EFFECT OF NITROGEN RATE, METHOD OF APPLICATION AND RESIDUE MANAGEMENT ON ESTIMATED N LOSS IN WINTER WHEAT

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INTRODUCTION

Two field experiments were conducted to evaluate potential N loss in winter wheat. The objectives of this experiment were to estimate total N accumulation in winter wheat at various growth stages and to determine N gain/loss between physiological stages as a function of N rate, method of application and crop residue incorporation.

This thesis is presented in a format suitable for publication in a professional journal.

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ABSTRACT

Loss of nitrogen (N) as ammonia from plant tissue may increase with higher rates of applied N fertilizer. This research project was initiated to estimate the potential N loss in winter wheat (*Triticum aestivum L.*). Two experiments were selected that evaluated N rate, method of application and crop residue incorporation. Wheat N accumulation was determined at various growth stages and N gain/loss was evaluated between physiological stages. Plant tissue samples were collected at Feekes 7, anthesis, post-anthesis (14 days after anthesis) and maturity (grain and straw). Dry matter yield and total N accumulated was determined at each of these stages. Field trials were conducted on a Teller sandy loam (fine-loamy, mixed, thermic Udic Argiustoll) in Perkins, OK and on a Norge loam (fine-silty, mixed, thermic Pachic Argiustoll) in Stillwater, OK. Significant differences were observed among the treatments for forage, grain and straw yield, N uptake and N loss. Estimates of N loss over the last two years at Stillwater and Perkins ranged from 0.95 to 59.21 kg N ha^{-1} and 2.50 to 39.50 kg ha^{-1}, respectively. The results of this study indicate the gaseous plant N loss should be considered as a N loss pathway when studying the fate of applied N in the environment.

INTRODUCTION

Nitrogen is an essential nutrient needed for plant growth and is the most costly fertilizer input used in producing non-legume crops. The growing concern of groundwater contamination with the increased use of fertilizer N has lead to investigating alternative N loss pathways. Volatile plant N losses in wheat which are affected by management practices have not been thoroughly evaluated. Daigger et al. (1972) found that 20 - 80% of the total N can be lost from the plant. Maximum N accumulation in wheat has been found to take place at or near anthesis (Harper et al., 1987). Diagger et al. (1976) found a 30% loss of N has been reported from anthesis to maturity in wheat. Daigger et al. (1976) also stated that with increased N fertilization rates there was an increase in N loss. When no N fertilizer was applied, N loss from anthesis to maturity was 25 kg ha^{-1}. This loss increased to 80 kg ha^{-1} when N was applied at a rate of 150 kg ha^{-1}. Ammonia (NH_3) is the primary form of N volatilization from the wheat plant and this gas can be found in large amounts after anthesis (O' Deen, 1989). In cereal grasses, 50 - 80% of the N present in the vegetative plant parts at anthesis may be retranslocated to the head (Harper et al., 1987). Remobilization of N in the plant occurs during senescence when proteins in the stem and leaves degrade to their constituent amino acids and NH_3. The lack of NH_3 translocation and/or reassimilation in wheat at senescence seems to be the cause of volatile N loss (Harper et al., 1987; Parton et al., 1988). Other studies have also found N loss from NH_3 volatilization in wheat, but at different rates. O'Deen and Porter (1986) found that losses due to NH_3 volatilization were only 1.6 kg ha^{-1} in a laboratory study. Greater N losses may occur in a field experiment since climate cannot be controlled. Even though these data differ, they still show potential N loss due to NH_3 volatilization. Ammonia volatilization from plants should assist in accounting for plant N loss from anthesis to maturity. If NH_3 could be redistributed within the wheat plant, instead of lost, the use of applied N would be much more efficient and protein contents could increase as could grain yields (Daigger et al., 1976).

Timing of residue incorporation and method of N application are important factors that affect plant N availability and N uptake. When residue incorporation is delayed until prior to planting, soil N is immobilized by enhanced microbial activity (Johnson, 1982). Therefore, applied N in the fall must be adjusted upward to compensate for the immobilized N (Parr and Papendick, 1978). Decay of the straw residue through the growing season can release a supply of N for spring growth. Elliot et al. (1981), noted that N uptake and wheat yields were increased when N was incorporated into the soil and not applied to the soil surface. Sharpe et al. (1980), found that plant N uptake is increased and N immobilization is decreased when fertilizer N is applied below the soil surface layer.

The objective of this experiment was to estimate total N uptake and N gain/loss at various physiological stages as a function of N rate, method of application and crop residue incorporation.

MATERIALS AND METHODS

Two field trials were initiated in 1993 at the Agriculture Experiment Stations in Perkins and Stillwater, OK to estimate total N uptake and N gain/loss at various physiological stages in winter wheat as a function of N rate, method of application and crop residue incorporation. Soil classification and initial soil test characteristics for Perkins and Stillwater are reported in Table 1. Wheat was planted at a rate of 67 kg ha^{-1} with a row spacing of 25.4 cm at both locations. Individual plot size was 4.9 m wide and 15.2 m in length. An incomplete factorial arrangement of treatments was used that evaluated N rate, residue management and method of N application (Table 2). Ammonium nitrate (34-0-0) was used as the source of N fertilizer and was applied at rates of 90, 180 and 270 kg ha^{-1}. Methods of application included N applied immediately following harvest, prior to planting and half applied at planting + half spring topdress. Wheat stubble was either incorporated following harvest and disked again prior to planting or left in the field and incorporated prior to planting.

Weeds (Avena fatua, Vicia villosa, Amaranthus palmeri, Ipomoea purpea, Convolvulus arvensis and Cynodon dactylon) were controlled during the idle period from harvest to planting at each location by using a spring-tooth chisel plow in the residue incorporated after harvest treatments. Tillage dates between the 1993-94 and 1994-95 growing seasons at Stillwater and Perkins were June 21, July 19 and June 27, July 28, respectively. Roundup was sprayed at the rate of 5.2 l ha^{-1} in the treatments where residues were not incorporated until prior to planting. Spraying dates for Stillwater and Perkins were July 20 and July 28, respectively. In the 1993-94 growing season, Dimethoate 4ec was sprayed at Stillwater (January 13, 1994) at the rate of 0.7 l ha^{-1} for the control of aphids (Shizaphis graminum).

A randomized complete block experimental design with three replications was used at both sites.

Forage harvests were taken at Feekes physiological stage 7 (Large, 1954) and at anthesis for the 1993-94 crop year and at anthesis and post-anthesis (14 days after anthesis) for the 1994-95 crop year. Forage was harvested from an area of 96 x 300 cm within each plot using a self propelled John Deere 256 rotary mower (9.5 cm height) with a modified blower. Grain yield was determined by harvesting a 3.1 x 15.2 m area from the center of each plot using a Gleaner-A combine. Straw yield was determined by hand raking all remaining combine residue from the same area used for grain yield. This was made possible by employing a header capable of operating just above the soil surface (complete straw removal). Subsamples from each respective harvest were collected for moisture and total N analysis. All plant samples (forage and grain) were dried in a forced air oven at 70 °C immediately following collection, after which they were ground to pass a 100 mesh screen. Total N was determined on forage, grain and straw subsamples using a Carlo-Erba NA 1500 analyzer (Schepers *et al.*, 1989). Total N uptake at each stage was determined by multiplying the dry matter yield by the percent N from dry combustion analysis. Nitrogen loss was estimated as the difference between total forage N uptake at anthesis and total N (grain and straw) uptake at maturity. Data analysis was performed using SAS (SAS Institute Inc., 1988). Analysis of variance is reported by year and location due to heterogeneity of error (by year and location) which restricted using a combined model.

RESULTS AND DISCUSSION

Stillwater and Perkins 1994

Results from analysis of variance and associated single-degree-of-freedom-contrasts for all dry matter yield and nitrogen uptake variables are reported in Tables 3, 4, 5 and 6. Associated means over N rate, residue management and method of application are included in Tables 7 and 8 for Stillwater and Perkins, respectively. Dry matter yield at Feekes stages 7, anthesis and maturity (grain and straw) and nitrogen uptake at each of these stages increased significantly with increasing N applied at both locations. However, all response variables tended to peak at the 180 kg ha^{-1} rate (Tables 7 and 8). When residues were incorporated after harvest, N applied broadcast and incorporated preplant (BIPP) and half broadcast and incorporated preplant + half spring topdress (½BIPP + ½TD) had higher grain yields as compared to N broadcast and incorporated after harvest (Tables 7 and 8). When straw residues were incorporated after harvest, grain yields were higher when compared to residues incorporated prior to planting (all N broadcast and incorporated preplant).

Residue and N management had no affect on forage N uptake at Feekes 7 (Table 4 and 6). Nitrogen uptake at anthesis was also not affected by residue incorporation or N management. Residue incorporated after harvest with N applied half broadcast and incorporated preplant + half spring topdress had the largest amount of N uptake for grain. An increase in straw and grain N uptake with increasing N rate was observed for each residue and N management scheme. Nitrogen applied broadcast and incorporated after harvest had an increased effect on straw N uptake as compared to N broadcast and incorporated preplant when residues were incorporated after harvest. This could suggest that the N broadcast and incorporated immediately following harvest could have been immobilized, but which provided slow release N at later stages of growth. This is reflected in the high straw N uptake and straw yield levels when N was broadcast and incorporated after harvest.

Nitrogen loss increased with increasing N rate ranging from -0.95 to 54.28 kg ha^{-1} at Stillwater and 2.50 to 39.50 at Perkins (Tables 7 and 8, respectively). When residue was incorporated before planting (no N applied) an increase in N uptake from anthesis to maturity was observed. N uptake increased from Feekes 7 to anthesis but decreased from anthesis to maturity for all N treatments (Figures 1 and 2). Generally, yield, N uptake and N loss increased with increased N application for the parameters measured (Tables 7 and 8). Although significance levels were low at Perkins, these findings are similar to results reported by Daigger et al. (1976), which found that 20-80 % of plant N can be lost from anthesis to maturity. It should be noted that N loss differed for these two locations in 1994 when comparing residue and N management.

Stillwater and Perkins 1995

Unlike 1994, the two forage harvests were collected near anthesis (instead of one at Feekes 7) since N uptake and estimated loss has been shown to be more important at this stage of growth. Analysis of variance and single-degree-of-freedom-contrasts for all dependent variables are reported in Tables 9, 10, 11 and 12. Means over N rate, residue management and method of application are included in Tables 13 and 14 for Stillwater and Perkins, respectively. Unlike 1994, the 1995 crop year was characterized by an extremely wet spring with heavy disease pressure during and following anthesis. Because of this, grain yield levels were less than half that reported for 1994. Because grain yield levels were less than 1 Mg ha^{-1} and harvest indices (grain yield / total dry matter) did not exceed 40% for any treatment, it was difficult to evaluate any of the dependent variables at either location in terms of reliability. Residue and N management had no effect on straw yield at either location (Tables 9 and 11).

Forage N uptake at anthesis, post-anthesis and in the grain and straw increased with increasing N applied at both locations (Tables 13 and 14). An increase in N uptake from anthesis to post-anthesis was found at the high N rates (Figures 3 and 4). In spite of the heavy disease pressure and low yields, estimates of N loss were similar when comparing 1994 and 1995 crop years (Tables 7 and 8 versus 13 and 14). In fact it was interesting to find that total N uptake at anthesis was very similar between years. It should be noted, however, that total N uptake at anthesis was always greater at Stillwater versus Perkins, as was N loss and grain yield. Residue management apparently had no effect on estimated N loss. However, nitrogen applied broadcast and incorporated preplant and half broadcast and incorporated preplant + half spring topdress tended to have increased N loss as compared to N broadcast and incorporated after harvest. N loss ranged from 9.54 to 35.82 kg N ha^{-1} at Perkins. At both sites, N uptake at anthesis, post-anthesis and maturity and N loss increased with increased N applied. Nitrogen uptake increased from anthesis to post-anthesis showing that most N loss probably occurred from post-anthesis to maturity (Figures 3 and 4).

CONCLUSIONS

Generally, forage, grain, and straw N uptake and yield increased with N applied half broadcast and incorporated preplant + half spring topdress. The supply of N in the spring allowed immediate N uptake by the plant. However, N loss was highest at Perkins with the split application.

Residue incorporated after harvest generally resulted in increased N uptake, yield and N loss when compared to residue incorporated prior to planting. Residue incorporated after harvest allowed microbes time to decompose the straw before planting. When residue incorporation was delayed until planting, no time was given for straw decomposition. Therefore N applied at planting, when residues are also first incorporated, will likely be immobilized due to a high C:N residue-fertilization pool (Parr and Papendick, 1978). Residue incorporated after harvest allowed the fall applied N to be immediately available for plant uptake. When straw was incorporated prior to planting, the applied N was immobilized by enhanced microbial activity and was not immediately plant available. However, if residue incorporated prior to planting can decompose through the growing season, the immobilized N can slowly be released and become available for plant uptake.

Generally, N loss was greater at the Stillwater location. At Perkins, a higher amount of N uptake was observed for the 180 kg N ha^{-1} rate. The majority of the estimated loss occurred from anthesis to maturity as stated by Daigger et al. (1976). However, the results from each location in 1995 indicated no decrease in N from anthesis to post-anthesis (14 days). Apparently, the variety used in this study continued to assimilate N after anthesis. The results indicate that N has the greatest potential of being lost from post-anthesis to maturity. Most N loss occurs when N is being translocated to the head from other parts of the plant during the grain filling period (Harper et al. 1987; Parton et al., 1988). Ammonia is formed when amino acids in the stem and leaves degrade. The free NH_3 is incorporated into amino acids during NH_3 assimilation in the grain.

The estimates of plant N loss from this study show that this pathway should be taken into account when evaluating the fate of fertilizer N in the environment.

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Table 1. Soil chemical characteristics and classification, Stillwater and Perkins, OK.

Location Depth	pH	Total N	Organic C	CEC	NH_4-N	NO_3-N	P	K
		------------g kg^{-1}------------		cmol kg^{-1}	--------mg kg^{-1}---------		------mg kg^{-1}-----	
Stillwater								
Surface-soil (0 - 15 cm)	5.8	1.1	11.8	13.0	7.0	5.0	30.0	53.0
Sub-soil (15 - 60 cm)	6.7	0.1	5.5	--	2.4	3.3	3.3	20.1
Classification: Norge loam (fine-silty, mixed, thermic Pachic Argiustoll)								
Perkins								
Surface-soil (0 - 15cm)	5.6	0.6	8.6	20.8	10.9	7.9	26.0	65.0
Sub-soil (15 - 60 cm)	6.5	0.3	3.7	--	1.6	2.8	3.8	14.4
Classification: Teller sandy loam (fine-loamy, mixed, thermic Udic Argiustoll)								

pH - 1:1 soil:water, Organic C and Total N - dry combustion, CEC - 1M NH_4Ac extraction, NH_4-N and NO_3-N - 2M KCl extraction, K and P- Melich III extraction.

Table 2. Treatment structure employed, Stillwater and Perkins, OK.

Treatment	N Rate kg ha^{-1} (at planting)	N Rate kg ha^{-1} (spring)	Residue Management	Method of N Application
1.	90	0	Incorporated after harvest	Broadcast incorporated after harvest
2.	180	0	Incorporated after harvest	Broadcast incorporated after harvest
3.	270	0	Incorporated after harvest	Broadcast incorporated after harvest
4.	90	0	Incorporated after harvest	Broadcast incorporated preplant
5.	180	0	Incorporated after harvest	Broadcast incorporated preplant
6.	270	0	Incorporated after harvest	Broadcast incorporated preplant
7.	45	45	Incorporated after harvest	Half broadcast incorporated preplant + half spring topdress
8.	90	90	Incorporated after harvest	Half broadcast incorporated preplant + half spring topdress
9.	135	135	Incorporated after harvest	Half broadcast incorporated preplant + half spring topdress
10.	90	0	Incorporated prior to planting	Broadcast incorporated preplant
11.	180	0	Incorporated prior to planting	Broadcast incorporated preplant
12.	270	0	Incorporated prior to planting	Broadcast incorporated preplant
13.	0	0	Incorporated after harvest	-
14.	0	0	Incorporated prior to planting	-

Table 3. Analysis of variance and single-degree-of-freedom-contrasts for dry matter yield determined at various growth stages (Mg ha^{-1}), Stillwater, OK, 1994.

Source of variation	Effect	df	Feekes 7	Anthesis	Grain	Straw
					yield (Mg ha^{-1})	
			--------------------	--------------------	mean squares	--------------------
Replication		2	0.74	6.05	0.06	0.21
Treatment		13	0.74*	11.58**	0.63**	4.33**
Error		26	2.45	2.20	0.03	0.62
Contrasts	Effect					
N linear	IAH,BIAH (13,1,2,3)	1	1.68*	46.27**	1.08**	16.04**
N quadratic	IAH,BIAH (13,1,2,3)	1	1.04*	35.15**	0.83**	8.48**
N linear	IAH,BIPP (13,4,5,6)	1	1.19*	29.83**	2.30**	18.16**
N quadratic	IAH,BIPP (13,4,5,6)	1	0.52	6.28	0.48**	0.96
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	0.83@	44.59**	1.78**	10.25**
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	0.58	6.41@	1.45**	6.22**
N linear	IPP,BIPP (14,10,11,12)	1	4.08**	45.72**	1.30**	22.89**
N quadratic	IPP,BIPP (14,10,11,12)	1	1.84*	17.01**	1.23**	3.92*
N linear (over management)		1	4.22**	98.60**	3.78**	39.42**
N quadratic (over management)		1	1.63*	20.60**	2.50**	11.08**
BIAH vs BIPP (1,2,3 vs 4,5,6)		1	0.14	0.06	0.30**	1.05
BIAH vs ½BIPP,½TD (1,2,3 vs 7,8,9)		1	0.00	0.42	0.54**	1.15
BIPP vs ½BIPP,½TD (4,5,6 vs 7,8,9)		1	0.00	0.17	0.04	0.00
IAH vs IPP (13,4,5,6 vs 14,10,11,12)		1	0.22	2.49	0.74**	0.08
SED			0.40	1.21	0.15	0.64

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED - standard error of the difference between two equally replicated means. IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 4. Analysis of variance and single-degree-of-freedom-contrasts for total N uptake at various growth stages and estimated N loss (kg ha^{-1}), Stillwater, OK, 1994.

Source of variation		df	Feekes 7	Anthesis	Grain	Straw	N Loss
					N uptake (kg ha^{-1})		
			mean squares				
Replication		2	714.93	644.59	45.10	114.744	1085.94
Treatment		13	2644.03**	6958.04*	731.15**	749.17*	1963.53
Error		26	319.10	2763.09	35.61	309.57	3096.74
Contrasts	Effect						
N linear	IAH,BIAH (13,1,2,3)	1	10026.84**	31419.90**	1778.48**	1404.38*	9527.62@
N quadratic	IAH,BIAH (13,1,2,3)	1	7229.73**	27119.78**	1474.64**	1156.02@	8515.51
N linear	IAH,BIPP (13,4,5,6)	1	8970.66**	26384.34**	4068.17**	1362.42*	3811.76
N quadratic	IAH,BIPP (13,4,5,6)	1	1553.82*	225.73	49.80	177.94	28.86
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	8555.17**	22488.97**	3040.11**	2390.31**	2110.05
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	1681.83*	7804.40	666.02**	166.02	2465.14
N linear	IPP,BIPP (14,10,11,12)	1	15623.47**	29266.22**	1670.90**	2486.58**	6453.14
N quadratic	IPP,BIPP (14,10,11,12)	1	19.02*	2569.20	724.53**	548.78	0.12
N linear (over management)		1	25376.23**	65158.07**	6088.23**	4474.37**	12175.57@
N quadratic (over management)		1	3012.21**	8414.25@	1044.33**	2090.21*	187.53
BIAH vs BIPP (1,2,3 vs 4,5,6)		1	527.27	1820.07	301.63**	1344.97*	545.49
BIAH vs ½BIPP + ½TD (1,2,3 vs 7,8,9)		1	248.39	294.73	510.24**	223.73	614.97
BIPP vs ½BIPP + ½TD (4,5,6 vs 7,8,9)		1	51.87	649.97	27.26	471.59	2.08
IAH vs IPP (13,4,5,6 vs 14,10,11,12)		1	2.92	8.94	543.48**	32.20	212.02
SED			14.59	42.92	4.87	14.37	45.45

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED - standard error of the difference between two equally replicated means. IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 5. Analysis of variance and single-degree-of-freedom-contrasts for dry matter yield determined at various growth stages (Mg ha^{-1}), Perkins, OK, 1994.

			Feekes 7	Anthesis	Grain	Straw
			yield (Mg ha^{-1})			
Source of variation		df	mean squares			
Replication		2	3.80**	4.04@	0.14	0.61
Treatment		13	0.44**	8.07**	0.57**	1.70**
Error		26	0.12	1.34	0.10	0.32
Contrasts	Effect					
N linear	IAH,BIAH (13,1,2,3)	1	0.80*	19.62**	0.81**	5.43**
N quadratic	IAH,BIAH (13,1,2,3)	1	0.63*	9.44*	0.63*	2.50**
N linear	IAH,BIPP (13,4,5,6)	1	0.80*	21.34**	1.46**	4.80**
N quadratic	IAH,BIPP (13,4,5,6)	1	0.59*	9.13*	0.01	0.40
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	1.52**	27.22**	1.76**	4.63**
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	0.57*	16.59**	0.78**	3.76**
N linear	IPP,BIPP (14,10,11,12)	1	1.22**	25.73**	1.65**	2.96**
N quadratic	IPP,BIPP (14,10,11,12)	1	1.08**	18.40**	0.78**	4.80**
N linear (over management)		1	2.54**	55.82**	3.33**	10.52**
N quadratic (over management)		1	1.73**	38.55**	0.76*	6.26**
BIAH vs BIPP (1,2,3 vs 4,5,6)		1	0.13	0.02	0.28	0.18
BIAH vs ½BIPP + ½TD (1,2,3 vs 7,8,9)		1	0.21	1.90	1.18**	0.03
BIPP vs ½BIPP + ½TD (4,5,6 vs 7,8,9)		1	0.01	2.33	0.31@	0.37
IAH vs IPP (13,4,5,6 vs 14,10,11,12,)		1	0.23	0.85	0.287@	0.28
SED			0.29	0.95	0.26	0.46

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED - standard error of the difference between two equally replicated means. IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 6. Analysis of variance and single-degree-of-freedom-contrasts for total N uptake at various growth stages and estimated N loss (kg ha^{-1}), Perkins, OK, 1994.

			Feekes 7	Anthesis	Grain	Straw	N Loss
					N uptake (kg ha^{-1})		
Source of variation		df	mean squares				
Replication		2	832.83**	1586.34	62.62	68.47	890.13
Treatment		13	765.96**	3865.39**	712.46**	332.69**	695.98
Error		26	137.53	822.21	68.24	50.96	497.64
Contrasts	Effect						
N linear	IAH,BIAH (13,1,2,3)	1	1509.49**	7655.21**	1510.89**	1345.64**	142.58
N quadratic	IAH,BIAH (13,1,2,3)	1	971.34*	4800.53*	1267.13**	880.39**	16.15
N linear	IAH,BIPP (13,4,5,6)	1	2117.34**	12925.07**	2772.96**	1073.79**	798.68
N quadratic	IAH,BIPP (13,4,5,6)	1	697.59*	1574.33	14.02	14.87	1028.90
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	3660.31**	15231.87**	3436.59**	1307.13**	820.29
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	1917.98**	9182.04**	466.00*	523.20**	2638.09*
N linear	IPP,BIPP (14,10,11,12)	1	1784.22**	13710.58**	2461.55**	729.74**	1637.37@
N quadratic	IPP,BIPP (14,10,11,12)	1	1070.20**	4456.07*	369.88*	593.98**	535.90
N linear (over management)		1	5253.20**	29118.20**	5956.15**	2625.07**	1783.29@
N quadratic (over management)		1	3292.26**	14060.17**	269.29**	587.30**	4967.65**
BIAH vs BIPP (1,2,3 vs4,5,6)		1	54.57	2.77	310.48*	13.17	151.92
BIAH vs ½BIPP vs ½TD (1,2,3 vs 7,8,9)		1	891.81*	2908.87@	965.43**	81.46	191.47
BIPP vs ½BIPP + ½TD (4,5,6 vs 7,8,9)		1	505.17@	2732.00@	180.93	160.14@	684.49
IAH vs IPP (13,4,5,6 vs 14,10,11,12)		1	92.69	95.90	241.69	8.50	75.16
SED			9.58	23.41	6.74	5.83	18.21

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED -standard error of the difference between two equally replicated means. IAH- residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 7. Dry matter yield at Feekes 7, anthesis and maturity (grain and straw), and corresponding estimates of N uptake and N loss, Stillwater, OK, 1994.

Treatments	Feekes 7	Anthesis	Grain	Straw	Feekes 7	Anthesis	Grain	Straw	N loss (kg ha^{-1})
	Yield (Mg ha^{-1})				N uptake (kg ha^{-1})				
means (over residue management)									
0	1.33	3.17	1.15	1.04	22.00	34.19	23.80	11.34	-0.95
90	2.53	7.42	2.13	3.73	74.95	111.61	48.78	42.20	20.63
180	2.51	8.07	2.40	4.12	95.27	155.03	62.51	49.20	43.31
270	2.66	8.87	2.23	4.48	107.50	166.12	64.15	47.68	54.28
SED[1]	0.20	0.60	0.07	0.32	7.29	21.46	2.44	7.18	22.72
means (over N rate)									
IAH, BIAH	2.48	8.07	2.13	4.42	84.35	155.33	54.41	55.51	45.41
IAH, BIPP	2.66	8.19	2.38	3.93	95.18	135.22	65.60	38.22	34.40
IAH, ½BIPP+ ½TD	2.48	8.38	2.48	3.91	91.78	147.24	65.07	48.46	33.72
IPP, BIPP	2.62	7.83	2.02	4.19	98.98	139.23	51.86	43.25	44.11
IAH (0 N)	1.70	3.93	1.31	1.19	29.10	42.65	26.73	14.18	1.73
IPP (0 N)	0.95	2.42	0.99	0.90	14.91	25.74	20.87	8.50	-3.63
SED[2]	0.23	0.70	0.08	0.37	8.42	24.78	2.81	8.29	26.23

IAH- residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. [1] - SED used for comparing 90, 180 and 270. [2] - SED used for comparing IAH and BIAH combinations over N rate.

Table 8. Dry matter yield for Feekes 7, anthesis and maturity (grain and straw), and corresponding estimates of N uptake and N loss, Perkins, OK, 1994.

Treatments	Feekes 7	Anthesis	Grain	Straw	Feekes 7	Anthesis	Grain	Straw	N loss (kg ha^{-1})
	Yield (Mg ha^{-1})				N uptake (kg ha^{-1})				
means (over residue management)									
0	1.63	2.87	1.12	0.70	26.65	33.02	13.10	4.33	2.50
90	2.35	6.83	1.92	2.50	59.41	106.04	51.38	21.91	32.75
180	2.69	7.39	2.05	2.53	69.69	129.79	60.42	29.86	39.50
270	2.46	7.00	2.18	2.57	63.60	121.34	67.82	30.63	22.90
SED[1]	0.14	0.47	0.13	0.23	4.79	11.71	3.37	2.91	9.11
means (over N rate)									
IAH, BIAH	2.41	7.02	1.84	2.66	60.28	113.24	53.62	27.52	32.10
IAH, BIPP	2.57	6.95	2.09	2.46	63.67	114.03	61.93	25.81	26.29
IAH, ½BIPP+ ½TD	2.62	7.67	2.35	2.75	74.36	138.67	68.27	31.77	38.62
IPP, BIPP	2.40	6.65	1.92	2.26	58.53	110.30	55.66	24.78	29.86
IAH (0 N)	1.74	3.17	1.30	0.84	26.66	35.42	29.48	5.16	0.77
IPP (0 N)	1.52	2.57	0.95	0.57	26.65	30.62	22.91	3.49	4.22
SED[2]	0.17	0.55	0.15	0.27	5.53	13.52	3.86	3.37	10.52

IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. [1] - SED used for comparing 90, 180 and 270. [2] - SED used for comparing IAH and BIAH combinations over N rate.

Table 9. Analysis of variance and single-degree-of-freedom-contrasts for dry matter yield determined at various growth stages (Mg ha^{-1}), Stillwater, OK, 1995.

		df	Anthesis	Post-anthesis	Grain yield (Mg ha^{-1})	Straw
Source of variation			mean squares			
Replication		2	0.26	0.16	0.07*	0.47
Treatment		13	3.45**	5.60**	0.14**	1.48**
Error		26	0.39	0.50	0.02	0.46
Contrasts	Effect					
N linear	IAH,BIAH (13,1,2,3)	1	10.92**	16.53**	0.52**	7.81**
N quadratic	IAH,BIAH (13,1,2,3)	1	7.63**	12.51**	0.42**	5.66**
N linear	IAH,BIPP (13,4,5,6)	1	8.30**	21.18**	0.45**	1.54@
N quadratic	IAH,BIPP (13,4,5,6)	1	5.01**	12.71*	0.00	5.90**
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	11.93**	17.95**	0.49**	2.76*
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	2.27*	5.98**	0.82*	1.42@
N linear	IPP,BIPP (14,10,11,12)	1	16.83**	30.59**	0.57**	3.81**
N quadratic	IPP,BIPP (14,10,11,12)	1	4.94**	6.48**	0.00	0.98
N linear (over management)		1	28.19**	50.73**	1.21**	8.73**
N quadratic (over management)		1	9.80**	15.86**	0.00	4.13**
BIAH vs BIPP (1,2,3 vs 4,5,6)		1	0.11	0.02	0.01	0.15
BIAH vs ½BIPP + ½TD (1,2,3 vs 7,8,9)		1	0.33	0.01	0.09*	0.02
BIPP vs ½BIPP + ½TD (4,5,6 vs 7,8,9)		1	0.06	0.06	0.04	0.27
IAH vs IPP (13,4,5,6 vs 14,10,11,12)		1	0.74	0.15	0.02	0.77
SED			0.51	0.57	0.12	0.55

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED - standard error of the difference between two equally replicated means. IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 10. Analysis of variance and single-degree-of-freedom-contrasts for total N uptake at various growth stages and estimated N loss (kg ha^{-1}), Stillwater, OK, 1995.

			Anthesis	Post-anthesis	Grain	Straw	N Loss
			N uptake (kg ha^{-1})				
Source of variation		df	--mean squares--				
Replication		2	133.26	92.51	78.31*	44.71	29.02
Treatment		13	4440.74**	4713.68**	219.76**	485.30**	1314.30**
Error		26	256.40	199.38	18.34	98.92	339.35
Contrasts	Effect						
N linear	IAH,BIAH (13,1,2,3)	1	14756.81**	12959.89**	872.88**	3177.62**	1264.70@
N quadratic	IAH,BIAH (13,1,2,3)	1	12799.40**	11573.35**	718.86**	2774.18**	1132.48@
N linear	IAH,BIPP (13,4,5,6)	1	18135.24**	18419.76**	819.44**	950.16**	5657.54**
N quadratic	IAH,BIPP (13,4,5,6)	1	1431.19*	4.94	2.07	353.00@	309.94
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	17343.15**	23522.55**	935.12**	2172.95**	2970.11**
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	1500.95*	580.23@	71.35@	16.48	688.29
N linear	IPP,BIPP (14,10,11,12)	1	25075.86**	23558.84**	881.98**	1754.60**	7528.61**
N quadratic	IPP,BIPP (14,10,11,12)	1	1668.11*	462.48	0.14	22.92	1327.49@
N linear (over management)		1	44526.19**	46209.48**	2094.03**	4607.42**	9481.64**
N quadratic (over management)		1	3253.97**	931.08*	6.23	137.68	1832.22*
BIAH vs BIPP (1,2,3 vs 4,5,6)		1	990.56@	60.35	7.76	81.11	1420.80@
BIAH vs ½BIPP + ½TD (1,2,3 vs 7,8,9)		1	1364.65*	1579.12**	103.63*	32.26	1052.41@
BIPP vs ½BIPP + ½TD (4,5,6 vs 7,8,9)		1	29.90	1022.05*	54.67@	11.06	27.59
IAH vs IPP (13,4,5,6 vs 14,10,11,12)		1	21.76	41.97	11.92	16.76	149.11
SED			13.07	11.53	12.23	8.12	15.04

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED - standard error of the difference between two equally replicated means. IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 11. Analysis of variance and single-degree-of-freedom-contrasts for dry matter yield determined at various growth stages (Mg ha^{-1}), Perkins, OK, 1995.

Source of variation		df	Anthesis	Post-anthesis	Grain yield (Mg ha^{-1})	Straw
			-------------------	mean squares	-------------------	
Replication		2	1.93*	2.14**	0.05	0.06
Treatment		13	2.05**	2.70**	0.04@	0.57@
Error		26	0.47	0.44	0.02	0.29
<u>Contrasts</u>	<u>Effect</u>					
N linear	IAH,BIAH (13,1,2,3)	1	7.78**	7.49**	0.04	1.45*
N quadratic	IAH,BIAH (13,1,2,3)	1	7.24**	4.90**	0.01	0.70
N linear	IAH,BIPP (13,4,5,6)	1	7.47**	6.38**	0.13*	1.77*
N quadratic	IAH,BIPP (13,4,5,6)	1	1.55@	2.56*	0.00	1.25*
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	7.11**	7.18**	0.02	1.14@
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	3.15*	6.86**	0.06	0.97@
N linear	IPP,BIPP (14,10,11,12)	1	7.26**	6.82**	0.03	0.55
N quadratic	IPP,BIPP (14,10,11,12)	1	3.74**	2.56*	0.10@	0.89@
N linear (over management)		1	17.68**	16.61**	0.12*	2.81**
N quadratic (over management)		1	5.83**	8.15**	0.04	2.12*
BIAH vs BIPP (1,2,3 vs 4,5,6)		1	0.39	0.23	0.04	0.55
BIAH vs ½BIPP + ½TD (1,2,3 vs 7,8,9)		1	1.38@	1.70@	0.05	0.25
BIPP vs ½BIPP + ½TD (4,5,6 vs 7,8,9)		1	0.31	0.68	0.00	0.06
IAH vs IPP (13,4,5,6 vs 14,10,11,12)		1	0.02	0.07	0.06	1.09@
SED			0.56	0.54	0.13	0.44

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED - standard error of the difference between two equally replicated means. IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 12. Analysis of variance and single-degree-of-freedom-contrasts for total N uptake at various growth stages and estimated N loss (kg ha^{-1}), Perkins, OK, 1995.

Source of variation		df	Anthesis	Post-anthesis	Grain	Straw	N Loss
					N uptake (kg ha^{-1})		
					mean squares		
Replication		2	1314.94*	788.23@	84.39@	12.20	1330.02**
Treatment		13	1521.61**	1169.29**	94.68*	125.08**	561.38**
Error		26	266.27	238.81	32.97	41.89	174.26
Contrasts	Effect						
N linear	IAH,BIAH (13,1,2,3)	1	3955.93**	4048.56**	198.93*	375.58**	863.55*
N quadratic	IAH,BIAH (13,1,2,3)	1	3667.97**	3209.55**	85.35	247.23*	1267.49*
N linear	IAH,BIPP (13,4,5,6)	1	6012.44**	3444.72**	464.89**	584.50**	1011.38*
N quadratic	IAH,BIPP (13,4,5,6)	1	1058.55@	1331.78*	0.27	173.38@	395.37
N linear	IAH,½BIPP,½TD (13,7,8,9)	1	5453.76**	5148.93**	130.02@	446.82**	1706.44**
N quadratic	IAH,½BIPP,½TD (13,7,8,9)	1	2645.76**	2730.54**	112.80@	164.47@	783.52*
N linear	IPP,BIPP (14,10,11,12)	1	5783.57**	3580.73**	128.85@	220.79*	2483.97**
N quadratic	IPP,BIPP (14,10,11,12)	1	1242.40*	1149.25*	147.53*	102.04	169.00
N linear (over management)		1	12581.30**	9622.84**	509.38**	945.20**	3463.66**
N quadratic (over management)		1	3257.11**	3383.18**	72.42	297.56*	980.39*
BIAH vs BIPP (1,2,3 vs 4,5,6)		1	1035.96@	321.26	108.84@	122.18@	114.49
BIAH vs ½BIPP + ½TD (1,2,3 vs 7,8,9)		1	2790.08**	1774.88*	71.55	116.75	1126.11*
BIPP vs ½BIPP + ½TD (4,5,6 vs 7,8,9)		1	425.80	585.91	3.90	0.06	522.46@
IAH vs IPP (13,4,5,6 vs 14,10,11,12)		1	8.13	31.20	104.33@	159.29@	399.32
SED			13.32	12.62	4.69	5.28	10.78

@, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively. SED - standard error of the difference between two equally replicated means. IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. df - degrees of freedom.

Table 13. Dry matter yield at Feekes 7, anthesis and maturity (grain and straw), and corresponding estimates of N uptake and N loss, Stillwater, OK, 1995.

Treatments	Anthesis	Post-anthesis	Grain	Straw	Anthesis	Post-anthesis	Grain	Straw	N loss (kg ha^{-1})
	Yield (Mg ha^{-1})				N uptake (kg ha^{-1})				
means (over residue management)									
0	1.92	2.07	0.38	1.23	29.66	22.98	10.11	10.02	9.54
90	4.45	4.91	0.58	2.88	82.41	65.16	17.79	26.61	38.01
180	4.76	5.89	0.80	2.75	123.16	109.47	27.10	36.85	59.21
270	4.98	5.87	0.93	2.97	135.45	129.46	32.79	44.95	57.71
SED[1]	0.25	0.29	0.05	0.28	6.54	5.76	1.75	4.06	7.52
means (over N rate)									
IAH, BIAH	4.63	5.57	0.72	2.89	100.65	93.46	24.41	39.30	36.94
IAH, BIPP	4.79	5.51	0.77	3.07	115.49	97.12	25.72	35.06	54.71
IAH, ½BIPP+ ½TD	4.90	5.63	0.86	2.83	118.07	112.19	29.21	36.63	52.23
IPP, BIPP	4.59	5.52	0.72	2.67	120.49	102.68	24.24	33.56	62.69
IAH (0 N)	2.32	2.40	0.41	1.34	33.36	26.04	10.70	11.11	11.55
IPP (0 N)	1.52	1.74	0.38	1.11	25.97	19.93	9.52	8.93	7.53
SED[2]	0.29	0.33	0.06	0.32	7.54	6.66	2.02	4.69	8.68

IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. [1] - SED used for comparing 90, 180 and 270. [2] - SED used for comparing IAH and BIAH combinations over N rate.

Table 14. Dry matter yield for Feekes 7, anthesis and maturity (grain and straw), and corresponding estimates of N uptake and N loss, Perkins, OK, 1995.

Treatments	Anthesis	Post-anthesis	Grain	Straw	Anthesis	Post-anthesis	Grain	Straw	N loss (kg ha^{-1})
	Yield (Mg ha^{-1})				N uptake (kg ha^{-1})				
means (over residue management)									
0	1.52	1.74	0.47	0.72	23.10	19.80	13.63	6.45	3.02
90	2.99	3.45	0.70	1.78	59.20	55.49	24.33	19.09	15.78
180	3.81	4.00	0.63	1.66	80.73	71.65	22.97	21.94	35.82
270	3.60	3.80	0.71	1.72	78.29	68.50	27.28	22.76	28.25
SED[1]	0.28	0.27	0.06	0.22	6.67	6.31	2.34	2.64	5.39
means (over N rate)									
IAH, BIAH	3.14	3.53	0.63	1.62	59.35	56.97	22.58	19.05	17.71
IAH, BIPP	3.44	3.75	0.73	1.97	74.52	65.42	27.50	24.27	22.75
IAH, ½BIPP+ ½TD	3.70	4.14	0.73	1.86	84.35	76.83	26.57	24.15	33.53
IPP, BIPP	3.51	3.57	0.63	1.44	72.84	61.65	22.78	17.58	32.48
IAH (0 N)	1.51	1.69	0.52	0.77	22.90	18.71	14.88	6.73	1.29
IPP (0 N)	1.53	1.79	0.42	0.68	23.29	20.88	12.38	6.17	4.75
SED[2]	0.32	0.31	0.07	0.25	7.69	7.28	2.71	3.05	6.22

IAH - residue incorporated after harvest. IPP - residue incorporated prior to planting. BIAH - N broadcast and incorporated after harvest. BIPP - N broadcast and incorporated prior to planting. TD - N applied spring topdress. [1] - SED used for comparing 90, 180 and 270. [2] - SED used for comparing IAH and BIAH combinations over N rate.

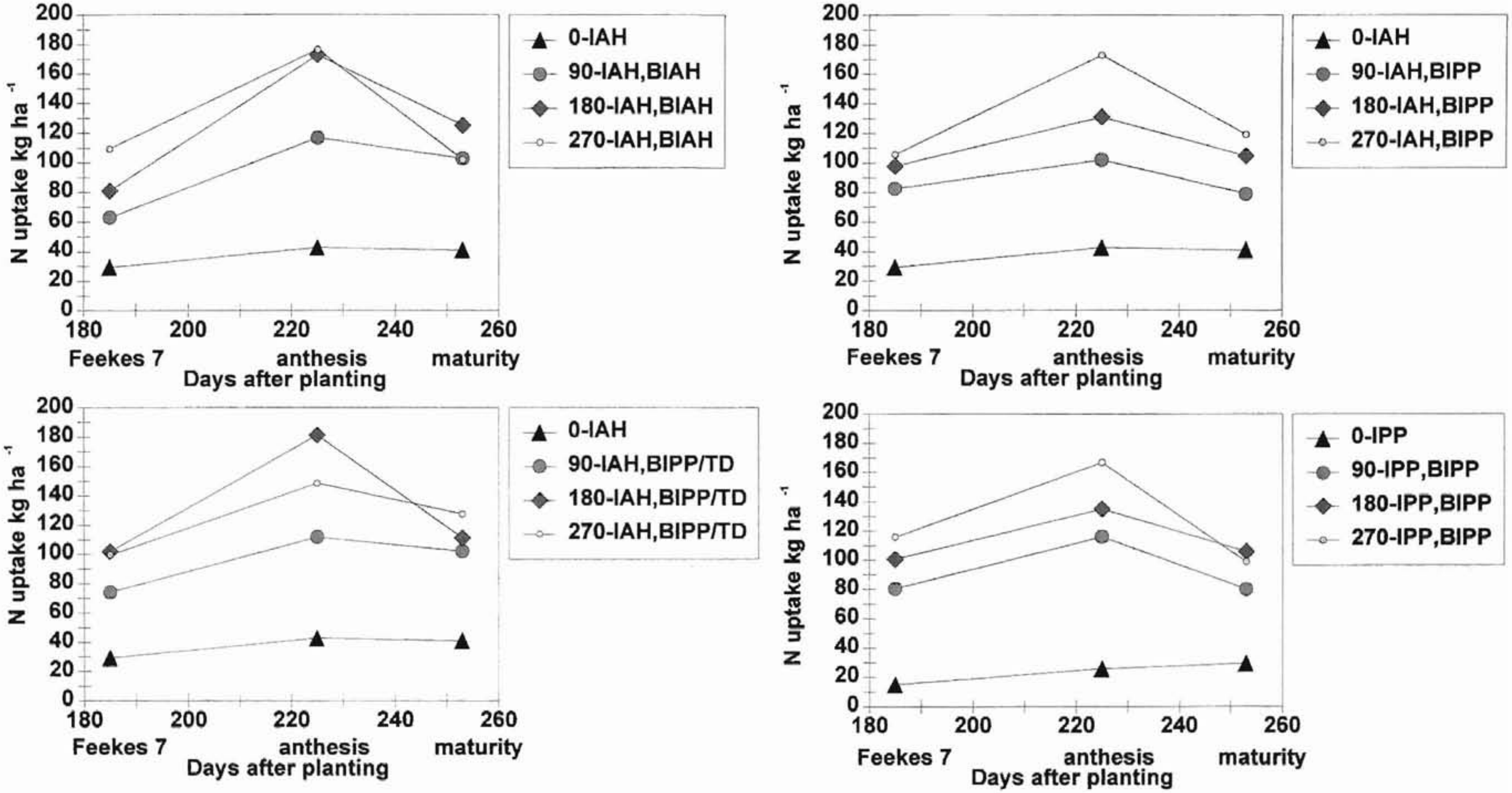

Figure 1. Change in total nitrogen uptake from Feekes 7 to maturity, Stillwater, 1994.

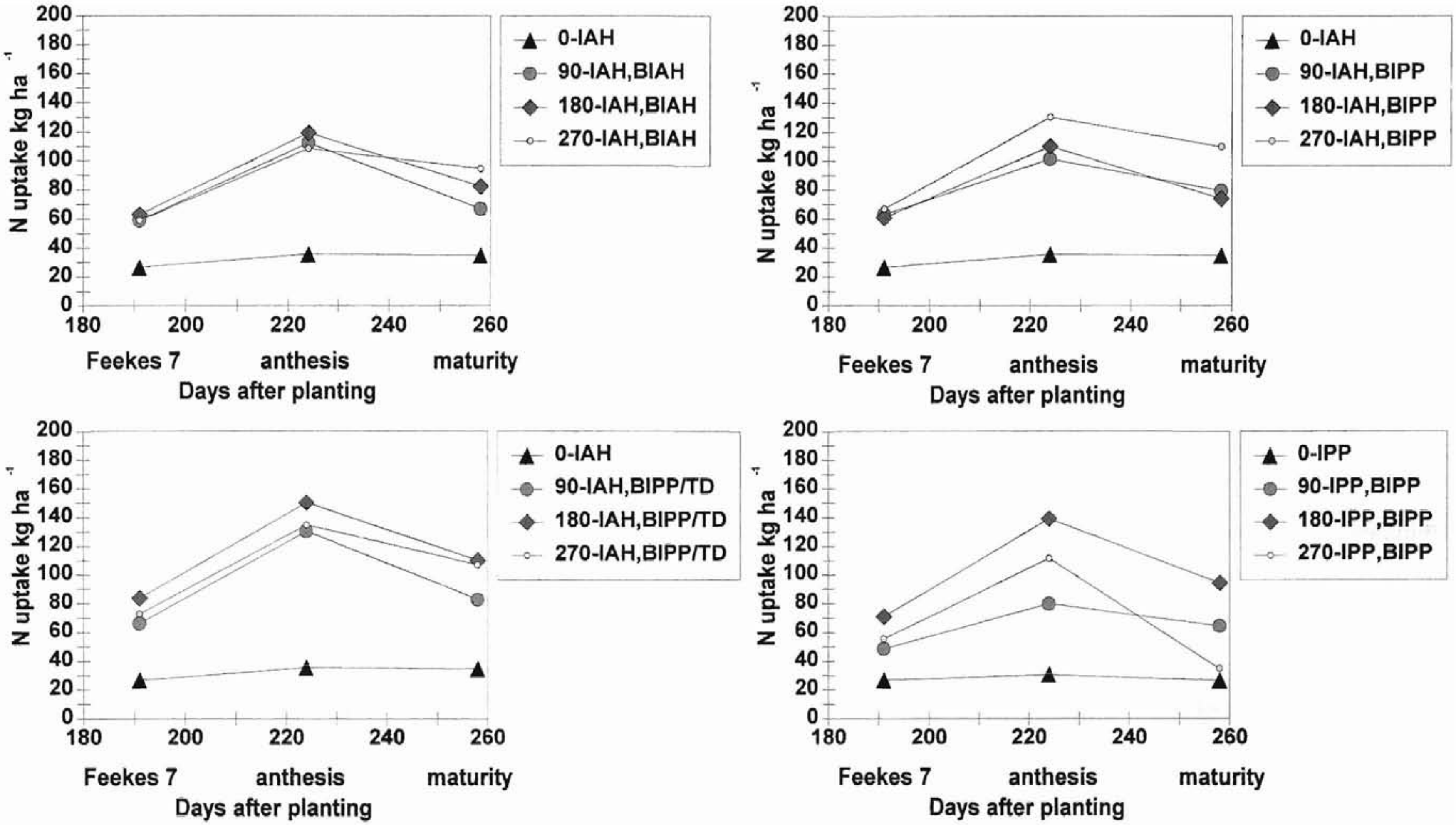

Figure 2. Change in total nitrogen uptake from Feekes 7 to maturity, Perkins, 1994

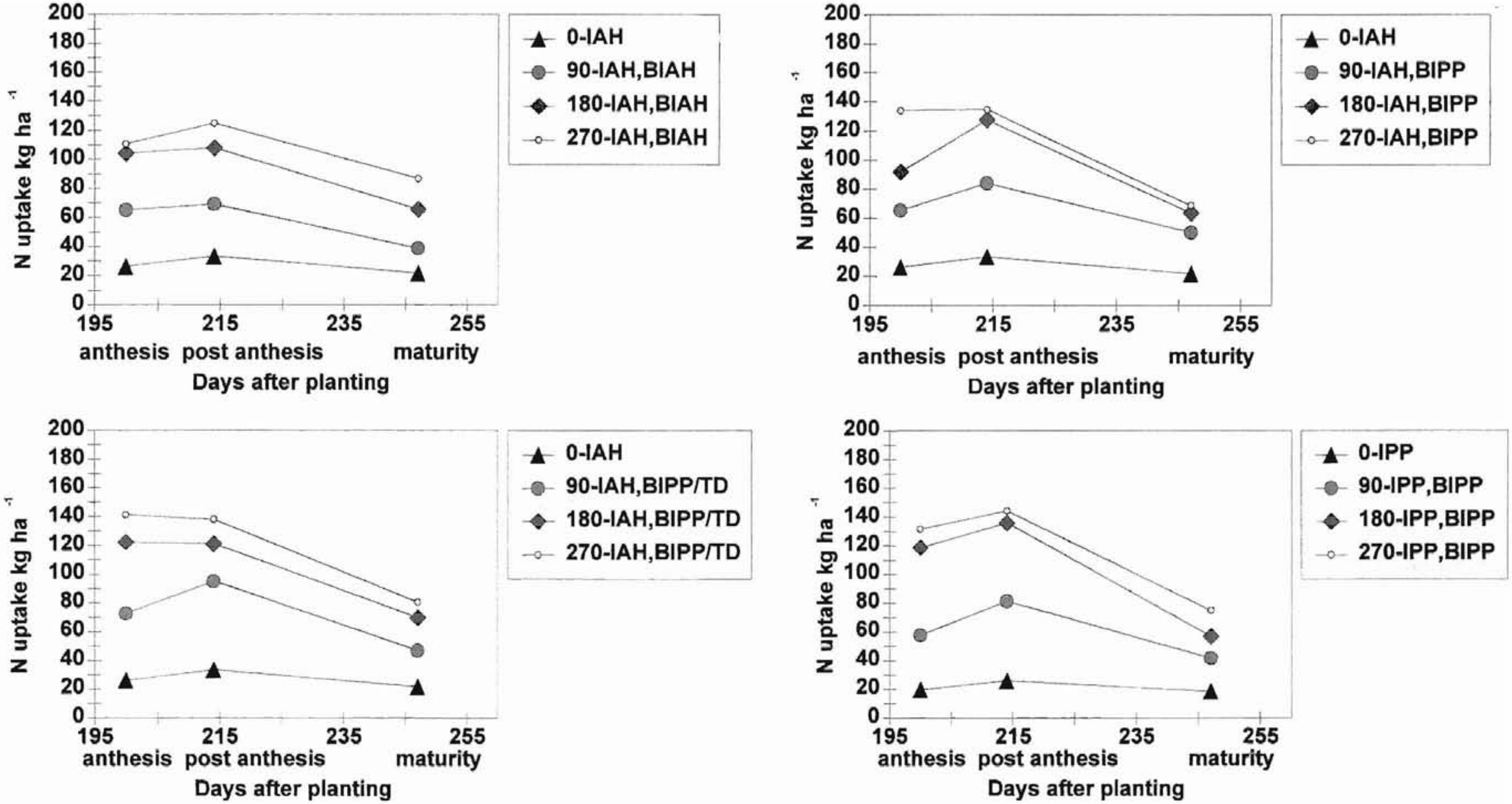

Figure 3. Change in total nitrogen uptake from anthesis to maturity, Stillwater, 1995.

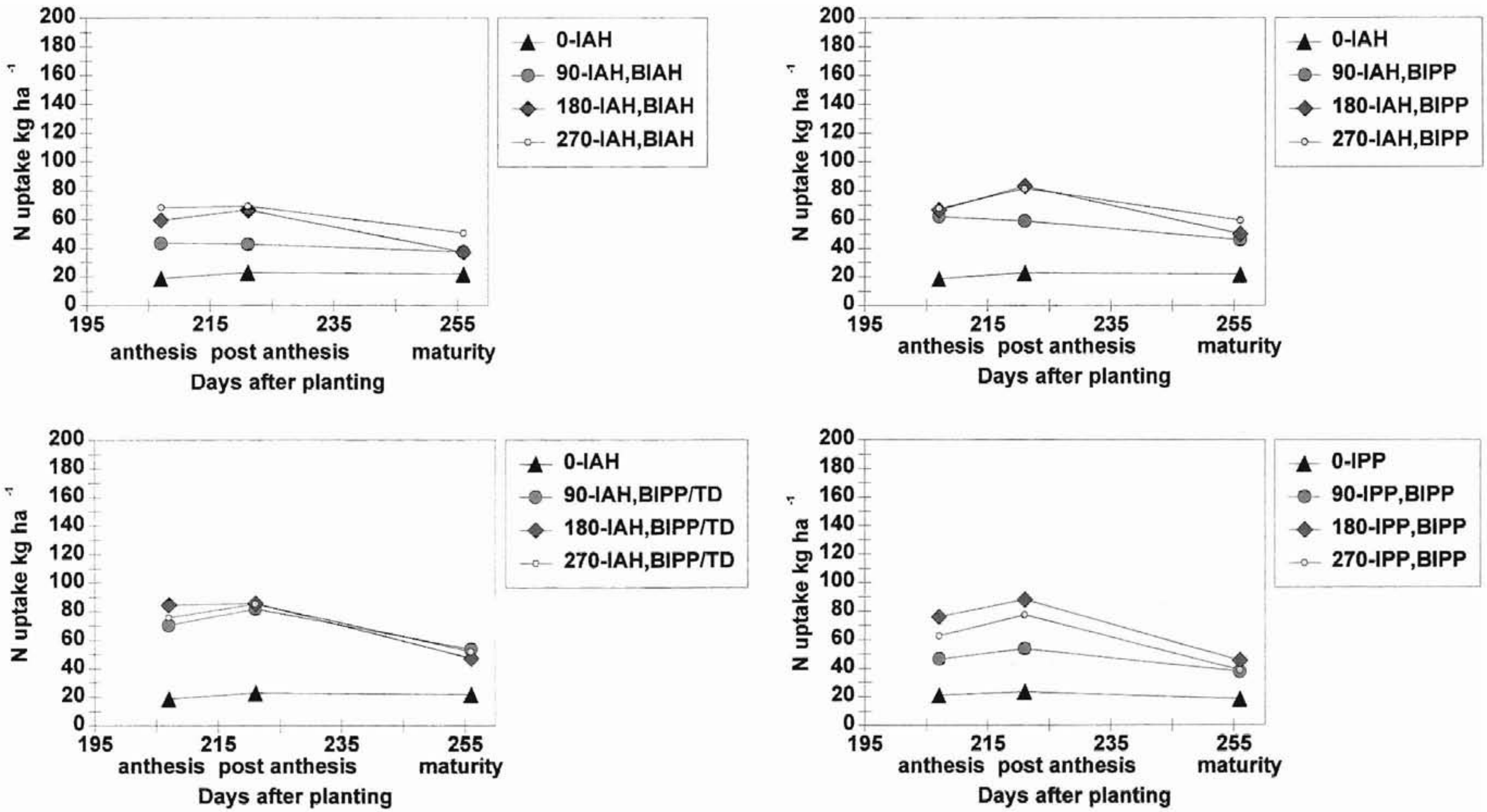

Figure 4. Change in total nitrogen uptake from anthesis to maturity, Perkins, 1995.

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Candidate for the Degree of

Master of Science

Thesis: EFFECT OF NIRTOGEN RATE, METHOD OF APPLICATION AND RESIDUE MANAGEMENT ON ESTIMATED N LOSS IN WINTER WHEAT

Major Field: Agronomy

Biographical:

Personal Data: Born in Shawnee, Oklahoma, on January 27, 1971, the son of Clarence H. and Carolyn Sue (Warren) Ball; and married Kara Michelle McCullar on June 11, 1994.

Education: Graduated from Tecumseh High School, Tecumseh, OK, in May 1989; received the Bachelor of Science Degree in Agriculture in Agronomy from Oklahoma State University, Stillwater, in December, 1993; and completed the requirements for the Master of Science Degree in Soil Science from Oklahoma State University in December, 1995.

Experience: Employed as a farming assistant through the summers of 1986-1989; employed by ESTES Inc. for the summer of 1993; employed by Oklahoma State University, Department of Agronomy as a Graduate Research Assistant in the soil Fertility Project from January, 1994 to present.

Professional Membership: American Society of Agronomy