INFLUENCE OF LATE-SEASON FOLIAR NITROGEN APPLICATIONS ON GRAIN PROTEIN IN WINTER WHEAT

By

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Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1997

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment
of the requirements for
the Degree of
MASTER OF SCIENCE
May, 2000

INFLUENCE OF LATE-SEASON FOLIAR NITROGEN

APPLICATIONS ON GRAIN PROTEIN

IN WINTER WHEAT

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ACKNOWLEGEMENTS

I would like to express my appreciation to Oklahoma State University Plant and Soil Sciences Department for the many opportunities which I have been allowed to pursue. In special recognition, I owe a great deal of respect to my major advisor Dr. William R. Raun for his stamina, focus, and guidance. My advisor along with members of the Soil Fertility project made this research possible. This special team of individuals includes: Steven Phillips, Wade Thomason, Jeremy Dennis, Joanne LaRuffa, Tina Johnston, Darin Drury, Shawn Norton, Corey Lively, Kathie Wynn, Robert Mullen, Erna Lukina, Drew Conklin, and Aaron Witt. The working environment offered by my fellow colleagues/close friends was invaluable in the pursuit of this degree. I would also like to thank committee members Dr. Gordon Johnson and Dr. Eugene Krenzer for their time and input required for this study. Dr. Gordon Johnson's experience and excellence in explaining subject matter is, and always will be, invaluable. A special debt is owed to Mr. Doug Cossey for his friendship and editorial contributions.

Finally, I would like to thank my family Curtis, Wynelda, and Kristen Miller, and my father J.R. Woolfolk for the unequalled support that they have given me.

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ABSTRACT

Increasing grain protein in new higher yielding cereal grains is often difficult. Hard red winter wheat (*Triticum aestivum* L.) studies were conducted at two locations in Oklahoma in 1997-98 and 1998-99 to evaluate the effects of late-season foliar N applications on grain yield, total grain N (grain protein in percent = total grain N in g $kg^{-1}/10 * 5.7$), straw yield, and total straw nitrogen. Simulated aerial applications of N were made at two different times, relative to wheat stage of growth (pre and post flowering), using urea-ammonium nitrate (UAN) at rates of 0, 11, 22, 33, and 44 kg N ha^{-1}. Ammonium sulfate [AS-$(NH_4)_2SO_4$] was also applied at a single rate of 22 kg N ha^{-1} both pre and post flowering, but did not produce differing results from that of UAN. Limited foliar burn was observed, however, there was a tendency for increased foliar burn with AS compared to UAN. In both years and at both sites, a significant linear increase in total grain N was observed for post flowering application times using UAN. In three out of the four site-years, a significant linear increase was observed for preflowering application times using UAN. No consistent increases or decreases were observed for grain yield, straw yield, or straw N from foliar N applications. Late-season foliar nitrogen applications prior to or immediately following flowering may significantly enhance total grain N and thus protein contents in winter wheat.

INTRODUCTION

Grain protein is the most important factor in determining milling and baking quality of wheat. Market adjustments for wheat have been established worldwide based on protein content, with premiums commonly paid for increases above baseline levels. In hard red winter wheat, grain protein contents less than 11.5-12 % often do not attract protein premiums and may indicate N deficiencies (Strong,1982). The desired protein of wheat is dependent upon the type and/or use of the wheat. High protein content is desirable in hard red winter wheat varieties. Bread flour, certain foods (i.e., macaroni and egg noodles), and animal feeds require a high protein content (12-16 %), while low protein content (8-11 %) is preferred in many soft red winter wheats (Hunter and Stanford, 1973). Nitrogen (N) is the essential component of amino acids, thus proteins, within a plant. Early investigations concluded that climate was the influencing factor for grain protein, but as soil N became more limiting, it became apparent that grain protein levels in the High Plains region of the U.S. were being limited by N deficiencies (Daigger et al., 1976). Many have studied content of N in the wheat plant to better understand the nutrition of wheat. A better understanding of N content and distribution within the wheat plant would enable researchers to increase the effectiveness of N fertilization. As native soil fertility levels continue to decline and environmental concerns heighten, the need for efficient use of inorganic fertilizers, especially nitrogen, continues to increase. While most nitrogen fertilizers are highly effective and have been extensively studied, increasing nitrogen use efficiency (NUE) has not been a priority in agricultural research until recently. A better scientific understanding involving the efficient use of nitrogen fertilizers is essential for sustained economic crop production, environmental stewardship, and increased grain quality in wheat.

Although constantly surrounded by nitrogen in the atmosphere, humans cannot synthesize this element from the air to produce crucial proteins and other biological molecules essential for life. While only a minimal amount of nitrogen can be absorbed and transformed into protein by growing plants and animals, human nutrition relies on these transformations to supply key proteins for life. The movement of nitrogen from the atmosphere to crops is a difficult task, and thus the need for efficient utilization of nitrogen fertilizers by plants for protein becomes imperative. (Smil 1997)

Nitrogen is taken up by the roots of plants as ammonium and nitrate. In wheat and maize, up to 80 % of the nitrate entering the plant passes unaltered through the roots. There is a constant flow and recycling of nitrogen around the plant. Nitrogen taken up and assimilated by the roots passes in the xylem to the shoot, where it may be temporarily stored as protein. This may be degraded to provide amino acids which are re-exported in the phloem to support growth of other parts of the plant. In plants such as wheat, nitrogen is exported from the leaves mainly as glutamine. Much of the nitrogen found in seeds is taken up from the soil before flowering, and may have been cycled several times and into several different organs before reaching the seeds. It is estimated that up to 40 % of seed nitrogen is derived from leaves, and the remaining nitrogen is assimilated during seed fill. The redistribution of nitrogen in cereals during the growing season may be great. Up to 90 % of the nitrogen found in the mature plant may be taken up from the soil by the time the plant is half-grown with 85 % of the nitrogen in wheat leaves being transported to the developing grain. The photosynthetic tissues closest to the spikelet, including the glumes and flag leaves, normally provide much of the nitrogen. (Chesworth, 1998)

Nitrogen use efficiency was defined by Moll et al. (1982) as the amount of grain production per unit of N available in the soil. An important component of this definition includes the efficiency with which N is absorbed and utilized to produce grain. Other components of this definition included: (a) efficiency of the plant to assimilate applied N; (b) efficiency of the soil to supply and retain applied N for plant assimilation; and (c) composite system efficiency. Many considerations must be taken into account when evaluating NUE. Some of these considerations include: soil moisture, soil type, variety of wheat, N source, N application timing, N application method, tillage, N rate, and type of production system. Climatic conditions following N applications are also extremely important factors. The realization that modern cultivated crops often recover less than half of the nitrogen added as fertilizer has only recently been explored. The use of lower fertilizer rates and less demanding hybrid crops in the past have not fully exposed the unacceptable recovery rates of nitrogen by plants such as wheat.

Nitrogen is extremely susceptible to loss when considering that average recovery rates fall in the range of 20-50% for grain production systems in winter wheat. Strong (1982) noted that the introduction of high yielding semi-dwarf wheat varieties had added to the quantity of low protein wheat produced and stated that little or no change in fertilizer strategy had accompanied the shorter, higher yielding wheat cultivars. Cassman et al. (1992) emphasized the complexities of N fertilizer management involved in optimizing both yield and protein in wheat due to the economics of protein premiums.

Wheat producers in the Great Plains typically use two options for applying N fertilizer: (i) all N fall-applied prior to planting or (ii) a small amount of N fall-applied, followed by a late winter or early spring topdressing (Kelley, 1995). Cooper (1974) demonstrated that dryland wheat receiving N at planting or before ear emergence may respond to increases in grain yield, but may have little or no effect on grain protein content. Preplant N applications are designed to eliminate potential nutrient deficiencies. Although preplant fertilizer applications decrease the potential for nutrient deficiencies in early stages of growth, residual soil nitrate-N may pose a risk to the environment. Many researchers have found that preplant applications may lead to losses or immobilization prior to plant uptake, thus greatly affecting NUE (Welch et al., 1966; Olson and Swallow, 1984; Lutcher and Mahler, 1988; Fowler and Brydon, 1989; Wuest and Cassman, 1992a). The common practice of using soil test analysis for adjusting fertilizer N prior to planting does not allow for late-season deficiency symptoms to be corrected. Mascagni and Sabbe (1991) and Boman et al.(1995) found that split applications are extremely important to maximize crop utilization of applied fertilizer N throughout the growing season. Late-season applied nitrogen provides increased management flexibility by allowing farmers to adjust N rates according to crop growth. Late-season N applications may also reduce potential N losses from leaching or denitrification over the winter. Plant availability of N late in the season when soil moisture content is low and root uptake is slowed is particularly necessary for increasing grain protein contents and many times yield (Ellen and Spiertz, 1980).

Management goals of the producer and type of production system are important factors in discussing plant N losses and composite NUE. Wuest and Cassman (1992b) and Moll et al. (1982) reported decreased NUE with increasing N applied for grain production systems of various crops, whereas in forage production systems NUE does not decrease with increasing N applied. Altom et al. (1996) found that forage production systems may have lower plant gaseous N loss (improved NUE) because the plant is never allowed to approach flowering. Gaseous plant N losses in winter wheat have been found to be greatest between anthesis and maturity, and increase with increasing N content in the tops of plants (Hooker et al., 1980; Parton et al., 1988; Wetselaar 1980). Applications of N near flowering have been found to increase post flowering N uptake, grain protein content, and grain protein concentration (Bänziger et al., 1994; Bulman and Smith, 1993).

Yield increases from foliar applications are greatly varied among studies. An early review of this type of research was presented by Finney et al. (1957). They found that nitrogen applied preplant will normally give a response equal to that of nitrogen applied up to tillering. Nitrogen applied after tillering, and up to heading will normally give progressively smaller yield increases. They also found that nitrogen applied after heading usually did not result in yield increases in most years unless N deficiency was severe. Finney proposed that the greatest grain protein increases occurred when foliar nitrogen applications were applied at anthesis (flowering), and that responses declined rapidly before or after that time.

Modern high yielding wheat varieties require large amounts of available N. The amount of N present in the plant at flowering and potentially utilizable for remobilization to the grain may not meet this requirement. Spiertz (1983) found that with a regular nitrogen supply, wheat will usually attain 65-80% of its grain nitrogen from the vegetative parts, with the remainder originating from root uptake after flowering. Bhatia and Rabson (1976) found that cereals with a typical protein concentration would require an additional 6-11% nitrogen for a 1 percent increase in grain protein, depending on the crop variety and the initial protein concentration within the plant. Wuest and Cassman (1992) found that while the availability of soil N and water may often constrain post flowering N uptake, applications of N near flowering were found to increase post flowering N uptake, grain protein content and grain protein concentrations. Dhugga and Waines (1989) postulated that the N uptake capacity of grain is a determining factor for post flowering N uptake. Austin et al. (1977) found a negative correlation between dry weight loss from the straw and N uptake during grain fill.

In a five year study, Olson and Swallow (1984) found that 27-33% of the applied N fertilizer was removed by the grain over the time of the experiment. Harper et al. (1987) reported that 21% of the applied N fertilizer was lost as volatile NH_3, 11.4% was lost from both the soil and plants soon after fertilization, and 9.8% was lost from the leaves of wheat between anthesis and physiological maturity. Francis et al. (1993) summarized that the failure to include direct plant N losses when calculating a N budget led to an overestimation of N loss from the soil by denitrification, leaching and ammonia volatilization. Kanampiu et al. (1997) proposed estimating potential plant N loss by subtracting the N (grain + straw) removed at harvest from the N uptake at flowering (pt. of max. N accumulation). More N is assimilated at earlier stages of growth, therefore, uptake efficiency should be estimated at the stage of maximum N accumulation and not at maturity when less N can be accounted for.

Increasing grain protein content by applying higher rates of fertilizer is relatively inefficient (NUE decreases with increasing N level), especially under dry soil conditions

(Gauer et al., 1992). In-season N applied with point injection or topdressing can maintain or increase NUE compared with preplant N in wheat (Sowers et al., 1994).
As discussed by Raun and Johnson (1999), late season foliar N is critical when considering increased NUE, thus differences in total grain and straw N.

Sulfur is an important constituent in many amino acids within the plant. Fertilizer applications containing sulfur may lead to increased grain quality due to beneficial N:S ratios within the plant. Gooding and Davies (1992) speculated that improvements in breadmaking quality might be achieved if sulfur nutrition was improved to maintain this ratio in the grain. Sulfur is an important constituent of wheat flour gluten, and if sulfur supply to wheat plants is inadequate, breadmaking quality of the flour is reduced (Griffiths and Kettlewell, 1990).

In this study, late-season foliar applications of nitrogen were applied without dilution in order to simulate aerial applications. Other studies involving foliar applications have involved N source dilution and have shown visual signs of "scorching," "burning," or "tipping" even at relatively low rates and similar sources. Severe burn has also been associated with early morning applications when dew is still on the crop. Gooding and Davies (1992) found increases in leaf burn with AN (ammonium nitrate) and AS (ammonium sulfate) when compared to urea. They further noted three important reasons for foliar applications: (a) foliar application could decrease leaching and/or denitrification; (b) make uptake less dependent on soil conditions; and (c) foliar N applications may suppress disease pressures. Nitrogen uptake prior to or immediately following flowering (the physiological stage of a grass in which anthesis occurs) must be more extensively researched in order to better understand nitrogen use efficiency in winter wheat.

OBJECTIVE

The objective of this experiment was to determine the effects of late-season applications of varying rates of two N fertilizer sources (urea-ammonium nitrate vs. ammonium sulfate) at two times of application (pre vs. post flowering) on grain yield, total grain N, straw yield, and total straw N.

MATERIALS AND METHODS

In October 1997, two studies were initiated at Perkins, Oklahoma on a Teller sandy loam (fine-mixed, thermic, Udic Argiustolls) and Stillwater, Oklahoma on a Kirkland silt loam (fine-mixed, thermic, Udertic Paleustolls). Studies were repeated at both locations in 1998-99. A randomized complete block experimental design was employed at both locations with 3 and 4 replications for the 1997-98 and 1998-99 crop years, respectively. At both sites, plot size was 3.05 x 2.44 m. Results of soil test data from samples collected prior to treatment application are reported in Table 1. Nitrogen and phosphorus fertilizers were applied and incorporated prior to planting under a conventional tillage system (repeated disk incorporation of wheat straw residues following harvest until planting) at both locations. Nitrogen was broadcast applied preplant as ammonium nitrate (N-P-K, 34-0-0) at a rate of 67.2 kg N ha^{-1} the first year and 44.8 kg N ha^{-1} the second year. These rates were based on soil test N and high to moderate yield goals in respective years. Phosphorus, as triple super phosphate (0-46-0), was applied with the nitrogen in 1997 at both locations at a rate of 44.8 kg P ha^{-1} to ensure adequate phosphorus availability over the two year study period. Hard red winter wheat ('Tonkawa') was planted at both sites on October 20, 1997, and October 15, 1998, respectively. Dates of field procedures and environmental conditions for both locations are shown in Tables 2 and 3. At both locations and for both years, wheat was planted in 19 cm rows at a seeding rate of 78.5 kg ha^{-1} .

Relative to the physiological maturity of the wheat plant, foliar applications of nitrogen were applied at preflowering (Feekes 10.5) and post flowering (Feekes 10.5.4) stages of growth (Large, 1954). The treatment structure employed at both sites is reported in Table 4. Foliar N application dates for each experiment were determined by collecting 20 random wheat heads from each experimental area and examining them under a 10x hand lens to assess maturity. Two N sources commonly available in the central Great Plains were evaluated in the study. Liquid UAN (28% N) was foliar applied with no dilution at rates of 0, 11.2, 22.4, 33.6, and 44.8 kg N ha^{-1}. These rates corresponded to volumes of 24, 47. 70, and 93 ml applied to each 7.43 m^2 plot. For the AS solution, 700 g of material (21% N) was dissolved in 1,000 ml of water, resulting in a total volume of 1300 ml (ammonium sulfate crystals occupy less volume when dissolved in water). The AS solution was 8.7% N by weight and 11.4% N by volume, therefore, this solution required a higher volume (114 ml) than UAN to achieve the single rate of 22.4 kg N ha^{-1}. Both nitrogen sources were applied using 175 ml mechanically-pressurized spray bottles (Marianna® Research Labs-#413) in order to simulate an aerial application. Because of the small plot size and application method, spray patterns were simulated on paper prior to each application timing. Sufficient leaf surface, good plant density, and small spray volumes allowed for interception of UAN and AS spray with minimal, if any, runoff of the foliage. Treated plots were visually monitored for variation in leaf burn following the applications. At maturity, wheat was harvested using a Massey Ferguson 8XP combine from a 2.0 x 3.05 m area in each plot. Straw samples were also collected from the harvested area in each plot. Both grain and straw samples were dried and ground to pass a 140 mesh sieve (100um). The samples were analyzed for total N content utilizing a Carlo-Erba NA 1500 Series II dry combustion analyzer (Schepers et al., 1989). Grain N uptake and straw N uptake were calculated by multiplying yield by total N concentration within the respective plant part. Wheat grain protein can be determined by the following: total grain N in g $kg^{-1}/10 * 5.7$ (Martin del Molino, 1991). Treatment effects on grain yield, grain N uptake, grain total N (protein), straw yield, and straw N uptake were evaluated using the PROC GLM procedure (SAS, 1988).

RESULTS AND DISCUSSION

Analysis of variance and associated means for grain yield, grain N uptake, grain N, straw yield, and straw N uptake are reported in Tables 5-8 for Perkins (1998 and 1999) and Stillwater (1998 and 1999), respectively. Single degree of freedom contrasts are also included in each AOV table.

Limited foliar burn was observed at either site in both years. There was, however, a tendency for increased foliar burn with AS compared to UAN applications. Foliar burn from AS at a rate of 22 kg N ha^{-1} was similar to that for UAN applications at 44 kg N ha^{-1}. Increased awn burn was observed with increasing rates of UAN, but even at 44 kg N ha^{-1} there was little visual effect on spikelet or leaf color. Differences between UAN and AS at the 22 kg N ha^{-1} rate applied either pre or post flowering were not consistent for any of the dependent variable analyzed.

Grain yield

With one exception, grain yield increases due to foliar applications of nitrogen were not observed. This exception was found at Stillwater in 1999 where UAN applied preflowering showed a significant quadratic response, and N applied as UAN post flowering showed a significant linear response (Table 8). Maximum grain yields were generally observed when N, as UAN, was applied post flowering at rates between 22 and 33 kg N ha^{-1}, although differences were small. No significant yield differences were noted with AS treatments, although this treatment applied post flowering resulted in the maximum yield at Perkins in 1998 (Table 5).

Grain N uptake

Similar to grain yield data, only limited differences in grain N uptake were observed in either year at both sites. In one out of the four site-years (Stillwater 1999), a significant quadratic trend was observed with preflowering UAN treatments. At this site, grain N uptake decreased at lower N rates and then increased up to 107 kg N ha^{-1} when 44 kg N ha^{-1} was applied preflowering, closely following changes in grain yield (Table 6). However, for all site-years, limited differences were observed among treatments in grain N uptake.

Total N in the grain (protein)

For both years at Stillwater, total grain N was highest with a post flowering UAN application of 44 kg N ha^{-1}. The highest grain N values at Perkins were observed for preflowering AS applications at 22 kg N ha^{-1} and preflowering UAN applications at 33 kg N ha^{-1} for harvest years 1998 and 1999, respectively. Post flowering UAN treatments resulted in a linear increase in total N (grain protein) for both years at both locations. Maximum grain N was achieved at rates between 33 and 44 kg N ha^{-1} applied post flowering as UAN at Stillwater in both years. In three out of the four site-years, preflowering applications of UAN significantly increased grain N (Stillwater 1998 as the exception, Tables 5-8). At Perkins, maximum grain N was observed with AS applied preflowering at 22 kg N ha^{-1} in 1998 and a 33 kg N ha^{-1} preflowering UAN application in 1999. Considering preplant soil test levels (Table 1) and the amount of N applied prior to planting (45-67 kg N ha^{-1}, Tables 2-3) at both sites and both years, it was important to find significant increases in total grain N under moderate to high fertility levels.

Straw yield

Straw yield responses to pre and post flowering N applications were variable at both sites. Straw yield means were highest for post flowering treatments at 11 and 22 kg N ha^{-1} rates for Perkins 1998 and 1999, respectively. At Stillwater straw yields were highest for the check in 1998. In general, differences in straw yield were small regardless of rate or time of application.

Straw N uptake

Differences due to treatment in straw N uptake were generally small excluding Stillwater in 1998. At Stillwater in 1998 (Table 7) straw N uptake ranged from 35 to 73 kg N ha^{-1}, far greater than that observed in other site-years. In 1999 at Stillwater, straw N uptake was greatest when foliar N was applied preflowering as UAN at rates between 22 and 44 kg N ha^{-1}. Similar to grain yield and grain N uptake data, only limited differences in straw N uptake were observed over the two-year period at both sites.

Straw total N

Total straw N results were highly variable. At Perkins, significant linear trends were observed with post UAN applications and pre UAN applications in 1998 and 1999, respectively. In 1998, preflowering AS treatments resulted in higher total straw N than preflowering UAN applications at Perkins (Table 5), however, at Stillwater preflowering applications of UAN increased total straw N over UAN applied post flowering (Table 7). Total straw N at Perkins showed a significant linear trend with post flowering UAN applications in 1998, while the following year showed a significant linear response to preflowering UAN treatments.

CONCLUSIONS

Increased total grain N (grain protein in percent = total grain N in g $kg^{-1}/10 * 5.7$) was observed in three out of the four site-years when N was applied preflowering at the 33.6 kg N ha^{-1} rate. From the increased total grain N values, these preflowering applications resulted in an average total grain N increase of 2.8 g kg^{-1} (1.6 % protein). Increased total grain N was observed at both sites for both years with post flowering applications at the 33.6 kg N ha^{-1} rate. Post flowering applied N as UAN resulted in an average total grain N increase of 2.7 g kg^{-1} (1.5 % protein). In general, grain yield, straw yield, and straw N were not affected by foliar N applications. Apparently, ammonia volatilization losses from UAN were not significant. Late-season foliar N applications prior to or immediately following flowering may significantly enhance total N even under moderate to high fertility conditions. No consistent differences were observed between N sources, AS and UAN, for any of the variables analyzed. Increased total grain N resulting from pre or post flowering applied N may result in higher nutritional value, protein premiums, and thus economic gains.

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Table 1. Initial surface (0-15cm) soil test characteristics and soil classification at Perkins and Stillwater, OK, 1997.

Location	pH[a]	NH_4-N	NO_3-N	P[b]	K[b]	Total N[c]	Organic C[c]
		----------------mg kg^{-1}---------------				-------g kg^{-1}-------	
Perkins	5.8	18.87	4.9	12	140	0.63	4.03
Classification: Teller sandy loam (fine-mixed, thermic Udic Argistolls)							
Stillwater	5.5	3.47	14.7	31	222	0.94	10.51
Classification: Kirkland silt loam (fine-mixed, thermic, Udertic Paleustolls)							

[a]pH: 1:1 soil:water
[b]P and K: Mehlich III extraction
[c]Total N and Organic C: dry combustion

Table 2. Dates of field procedures and environmental conditions for Perkins and Stillwater, OK, 1997-1998.

September 15, 1997	67.2 kg N ha^{-1} blanket of AN (34-0-0) 44.8 kg P ha^{-1} blanket of TSP (0-46-0) applied and incorporated
October 20, 1997	'Tonkawa' planted at 78.5 kg ha^{-1}
April 30,1998	**Preflowering** treatments applied Air temp at application-------- 68^0 F Average daily temp------------ 57.4 Dewpoint------------------------ 47.4 Humidity------------------------ 72 Wind---------------------------- 5 mph W Soil temp------------------------ 56^0 F Rainfall-------------------------- 0.00
May 8,1998	**Post flowering** treatments applied Air temp at application-------- 75^0 F Average daily temp------------ 65.2 Dewpoint------------------------ 51.7 Humidity------------------------ 64 Wind---------------------------- 8 mph E Soil temp------------------------ 66.8^0 F Rainfall-------------------------- 0.00
June 10, 1998	Grain and straw harvest, Stillwater
June 15,1998	Grain and straw harvest, Perkins

Table 3. Dates of field procedures and environmental conditions for Perkins and Stillwater, OK, 1998-1999.

September 16, 1998	44.8 kg N ha^{-1} blanket of AN (34-0-0)
October 15, 1998	'Tonkawa' planted at 78.5 kg ha^{-1}
April 28,1999	**Preflowering** treatments applied
	Air temp at application-------- 65^0 F
	Average daily temp------------ 59^0 F
	Dewpoint-----------------------53.5
	Humidity----------------------- 83
	Wind---------------------------- 5 mph W
	Soil temp----------------------- 63^0 F
	Rainfall------------------------- 0.00
May 8,1999	**Post flowering** treatments applied
	Air temp at application-------- 62^0 F
	Average daily temp------------ 70^0 F
	Dewpoint----------------------- 55
	Humidity----------------------- 63
	Wind---------------------------- 8 mph E
	Soil temp----------------------- 65^0 F
	Rainfall------------------------- 0.00
June 9, 1999	Grain and straw harvest, Perkins
June 10,1999	Grain and straw harvest, Stillwater

Table 4. Treatment structure employed: N source, N rate, and time of application, Perkins and Stillwater, OK, 1997-98 and 1998-99.

Treatment	N source	N rate (kg N ha^{-1})	Time of Application
1	----	0	Check
2	UAN	11.2	Preflowering
3	UAN	22.4	Preflowering
4	UAN	33.6	Preflowering
5	UAN	44.8	Preflowering
6	AS	22.4	Preflowering
7	UAN	11.2	Post flowering
8	UAN	22.4	Post flowering
9	UAN	33.6	Post flowering
10	UAN	44.8	Post flowering
11	AS	22.4	Post flowering

Preflowering: foliar N applied just prior to flowering (late April-Feekes 10.5)
Post flowering: foliar N applied immediately following flowering (early May-Feekes 10.5.4)

Table 5. Analysis of variance, treatment means, and single degree of freedom contrasts for grain yield, grain N uptake, total grain N, straw yield, straw N uptake, and total straw N, Perkins, OK, 1998.

		Grain			Straw		
		Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}	Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}
Source of variation	df	Mean squares					
Rep	2	352357	174.9	3.35	1141874	24.8	1.82
Trt	10	77111	49.1	8.16**	592963	44.7*	3.52*
Contrast							
UAN lin pre	1	32295	65.0	35.65**	623216	48.3	2.83
UAN quad pre	1	61	46.5	8.48*	289772	13.3	0.10
UAN lin post	1	127002	11.1	31.46**	64333	53.9	7.08*
UAN quad post	1	479	6.8	2.11	917947	27.8	0.04
AS pre vs. UAN pre	1	75184	3.1	7.26*	418976	181.1**	12.63**
AS post vs. UAN post	1	230739	14.8	18.13**	426633	65.4*	1.89
UAN pre vs. UAN post	1	61629	124.2	5.22	2263374*	84.7*	0.01
AS pre vs. AS post	1	230739	14.8	18.13**	26634	65.4*	1.89
AS pre vs. check	1	34133	127.1	56.03**	705675	212.1**	17.66**
AS post vs. check	1	87380	228.8	10.42**	34921	41.9	7.99*
Residual error	20	136586	114.6	1.25	399890	13.8	1.44
SED		302	8.7	0.91	516	3.0	0.98
CV		17	17.9	4.13	29	27.2	18.70

Source	Treatment Timing	Rate, kg ha^{-1}	Grain Yield	Grain N uptake	Grain Total N	Straw Yield	Straw N uptake	Straw Total N
			Treatment means					
nt	nt	0	2269	53	23.54	1795	10	5.31
UAN	Pre	11.2	2338	62	26.84	1413	9	5.71
UAN	Pre	22.4	2342	64	27.46	1953	10	5.83
UAN	Pre	33.6	2040	58	28.23	1777	11	6.65
UAN	Pre	44.8	2254	63	28.30	2334	15	6.37
AS	Pre	22.4	2118	63	29.66	2481	21	8.74
UAN	Post	11.2	2350	59	25.30	2939	14	4.92
UAN	Post	22.4	2012	55	27.18	2139	13	5.95
UAN	Post	33.6	2176	58	26.60	2718	19	6.87
UAN	Post	44.8	2030	57	28.01	2137	14	6.76
AS	Post	22.4	2510	66	26.18	1948	15	7.61

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

SED-Standard error of the difference between two equally replicated means

Pre----Foliar N applied just prior to flowering (late April-Feekes 10.5)

Post----Foliar N applied immediately following flowering (early May-Feekes 10.5.4)

Table 6. Analysis of variance, treatment means, and single degree of freedom contrasts for grain yield, grain N uptake, total grain N, straw yield, straw N uptake, and total straw N, Perkins, OK, 1999.

		Grain			Straw		
		Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}	Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}
Source of variation	df	Mean squares					
Rep	3	302802	306.8	3.30	1441828	115.8*	0.43
Trt	10	169398	293.6	11.96*	253804	18.6	0.97
Contrast							
UAN lin pre	1	75107	507.3	43.58**	244798	57.8	3.61*
UAN quad pre	1	107558	288.9	6.40	20718	2.7	0.01
UAN lin post	1	85058	700.4	66.27**	78286	15.2	0.86
UAN quad post	1	150457	269.2	2.90	133838	0.4	1.05
AS pre vs. UAN pre	1	2525	78.7	8.13	45541	7.3	0.01
AS post vs. UAN post	1	133216	37.8	6.13	8758	0.2	0.01
UAN pre vs. UAN post	1	57814	37.0	0.94	27618	11.9	1.14
AS pre vs. AS post	1	133216	37.8	6.13	8758	0.2	0.01
AS pre vs. check	1	161231	231.6	0.96	153897	14.3	0.24
AS post vs. check	1	1336	82.2	11.95	89229	17.9	0.25
Residual error	30	289745	464.4	5.02	535830	37.0	0.77
SED		381	15.2	1.58	518	4.3	0.62
CV		29	34.9	7.87	34	36.9	11.38

Treatment Source	Treatment Timing	Rate, kg ha^{-1}	Grain Yield	Grain N uptake	Grain Total N	Straw Yield	Straw N uptake	Straw Total N
			Treatment means					
nt	nt	0	1657	50	25.87	1948	14	7.48
UAN	Pre	11.2	1955	62	27.00	1939	13	6.96
UAN	Pre	22.4	1977	67	28.58	2376	19	7.85
UAN	Pre	33.6	1861	66	30.74	2045	17	8.67
UAN	Pre	44.8	1921	65	29.22	2286	18	8.13
AS	Pre	22.4	1941	61	26.56	2225	17	7.83
UAN	Post	11.2	1591	49	26.73	1796	14	7.34
UAN	Post	22.4	2292	79	29.26	2636	19	7.05
UAN	Post	33.6	1616	57	30.50	1823	14	7.68
UAN	Post	44.8	1875	67	30.42	2156	17	8.04
AS	Post	22.4	1683	56	28.31	2159	17	7.84

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

SED-Standard error of the difference between two equally replicated means

Pre----Foliar N applied just prior to flowering (late April-Feekes 10.5)

Post----Foliar N applied immediately following flowering (early May-Feekes 10.5.4)

Table 7. Analysis of variance, treatment means, and single degree of freedom contrasts for grain yield, grain N uptake, total grain N, straw yield, straw N uptake, and total straw N, Stillwater, OK, 1998.

				Grain			Straw	
				Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}	Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}
Source of variation			df	Mean squares					
Rep			2	319596*	81.1	8.56*	2684727*	390.3*	3.61
Trt			10	128308	176.4	1.89	1429040*	272.2*	1.95
Contrast									
UAN lin pre			1	7257	44.6	0.87	1330669	43.4	0.11
UAN quad pre			1	208833	199.2	0.06	8704134*	1109.5**	3.23
UAN lin post			1	37040	322.4	9.69*	700995	16.9	3.19
UAN quad post			1	1.37	0.3	0.01	321	44.8	0.83
AS pre vs. UAN pre			1	46260	84.6	0.49	4175328*	578.0*	2.20
AS post vs. UAN post			1	1700	2.6	0.01	35658	4.8	0.01
UAN pre vs. UAN post			1	62749	160.0	2.02	5006196**	1085.5**	6.42*
AS pre vs. AS post			1	1700	2.6	0.01	35658	4.8	0.01
AS pre vs. check			1	72527	40.7	0.04	714571	43.4	0.01
AS post vs. check			1	52019	22.9	0.09	1069481	77.1	0.01
Residual error			20	72885	76.9	2.08	555566	101.6	1.45
SED				220	7.2	1.18	609	2.6	0.90
CV				7	7.9	5.10	12	20.1	14.71
	Treatment								
Source	Timing	Rate, kg ha^{-1}		Treatment means					
nt	nt	0		4052	112	27.66	6989	56	8.06
UAN	Pre	11.2		3877	110	28.53	5746	46	7.90
UAN	Pre	22.4		3656	99	27.25	4631	31	6.88
UAN	Pre	33.6		4032	115	28.65	5108	40	7.61
UAN	Pre	44.8		4053	115	28.45	6255	53	8.51
AS	Pre	22.4		3832	107	27.82	6299	51	8.09
UAN	Post	11.2		3831	104	27.34	6078	45	7.40
UAN	Post	22.4		3824	112	29.25	6872	67	9.75
UAN	Post	33.6		4457	129	28.88	6362	57	8.99
UAN	Post	44.8		3915	116	29.73	6083	54	8.90
AS	Post	22.4		3866	108	27.90	6145	49	8.04

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

SED-Standard error of the difference between two equally replicated means

Pre----Foliar N applied just prior to flowering (late April-Feekes 10.5)

Post----Foliar N applied immediately following flowering (early May-Feekes 10.5.4)

Table 8. Analysis of variance, treatment means, and single degree of freedom contrasts for grain yield, grain N uptake, total grain N, straw yield, straw N uptake, and total straw N, Stillwater, OK, 1999.

		Grain			Straw		
		Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}	Yield kg ha^{-1}	N uptake kg ha^{-1}	Total N g kg^{-1}
Source of variation	df	Mean squares					
Rep	3	1478076**	2930**	22.46**	1045627*	238.3	7.24**
Trt	10	235916*	402**	5.16**	156415	20.2	0.54
Contrast							
UAN lin pre	1	81778	391.6	10.89*	11721	20.8	1.53
UAN quad pre	1	432779*	739.9*	1.42	170914	61.7	1.95
UAN lin post	1	404481*	174.3	13.74**	71531	7.5	0.02
UAN quad post	1	53358	40.6	0.96	3485	2.7	0.19
AS pre vs. UAN pre	1	2275	106.6	8.74*	152820	9.8	0.01
AS post vs. UAN post	1	18	24.8	1.48	98821	31.3	0.47
UAN pre vs. UAN post	1	158927	115.4	2.27	140956	11.7	0.08
AS pre vs. AS post	1	18	24.8	1.48	98821	31.3	0.47
AS pre vs. check	1	353221	708.7*	2.85	26039	2.8	0.02
AS post vs. check	1	358239	468.4	0.22	23407	15.3	0.28
Residual error	30	90799	135.9	1.62	258159	28.9	0.64
SED		213	8.2	0.90	359	3.8	0.57
CV		12	12.6	4.05	16	23.3	11.02

Source	Treatment Timing	Rate, kg ha^{-1}	Treatment means					
nt	nt	0	2775	100	31.04	3287	24	7.16
UAN	Pre	11.2	2453	85	29.90	3131	22	7.01
UAN	Pre	22.4	2388	88	31.94	2896	21	7.04
UAN	Pre	33.6	2772	102	31.64	3376	24	6.95
UAN	Pre	44.8	2841	107	32.78	3250	27	8.17
AS	Pre	22.4	2355	81	29.85	3173	23	7.05
UAN	Post	11.2	2518	91	31.20	2821	21	7.23
UAN	Post	22.4	2421	88	31.13	3215	23	7.12
UAN	Post	33.6	2842	108	32.97	3203	24	7.49
UAN	Post	44.8	2110	81	33.09	2885	20	6.92
AS	Post	22.4	2352	85	30.71	3395	27	7.54

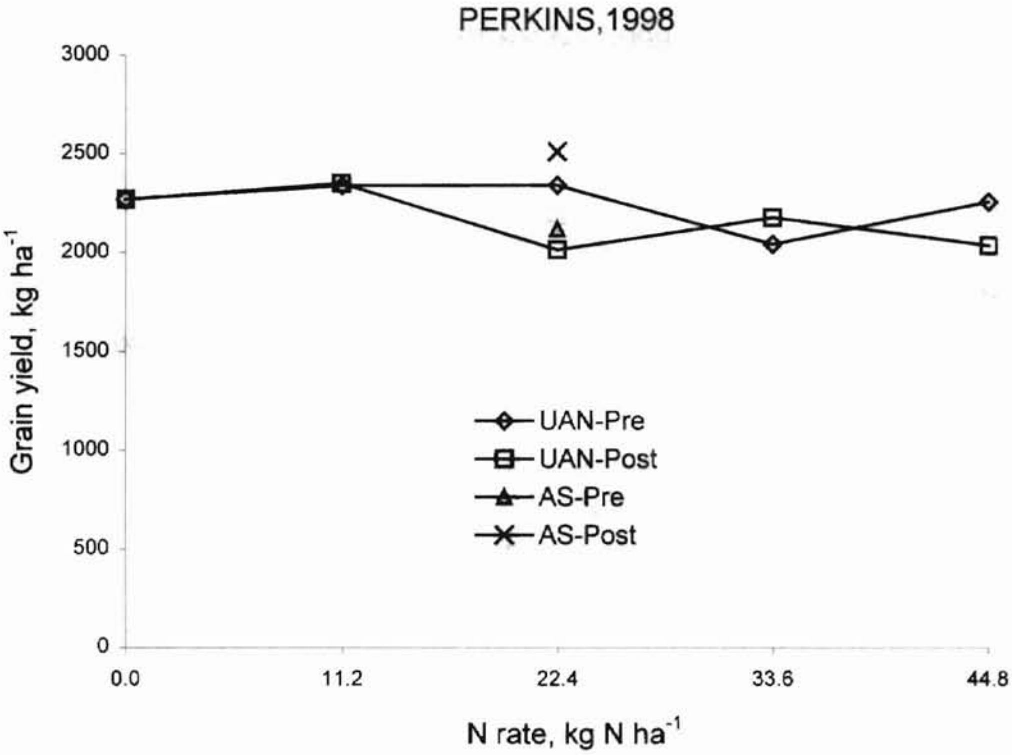
*,** - Significant at the 0.05 and 0.01 probability levels, respectively

SED-Standard error of the difference between two equally replicated means

Pre----Foliar N applied just prior to flowering (late April-Feekes 10.5)

Post----Foliar N applied immediately following flowering (early May-Feekes 10.5.4)

APPENDIX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2500
2000
1500
1000
500
0
Grain yield, kg ha-1
UAN-Pre
UAN-Post
AS-Pre
AS-Post
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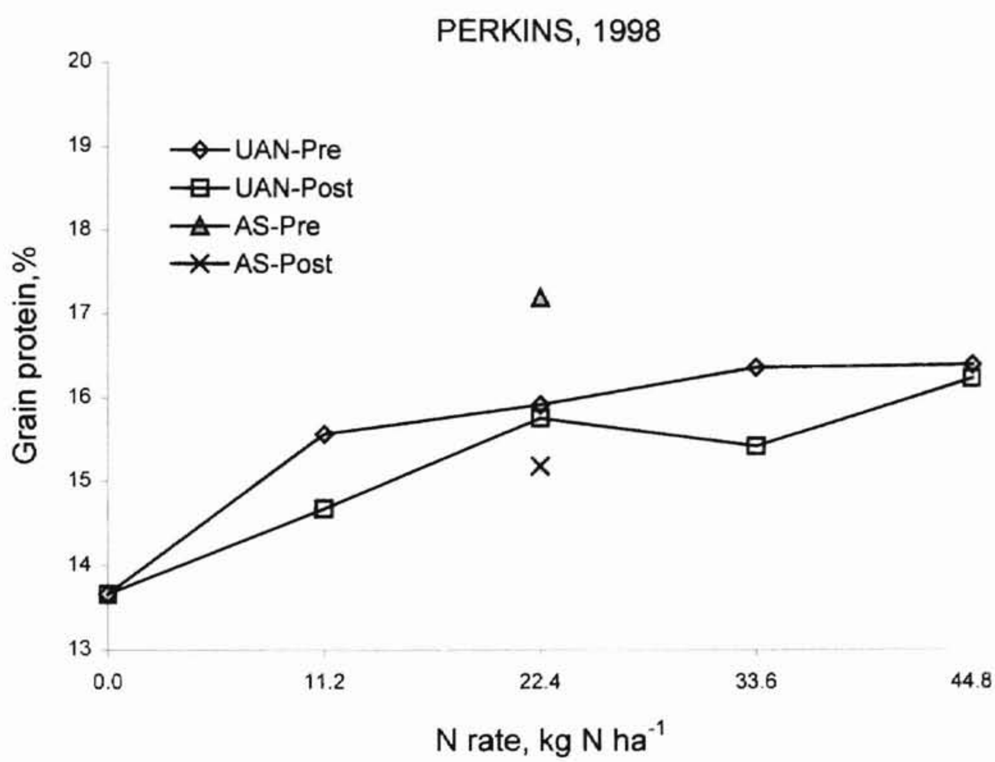
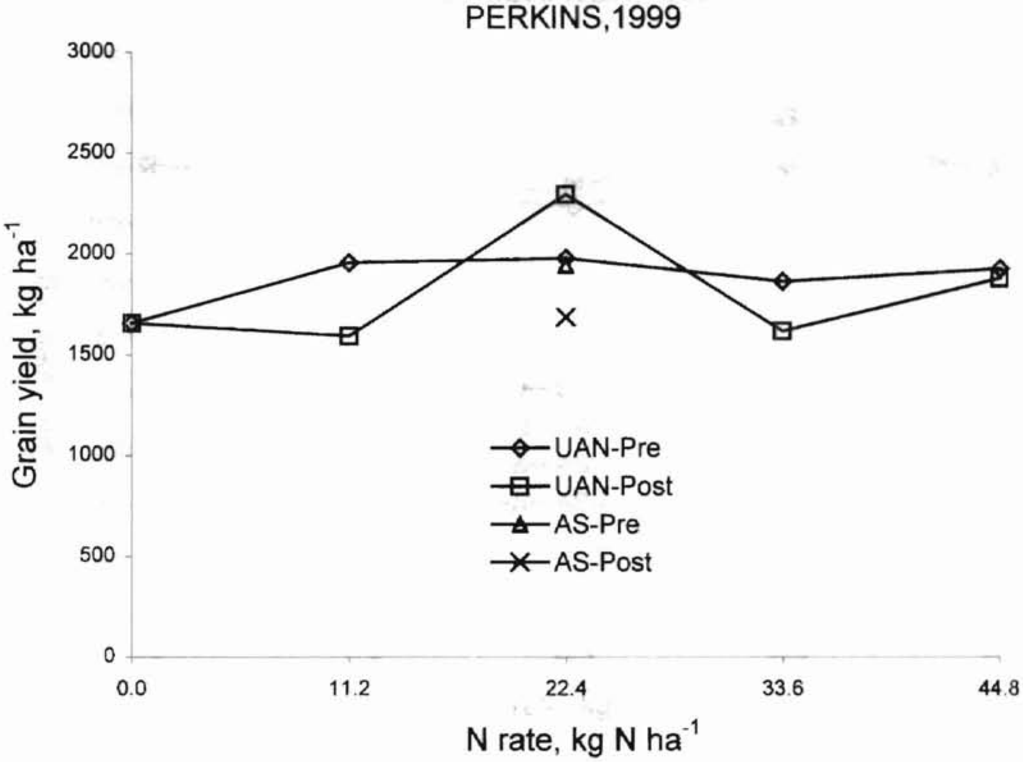
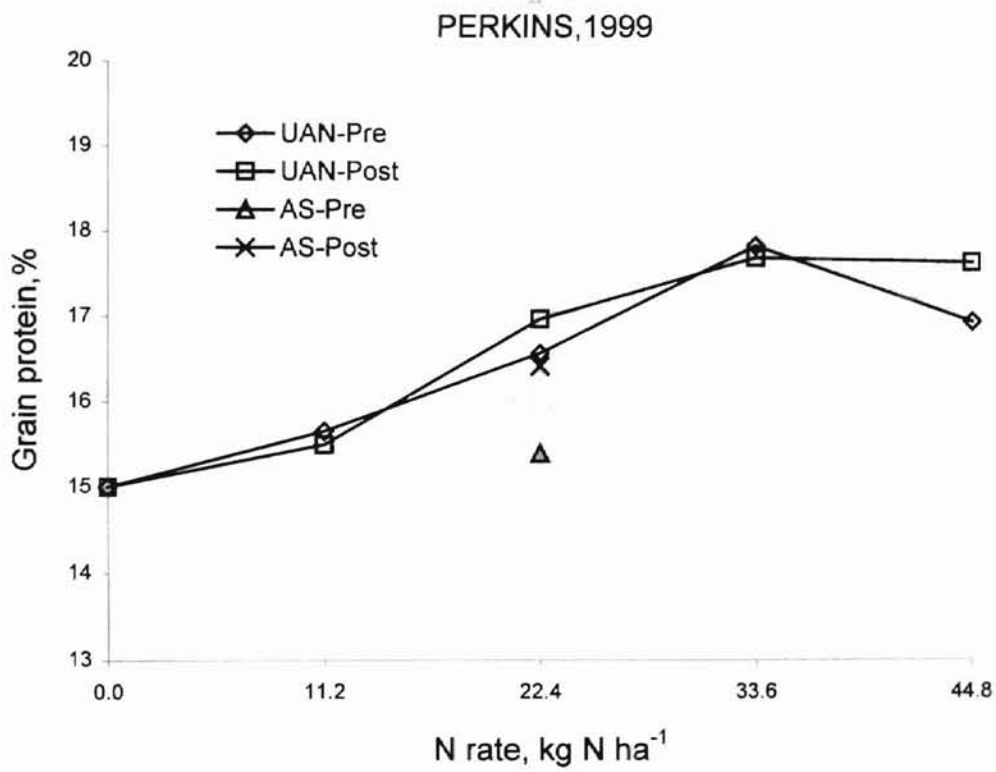
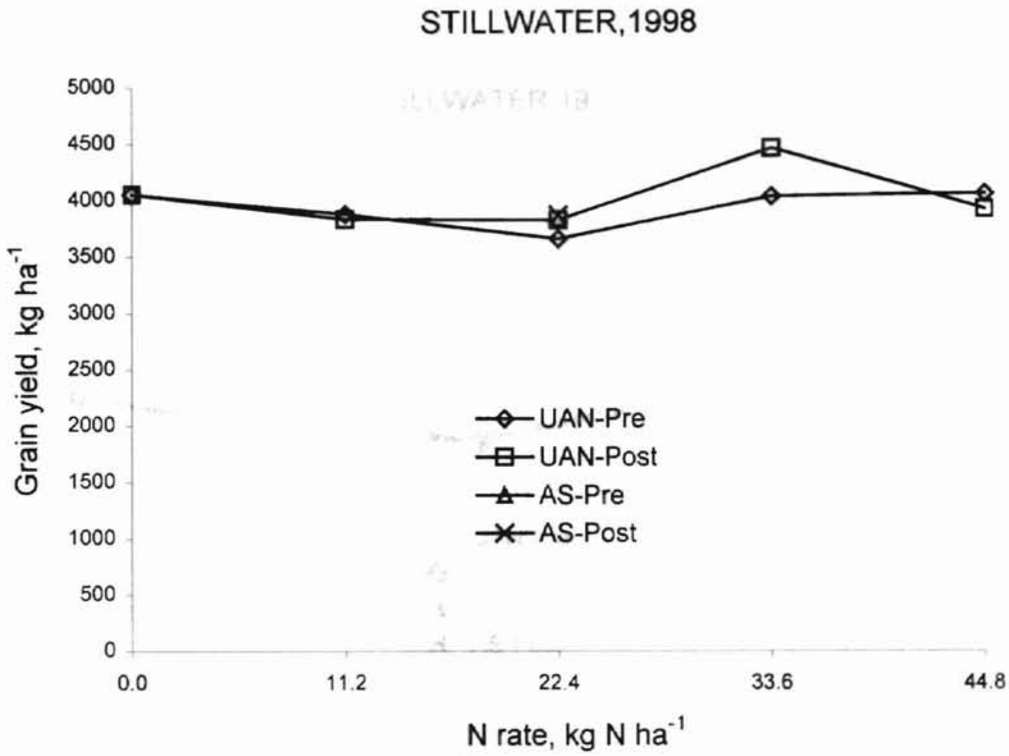
11.2
22.4
33.6
44.8
N rate, kg N ha-1


PERKINS, 1998
20
19
18
17
16
15
14
13
Grain protein,%
UAN-Pre
UAN-Post
AS-Pre
AS-Post
0.0
11.2
22.4
33.6
44.8
N rate, kg N ha-1


PERKINS,1999
Grain yield, kg ha-1
3000
2500
2000
1500
1000
500
0
0.0
11.2
22.4
33.6
44.8
N rate, kg N ha-1
UAN-Pre
UAN-Post
AS-Pre
AS-Post


PERKINS,1999
Grain protein, %
20
19
18
17
16
15
14
13
0.0
11.2
22.4
33.6
44.8
N rate, kg N ha-1
UAN-Pre
UAN-Post
AS-Pre
AS-Post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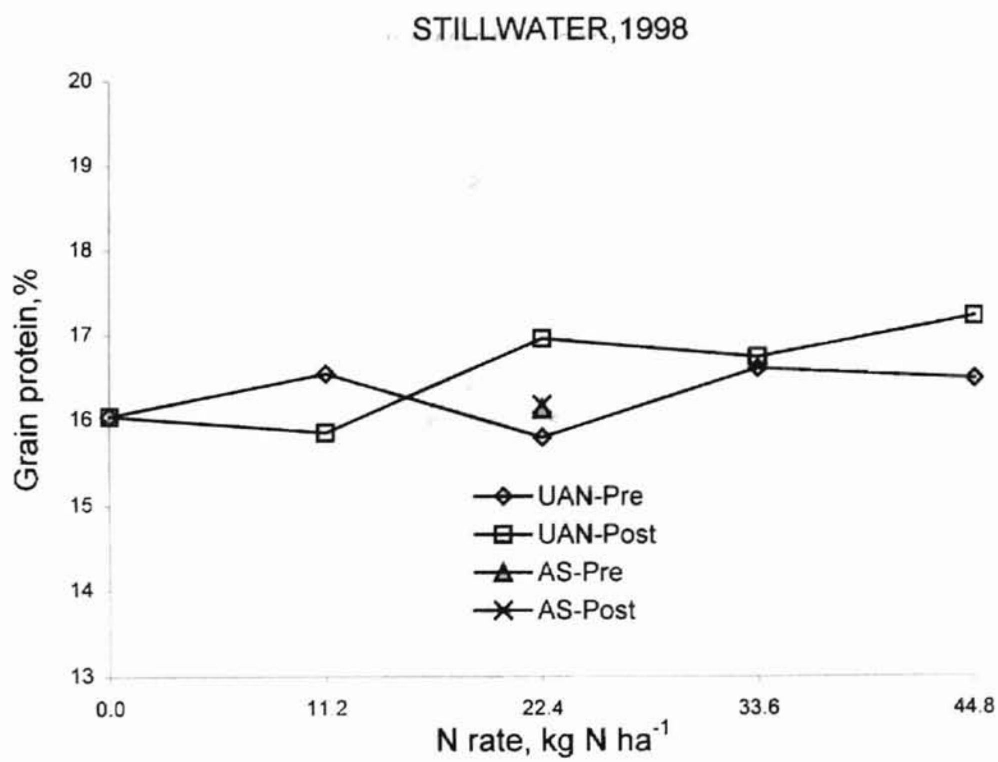
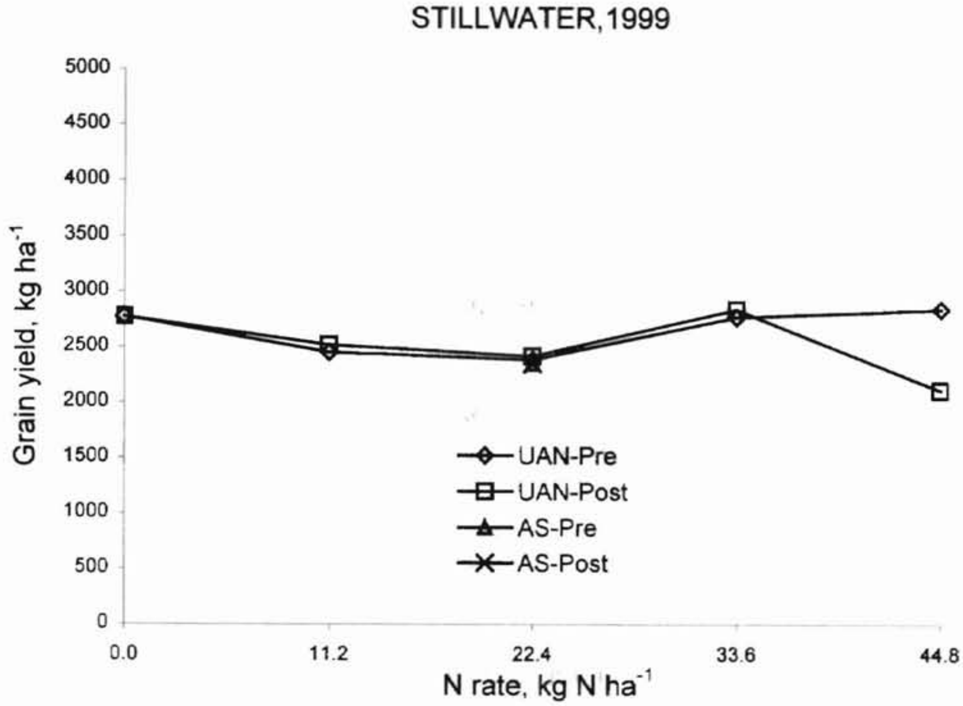
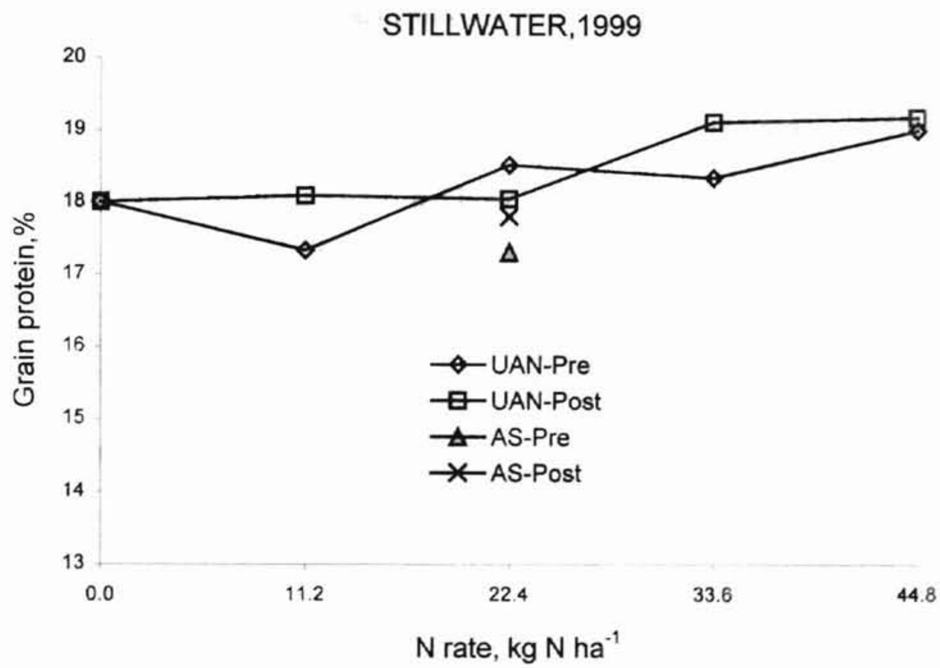
Grain yield, kg ha-1
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.0
11.2
22.4
33.6
44.8
N rate, kg N ha-1
UAN-Pre
UAN-Post
AS-Pre
AS-Post


STILLWATER, 1998
Grain protein, %
20
19
18
17
16
15
14
13
0.0
11.2
22.4
33.6
44.8
N rate, kg N ha-1
UAN-Pre
UAN-Post
AS-Pre
AS-Post


STILLWATER,1999
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Grain yield, kg ha-1
0.0
11.2
22.4
33.6
44.8
N rate, kg N ha-1
UAN-Pre
UAN-Post
AS-Pre
AS-Post


STILLWATER,1999
20
19
18
17
16
15
14
13
Grain protein,%
0.0
11.2
22.4
33.6
44.8
N rate, kg N ha-1
UAN-Pre
UAN-Post
AS-Pre
AS-Post

2

VITA

Curt Wayne Woolfolk

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF LATE-SEASON FOLIAR NITROGEN APPLICATIONS ON GRAIN PROTEIN IN WINTER WHEAT

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