Influence of Nitrogen Fertilizer Application Rate and Time on Winter Wheat Yields

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen (N) fertilizer is required on most soils in Arkansas to produce high-yielding soft red winter wheat (*Triticum aestivum* L.). The time and rate of N application are critical management decisions because they can influence the N-fertilizer uptake efficiency (Alcoz et al., 1993) and tillering (Weisz et al., 2001), which are highly correlated with wheat yields. In Arkansas, N fertilizer is usually applied in February when wheat plants are at Feekes stage 4 or 5, which coincides with the end of tillering. A small amount (~40 lbs N/acre) of N fertilizer is also recommended at planting for winter wheat following corn (*Zea mayes* L.), grain sorghum (*Sorghum bicolor* L.), and rice (*Oryza sativa* L.) to stimulate tillering. These crop residues have wide carbon to N ratios that may immobilize inorganic soil and fertilizer N.

Kelly (1995) reported that winter wheat following grain sorghum required higher N rates to produce near maximal yields than wheat following soybean in Kansas. Regardless of the previous crop, yields were similar for wheat receiving all N preplant in the fall, all N applied at Feekes stage 4, or N split between preplant and Feekes stage 4, suggesting that N can be applied either preplant or in late winter. Previous research in Arkansas has failed to provide conclusive evidence to support the need for a small proportion of fall-applied N to produce maximal yields (Fig. 1).

Both fall and late-winter N have advantages and disadvantages. Fall N must be applied, incorporated, and paid for before wheat is successfully established, which is undesirable since crop failure due to inadequate stand, pests, winter injury, or excessive moisture may occur. The primary disadvantage of late-winter N applications is that N fertilizer must often be applied by airplane, which increases application costs, because soil is too moist and soft for application with ground equipment. The topography, soil physical properties, and risk factors of individual fields may dictate the best N application time if there is little or no agronomic difference between N application times. The primary objectives of this research were to determine whether i) winter wheat following various summer crops requires fall N for producing maximum yields and ii) fall N alone produced similar yields as N applied in late-winter. If fall N is required to produce maximal grain yields, a secondary objective was to calibrate the appropriate fall and late-winter N-rate combinations required to produce maximal grain yields.

PROCEDURES

Field studies were established at five locations including two experiments at the Cotton Branch Experiment Station (CBES) in Marianna, Ark., and single experiments at Hickory Ridge, Ark. (HR), the Pine Tree Branch Station (PTBS) near Colt, Ark., and the Rice Research Extension Center (RREC) near Stuttgart, Ark., in 2003. The soils were mapped as a Calloway silt loam for both experiments at the CBES, a precision-graded Henry silt loam at HR, a Calhoun silt loam at the PTBS, and a Dewitt silt loam at the RREC. The crop grown immediately before seeding winter wheat was field corn at the HR, cowpea [*Vigna unguiculata* (L.) Walp.] and grain sorghum at the CBES, and rice at the PTBS and RREC. Rice straw was partially burned before seedbed preparation at the PTBS. Two composite soil samples (0- to 4-inch depth) were taken from each replicate at each site-year. The samples were mixed thoroughly, oven dried, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3-extractable nutrients, soilwater pH, and total soil carbon and N. Mehlich-3 extracts were analyzed using inductively coupled atomic plasma spectroscopy (ICPS). Soil nitrate (NO_3-N) and ammonium (NH_4-N) were extracted with 1 *N* KCl from oven-dried soil. Mean values of selected soil chemical properties are listed in Table 1.

'Sabbe' soft red winter wheat was drill-seeded at 115 lb seed/acre at all sites, except HR where 'Armor 3035' was drill-seeded into conventionally tilled seedbeds. Individual plots consisted of 9 or 10 rows of wheat that were 20-ft long and separated from adjacent plots by an 18- to 24- inch wide alley.

Nitrogen treatments consisted of all combinations of five fall- and late-winter-applied N rates, including 0, 40, 80, 120, and 160 lb N/acre, with the total N applied ranging from 0 to 320 lb N/acre. Fall N was broadcast as urea and mechanically incorporated before seeding at all locations except HR. At the HR, Agrotain-treated urea was applied to a dry soil surface after wheat emergence and incorporated by rain within 5 days. Late-winter N was applied as 100 lb ammonium sulfate/acre (20 lb N/acre) and the balance of the late-winter N rate was urea. Late winter N rates >80 lb N/acre were made in two split applications. A maximum of 80 lb N/acre was made for the first application with the balance of the rate >80 lb N/acre applied in the second split. Selected dates of agronomic importance are listed in Table 2.

The total number of tillers in a 3-ft section of the first inside row was counted before plant samples were taken at early heading from all fall N rates and the 0 and 160 lb N/acre rates applied in the late winter. Whole, aboveground plant samples were taken at the late-boot to early heading stage in each study to determine dry-matter accumulation, tissue-N concentration, and total aboveground N uptake (data not shown). A 3-ft row section of the first inside row was cut at the soil surface, placed in a paper bag, oven dried at 60°C to a constant weight, and ground to pass a 1-mm sieve. At maturity, grain yields were measured by harvesting each plot with a small-plot combine. Grain yields were adjusted to a uniform moisture content of 13% moisture.

For each experiment, N treatments were arranged as a randomized complete block design with a 5 (fall N rates) × 5 (spring N rates) factorial treatment structure. Each treatment was replicated four times. Because the previous crop differed among locations, each experiment was analyzed separately. Analysis of variance procedures were conducted with the PROC GLM procedure in SAS (SAS Institute, Inc., Cary, N.C.). Mean separations were performed by Fisher's Protected Least Significant Difference method at a significance level of 0.05.

RESULTS

Grain Yield

The fall × late-winter N-rate interaction was significant for all sites except the PTBS (Table 3), suggesting that application of fall only, late-winter only, and/or various combinations of fall and late-winter N applications may produce maximal wheat yields. Depending on the treatment, previous crop, and growing conditions at each site-year with a significant fall × late-winter N-rate interaction, total N rates required to produce maximal wheat yields ranged from 80 to 120 lb N/acre following corn, 80 to 160 lb N/acre following grain sorghum, 80 to 160 lb N/acre following cowpea, and from 160 to 240 lb N/acre following rice (RREC). In general, wheat receiving N only at late-winter achieved maximal grain yields with less N (40 to 80 lb N/acre) than when N was applied only at seeding, but only when wheat followed a crop other than rice. Good, but not excessive (i.e., sandy soils) soil drainage should likely be a requirement when N is to be applied in the fall. Wheat following rice at the RREC was the only site that showed preplant-N rates of 40 to 80 lb N/acre were required to achieve maximal yields. Yield data from the RREC suggest that the late-winter N rates may not have been high enough since wheat yields increased linearly and never reached a plateau (Table 3). A dense infestation of annual bluegrass (*Poa annua* L.) competed quite effectively with winter wheat for fertilizer N and poor drainage may have further limited the retention of inorganic N in the soil.

For wheat following rice at the PTBS, the main effects of fall and late-winter N rates were both significant (Table 4). Application of 80 to 160 lb N/acre applied in the fall, averaged across late-winter N rates, produced yields from 38 to 42 bu/acre that were significantly greater than mean yields of wheat receiving no fall N. Wheat yields showed a similar yield response pattern to late-winter N fertilizer rate, but wheat yields, averaged across fall N rates, had a wider range (22 to 50 bu/acre), indicating greater benefits from late-winter applied N. Maximal yields of 45 to 50 bu/acre were produced with 120 to 160 lb N/acre. Extremely poor drainage likely limited wheat growth and response to N, and also may have caused some N, especially fall-applied N, to be lost via denitrification.

PRACTICAL APPLICATIONS

Fall-applied N is not needed to maximize the yields of winter wheat, even when it is grown following crops like corn, grain sorghum, and cowpea. Tillering data suggested that preplant-N increased tillering (Table 5), but adequate rates of late-winter N were capable of producing sufficient tillering to achieve maximal grain yields (Table 6). Data also suggest that fall-applied N can produce maximal wheat yields without supplemental N applied in the late-winter, when fields have good internal and surface drainage to prevent waterlogged soil conditions. However, the optimal N-rate required to maximize wheat yields was higher for fall-applied N compared with late-winter applied N, presumably because of lower fertilizer recovery attributed to immobilization, leaching, runoff, and/or denitrification. Residual soil N from fertilization of corn and grain sorghum that preceded wheat may have provided adequate N to minimize immobilization of fertilizer N. Wheat following rice appears to be the lone situation where fall N may be of benefit, due at least in part to low soil inorganic-N concentrations, high amounts of rice straw that immobilize fertilizer N, or both.

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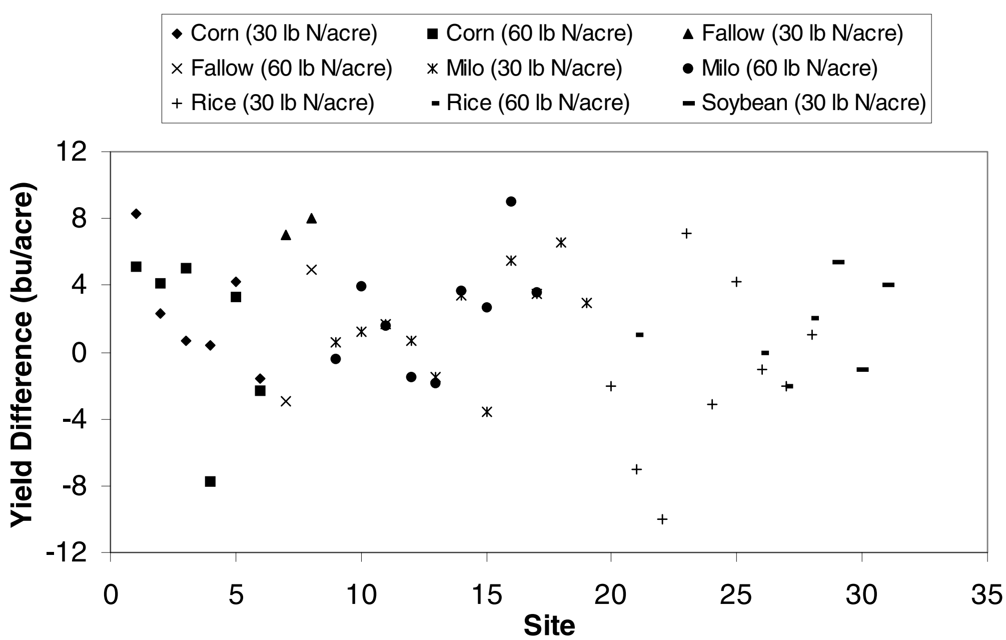

Fig. 1. Summary of 31 previously conducted research trials investigating the influence of preplant-incorporated N on winter wheat yield in Arkansas (results summarized from various issues of the Arkansas Soil Fertility Studies). Yield difference values <0 bu/acre indicate no benefit from fall N application.

Table 1. Mean soil-test information by site for N-rate trials with winter wheat in 2004.

Site[z]	Previous crop	Soil pH	Total soil C	Total soil N	Soil NO_3-N	Soil NH_4-N	Mehlich-3-extractable nutrients P	K	Ca	Mg	Mn	Zn	Cu
			------ (%) ------		---- (ppm) ----								
HR	Corn	6.8	1.200	0.118	32.5	10.3	28	159	1225	196	106	20.0	2.1
RREC	Rice	5.1	0.974	0.084	3.4	7.7	24	189	768	99	102	0.8	1.2
PTBS	Rice	6.6	1.432	0.136	2.5	6.7	38	184	1460	263	93	2.2	1.2
CBES	Milo	6.8	0.882	0.109	27.8	12.5	38	178	1362	227	114	1.5	1.9
CBES	Cow pea	6.4	0.818	0.085	8.1	14.0	39	162	989	272	83	1.5	1.7

[z] HR, Hickory Ridge; RREC, Rice Research Extension Center; PTBS, Pine Tree Branch Station; CBES, Cotton Branch Experiment Station.

Table 2. Selected agronomic dates of importance for five N-rate field trials conducted in 2003-2004.

Site[z]	Previous crop	Seeded	Fall N applied	Spring N application Split #1	Split #2	Heading sample	Harvest
		---- (day - month) ----					
HR	Corn	31 Oct.	11 Nov.	19 Feb.	10 March	13 April	4 June
CBES	Grain sorghum	23 Oct.	22 Oct.	18 Feb.	12 March	14 April	4 June
CBES	Cow pea	23 Oct.	22 Oct.	18 Feb.	12 March	14 April	3 June
PTBS	Rice	31 Oct.	30 Oct.	18 Feb.	10 March	14 April	9 June
RREC	Rice	21 Oct.	21 Oct.	19 Feb.	10 March	13 April	3 June

[z] HR, Hickory Ridge; RREC, Rice Research Extension Center; PTBS, Pine Tree Branch Station; CBES, Cotton Branch Experiment Station.

Table 3. The interaction between fall and late-winter N rates on wheat grain yield following corn, grain sorghum, cow pea, and rice at four sites during 2003-2004.

Late-winter N rate	Fall N rate (lb N/acre) 0	40	80	120	160
(lb N/acre)	---- [Grain yield (bu/acre)] ----				
Corn at HR [LSD(0.05) = 10 bu/acre]					
0	51	67	76	85	72
40	64	77	83	80	79
80	85	89	83	86	82
120	85	80	81	85	80
160	88	82	85	83	79
Grain sorghum at CBES [LSD(0.05) = 8 bu/acre]					
0	34	49	50	61	63
40	53	64	68	63	65
80	57	72	67	68	58
120	66	69	67	56	53
160	63	64	60	51	49
Cow pea at CBES [LSD(0.05) = 8 bu/acre]					
0	54	59	57	61	64
40	56	69	71	64	63
80	71	64	62	58	54
120	59	59	60	55	54
160	60	55	56	52	47
Rice at RREC [LSD(0.05) = 6 bu/acre]					
0	15	24	32	45	46
40	27	37	47	49	50
80	41	45	57	59	56
120	50	63	58	63	60
160	59	66	66	63	61

Table 4. Effect of fall N rate averaged across late-winter N rates, and late-winter N rate averaged across fall N rate, on grain yield of Sabbe wheat following rice at the Pine Tree Branch Station in 2003-2004.

N rate	Fall N rate	Spring N rate
(lb N/acre)	------------ [Grain yield (bu/acre)] ------------	
0	27	22
40	33	28
80	38	36
120	42	45
160	42	50
LSD(0.05)	7	7

Table 5. Effect of fall N rate, averaged across late-winter N rates, on the number of winter wheat tillers per 3 row-ft at multiple sites following various crops in 2003-2004.

	Site - previous crop[z]				
	HR[y]	RREC	PTBS	CBES	
Fall N rate	Corn	Rice	Rice	Grain sorghum	Cow pea
(lb N/acre)	---------- (tillers/3 linear-row ft) ----------				
0	150	56	76	74	78
40	160	70	84	98	93
80	175	69	92	92	94
120	177	75	89	104	95
160	164	81	92	108	98
LSD(0.05)	20	12	NS[x]	15	NS
P-value	0.0464	0.0038	0.1797	0.0005	0.0953
C.V., %	11.5	16.3	17.5	14.9	16.7

[z] Sabbe wheat at all sites except Hickory Ridge, which was seeded in Armor 3035.
[y] HR, Hickory Ridge; RREC, Rice Research Extension Center; PTBS, Pine Tree Branch Station; CBES, Cotton Branch Experiment Station.
[x] NS, not significant at the 0.05 level.

Table 6. Effect of late-winter N rate, averaged across fall N rates, on wheat tiller number at multiple locations and previous crops in 2004.

	Site - previous crop[z]				
	HR[y]	RREC	PTBS	CBES	
Spring N rate	Corn	Rice	Rice	Grain sorghum	Cow pea
(lb N/acre)	---------- (tillers/3 linear-row ft) ----------				
0	156	61	66	80	75
160	176	80	107	111	108
LSD(0.05)	12	12	10	9	10
P-value	0.0039	<0.0001	<0.0001	<0.0001	<0.0001

[z] 'Sabbe' wheat at all sites except Hickory Ridge, which was seeded in Armor 3035.
[y] HR, Hickory Ridge; RREC, Rice Research Extension Center; PTBS, Pine Tree Branch Station; CBES, Cotton Branch Experiment Station.