Influence of Late-Season Foliar Nitrogen Applications on Yield and Grain Nitrogen in Winter Wheat

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ABSTRACT

Increasing grain protein in new higher-yielding cereal grains has recently received added attention due to protein premiums paid to farmers. Hard red winter wheat (*Triticum aestivum* L.) studies were conducted at two locations in Oklahoma in 1997–1998, 1998–1999, and 1999–2000 to evaluate the effects of late-season foliar N applications on grain yield, total grain N, straw yield, and total straw N. Foliar applications of N were made at two different times (pre- and postflowering) using urea ammonium nitrate (UAN) at rates of 0, 11, 22, 34, and 45 kg N ha^{-1}. Ammonium sulfate [$(NH_4)_2SO_4$] was also applied at a single rate of 22 kg N ha^{-1} both pre- and postflowering. A significant linear increase in total grain N was observed for postflowering applications using UAN in five of six site-years. In four out of the six site-years, a significant linear increase was observed for preflowering applications of UAN. No consistent increases or decreases from foliar N applications were observed for grain yield, straw yield, or straw N. Over years and locations, UAN applied preflowering and postflowering at 34 kg N ha^{-1} increased total grain N over that of the check (no foliar N applied) by 2.7 and 2.4 g kg^{-1}, respectively. Late-season foliar N applications before or immediately following flowering may significantly enhance grain N content and, thus, percent protein in winter wheat.

Grain protein is an 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 irrigated hard red winter wheat, grain protein contents frequently are <11.4% and often do not attract protein premiums (Strong, 1982). The desired protein of wheat depends on the type and/or use of the wheat. High protein content is desirable in varieties of hard red winter wheat. 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 varieties of soft red winter wheat (Hunter and Stanford, 1973). Early research concluded that climate was an influential 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 USA were affected by N deficiencies (Daigger et al., 1976).

Nitrogen, which is a primary constituent of proteins, is extremely susceptible to loss when considering that average recovery rates fall in the range of 20 to 50% for grain production systems in winter wheat (Raun and Johnson, 1999). Cassman et al. (1992) noted the importance of both preplant and in-season N fertilizer management for optimizing both yield and protein in wheat.

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Wheat producers in the Great Plains typically use two options for applying N fertilizer: (i) all N fall-applied before 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 head emergence may respond with increases in grain yield but may show little or no effect in grain protein content. Although preplant fertilizer applications decrease the potential for nutrient deficiencies in early stages of growth, presence of residual soil NO_3–N (plant-available mineral N from the previous season) may pose a risk to the environment. Many researchers have found that preplant applications may lead to losses or immobilization before plant uptake, thus greatly affecting N use efficiency (NUE) (Welch et al., 1966; Olson and Swallow, 1984; Lutcher and Mahler, 1988; Fowler and Brydon, 1989; Wuest and Cassman, 1992). The common practice of using surface soil testing for adjusting fertilizer N before planting is not suited for detecting late-season deficiencies. 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 N 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 content and, many times, yield (Ellen and Spiertz, 1980).

Increasing grain protein by applying higher fertilizer N rates 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). Spiertz (1983) found that with a regular N supply, wheat would usually attain 65 to 80% of its grain N 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 to 11% fertilizer N for a 1% increase in grain protein, depending on the crop variety and the initial N concentration within the plant. Wuest and Cassman (1992) found that while the availability of soil N and water may often constrain postflowering N uptake, applications of N near flowering increased postflowering N uptake, grain protein content, and grain protein concentrations. Work by Dhugga and

Abbreviations: AS, ammonium sulfate; NUE, nitrogen use efficiency; UAN, urea ammonium nitrate.

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

Location	pH†	NH_4–N‡	NO_3–N‡	P§	K§	Total N¶	Organic C¶
		mg kg^{-1}				g kg^{-1}	
Perkins	5.8	18.87	4.9	12	140	0.63	4.03
Stillwater	5.5	3.47	14.7	31	222	0.94	10.51

† 1:1 soil/water.
‡ 2 *M* KCl extraction.
§ Mehlich 3.
¶ Dry combustion.

Waines (1989) showed that the N uptake capacity of grain is a determining factor for postflowering N uptake. Applications of N near flowering increased postflowering N uptake, grain protein content, and grain protein concentration (Bänziger et al., 1994; Bulman and Smith, 1993).

Yield increases from foliar applications vary greatly. Finney et al. (1957) found that N applied preplant will normally give a response equal to that of N applied up to tillering in wheat. Nitrogen applied after tillering and up to heading will normally give progressively smaller yield increases. These authors also found that N applied after heading usually did not result in yield increases in most years unless N deficiency was severe. Similar work by Below et al. (1985) reported no increases in corn (*Zea mays* L.) grain yield when foliar N was applied 7 d before and 7 d after anthesis at a total N rate of 22.3 kg N ha^{-1}. Finney et al. (1957) indicated that the greatest grain protein increases occurred when foliar N applications were applied at anthesis (flowering) and that responses declined rapidly before or after that time. In some cases, they noted that N applied during the fruiting period could increase wheat protein from 10.8 to 21.0%.

Foliar N applications are often associated with leaf burn when applications are made early morning and dew is still on the crop. Gooding and Davies (1992) found higher levels of leaf burn with ammonium nitrate (NH_4NO_3) and ammonium sulfate (AS) compared with urea [$(NH_2)_2CO$]. It should be noted that their work and that of several others reported here has not included urea ammonium nitrate (UAN), which is now a common foliar N source.

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

The objective of this experiment was to determine the effects of late-season applications of varying rates of two N fertilizer sources (UAN vs. AS) at two times of application (pre- vs. postflowering) on grain yield, total grain N, straw yield, and total straw N.

MATERIALS AND METHODS

In October 1997, two studies were initiated at Perkins, OK, on a Teller sandy loam (fine-mixed, thermic, Udic Argiustoll) and at Stillwater, OK, on a Easpur loam (fine-loamy, mixed, thermic, Fluventic Haplustoll). Studies were repeated for 3 yr (1997–1998, 1998–1999, and 1999–2000) on the same plots, year after year. A randomized complete block experimental design was used at both locations with four replications. At both sites, plot size was 3.05 by 2.44 m. Results of soil test data from samples collected before treatment application are reported in Table 1. Nitrogen and P fertilizers were applied and incorporated before planting under a conventional tillage system (two to three disk incorporations of wheat straw residues following harvest) at both locations. Nitrogen was broadcast preplant as ammonium nitrate (34–0–0) at a rate of 67 kg N ha^{-1} in the first year and 45 kg N ha^{-1} in the second and third year. These rates were based on soil test N and moderate to high yield goals. Phosphorus, as triple super phosphate (0–46–0), was applied with the N in 1997 at both locations at a rate of 45 kg P ha^{-1}, and an additional 45 kg P ha^{-1} was applied in 1999. Hard red winter wheat ('Tonkawa') was planted in 19-cm rows at a seeding rate of 78.5 kg ha^{-1} at both sites in mid-October of all 3 yr.

Foliar applications of N were applied at preflowering (Feekes 10.5) and postflowering (Feekes 10.5.4) stages of growth (Large, 1954). The treatment structure employed at both sites is reported in Table 2. Dates of foliar N application for each experiment were determined by collecting 20 random wheat heads from each experimental area and examining them under a 10× hand lens to assess maturity. Two N sources commonly available in the central Great Plains were evaluated in the study. Liquid UAN (28–0–0) was foliar-applied with no dilution at rates of 0, 11, 22, 34, and 45 kg N ha^{-1} (32.3, 63.3, 94.2, and 125.2 L ha^{-1}, respectively). 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 1000 mL of water, resulting in a total volume of 1300 mL. The AS solution was 8.6% N by weight and 11.4% N on a weight/volume basis; therefore, this solution required a higher volume (114 mL) than UAN to achieve the single rate of 22.4 kg N ha^{-1}. Both N sources were applied using 175 mL of mechanically pressurized spray bottles (No. 413, Marianna Research Labs, Omaha, NE) to simulate an aerial application. Because of the small plot size and application method, spray patterns were simulated on paper to ensure

Table 2. Treatment structure employed that included N source, N rate, and time of application, Perkins and Stillwater, OK (1997–1998, 1998–1999, and 1999–2000).

Treatment	N source†	N rate	Time of application‡
		kg ha^{-1}	
1	–	0	Check
2	UAN	11	Preflowering
3	UAN	22	Preflowering
4	UAN	34	Preflowering
5	UAN	45	Preflowering
6	AS	22	Preflowering
7	UAN	11	Postflowering
8	UAN	22	Postflowering
9	UAN	34	Postflowering
10	UAN	45	Postflowering
11	AS	22	Postflowering

† UAN, urea ammonium nitrate; AS, ammonium sulfate.
‡ Preflowering: foliar N applied just before flowering (late April, Feekes 10.5); and postflowering: foliar N applied immediately following flowering (early May, Feekes 10.5.4).

Table 3. Treatment means for grain yield, grain N uptake, grain N, straw yield, straw N uptake, and straw N, Perkins, OK, 1998.

			Grain			Straw		
Source†	Timing‡	N rate	Yield	N uptake	Grain N	Yield	N uptake	Straw N
			kg ha^{-1}		g kg^{-1}	kg ha^{-1}		g kg^{-1}
Check	Check	0	2269	53	23.5	1795	10	5.3
UAN	Pre	11	2338	62	26.8	1413	9	5.7
UAN	Pre	22	2342	64	27.5	1953	10	5.8
UAN	Pre	34	2040	58	28.2	1777	11	6.7
UAN	Pre	45	2254	63	28.3	2334	15	6.4
AS	Pre	22	2118	63	29.7	2481	21	8.7
UAN	Post	11	2350	59	25.3	2939	14	4.9
UAN	Post	22	2012	55	27.2	2139	13	6.0
UAN	Post	34	2176	58	26.6	2718	19	6.9
UAN	Post	45	2030	57	28.0	2137	14	6.8
AS	Post	22	2510	66	26.2	1948	15	7.6
SED§			302	8	0.9	516	3	1.0
CV, %			17	17	4.1	29	27	18.7
Contrast								
UAN pre lin			NS	NS	**	NS	NS	NS
UAN pre quad			NS	NS	*	NS	NS	NS
UAN post lin			NS	NS	**	NS	NS	*
AS pre vs. UAN pre			NS	NS	*	NS	**	**
AS post vs. UAN post			NS	NS	**	NS	*	NS
UAN pre vs. UAN post			NS	NS	NS	*	*	NS
AS pre vs. AS post			NS	NS	**	NS	*	NS
AS pre vs. check			NS	NS	**	NS	**	**
AS post vs. check			NS	NS	**	NS	NS	*

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† UAN, urea ammonium nitrate; AS, ammonium sulfate.
‡ Pre, foliar N applied just before flowering (late April, Feekes 10.5); Post, foliar N applied immediately following flowering (early May, Feekes 10.5.4).
§ SED, standard error of the difference of two equally replicated means.

uniform coverage. Sufficient leaf surface, good plant density, and small spray volumes allowed for interception of UAN and AS spray with minimal, if any, runoff from 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- by 3.05-m area in each plot. Straw samples from the entire plot were also collected from the harvested area in each plot. Grain and straw samples were dried and ground to pass a 100-μm sieve and 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 (g kg^{-1})/10 $\times$ 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 single degree-of-freedom, nonorthogonal contrasts (SAS, 1988).

RESULTS AND DISCUSSION

Means and single degree-of-freedom contrasts for grain yield, grain N uptake, grain N, straw yield, straw N uptake, and straw N are reported in Tables 3 through 8 for Perkins and Stillwater (1998, 1999, and 2000). Ammonia volatilization losses from UAN were not expected to be significant because N was applied during early morning hours when temperatures were cool and wind velocity was low.

Limited (<10% surface damage) foliar burn was ob-

Table 4. Treatment means for grain yield, grain N uptake, grain N, straw yield, straw N uptake, and straw N, Perkins, OK, 1999.

			Grain			Straw		
Source†	Timing‡	N rate	Yield	N uptake	Grain N	Yield	N uptake	Straw N
			kg ha^{-1}		g kg^{-1}	kg ha^{-1}		g kg^{-1}
Check	Check	0	1657	50	25.9	1948	14	7.5
UAN	Pre	11	1955	62	27.0	1939	13	7.0
UAN	Pre	22	1977	67	28.6	2376	19	7.9
UAN	Pre	34	1861	66	30.7	2045	17	8.7
UAN	Pre	45	1921	65	29.2	2286	18	8.1
AS	Pre	22	1941	61	26.6	2225	17	7.8
UAN	Post	11	1591	49	26.7	1796	14	7.3
UAN	Post	22	2292	79	29.3	2636	19	7.1
UAN	Post	34	1616	57	30.5	1823	14	7.7
UAN	Post	45	1875	67	30.4	2156	17	8.0
AS	Post	22	1683	56	28.3	2159	17	7.8
SED§			381	15	1.6	518	4	0.6
CV, %			29	35	7.9	34	37	11.4
Contrast								
UAN pre lin			NS	NS	**	NS	NS	*
UAN post lin			NS	NS	**	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† UAN, urea ammonium nitrate; AS, ammonium sulfate.
‡ Pre, foliar N applied just before flowering (late April, Feekes 10.5); Post, foliar N applied immediately following flowering (early May, Feekes 10.5.4).
§ SED, standard error of the difference of two equally replicated means.

Table 5. Treatment means for grain yield, grain N uptake, grain N, straw yield, straw N uptake, and straw N, Perkins, OK, 2000.

			Grain			Straw		
Source†	Timing‡	N rate	Yield	N uptake	Grain N	Yield	N uptake	Straw N
			kg ha^{-1}		g kg^{-1}	kg ha^{-1}		g kg^{-1}
Check	Check	0	2768	62	22.4	5957	33	6.2
UAN	Pre	11	2871	71	24.7	5582	40	7.8
UAN	Pre	22	2798	70	24.9	4968	40	7.3
UAN	Pre	34	2845	74	25.8	5305	40	7.9
UAN	Pre	45	2971	77	25.9	5043	38	8.1
AS	Pre	22	2665	71	26.7	4726	37	7.4
UAN	Post	11	2945	72	24.6	5005	54	7.8
UAN	Post	22	3708	85	24.9	4615	44	8.1
UAN	Post	34	2770	70	25.5	6117	34	6.7
UAN	Post	45	2735	74	26.8	5542	36	8.1
AS	Post	22	2838	70	24.5	4649	43	8.1
SED§			373	11	1.2	942	8	0.8
CV, %			18	22	6.9	26	28	14.8
Contrast								
UAN pre lin			NS	NS	**	NS	NS	*
UAN post lin			NS	NS	**	NS	NS	NS
UAN post quad			0.13	NS	NS	NS	NS	NS
AS pre vs. check			NS	NS	**	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† UAN, urea ammonium nitrate; AS, ammonium sulfate.
‡ Pre, foliar N applied just before flowering (late April, Feekes 10.5); Post, foliar N applied immediately following flowering (early May, Feekes 10.5.4).
§ SED, standard error of the difference of two equally replicated means.

served at either site in all years. However, a tendency for increased foliar burn was observed with AS compared with UAN applications. Foliar burn from AS at a rate of 22 kg N ha^{-1} was similar to that for UAN applications at 45 kg N ha^{-1}. Increased awn burn was observed with increasing rates of UAN, but even at 45 kg N ha^{-1}, there was little visual effect on spikelet or leaf color. Differences between UAN and AS applied either pre- or post flowering at the 22 kg N ha^{-1} rate were not consistent for any of the dependent variables analyzed.

Grain Yield

Grain yield increases due to foliar applications of N were not consistent over years and locations. Grain yields at Perkins in 2000 were increased by 940 kg ha^{-1} over that of the check (no N at flowering) when UAN was applied postflowering at the 22 kg N ha^{-1} rate (Table 5). At Stillwater in 1999, UAN applied preflowering and/or postflowering tended to decrease yields at the low N rates (Table 7), but that was likely a random effect. Preflowering application of AS at Stillwater significantly increased yields above the check in 2000 (Table 8). Maximum grain yields were generally observed when N, as UAN, was applied postflowering at rates between 22 and 34 kg N ha^{-1} although differences were small.

Grain Nitrogen Uptake

Similar to grain yield data, only limited differences in grain N uptake were observed in any year at both sites. At Stillwater in 1999, N applied as UAN preflowering resulted in lower grain N uptake at the low N rates and trends for increases at the higher 34 and 45

Table 6. Treatment means for grain yield, grain N uptake, grain N, straw yield, straw N uptake, and straw N, Stillwater, OK, 1998.

			Grain			Straw		
Source†	Timing‡	N rate	Yield	N uptake	Grain N	Yield	N uptake	Straw N
			kg ha^{-1}		g kg^{-1}	kg ha^{-1}		g kg^{-1}
Check	Check	0	4052	112	27.7	6989	56	8.1
UAN	Pre	11	3877	110	28.5	5746	46	7.9
UAN	Pre	22	3656	99	27.3	4631	31	6.9
UAN	Pre	34	4032	115	28.7	5108	40	7.6
UAN	Pre	45	4053	115	28.5	6255	53	8.5
AS	Pre	22	3832	107	27.8	6299	51	8.1
UAN	Post	11	3831	104	27.3	6078	45	7.4
UAN	Post	22	3824	112	29.3	6872	67	9.8
UAN	Post	34	4457	129	28.9	6362	57	9.0
UAN	Post	45	3915	116	29.7	6083	54	8.9
AS	Post	22	3866	108	27.9	6145	49	8.0
SED§			220	7	1.2	609	3	0.9
CV, %			7	8	5.1	12	20	14.7
Contrast								
UAN pre quad			NS	NS	NS	*	**	NS
UAN post lin			NS	NS	*	NS	NS	NS
AS pre vs. UAN pre			NS	NS	NS	*	*	NS
UAN pre vs. UAN post			NS	NS	NS	**	**	*

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† UAN, urea ammonium nitrate; AS, ammonium sulfate.
‡ Pre, foliar N applied just before flowering (late April, Feekes 10.5); Post, foliar N applied immediately following flowering (early May, Feekes 10.5.4).
§ SED, standard error of the difference of two equally replicated means.

Table 7. Treatment means for grain yield, grain N uptake, grain N, straw yield, straw N uptake, and straw N, Stillwater, OK, 1999.

			Grain			Straw		
Source†	Timing‡	N rate	Yield	N uptake	Grain N	Yield	N uptake	Straw N
			kg ha^{-1}		g kg^{-1}	kg ha^{-1}		g kg^{-1}
Check	Check	0	2775	100	31.0	3287	24	7.2
UAN	Pre	11	2453	85	29.9	3131	22	7.0
UAN	Pre	22	2388	88	31.9	2896	21	7.0
UAN	Pre	34	2772	102	31.6	3376	24	7.0
UAN	Pre	45	2841	107	32.8	3250	27	8.2
AS	Pre	22	2355	81	29.9	3173	23	7.1
UAN	Post	11	2518	91	31.2	2821	21	7.2
UAN	Post	22	2421	88	31.1	3215	23	7.1
UAN	Post	34	2842	108	33.0	3203	24	7.5
UAN	Post	45	2110	81	33.1	2885	20	6.9
AS	Post	22	2352	85	30.7	3395	27	7.5
SED§			213	8	0.9	359	4	0.6
CV, %			12	13	4.1	16	23	11.0
Contrast								
UAN pre lin			NS	NS	*	NS	NS	NS
UAN pre quad			*	*	NS	NS	NS	NS
UAN post lin			*	NS	**	NS	NS	NS
AS pre vs. UAN pre			NS	NS	*	NS	NS	NS
AS pre vs. check			NS	*	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† UAN, urea ammonium nitrate; AS, ammonium sulfate.
‡ Pre, foliar N applied just before flowering (late April, Feekes 10.5); Post, foliar N applied immediately following flowering (early May, Feekes 10.5.4).
§ SED, standard error of the difference of two equally replicated means.

kg N ha^{-1} rates (Table 7). In 2000 at Stillwater, grain N uptake increased significantly when UAN was applied pre- and postflowering (increase of 21 kg N ha^{-1} when UAN was applied preflowering at a rate of 34 kg N ha^{-1}; Table 8). In this case, NUE (N uptake treated minus N uptake check divided by the rate applied) was 62% for a preflowering UAN application.

Total Nitrogen in the Grain

In all 3 yr at Perkins, total grain N showed a linear response to foliar UAN for both pre- and postflowering treatments (Tables 3–5). At Stillwater in 1998 and 1999, a linear increase in total grain N was observed for postflowering-applied UAN while preflowering applications of UAN increased total grain N in 1999 and 2000 (Tables 6–8). Preflowering AS treatments at Stillwater resulted in decreased grain N below that of UAN applications in 1999 and 2000. Conversely, at Perkins in 1998, preflowering AS increased total grain N above UAN while postflowering AS decreased grain N below UAN treatments. It was important to find significant increases in total grain N from foliar applications of N under moderate to high soil fertility levels (Table 1) and where N was applied before planting at all sites.

Straw Yield

Straw yield responses to pre- and postflowering N applications were variable at both sites. Straw yield means were highest for postflowering treatments at rates of 11 and 22 kg N ha^{-1} for Perkins in 1998 and 1999,

Table 8. Treatment means for grain yield, grain N uptake, grain N, straw yield, straw N uptake, and straw N, Stillwater, OK, 2000.

			Grain			Straw		
Source†	Timing‡	N rate	Yield	N uptake	Grain N	Yield	N uptake	Straw N
			kg ha^{-1}		g kg^{-1}	kg ha^{-1}		g kg^{-1}
Check	Check	0	2826	75	26.8	6047	68	11.2
UAN	Pre	11	3079	81	26.2	5410	50	9.6
UAN	Pre	22	3024	88	29.3	5703	68	11.8
UAN	Pre	34	3366	96	28.5	6005	74	12.2
UAN	Pre	45	3178	91	28.7	5855	74	12.7
AS	Pre	22	3679	93	25.3	6525	61	9.2
UAN	Post	11	3519	95	27.1	6694	80	12.1
UAN	Post	22	3400	95	27.8	5721	68	12.3
UAN	Post	34	3245	88	27.2	6067	61	10.1
UAN	Post	45	3321	92	27.7	5500	59	10.9
AS	Post	22	3426	93	27.0	5233	51	9.5
SED§			374	9	1.4	794	14	1.7
CV, %			16	15	7.2	19	31	23.0
Contrast								
UAN pre lin			NS	*	0.06	NS	NS	NS
UAN post quad			NS	0.11	NS	NS	NS	NS
AS pre vs. UAN pre			NS	NS	**	NS	NS	NS
AS pre vs. check			*	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† UAN, urea ammonium nitrate; AS, ammonium sulfate.
‡ Pre, foliar N applied just before flowering (late April, Feekes 10.5); Post, foliar N applied immediately following flowering (early May, Feekes 10.5.4).
§ SED, standard error of the difference of two equally replicated means.

respectively. At Stillwater, straw yields were highest for the check in 1998. Straw yields were quite variable over locations and were not necessarily correlated with grain yield levels. In 1999, grain and straw yield levels were similar at both sites while in 2000, straw dry matter yields were nearly double those of grain.

Straw Nitrogen Uptake

Differences in straw N uptake due to treatment were generally small, excluding Stillwater in 1998. At Stillwater in 1998 (Table 6), straw N uptake ranged from 31 to 67 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 a rate of 45 kg N ha^{-1} (Table 7). Similar to grain yield and grain N uptake data, only limited differences in straw N uptake were observed over the 3-yr period at both sites.

Straw Total Nitrogen

Total straw N results were highly variable. At Perkins, significant linear trends were observed with postflowering UAN applications in 1998 and preflowering UAN applications in 1999 and 2000. In 1998, preflowering AS treatments resulted in higher total straw N than preflowering UAN applications at Perkins (Table 3). At Stillwater in 1998, postflowering applications of UAN increased total straw N over UAN applied preflowering (Table 6).

CONCLUSIONS

Foliar burn as a result of applying UAN pre- and/or postflowering was generally not observed. Limited tissue damage with AS was seen compared with UAN. Averaged over years and locations, grain N increased when UAN was applied either post- or preflowering. No consistent increases or decreases from foliar N applications (pre- or postflowering) were observed for grain yield, straw yield, or straw N. Averaged over years and locations, UAN applied preflowering and postflowering at 34 kg N ha^{-1} increased grain N content by 2.7 and 2.4 g kg^{-1}, respectively. Grain protein averaged over years and locations in control plots was 14.9% compared with 16.5 and 16.3%, respectively, for preflowering and postflowering UAN applied at 34 kg N ha^{-1}. Foliar N applications just before and following flowering can significantly enhance grain N content and, thus, percent protein in winter wheat.

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