WINTER WHEAT AND CHEAT RESPONSE TO LATE-SEASON FOLIAR NITROGEN APPLICATIONS

By

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ABSTRACT

Maximum wheat grain yields depend on a weed free environment and late season foliar nitrogen applications may provide an alternative method in cheat seed reduction. Cheat (*Bromus secalinus* L.) is a noxious grass weed in winter wheat that can lower yields by as much as 40 %. Two field experiments were initiated in the fall of 1996-97 crop year at the Efaw Research Station and Perkins Research Station, to evaluate the influence of N rate and source of foliar fertilizer on the growth of wheat and cheat. Wheat was planted in 19-cm rows at a density of 78 kg ha^{-1}, while cheat was broadcast planted at a rate of 50 kg ha^{-1} in the fall of each year. Foliar N was applied immediately following wheat flowering, but before cheat flowering as either urea-ammonium nitrate (UAN) or ammonium hydroxide at rates of 0, 11, 22, 33, 45 and 56 kg ha^{-1}. In both crop years and experiments, the winter wheat variety 'Jagger' was used. Nitrogen fertilizers were applied using a 'Wylie' sprayer with an offset boom. Yield of wheat, grain protein, yield of cheat and cheat germination were determined after harvest. Cheat reduction was determined using the following

formula: 1 - (CG * CY/B) * 100), where CG is cheat germination, CY is the cheat yield, and B is the product of the percentage cheat germination and the yield of the cheat where no foliar N was applied (check). Cheat reduction ranged between 23 and 52 % for the UAN 34 kg N ha^{-1} foliar application. Wheat grain yields were not affected by foliar applied N following wheat flowering, while wheat grain protein increased from 189 to 215 g kg^{-1} when foliar N was applied after wheat flowering.

INTRODUCTION

The traditional wheat market classes in the USA are based primarily on milling and baking quality with grain protein being the most important characteristic. In wheat production, nitrogen (N) plays an essential role in growth and production. With the correct placement and timing of application, N fertilizers can have an affect on the milling and baking qualities of wheat.

It is necessary to grow winter wheat cultivars in a weed-free environment for maximum grain production. Cheat (*Bromus secalinus* L.) is one of the most important grass weed species in winter wheat in Oklahoma. Wheat grain yield losses can exceed 40% in fields heavily infested with cheat (Ratliff and Peeper, 1987).

Methods of applying N fertilizers are important for both wheat and cheat growth development. Keeney (1982) reported that methods of fertilizer application could effect both crop yield and nitrogen uptake efficiency. The use of late-season foliar applied N needs to be studied more extensively, specifically, late-season N applied after wheat has flowered but before cheat flowering. This method can result in cheat desiccation and reduce seed set (Chen, 1997). Finney et al. (1957), Strong (1986), and Smith et al. (1989 and 1991) reported that grain protein increased significantly when foliar N was applied at or near winter wheat flowering. In some years, additional N applied at flowering produced significant increases in yield (Wuest and Cassman, 1992). Wuest and Cassman (1992) also reported that late-season N was more efficient than preplant fertilizer N. Wuest and Cassman (1992) noted that early season N management should be for grain yield and late-season N applications needed to be managed for grain protein. Wuest and Cassman, (1992) further demonstrated that the level of preplant N had little influence on post-anthesis N uptake. However, they reported that N fertilizer applied at anthesis increased post-anthesis N uptake and grain protein when applied rates were between 17 and 77 kg ha^{-1}. Finney et al. (1957) reported that spraying urea solutions on wheat plants during the grain fill period can increase grain protein from 9.3% to 16.1%. Smith et al. (1991) also reported that foliar N could be efficiently translocated to the head from the leaves and stems just prior to maturity causing a 50% longer grain fill period and producing a higher quality seed. Mahler et al. (1994) reported that fertilizer placement or N source had no significant effect on wheat grain yield or nitrogen use efficiency (NUE), while time of application did influence grain yield and NUE. Mahler et al. (1994) also reported that split fertilizer applications in the fall and spring can have both economic and environmental advantages. In the same experiment they found that N source and placement did not affect grain yield. Other work has shown that foliar N applied before physiological maturity in grain sorghum (*Sorghum bicolor* L.) accelerated grain drying and reduced grain yield (Donnelly et al., 1977).

Nitrogen applied to fallow wheat ground can speed up the germination process of weed seeds thus allowing subsequent tillage to reduce the number of viable seeds available. Sexsmith and Pittman (1963) reported that early spring application of N fertilizers increased the germination of wild oat (*Avena fatua* L.) seeds. Following the oats germination, a tillage practice was used to destroy the plants that had germinated.

The effects of preplant N fertilizer on the growth and composition of winter wheat and several weed species has been studied. However, foliar applications of N fertilizers have not been studied for their effectiveness to increase winter wheat grain protein and to reduce weed seed production at the same time. Unlike herbicides, foliar fertilizers acting as a desiccating salt for weed seed reduction can be applied without a label while providing a nutrient value.

OBJECTIVES

The objectives of this experiment were to evaluate the use of post-wheat flowering foliar applied N on grain yield, grain protein, and cheat seed reduction.

MATERIALS AND METHODS

Two field experiments were established in the fall of 1996 at the Efaw Research Station at Stillwater, OK and Perkins Research Station at Perkins, OK. The soil at Stillwater was a Norge loam (fine-silty, mixed, thermic, Udic Paleustolls) and the soil at the Perkins site was a Teller sandy loam (fine-loamy, mixed, thermic, Pachic Argiustolls). Initial soil test characteristics and soil classification at each site are reported in Table 1. A randomized complete block experimental design was used with three replications at each site. In both years and locations the winter wheat variety 'Jagger' was used. Two N sources, urea-ammonium nitrate (UAN) and ammonium hydroxide (NH_4OH) were evaluated at six N rates (0, 11, 22, 34, 45 and 56 kg ha^{-1}). The UAN solution contained 28 % N and the ammonium hydroxide solution contained 40 % N. Nitrogen rates consisted of increased volume of each specific source without dilution. Plot size for these experiments were 3.04 m x 6.08 m.

In the fall of 1996, 1997 and 1998 the entire experimental plot areas were fertilized with 45 and 67 kg N ha^{-1}, respectively, as ammonium nitrate broadcast and incorporated prior to planting. Preplant N applications, planting date, foliar and harvest dates for both sites and years are reported in Table 2. The seeding rate for wheat at both locations was 78-kg ha^{-1} and cheat seed was planted at 50 kg ha^{-1}. Wheat was planted in 19 cm rows 3 cm deep, while the cheat was broadcast and incorporated (3 cm deep) prior to wheat planting. Foliar N applications were applied to wheat and cheat after the wheat flowered but before the cheat flowered. Foliar applications over the three years and two locations were made with a 'Wylie' sprayer using an offset boom across the plot to simulate aerial application. Foliar application dates were May 5, 1997; May 11, 1998; and May 7, 1999. In 1997 the boom was equipped with 6-TJ 60 8002 VS twinjet spray tips to deliver a volume of 38 l ha^{-1} (10 gal ac^{-1}) for the 11 kg N ha^{-1} rate. For all foliar applications the surfactant 'X-77' (OTHO, St. Paul, MN) was applied at a rate 5 ml L^{-1}. In 1998, 6-TJ 60 65013 VS spray tips were used to apply the same volume as stated above. The surfactant Latron AG-98 (Rohm-Haas Co., Philadelphia, PA) was used at a rate of 7 ml L^{-1} for 1998 foliar N applications. In 1999, the same tips were used again as in the 1998 foliar applications with the same volume of output. The surfactant 'Surf-King' (Estes Co., Wichita Falls, TX) was used at a rate of 237 ml 379 L^{-1}.

At harvest, a Massey Ferguson 8XP self-propelled combine was used to harvest a 2 x 6.08 m area from the center of all plots. The combine was set to collect all of the cheat and wheat seed. Samples were then cleaned in a small seed cleaner to separate cheat from wheat seed and other material. Yield of wheat and cheat was determined after seed cleaning. Total N analyses of the wheat grain samples was measured using a Carlo-Erba NA-1500 dry combustion analyzer (Schepers et al., 1989). Cheat reduction was calculated as: 1- (CG * CY/B) * 100 where CG is cheat germination, CY is the yield cheat, B is the product of percentage cheat germination and the yield of cheat where no foliar N was applied (check treatment). Cheat germination was determined as per the work of Copeland (1978). One hundred seeds from each plot were placed in wet paper and refrigerated at 4° C for 5 days, then placed in a germination chamber at 25° C for 7 days and germination counts were subsequently recorded.

Nitrogen use efficiency (NUE) was determined by subtracting grain N uptake in the check (no N applied) from grain N uptake in treated plots and then divided by the N rate applied. Nitrogen applied at planting was the same for all treatments (including the check) and was not considered for computation of NUE.

RESULTS AND DISCUSSION

Efaw and Perkins 1996-97

At Efaw in 1997, foliar N applied as UAN post-wheat flowering significantly increased grain yields up to the 34 kg N ha^{-1} rate (Table 3). At the higher 56 kg ha^{-1} rate grain yields decreased. Nitrogen applied as ammonium hydroxide had no effect on grain yield.

When averaged over N rates, UAN was significantly higher for total N uptake when compared to ammonium hydroxide. When compared to ammonium hydroxide averaged over N rates, UAN resulted in increased grain protein. These results agree with work by Finney et al. (1957), Pushman and Bingham (1976), Strong (1986), Morris and Paulson (1985) and Smith et al. (1989 and 1991) who found that grain protein would increase when foliar N was applied close to wheat flowering. Also, it is important to note that a linear increase in grain protein was found when foliar N was applied as UAN.

Nitrogen use efficiency exceeded 80 % at Efaw at the 11 kg N ha^{-1} rate and was much higher for UAN when compared to ammonium hydroxide (Table 3). As expected NUE decreased with increasing N rates. A negative linear effect with increasing N rates was observed for UAN. This agrees with work by Mahler et al. (1994) who found that NUE was higher at lower N rates and decreased as N rates increased. Cheat seed yields were higher for ammonium hydroxide when averaged over all N rates, but no lower effects between sources were observed. A quadratic effect was found for foliar applied N as ammonium hydroxide up to 22 kg ha^{-1} then decreasing with the higher N rates (Table 3). No significant effects were found in the cheat germination. Averaged over all N rates, ammonium hydroxide showed a higher cheat reduction, yield and germination from foliar applied N when compared to UAN (Table 3). For ammonium hydroxide cheat reduction increased linearly with increasing N rates. The same was not found for UAN, however, there was a quadratic trend in the data for foliar applied N as UAN but that was not significant.

At the Perkins location, foliar N applications had a quadratic trend in grain yield with ammonium hydroxide up to 11 kg N ha^{-1} (Table 4). Total N uptake when averaged over all N rates was significantly higher for UAN when compared to ammonium hydroxide. Grain protein was significantly higher for UAN (P>0.01) when compared to ammonium hydroxide averaged over all N rates at Perkins (Table 4). In addition, there was a linear increase up to 34 kg N ha^{-1} in total grain N as well as in grain protein for UAN (Table 4).

Nitrogen use efficiencies were low at the Perkins location due to extremely low grain yields as a result of a late frost on April 18, 1997. Also, there were no differences in cheat reduction between the two N sources.

Efaw and Perkins 1997-98

Foliar applied N using UAN and ammonium hydroxide did not result in a significant change in grain yield, total N uptake or grain protein. Nitrogen use efficiency increased linearly up to 22 kg N ha^{-1} for ammonium hydroxide and then decreased at the higher N rates (Table 5). Cheat reduction tended to increase with increasing N rate for UAN up to 56 kg N ha^{-1} (Table 5), which would agree with the linear decrease in cheat yield (Table 5).

At Perkins, foliar applied N had a negative linear effect on grain yields (Table 6). Total N uptake was significantly higher for UAN when compared and averaged over all N rates to ammonium hydroxide (Table 6). A linear increase for foliar applied N as UAN was found for total N uptake (Table 6). Grain protein increased with increasing N applied for UAN, and was generally higher for ammonium hydroxide averaged over all N rates (Table 6).

Grain protein was higher for UAN when compared to ammonium hydroxide when averaged over all N rates (Table 6). Grain protein increased up to 22 kg N ha^{-1} for UAN while no significant response was noted for ammonium hydroxide.

Nitrogen use efficiency was higher for UAN when averaged over all N rates (Table 6). Nitrogen use efficiencies exceeded 75% for the 11 and 22 kg N ha^{-1} rates, but declined at the higher rates of applied N (Table 6).

Increasing N rates beyond the 11 kg N ha^{-1} for UAN had less of an effect on cheat reduction (significant quadratic contrast, Table 6). No differences were found in cheat reduction for ammonium hydroxide.

In 1998, foliar N was not applied until May 11, which was approximately two to five days later than optimum. Due to wet field conditions that prevented a timely application at Efaw, cheat heads were more mature thus reducing injury. The window of opportunity (post-wheat flowering and pre-cheat flowering) is narrow (approximately 7-10 days). However, assuming that this practice will be feasible for aerial applications, delay due to wet soil moisture conditions will likely be avoided.

Efaw and Perkins 1998-99

Foliar applied N using UAN and ammonium hydroxide did not result in a significant change in grain yield or NUE at either location (Table 7 and 8). Total N uptake had a significant linear effect up through the 56 kg N ha^{-1} rate for foliar applied N at Efaw (Table 7). Grain protein was significantly higher for UAN when compared to ammonium hydroxide averaged over all N rates, increasing up to the 56 kg N ha^{-1} rate (Table 7).

Total N uptake at Perkins did not have any significant effects due to foliar N applications. Grain protein, at Perkins increased with increasing N applied up to 34 kg N ha^{-1} and was higher for UAN compared to ammonium hydroxide (Table 8). No differences in nitrogen use efficiency were detected as a function of N source or rate at either Efaw or Perkins in 1999 (Tables 7 and 8).

Cheat yields did not change significantly at either location due to foliar applied N (Tables 7and 8). However, cheat germination at the Efaw location when compared and averaged over all N rates, was higher for UAN (Table 7). Cheat reduction was higher for ammonium hydroxide when compared to UAN at Efaw, averaged over all N rates (Table 7).

Conclusions

UAN applications showed a positive or increased improvement on grain yield, grain protein and total N in the grain when compared to ammonium hydroxide. Foliar N rates applied after wheat flowering in excess of 34 kg N ha^{-1} resulted in lower grain yields. This was likely due to fertilizer burn that inhibited grain fill. Foliar N applied as UAN significantly increased grain protein and total N in the grain at the 22 and 34 kg N ha^{-1} rates. Nitrogen use efficiencies were generally highest for N rates less than 22 kg N ha^{-1} and were found to exceed 80 % when UAN was used. Averaged over N rates, UAN consistently had higher grain protein and grain yield, when compared to ammonium hydroxide. This may be due to the volatile nature of the ammonium hydroxide, since it may volatilize faster than it can be taken up by the plant. Although not tested in this work, cheat yields tended to be higher at Efaw where soil pH is lower (Table 1).

Cheat reduction was inconsistent over sites and years, and generally less than 80 %. There was a tendency for UAN to result in increased cheat reduction when compared to ammonium hydroxide, however, this was not consistent over all N rates. Cheat yields in the treated plots were not always less than the control. The variability in cheat response to applied N was likely a function of timing of applied N, and spraying conditions at the time of application.

Future work will be needed in order to justify applying foliar N to reduce cheat seed. These results do look promising considering the consistent increase in grain protein at low rates of applied N.

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Table 1. Initial soil test characteristics at Stillwater (Efaw) and Perkins, OK.

Location	Depth	pH	Total N	Organic C	NH_4-N	NO_3-N	P	K
	-cm-		----------g kg^{-1}----------		------------------kg ha^{-1}------------------			
Stillwater(Efaw)	0-15	5.5	1.038	10.231	8	34	69	497
Perkins	0-15	6.25	0.788	7.023	9	11	13	309

Organic C, Total N - Dry combustion; NH_4-N, NO_3-N - 2M KCL extract; P, K - Mehlich III; pH – 1 : 1 soil-water.

Table 2. Preplant N fertilization, foliar N application and harvest dates, Stillwater and Perkins, OK.

Location		Preplant N	Planting Date	Foliar N	Harvest Date
Stillwater(Efaw)	1996-97	9-26-96	10-3-96	5-6-97	6-19-97
	1997-98	10-3-97	10-20-97	5-11-98	6-20-98
	1998-99	9-20-98	10-15-98	5-8-99	6-17-99
Perkins	1996-97	10-4-96	10-4-96	5-5-97	6-20-97
	1997-98	9-30-97	10-21-97	5-11-98	6-16-98
	1998-99	9-16-98	10-12-98	5-7-99	6-14-99

Table 3. Treatment structure, grain yield, total grain N, grain protein, nitrogen use efficiency and cheat reduction, Stillwater (Efaw) 1996-97.

N rate	Source	Grain Yield	Total N Uptake	Grain Protein	Nitrogen Use Efficiency	Cheat Yield	Cheat Germination	Cheat Reduction	Cheat Increase
kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	g kg^{-1}	%	kg ha^{-1}	%	%	%
0	-	2847	80	190.2	0	673	97	0	
11	UAN	2704	92	200.1	87	635	97	6	
22	UAN	2801	94	196.3	49	559	98	16	
34	UAN	3170	108	199.0	76	588	98	11	
45	UAN	2386	85	208.9	13	703	90		+10
56	UAN	2464	90	215.3	19	736	95		+12
11	AH	2443	78	187.8	0	633	93	13	
22	AH	2762	88	186.9	27	638	91	10	
34	AH	2770	92	194.9	27	602	95	14	
45	AH	2635	88	195.2	12	522	87	30	
56	AH	2669	87	192.3	10	480	93	32	
SED		202	6	7	12	74	4	10	
UAN average‡		2705	94	203.9	49	646	95	12	
AH average‡		2659	87	191.4	18	577	92	13	
Contrast									
UAN vs AH†		NS	*	**	**	NS	NS	*	
UAN_linear		*	NS	**	**	NS	NS	NS	
UAN_quadratic		NS	NS	NS	NS	*	NS	NS	
AH_ linear		NS	NS	NS	NS	**	NS	*	
AH_quadratic		NS	NS	NS	*	NS	NS	NS	

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
SED, Standard error of the difference between two equally replicated means
UAN, urea-ammonium nitrate
AH, ammonium hydroxide
NS, not significant
† UAN and AH averaged over all N rates
‡ averaged over N Rates

Table 4. Treatment structure, grain yield, total grain N, grain protein, nitrogen use efficiency and cheat reduction, Perkins 1996-97.

N rate	Source	Grain Yield	Total N Uptake	Grain Protein	Nitrogen Use Efficiency	Cheat Yield	Cheat Germination	Cheat Reduction	Cheat Increase
kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	g kg^{-1}	%	kg ha^{-1}	%	%	%
0	-	520	15	174.8	0	424	92	0	
11	UAN	420	13	185.1	5	280	81	42	
22	UAN	491	16	195.1	19	418	93	7	
34	UAN	414	14	202.3	4	354	89	28	
45	UAN	506	17	202.1	8	407	88	27	
56	UAN	419	14	198.7	2	257	95	37	
11	AH	442	13	176.5	6	331	97	30	
22	AH	394	12	178.8	2	348	98	27	
34	AH	376	11	167.4	0	251	98	37	
45	AH	391	11	160.5	2	215	95	48	
56	AH	435	13	177.2	1	297	95	28	
SED		59	2	8	6	100	5	14	
UAN average‡		450	15	196.6	8	343	89	38	
AH average‡		418	12	172.7	2	288	97	43	
Contrast									
UAN vs AH†		NS	**	**	*	NS	**	NS	
UAN_linear		NS	NS	**	NS	NS	NS	NS	
UAN_quadratic		NS	NS	*	NS	NS	NS	NS	
AH_ linear		NS	NS	NS	NS	NS	NS	NS	
AH_quadratic		*	NS	NS	NS	NS	NS	NS	

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
SED, Standard error of the difference between two equally replicated means
UAN, urea-ammonium nitrate
AH, ammonium hydroxide
NS, not significant
† UAN and AH averaged over all N rates
‡ averaged over all N rates

Table 5. Treatment structure, grain yield, total grain N, grain protein, nitrogen use efficiency and cheat reduction, Stillwater (Efaw) 1997-98.

N rate	Source	Grain Yield	Total N Uptake	Grain Protein	Nitrogen Use Efficiency	Cheat Yield	Cheat Germination	Cheat Reduction	Cheat Increase
kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	g kg^{-1}	%	kg ha^{-1}	%	%	%
0	-	2613	71	164.2	0	782	97	0	
11	UAN	2570	69	157.9	11	802	94		+6
22	UAN	2429	74	178.8	27	698	96	15	
34	UAN	2555	76	173.6	31	691	93	11	
45	UAN	2206	63	173.2	2	647	87	23	
56	UAN	2665	81	178.5	23	529	92	32	
11	AH	2550	66	153.6	26	742	96	8	
22	AH	2839	78	160.9	53	730	94	8	
34	AH	2089	60	169.1	0	799	96		+8
45	AH	2475	72	170.1	10	563	94	26	
56	AH	2308	68	173.5	6	678	96	10	
SED		244	7	9.2	17	86	3	6	
UAN average‡		2485	73	172.4	19	673	92	17	
AH average‡		2449	69	165.4	19	702	95	12	
Contrast									
UAN vs AH†		NS	NS	NS	NS	NS	*	NS	
UAN_linear		NS	NS	NS	NS	**	**	**	
AH_quadratic		NS	NS	NS	NS	NS	NS	NS	
AH_ linear		NS	NS	NS	*	NS	NS	NS	
AH_quadratic		NS	NS	NS	NS	NS	NS	NS	

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

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

UAN, urea-ammonium nitrate

AH, ammonium hydroxide

NS, not significant

† UAN and AH averaged over all N rates

‡ averaged over all N rates

Table 6. Treatment structure, grain yield, total grain N, grain protein, nitrogen use efficiency and cheat reduction, Perkins 1997-98.

N rate	Source	Grain Yield	Total N Uptake	Grain Protein	Nitrogen Use Efficiency	Cheat Yield	Cheat Germination	Cheat Reduction	Cheat Increase
kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	g kg^{-1}	%	kg ha^{-1}	%	%	%
0	-	2655	49	110.6	0	336	92	0	
11	UAN	2498	53	123.0	75	228	94	31	
22	UAN	2708	63	136.2	82	273	92	17	
34	UAN	2219	49	128.5	14	324	94	11	
45	UAN	2225	50	128.6	16	286	94	3	
56	UAN	2056	45	128.1	6	229	80	16	
11	AH	2330	46	113.2	27	310	92	7	
22	AH	2079	41	115.1	0	289	95	25	
34	AH	2099	42	116.8	13	298	92	7	
45	AH	2217	43	112.1	4	275	89	32	
56	AH	1968	39	113.3	0	204	88	40	
SED		214	6	6.6	17	60	3	16	
UAN averaged‡		2341	52	128.9	39	268	90	16	
AH average‡		2139	42	114.1	9	275	91	20	
Contrast									
UAN vs AH†		*	**	**	**	NS	NS	NS	
UAN_linear		*	*	*	**	NS	**	NS	
UAN_quadratic		NS	NS	*	NS	NS	**	*	
AH_ linear		*	NS	NS	NS	NS	NS	NS	
AH_quadratic		NS	NS	NS	NS	NS	NS	NS	

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

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

UAN, urea-ammonium nitrate

AH, ammonium hydroxide

NS, not significant

† UAN and AH averaged over all N rates

‡ averaged over all N rates

Table 7. Treatment structure, grain yield, total grain N, grain protein, nitrogen use efficiency and cheat reduction, Stillwater (Efaw) 1998-99.

N rate	Source	Grain Yield	Total N Uptake	Grain Protein	Nitrogen Use Efficiency	Cheat Yield	Cheat Germination	Cheat Reduction	Cheat Increase
kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	g kg^{-1}	%	kg ha^{-1}	%	%	%
0	-	2425	63	173.2	0	614	77	0	
11	UAN	2170	62	170.1	20	808	78		+2
22	UAN	2382	69	171.3	52	768	84		+2
34	UAN	2598	71	160.6	39	559	80	7	
45	UAN	2327	72	180.8	18	778	82		+5
56	UAN	2777	89	189.8	43	599	91	19	
11	AH	2688	72	156.2	70	617	75		+14
22	AH	2358	64	158.1	35	610	85	18	
34	AH	2312	67	173.2	21	724	76		+15
45	AH	2556	70	164.2	27	479	73	34	
56	AH	2262	61	158.2	9	438	75	31	
SED		384	10	11.8	31	132	7	12	
UAN average‡		2451	73	174.5	34	702	83	7	
AH average‡		2435	67	162.0	32	574	77	22	
Contrast									
UAN vs AH†		NS	NS	*	NS	NS	*	*	
UAN_linear		NS	*	NS	NS	NS	NS	NS	
UAN_quadratic		NS	NS	NS	NS	NS	NS	NS	
AH_ linear		NS	NS	NS	NS	NS	NS	NS	
AH_quadratic		NS	NS	NS	NS	NS	NS	NS	

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
SED, Standard error of the difference between two equally replicated means
UAN, urea-ammonium nitrate
AH, ammonium hydroxide
NS, not significant
† UAN and AH averaged over all N rates
‡ averaged over N Rates

Table 8. Treatment structure, grain yield, total grain N, grain protein, nitrogen use efficiency and cheat reduction, Perkins 1998-99.

N rate	Source	Grain Yield	Total N Uptake	Grain Protein	Nitrogen Use Efficiency	Cheat Yield	Cheat Germination	Cheat Reduction	Cheat Increase
kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	g kg^{-1}	%	kg ha^{-1}	%	%	%
0	-	1707	43	124.5	0	405	84	0	
11	UAN	1888	45	137.8	88	358	87	17	
22	UAN	1971	49	147.1	74	490	67		+23
34	UAN	1837	44	140.0	27	450	84		+9
45	UAN	2379	58	141.4	51	502	74		+6
56	UAN	1496	38	149.4	11	495	87		+1
11	AH	1836	41	131.7	57	375	83	19	
22	AH	1446	30	123.7	0	382	83	19	
34	AH	1919	46	140.7	35	638	83		+1
45	AH	1771	39	129.5	10	325	81	23	
56	AH	1734	39	133.2	8	385	83	17	
SED		354	9	8.0	47	141	9	12	
UAN average‡		1914	47	143.1	50	459	80	34	
AH average‡		1742	39	131.8	22	421	83	26	
Contrast									
UAN vs AH†		NS	NS	**	NS	NS	NS	NS	
UAN_linear		NS	NS	*	NS	NS	NS	*	
UAN_quadratic		NS	NS	NS	NS	NS	NS	NS	
AH_ linear		NS	NS	NS	NS	NS	NS	NS	
AH_quadratic		NS	NS	NS	NS	NS	NS	NS	

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
SED, Standard error of the difference between two equally replicated means
UAN, urea-ammonium nitrate
AH, ammonium hydroxide
NS, not significant
† UAN and AH averaged over all N rates
‡ averaged over N Rates

APPENDIX

Table 1. N rates, application cost, fertilizer cost, total cost, and bushels of wheat required to pay for fertilizer and average wheat yield.

lb/ac	kg/ha	Application Cost $/ac	Fertilizer Cost $/ac	Total Cost $/ac	Bu. of Wheat required to pay for Fertilizer‡	Average Wheat Yield bushel/ac
-----N rate------						
Check						
0	0	0	0	0	0	32
UAN†						
10	11	3.00	1.96	4.96	2.2	30
20	22	3.00	3.92	6.92	3.2	32
30	34	3.00	5.88	8.88	4.1	32
40	45	3.00	7.84	10.84	5.0	30
50	56	3.00	9.80	12.80	6.0	29
Ammonium Hydroxide*‡						
10	11	3.00	1.09**	4.09	1.9	28
20	22	3.00	2.18	5.18	2.4	29
30	34	3.00	3.27	6.27	2.9	29
40	45	3.00	4.36	7.36	3.4	30
50	56	3.00	5.45	8.45	3.9	28

* Commercial grade ammonium hydroxide produced by bubbling anhydrous ammonia into water.

** Fertilizer cost is based on anhydrous ammonia 20% N solution ammonium hydroxide.

† UAN (28-0-0) $110/ ton which contains 560 lb N/ ton; cost 19.6¢/ lb N

‡ Ammonium hydroxide as aqua ammonia is (20 % N); cost of anhydrous ammonia is $180/ ton which contains 1640 lb N/ ton; cost 10.9¢/ lb N.

ǂ Bushels of wheat required to pay for fertilizer was calculated using $2.18/ bushel wheat price.

Table 2. Treatment structure, grain yield, total grain N, grain protein, nitrogen use efficiency and cheat reduction averaged over years (1997-99) and locations (Stillwater (Efaw) and Perkins).

N rate	Source	Grain Yield	Total N Uptake	Grain Protein	Nitrogen Use Efficiency	Cheat Yield	Cheat Germination	Cheat Reduction	Cheat Increase
kg ha^{-1}		kg ha^{-1}	kg ha^{-1}	g kg^{-1}	%	kg ha^{-1}	%	%	%
0	-	2128	54	156.3	0	539	90	0	
11	UAN	2024	56	162.3	48	519	89	17	
22	UAN	2130	61	170.8	51	534	88	13	
34	UAN	2132	60	167.3	32	494	90	13	
45	UAN	2005	58	172.5	18	554	86		+12
56	UAN	1980	60	176.6	17	474	90	20	
11	AH	1882	53	153.2	31	501	89	15	
22	AH	1980	52	153.9	20	500	91	18	
34	AH	1928	53	160.4	16	552	90		+14
45	AH	2008	54	155.3	11	397	87	32	
56	AH	1896	51	158.0	6	414	88	26	

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VITA

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