 0 0 0 0 0 0 -1 0 0 1/E=REP*TRT;
   CONTRAST ’UAN90 VS UAN+DCD90’ TRT 0 0 0 0 0 0 0 -1 0 0 1/E=REP*TRT;
   CONTRAST ’AA VS UAN’ TRT 0 0 -1 -1 -1 1 1 1/E=REP*TRT;
   CONTRAST ’AA VS UAN+DCD’ TRT 0 0 -1 -1 -1 0 0 0 1 1 1/E=REP*TRT;
   CONTRAST ’UAN VS UAN+DCD’ TRT 0 0 0 0 0 -1 -1 -1 1 1 1/E=REP*TRT;
   MEANS TRT YR YR*TRT;
DATA FIVE; SET FOUR;
   IF TRT < 3 THEN DELETE;
PROC SORT DATA=FIVE; BY YR REP NSOURCE NRATE;
PROC GLM DATA=FIVE; BY YR;
   CLASSES REP NSOURCE NRATE;
   MODEL BUSHELS KG_HA NPCT GNUP GNUP_KG PCTFNREC =REP
      NSOURCE NRATE NSOURCE*NRATE;
  CONTRAST ’AA VS UAN’ NSOURCE 1 -1 0;
  CONTRAST ’AA VS UAN+DCD’ NSOURCE 1 0 -1;
  CONTRAST ’UAN VS UAN+DCD’ NSOURCE 0 1 -1;
  CONTRAST ’NRATE LINEAR’ NRATE -1 0 1;
  CONTRAST ’NRATE QUADRATIC’ NRATE 1 -2 1;
  CONTRAST ’AA VS UAN * NLIN’ NSOURCE*NRATE
      -1 0 1 1 0 -1 0 0 0;
  CONTRAST ’AA VS UAN * NQUAD’ NSOURCE*NRATE
       1 -2 1 -1 2 -1 0 0 0;
  CONTRAST ’AA VS UAN+DCD * NLIN’ NSOURCE*NRATE
       -1 0 1 0 0 0 1 0 -1;
  CONTRAST ’AA VS UAN+DCD* NQUAD’ NSOURCE*NRATE
        1 -2 1 0 0 0 -1 2 -1;
  CONTRAST ’UAN VS UAN+DCD*NLIN’ NSOURCE*NRATE
        0 0 0 -1 0 1 1 0 -1;
  CONTRAST ’UAN VS UAN+DCD*NQUAD’ NSOURCE*NRATE
        0 0 0 1 -2 1 -1 2 -1;
  MEANS NSOURCE NRATE NSOURCE*NRATE;
PROC GLM DATA=FIVE;
   CLASSES YR REP NSOURCE NRATE;
```

```
      MODEL BUSHELS KG_HA NPCT GNUP GNUP_KG PCTFNREC
      = REP NSOURCE NRATE NSOURCE*NRATE REP*NSOURCE*NRATE YR
        YR*NSOURCE YR*NRATE YR*NSOURCE*NRATE;
      TEST H = REP NSOURCE NRATE NSOURCE*NRATE
           E = REP*NSOURCE*NRATE;
     CONTRAST 'AA VS UAN’ NSOURCE 1 -1 0/E=REP*NSOURCE*NRATE;
     CONTRAST 'AA VS UAN+DCD’ NSOURCE 1 0 -1/E=REP*NSOURCE*NRATE;
     CONTRAST 'UAN VS UAN+DCD’ NSOURCE 0 1 -1/E=REP*NSOURCE*NRATE;
     CONTRAST 'NRATE LINEAR’ NRATE -1 0 1/E=REP*NSOURCE*NRATE;
     CONTRAST 'NRATE QUADRATIC’ NRATE 1 -2 1/E=REP*NSOURCE*NRATE;
     CONTRAST 'AA VS UAN * NLIN’ NSOURCE*NRATE
         -1 0 1 1 0 -1 0 0 0/E=REP*NSOURCE*NRATE;
     CONTRAST 'AA VS UAN * NQUAD’ NSOURCE*NRATE
          1 -2 1 -1 2 -1 0 0 0/E=REP*NSOURCE*NRATE;
     CONTRAST 'AA VS UAN+DCD * NLIN’ NSOURCE*NRATE
          -1 0 1 0 0 0 1 0 -1/E=REP*NSOURCE*NRATE;
     CONTRAST 'AA VS UAN+DCD* NQUAD’ NSOURCE*NRATE
           1 -2 1 0 0 0 -1 2 -1/E=REP*NSOURCE*NRATE;
     CONTRAST 'UAN VS UAN+DCD*NLIN’ NSOURCE*NRATE
           0 0 0 -1 0 1 1 0 -1/E=REP*NSOURCE*NRATE;
     CONTRAST 'UAN VS UAN+DCD*NQUAD’ NSOURCE*NRATE
           0 0 0 1 -2 1 -1 2 -1/E=REP*NSOURCE*NRATE;
      CONTRAST 'YR 1 VS YR 2’ YR -1 1 0;
      CONTRAST 'YR 1 VS YR 3’ YR -1 0 1;
      CONTRAST 'YR 2 VS YR 3’ YR 0 -1 1;
      CONTRAST 'YR 1,2 VS YR 3’ YR -1 -1 2;
      CONTRAST 'YR 1,3 VS YR 2’ YR -1 2 -1;
      CONTRAST 'YR 2,3 VS YR 1’ YR 2 -1 -1;
      MEANS NSOURCE NRATE NSOURCE*NRATE YR YR*NSOURCE YR*NRATE
           YR*NSOURCE*NRATE;
RUN; QUIT;
```

SAS PROGRAM FOR PERKINS EXPERIMENT
QUADRATIC RESPONSE SURFACE REGRESSION ANALYSIS USING PROC RSREG

```
OPTIONS LINESIZE=78;
DATA ONE; INFILE 'C:\NTIM\PK9093P.TXT’;
    INPUT YR REP TRT RATE DATE DRYWT PLOTWT FORNPCT GRNNPCT;
    IF TRT=1 THEN DELETE;
    IF REP=4 THEN DELETE;
    IF YR=1990 THEN FYIELD=(DRYWT/97)*100;
    IF YR=1990 THEN GYIELD=(PLOTWT/24)*100;
    IF YR=1991 THEN FYIELD=(DRYWT/164)*100;
    IF YR=1991 THEN GYIELD=(PLOTWT/24.6)*100;
    IF YR=1992 THEN FYIELD=(DRYWT/102)*100;
    IF YR=1992 THEN GYIELD=(PLOTWT/24)*100;
    IF YR=1993 THEN FYIELD=(DRYWT/167)*100;
    IF YR=1993 THEN GYIELD=(PLOTWT/23.65)*100;
    IF DATE=1 THEN DAP=0;
    IF YR=1990 AND DATE=2 THEN DAP=68;
    IF YR=1990 AND DATE=3 THEN DAP=96;
    IF YR=1990 AND DATE=4 THEN DAP=131;
    IF YR=1990 AND DATE=5 THEN DAP=161;
    IF YR=1991 AND DATE=2 THEN DAP=59;
```

```
    IF YR=1991 AND DATE=3 THEN DAP=93;
    IF YR=1991 AND DATE=4 THEN DAP=123;
    IF YR=1991 AND DATE=5 THEN DAP=154;
    IF YR=1992 AND DATE=2 THEN DAP=82;
    IF YR=1992 AND DATE=3 THEN DAP=112;
    IF YR=1992 AND DATE=4 THEN DAP=144;
    IF YR=1992 AND DATE=5 THEN DAP=168;
    IF YR=1993 AND DATE=2 THEN DAP=74;
    IF YR=1993 AND DATE=3 THEN DAP=102;
    IF YR=1993 AND DATE=4 THEN DAP=137;
    IF YR=1993 AND DATE=5 THEN DAP=158;
FILENAME GRAFOUT 'C:\NTIM\FDR.GSF';
GOPTIONS NODISPLAY GSFMODE=REPLACE  DEVICE=VGA16
  GSFNAME=GRAFOUT  GWAIT=15 FBY=XSWISS HBY = 1.75 GOUTTYPE=DEPENDENT;
TITLE F=XSWISS 'PERKINS ALL YEARS';
PROC RSREG DATA = ONE OUT = PIG;
  MODEL FYIELD = DAP RATE/PREDICT;
PROC G3GRID DATA = PIG OUT = DOG;
  GRID RATE*DAP=FYIELD/SPLINE;
PROC G3D DATA = DOG GOUT=NEW;
  PLOT RATE*DAP=FYIELD/
        ZMIN = 0
        ZMAX = 100;
RUN;
FILENAME GRAFOUT 'C:\NTIM\GDR.GSF';
PROC RSREG DATA = ONE OUT = CAT;
  MODEL GYIELD = DAP RATE/PREDICT;
PROC G3GRID DATA = CAT OUT = BIRD;
  GRID RATE*DAP=GYIELD/SPLINE;
PROC G3D DATA = BIRD GOUT=NEW;
  PLOT RATE*DAP=GYIELD/
        ZMIN = 0
        ZMAX = 100;
FILENAME GRAFOUT 'C:\NTIM\GFD.GFD';
DATA TWO; SET ONE;
  PROC SORT; BY DATE;
PROC RSREG DATA = TWO OUT = FROG; BY DATE;
  MODEL FYIELD = GYIELD RATE/PREDICT;
PROC G3GRID DATA = FROG OUT = MOOSE; BY DATE;
  GRID GYIELD*RATE=FYIELD/SPLINE;
PROC G3D DATA = MOOSE GOUT=NEW; BY DATE;
  PLOT GYIELD*RATE=FYIELD/
        ZMIN = 0
        ZMAX = 100;
RUN; QUIT;
```

VITA 2

Randal Keith Boman

Candidate for the Degree of

Doctor of Philosophy

Thesis: NITROGEN FERTILIZER MANAGEMENT EXPERIMENTS: RATES, APPLICATION TIMES, SOURCES, AND RESIDUAL NITRATE IN SOILS CROPPED TO WINTER WHEAT AND RATES VERSUS MEPIQUAT CHLORIDE IN SHORT-SEASON COTTON

Major Field: Soil Science

Biographical:

Personal Data: Born October 5, 1957, in Frederick, OK, a son of William G., Jr., and Velma Lorene (Saville) Boman; and married Dayna Darlene Walker on December 24, 1977. A son, William Derek, was born May 19, 1982. A second son, James Blake, was born March 11, 1985.

Education: Graduated from Snyder High School, Snyder, OK, in May, 1975; received the Bachelor of Science in Agriculture degree in Agronomy from Oklahoma State University, Stillwater, in May, 1979; received the Master of Science degree in Agronomy from Oklahoma State University in December, 1981; and completed the requirements for the Doctor of Philosophy degree in Soil Science from Oklahoma State University in May, 1994.

Professional Experience: Graduate Research Assistant, Oklahoma State University, 1979-1981. Soil Fertility Consultant, Young's Farm and Garden, Tipton, OK, January, 1982 to July, 1982. Assistant Superintendent, OSU Southwest Oklahoma Agronomy Research Stations, July, 1982 to March, 1987. Superintendent, OSU Southwest Oklahoma Agronomy Research Stations, April, 1987, to May, 1988. Senior Agriculturist in OSU Soil Fertility Project, June, 1988 to the present.

Member: American Society of Agronomy, Soil Science Society of America, and Sigma Xi