Improved Nitrogen Management in Irrigated Wheat Production Using Stem Nitrate Analysis

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ABSTRACT

The method for predicting the nitrogen (N) requirements of irrigated wheat that is recommended by the University of Arizona requires preplant soil, plus mid-season stem nitrate analysis. Additional information on the relationships between N rates, stem NO3-N levels and grain yields are needed for the wide range of agronomic conditions typical of Arizona's wheat growing areas. Three N fertility trials were conducted at the Maricopa Agricultural Center to, 1) measure the accuracy of the current University of Arizona procedure on soils of contrasting texture; 2) to evaluate the use of the current stem testing procedure on two durum varieties, "Aldura" and "Westbred-881"; and 3) to evaluate the effect of various N forms on the levels of NO3-N in stem tissue for wheat grown in a clay loam soil. The University of Arizona procedure was found to over-predict slightly the amount of N required for optimum economic return on sandy soils where the maximum yields obtained did not exceed 5100 lbs. grain/a which is considerably below the expected yield possibility for these sites. The procedure accurately predicted the amount of N required for optimum production on a clay loam soil (175 lbs. N/a) at a maximum yield of 6000 lbs. grain/acre. "Aldura" and "Westbred-881" were remarkably similar in their response to a wide range of N applications. There was no significant difference in the yields of these two varieties, but "Westbred-881" did contain somewhat higher protein levels. Little statistical or practical differences were observed in the quantities of N contained in the stem tissue of these two varieties; this should help simplify the interpretation of stem NO3-N values for various wheat cultivars. The chemical form of N applied to wheat grown in a clay loam soil had no significant effect on the quantity of NO3-N measured in stem tissue at any time during the growing season. The currently recommended procedure for predicting optimum N fertilization rates in wheat productions shows considerable promise but needs further evaluation, particularly under high-yielding conditions.

INTRODUCTION

Profitable production of small grains in Arizona nearly always requires using appreciable amounts of nitrogen (N) fertilizers to attain high grain yields with acceptable quality. However, regulation of many farming practices is becoming more and more stringent, and the presence of agricultural chemicals in groundwater supplies, including nitrate-nitrogen (NO3-N), is already a serious issue. Thus, the ability to precisely predict the minimum quantity of N required by wheat for optimum production is desirable, both for farm profitability and environmental protection.

The use of preplant soil NO3-N analysis and stem NO3-N tissue tests taken at the 3-4 leaf, jointing and boot growth stages comprise the method currently recommended by the University of Arizona for monitoring the N status of wheat crops. It has also shown promise in predicting the quantity of N to apply to wheat for optimum profitability (Doerge and Ottman, 1986; Gardner and Jackson, 1976; Pennington et al., 1983).

Relatively few Arizona growers or crop consultants currently use this testing procedure because growers find it inconvenient to sample plants at regular intervals or because they are uncertain about the reliability or accuracy of this method. A greater understanding of the relationships between stem NO_3-N levels, grain yields and N application rates is needed, with respect to other factors such as soil texture, varietal differences, and the method, timing and chemical form of the N fertilizers used.

Three experiments were conducted at the Maricopa Agricultural Center during the 1986-87 crop year with the following objectives: 1) to determine the accuracy of the method currently recommended by the University of Arizona for predicting the amount of N fertilizer needed on a sandy loam soil, and a clay loam soil for maximum economic yield of durum wheat; 2) to evaluate the response of two popular durum wheat varieties to a wide range of N application rates in terms of stem NO_3-N levels, grain yield, grain protein content, and other growth characteristics; and 3) to evaluate the effect of ammonium (NH_4), nitrate (NO_3) or NH_4 + NO_3 fertilizer applications on the levels of NO_3-N measured in the stem tissue of durum wheat grown in a clay loam soil.

METHODS AND MATERIALS

Three N fertility trials were conducted with durum wheat using similar cultural practices on each. The cropping history, soil test characteristics, and N treatments used on each of the three sites will be detailed below.

All plots received a uniform application of 100 lbs. P_2O_5/A, as treble superphosphate, was hand-broadcast and worked into the surface 4-6 inches of soil prior to pre-irrigation. All mid-season applications of N were hand-broadcast onto dry soil no more than two hours before irrigation. Individual irrigations were scheduled, using a neutron probe, to supply adequate, but not excessive, moisture based on measurements taken from plots receiving adequate N for maximum yield (Erie et al., 1982).

Stem tissue samples were taken periodically from all three trials, according to the recommended procedure of Pennington et al. (1983). With this method, the plant part sampled was the stem between ground level and the seed for sample taken prior to jointing and the two inches of stem just above ground level for the remaining dates. Samples were separated from the wheat plants immediately in the fields and then dried at 60xC, ground to pass a 30 mesh screen and analyzed for NO_3-N content using a specific ion electrode (Knowles et al., 1987).

Grain yields were estimated using a small plot combine with a swath of 4.5 feet. Following harvest, a subsample of grain from each plot was dried, ground and analyzed for total ammonium + organic-N, using the Kjeldahl digestion-steam distillation method. A subsample of grain from each plot was separated into vitreous and non-vitreous kernels for determination of percent yellow berry. Bushel weights were also determined on subsamples for all plots.

EXPERIMENT I - ACCURACY OF STEM TEST PROCEDURE

This trial was conducted on a Casa Grande sandy loam [coarse-loamy, mixed, hyperthermic, Typic Natrargid (reclaimed)]. The plots had been cropped to wheat the preceding year and had an average preplant soil test value of 10.5 ppm NO_3-N in the surface foot of soil. Other chemical properties of the surface soil were pH, 8.2; electrical conductivity 1.6 dS/m; organic matter, 0.5%; ammonium acetate extractable sodium, 0.89 meq/100g; free $CaCO_3$, "high"; and cation exchange capacity, 11 meq/100g.

The N treatments used are listed in Table 1. All preplant applications of N were as ammonium sulfate and were made simultaneously with the treble superphosphate used. All midseason N was applied as urea. The amount of N applied in Treatment 2 was made in accordance with the current University of Arizona procedure (Pennington et al., 1983), with Treatments 1 and 3 being 80 and 120% of that amount, respectively.

Table 1. Rates and timing of N applied to "Aldura" wheat grown on a Casa Grande sandy loam.

	Nitrogen Applied				
Treatment	Preplant	5-6 Leaf	Boot	Anthesis	Total
	..........................lbs./a..........................				
1. 80% N	24	16	60	28	128
2. 100% N	30	20	75	35	160
3. 120% N	36	24	90	42	192
4. Control	0	0	0	0	0

"Aldura" wheat seed was drilled into moist soil on flat borders at the rate of about 80 lbs./a on 14 November, 1986. A total of 24 inches of water containing about 36 lbs. NO_3-N/a was applied in six irrigations (including pre-irrigation). Rainfall during the growth period was 2.6 inches. Individual plots were 8 x 50 feet; treatments were replicated four times in a randomized complete block design. No pesticides of any kind were applied. Weed control was accomplished by hoeing and hand-rouging.

Stem tissue samples were taken at the 3-4 leaf, joint and boot growth stages on 26 December, 20 February and 3 March, respectively. Grain was harvested on 2 June.

EXPERIMENT II - DURUM WHEAT VARIETY X NITROGEN RATE TRIAL

The soil used in this trial was also a Casa Grande sandy loam. It had been cropped to unfertilized Sudan grass in the preceding season and had been soil tested for NO_3-N and NH_4-N levels in the surface foot of 5.6 and 2.9 ppm, respectively. Other soil chemical characteristics were similar to those measured in Experiment I.

The rates and timing of N treatments used are listed in Table 2. All preplant N was from ammonium sulfate with mid-season N supplied as urea. The amount of N applied in Treatment 4 was determined by using the current University of Arizona procedure for predicting the N needs of wheat (Pennington et al., 1983). Treatments 2, 3, 5 and 6 were then assigned to cover a range of total N applied of 200 lbs. N/A in 50 lb. increments.

Table 2. Rates and timing of N applied to "Aldura" and "Westbred-881" durum wheat varieties grown on a Casa Grande sandy loam.

Treatment	Nitrogen Applied				
	Preplant	5-6 Leaf	Boot	Flower	Total
	......................lbs./a......................				
1	0	0	0	0	0
2	30	0	40	30	100
3	45	10	55	40	150
4	60	30	70	40	200
5	75	50	85	40	250
6	90	70	100	40	300

Two popular durum wheat varieties, "Aldura" and "Westbred-881", were planted in a split plot design with variety as main plots and the six N rates as subplots. There were four replications. These plots were established on the same date as in Experiment I and were subject to the same irrigation and rainfall conditions. Individual plots were 9 x 33 feet in size. Weed control was obtained by hoeing and hand rouging with no other pesticides applied. Stem tissue samples were taken at the 3-4 leaf, 5 leaf, joint, boot and anthesis growth stages on 26 December, 2 January, 7 February, 3 March and 31 March, respectively. Grain was harvested on 2 June.

EXPERIMENT III - N RATE AND N FORM TRIAL

This N fertility trial with durum wheat was conducted on a Trix clay loam [fine-loamy, mixed (calcareous), hyperthermic Typic Torrifluvent] with similar experimental design and management used in a previous trial on a sandy loam soil (Doerge and Ottman, 1986). The plot area was cropped with unfertilized Sudan grass prior to the planting of wheat to reduce the level of available N in the rooting zone. Chemical properties of the surface soil were pH, 7.5; sodium bicarbonate extractable P, 16 ppm; electrical conductivity, 2.5 dS/m; ammonium acetate extractable sodium 2.4 meq/100g; organic matter 0.9%; and free $CaCO_3$, medium. The cation exchange capacity in an adjacent field within the same Trix mapping unit was 26.4 meq/100g. Prior to planting, composite soil profile samples within the experimental area were taken in one foot increments and analyzed for nitrate and ammonium-N using 1N KCl extraction and Kjeldahl steam distillation. Nitrate-N values in the 0-1, 1-2, 2-3, 3-4 and 4-5 foot samples were 3.2, 1.3, 0.9, 0.8 and 0.8 ppm, respectively. The ammonium-N values for the corresponding samples were 1.3, 1.3, 1.1, 1.4 and 0.8 ppm, respectively.

The rates, timing and N sources of the eight treatments used are listed in Table 3. The N rates for treatments 1-5 were preassigned while those for treatments 6-8 were equivalent and based on p replant soil and stem NO_3-N tests taken from treatment 6 during the growing season, in accordance with the current University of Arizona procedure (Pennington et al., 1983). "Aldura" wheat seed was drilled on flat borders at the rate of about 80 lbs./a on 25 November, 1986. Individual plots were 8 x 50 feet and all treatments were replicated four times in a randomized complete block design.

A total of 41 inches of water containing about 81 lbs. NO_3-N/A was applied in six irrigations (including pre-irrigation). Rainfall during the growth period was 2.6 inches. A visual estimate of the percent area lodged within each plot was recorded on 2 June, 1987 prior to harvest. Weed control was achieved with hoeing and hand-rouging.

Table 3. Rates, timing and N sources applied to "Aldura" wheat grown on a Trix clay loam.

		Nitrogen Applied				
Treatment	N Source(s)	Preplant	5-6 Leaf	Boot	Anthesis	Total
		....	....	lbs./a	....	....
1	-----	0	0	0	0	0
2	$(NH_4)_2SO_4$ + urea*	30	65	0	30	125
3	" "	60	125	35	30	250
4	" "	90	190	65	30	375
5	" "	120	225	100	30	500
6	NH_4 NO_3	60	30	55	30	175
7	$Ca(NO_3)_2$	60	30	55	30	175
8	$(NH_4)_2SO_4$	60	30	55	30	175

* in Treatments 2-5, preplant N was applied as $(NH_4)_2SO_4$ with all midseason N applied as urea.

Stem tissue samples were taken at the 3-4 leaf, 5 leaf, joint, boot and anthesis growth stages on 13 January, 25 January, 24 February, 17 March, and 14 April, respectively. Grain yields were measured on 3 June. Estimates of seed weights were determined by counting 1000 seeds from a subsample of grain from each plot.

RESULTS AND DISCUSSION

EXPERIMENT I - ACCURACY OF STEM TEST PROCEDURE

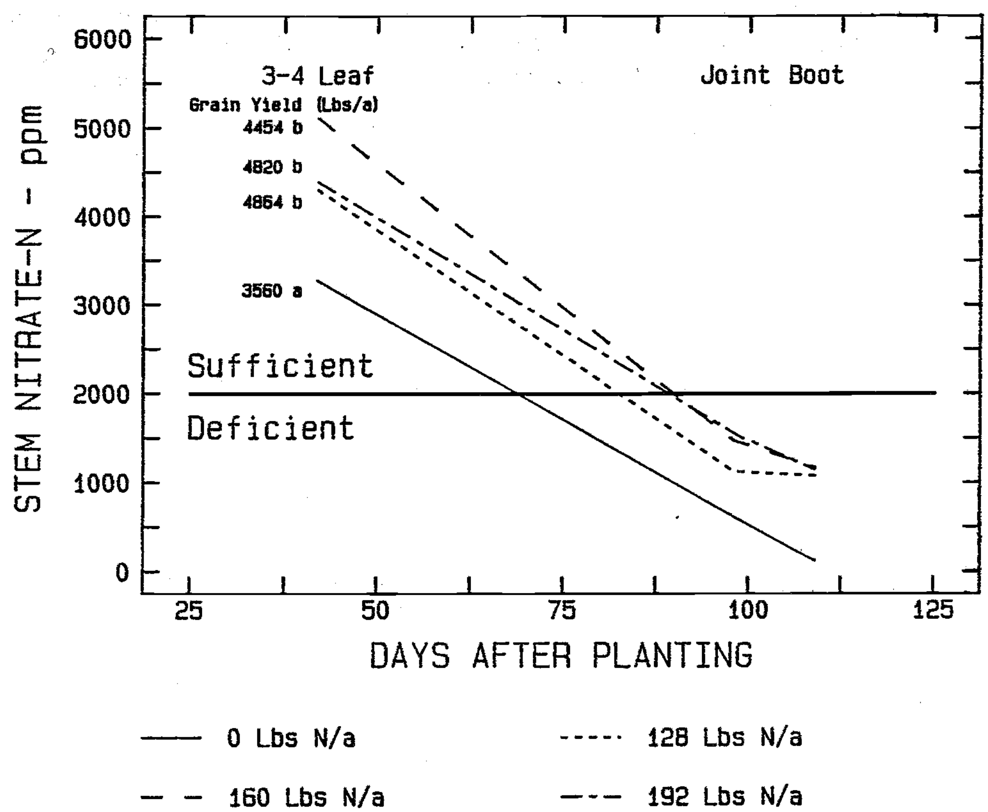
The grain yields obtained in this trial, as well as the other two, were somewhat lower than expected and considerably lower than the yields obtained in the same area the preceding year (Doerge and Ottman, 1986). Unseasonably high temperatures during the grain filling period are suspected to have shortened this important yield-determining growth period which could have contributed to lower grain yields across all N treatments. The growth characteristics of wheat grown in this trial are listed in Table 4.

Table 4. Growth characteristics of "Aldura" wheat receiving 80, 100 and 120% of the N requirement predicted by soil + stem nitrate analysis.

Treatment	Lodging	Grain Protein	Yellow Berry	Bushel Weight	Grain Yield
	%	%	%	lbs./bu	lbs./a
1. 80% N	0 a*	15.4 b	0 a	62.4 a	4864 a
2. 100% N	0 a	16.1 ab	0 a	61.4 b	4454 a
3. 120% N	0 a	17.1 a	0 a	61.4 b	4820 a
Control (ON)	0	------	18	63.5	3560

* means followed by the same letter within each column are not significantly different at the 0.05 level according to the SNK method.

The patterns of NO3-N contents in wheat stems throughout the season are shown in Figure 1. The levels measured in the three N treatments were very similar at the three diagnostic growth stages. The only significant difference observed in the stem NO3-N levels measured on the three sampling dates was a significantly lower value for the 80% N treatment at the joint stage. A trend toward lower stem NO3-N levels in the 80% N treatment was observed on the other two sampling dates as well.



The NO_3-N measured in wheat stems from all treatments declined below 2000 ppm just prior to the joint growth stage. Stem nitrate-N values below 2000 ppm are considered by some to indicate N deficient conditions (Gardner and Jackson, 1976). Others have suggested 1000 ppm NO_3-N as the "critical level" for wheat at all growth stages (Papastylianou et al., 1982). The results of this study suggest that a critical level of less than 2000 ppm NO3-N may have been the case as applications of N above 128 lbs./a did not result in significant increases in grain yield (Table 4).

The only economically important trend in the response of "Aldura" wheat to the range of N applications made in this study was a significant increase in grain protein as the amount of N increased. This may or may not have an economic impact depending on the pricing structure for durum wheat as affected by protein content.

The somewhat lower than normal yield levels achieved in this experiment may have resulted in a lower "apparent" critical NO_3-N level than would be observed with grain yields in the 6500 to 7500 lbs./a range. Under the conditions of this trial, the soil plus stem NO_3-N testing procedure currently recommended by the University of Arizona slightly over-predicted the quantity of N required for optimum economic return. It is hypothesized that this over-prediction was at least in part due to yield limiting factors (duration of grain-filling period) which were unrelated to the N treatments used in this trial. Additional research on the accuracy of the stem testing procedure under more typical high-yielding conditions is needed.

EXPERIMENT II - DURUM WHEAT VARIETY X NITROGEN RATE TRIAL

This experiment permitted a detailed evaluation of the growth response of "Aldura" and "Westbred-881" durum wheats to a wide range of N application rates. Tables 5 - 10 give the statistical interpretations of the growth characteristics analyzed in this study. In general, "Westbred-881" and "Aldura" showed no significant difference in grain yield or percent yellow berry over the range of N applications made in this study. "Westbred-881" was characterized by higher protein levels, taller plant heights, lower bushel weights, and a greater tendency to lodge with increasing N application. With the exception of lodging, there were no significant variety X N rate interactions. One interesting observation was the significant decrease in grain protein content as the amount of N applied exceeded 200 lbs./a (Table 5).

Table 5. Growth characteristics of "Aldura" and "Westbred-881" durum wheats receiving various N fertilizer treatments.

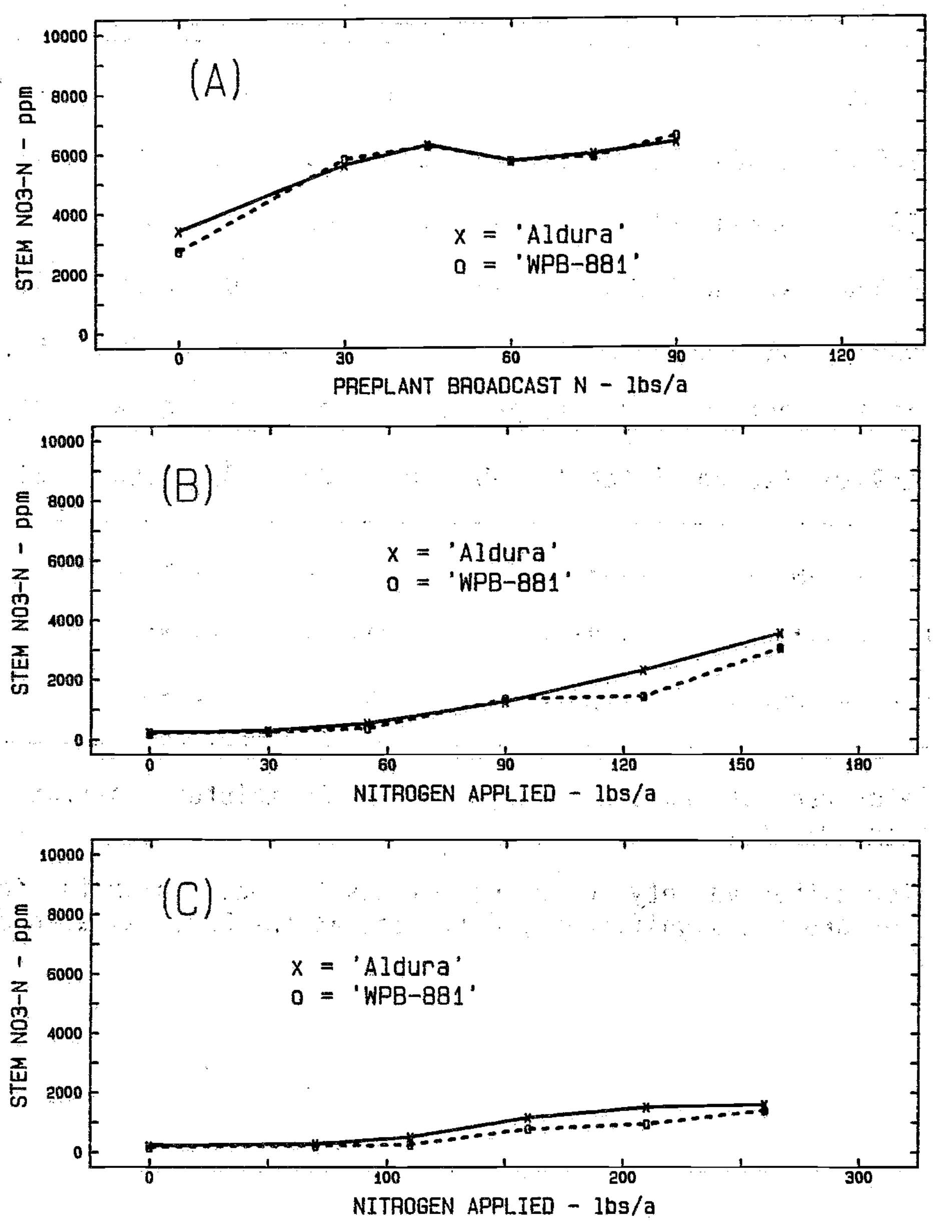
N Rate	Grain Yield+ Ald.	Grain Yield+ 881	Protein Ald.	Protein 881	Yellowberry Ald.	Yellowberry 881	Lodging Ald.	Lodging 881	Bushel Wt. Ald	Bushel Wt. 881
lbs./a	---lbs./a---		-----------------%-----------------						--lbs./bu--	
0	2750b#	2960b	11.7c	12.1c	6.2b	9.2a	0b	0b	63.7a	62.9ab
100	5068a	4264ab	14.7b	15.2b	0.2c	0c	0b	0b	63.2a	62.0b
150	4959a	4539ab	15.1b	15.7ab	0c	0c	0b	0.8b	62.8ab	62.1b
200	4902a	4190ab	16.2ab	17.2a	0c	0c	0b	6.2b	61.9bc	60.8d
250	4873a	3895ab	15.9ab	17.2a	0c	0c	0b	6.2b	61.9bc	60.8d
300	4599ab	4281ab	15.6ab	15.6ab	0c	0c	0b	30.0a	61.0cd	61.0cd
Variety F	----NS----		---*---		----NS----		---**---		---**---	
N Rate F	----**----		--**--		----**----		---**---		---**---	
VxN Rate F	----NS----		--NS--		----NS----		---**---		---NS---	

+ the yields reported have been adjusted to 10% moisture content and represent clean grain weights.

means for either variety under the columns for each parameter followed by the same letter are not significantly different at the 5% level according to the SNK methods.

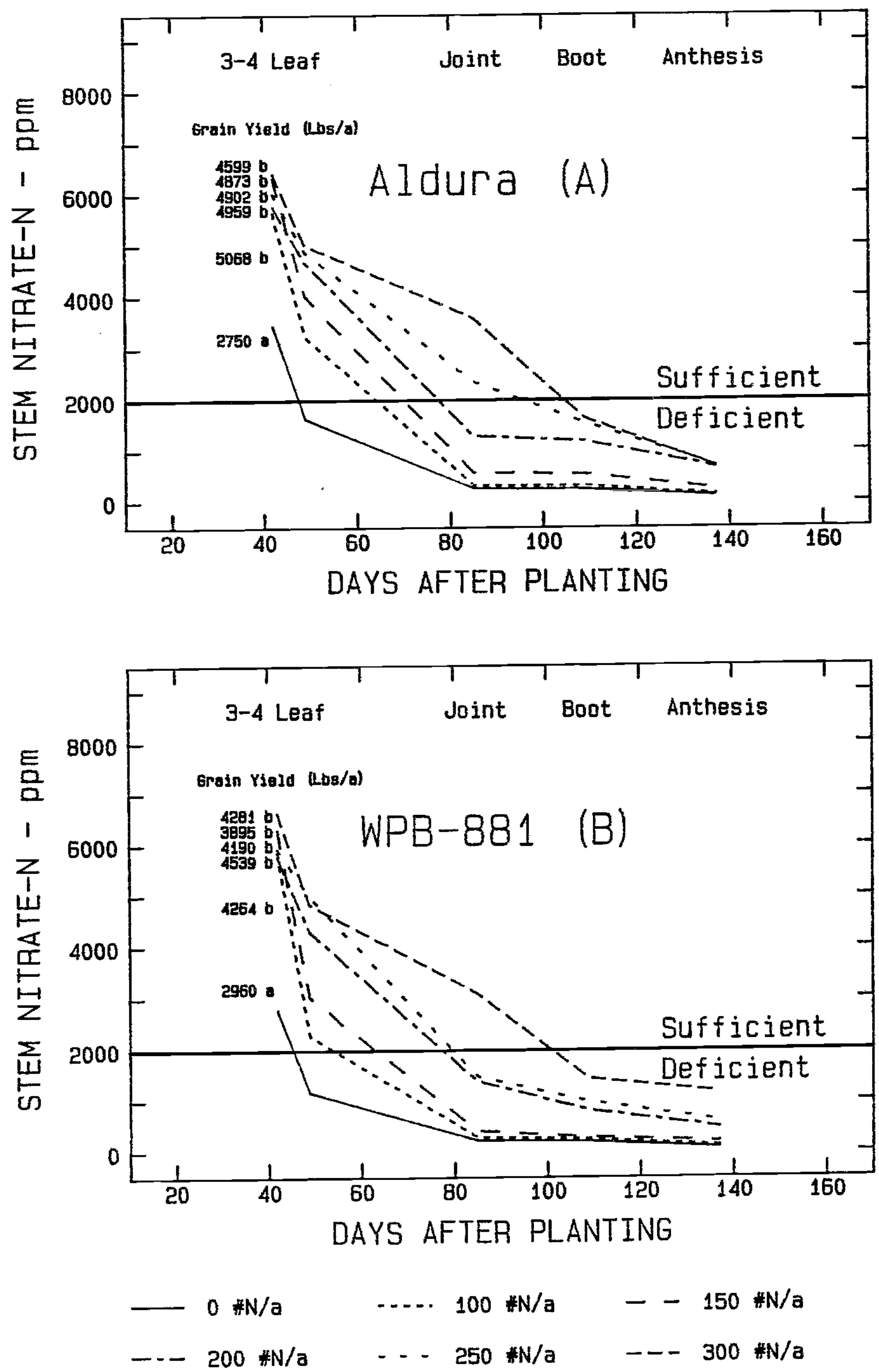
Figure 2 gives comparisons of stem NO_3-N levels measured in "Aldura" and "Westbred-881" wheat plants at the 3-4 leaf, joint and boot growth stages that had received varying N treatments. No significant effect of variety on stem NO_3-N content was measured on any of these three sampling dates. This confirms the findings of Gardner and Jackson (1976); they reported no significant effect of variety on stem NO_3-N levels in six bread wheat cultivars.

Figure 2. Comparison of stem NO_3-N levels measured in "Aldura" and "Westbred-881" wheat plants at the 3-4 leaf (A), joint (B) and boot (C)growth stages which had received varying N treatments.



The similarity of stem NO3-N levels measured in the two varieties is further demonstrated in Figure 3. The NO3-N levels in "Aldura" tended to be somewhat higher on most of the sampling dates but the difference was statistically significant at the 0.05 level only at the 5-leaf stage (day 49). These findings strongly suggest that there is little statistical or practical difference in the amount of NO3-N accumulated in stem tissue byvarious wheat varieties. It further suggests that interpretation of stem NO3-N levels for various wheat cultivars can be safely made using one set of general guidelines.

Figure 3. Seasonal stem nitrate-N levels measured in "Aldura" (A) and "Westbred-881" (B) durum wheats receiving different quantities of N fertilizer.



As in Experiment I, stem NO_3-N levels dropped below 2000 ppm prior to the joint growth stage for the treatment that attained the maximum grain yield with the minimum application of fertilizer N (Treatment 2). This again suggests that the "critical" NO_3-N level between the joint and boot stages is below 2000 ppm. However, as stated previously, additional research isneeded to verify this under conditions which more nearly achieve what is considered to be the maximum yield possibility of this site (i.e. 6500 -7500 lbs./a).

A second similarity between this experiment and Experiment I is the over-prediction of the amount of fertilizer N required to achieve maximum economic yield. The amount of N applied in Treatment 4 was that predicted by the current University of Arizona procedure. However, it is again suggested that this over-prediction may not occur under more high-yielding conditions where greater quantities of N per acre are assimilated.

EXPERIMENT III - N RATE AND N FORM TRIAL

The application of up to 175 lbs. N/A increased wheat yields to the maximum level attained at this site (5800 lbs. grain/acre). Applications of N above this resulted in decreased grain yield, higher protein content, increased lodging, decreased bushel weight, and decreased seed weight (Table 6).

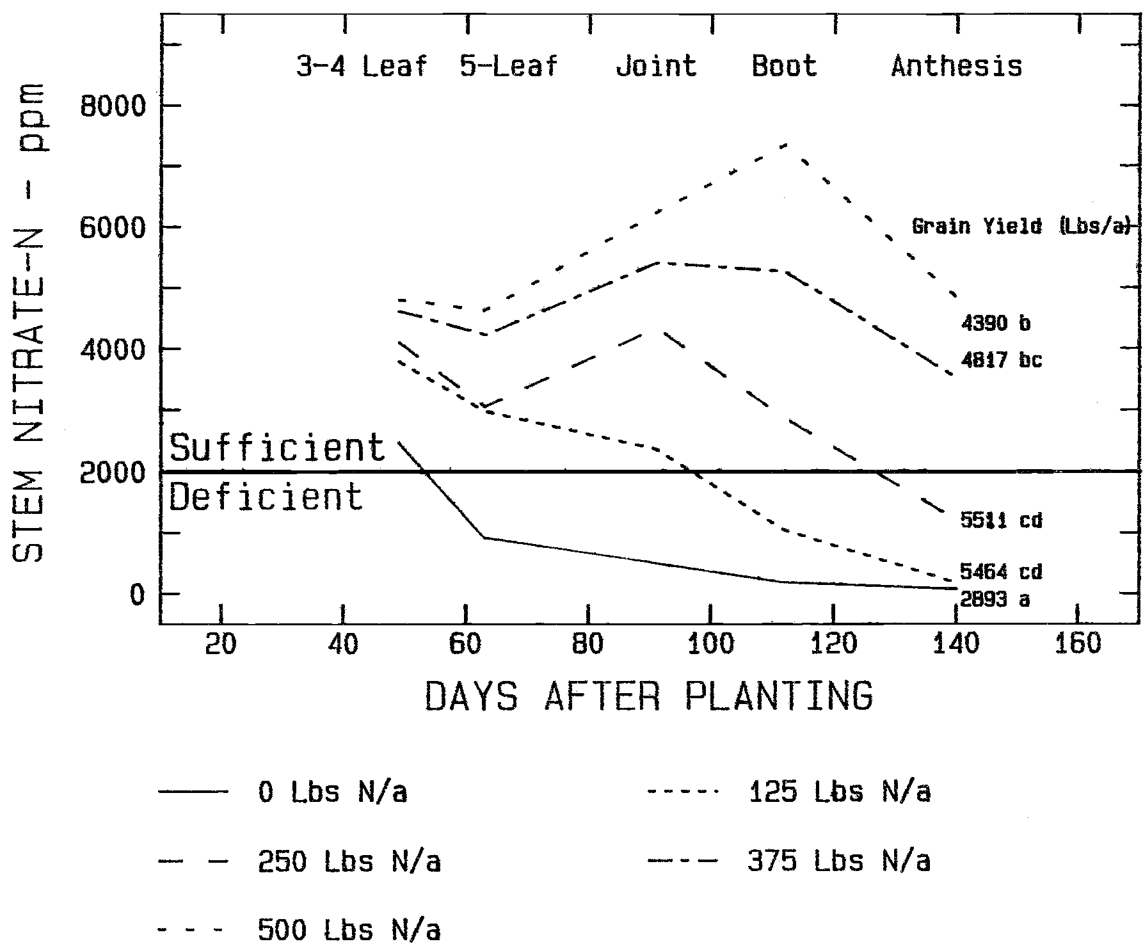
Table 6. Growth characteristics of "Aldura" wheat receiving various N treatments.

Treatment	Lodging	Grain Protein	Yellowberry	Bushel Weight	1000 Seed Weight	Grain Yield*
	%	%	%	lbs./bu	gm	lbs./a
1	0 c#	11.0 d	41.2 a	63.0 a	44.5 b	2693 d
2	2.5 c	13.4 c	1.8 b	63.3 a	45.0 b	5464 ab
3	31.2 b	16.9 a	0 b	61.7 b	41.3 c	5511 ab
4	50.0 a	17.1 a	0 b	60.1 c	36.9 d	4817 bc
5	42.5 ab	17.8 a	0 b	59.7 c	37.3 d	4390 c
6	6.2 c	15.3 b	0 b	63.3 a	47.3 ab	5582 ab
7	2.5 c	16.0 b	0 b	63.4 a	47.2 ab	6033 a
8	0 c	15.8 b	0 b	63.6 a	49.4 a	5631 ab
LSD 0.05	13.7	0.76	10.0	1.1	2.8	596

means followed by the same letter are not significantly different at the 5% according to the SNK method.

* the yields reported have been adjusted to 10% moisture content and represent clean grain weights.

Figure 4 shows the pattern of NO3-N measured in wheat stem tissue throughout the growing season for treatments 1-5. These values are comparable to those reported by Gardner and Jackson (1976) and are considerably higher than those measured in "Aldura" wheat grown in a sandy loam soil in a very similar experiment (Doerge and Ottman, 1986).

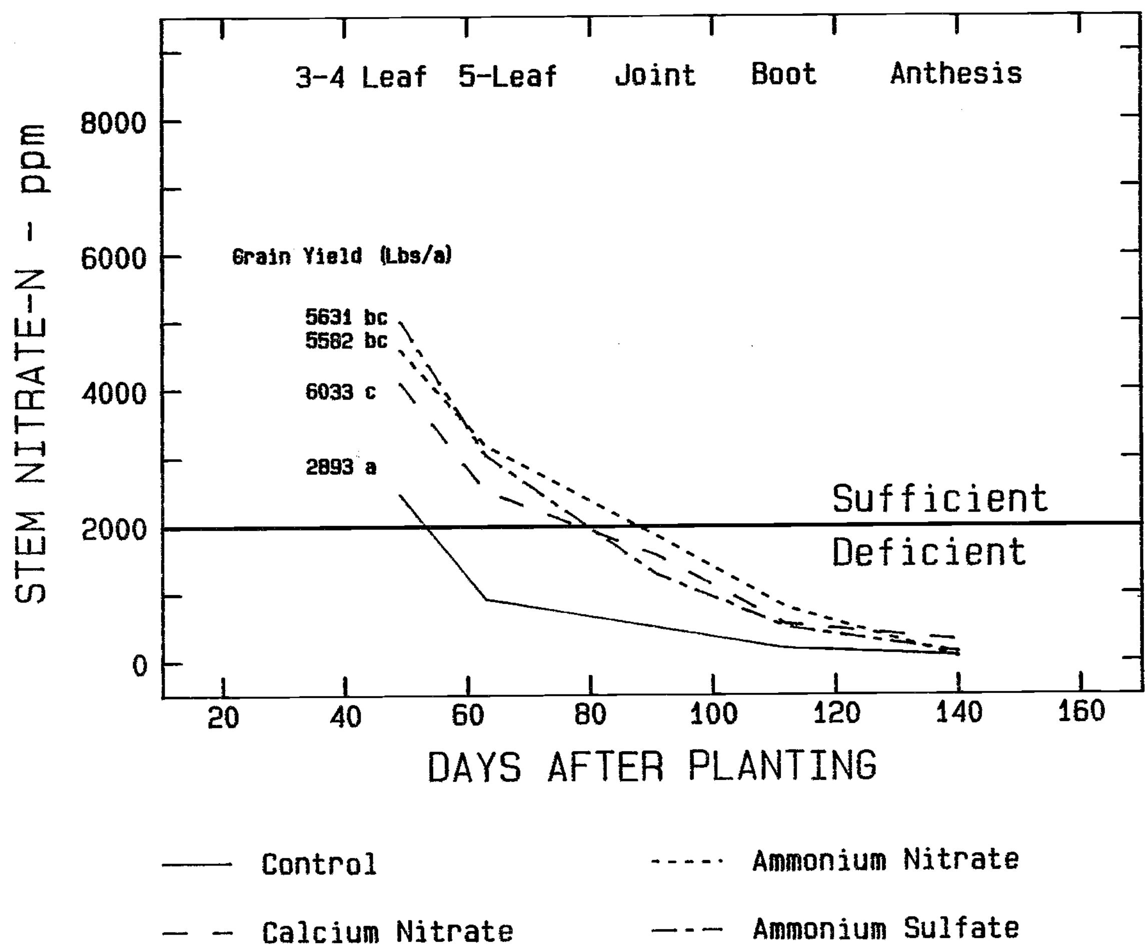


Gardner and Jackson's (1976) work was done on soils of the Glendale series which were very similar in texture and other physical properties to the Trix soil used in this study. In contrast to the findings of Doerge and Ottman (1986), cumulative N applications of as little as 250 lbs./a resulted in the maintenance of stem NO_3-N levels in excess of 2000 ppm for all or most of the growth period prior to anthesis.

The precise reason why wheat grown in heavier textured soils can accumulate much higher levels of NO_3-N in lower stem tissue compared to plants grown in sandier soils cannot be explained from the results presented. One reason may be that NO_3-N in soil solution is not as subject to leaching losses in a heavier textured soils and remains positionally available for a longer period of time during which plant uptake can occur. A second possible explanation for greater NO_3-accumulation in wheat grown in heavier textured soils may be related to a limitation on nitrate reductase activity in wheat due to some characteristic of these soils, such as lower temperature, lower oxygen content or higher CO_2 levels.

Considerable detailed work will be needed to elucidate this point. It is highly doubtful that nitrification does not proceed as rapidly in sandy soils, which would result in greater relative uptake of NH_4 forms of N directly from ammonium-containing fertilizer materials.

Figure 5 shows the mean nitrate-N levels measured in treatments 6-8, which received 175 lbs. N/A as ammonium nitrate, calcium nitrate and ammonium sulfate, respectively. There were no significant differences in the amount of NO_3-N measured in wheat stems on any of the five sampling dates for plants fertilized with all nitrate-N (Treatment 7), all ammonium-N (Treatment 8), or equal amounts nitrate and ammonium-N (Treatment 6).



This strongly suggests that the mobility of various N forms has much less effect on the positional availability of applied N on heavier textured soils than on sandy, more leachable soils (Doerge and Ottman, 1976). This also confirms earlier findings that suggested direct urea or ammonium uptake prior to the hydrolysis and/or nitrification of these forms of fertilizer N probably accounts for a very small fraction of the N nutrition of wheat grown under these conditions.

The grain yields resulting from these three N treatments represented the maximum grain yields measured in any of the other treatments (Table 6). As mentioned previously, the N rate used in Treatments 6, 7 and 8 was determined using the currently recommended interpretations of preplant soil analysis and mid-season stem analysis values. The accuracy of this procedure is further emphasized by the adjusted economic returns calculated for all N treatments (Table 7).

Table 7. Estimated adjusted economic returns for various N fertilizer treatments to "Aldura" wheat.

Treatment	N Rate	N Source	Estimated N Cost*	Adjusted Economic Return#
	lbs./a		$	$/a
1	0	-----	------	148 ab
2	125	$(NH_4) SO_4$ + urea	37.35	278 c
3	250	" "	74.70	256 c
4	375	" "	112.05	177 b
5	500	" "	149.40	114 a
6	175	$NH_4 NO_3$	61.25	274 c
7	175	$Ca (NO_3)_2$	105.00	257 c
8	175	$(NH_4)_2 SO_4$	68.25	270 c
LSD 0.05	---	-----	------	40

* estimated costs of N per pound supplied as ammonium sulfate, urea, calcium nitrate and ammonium nitrate are 0.39, 0.27, 0.60 and 0.35 respectively.

assumes prices of 6.00, 5.75 and 5.50 per cwt. for grain with protein contents of above 14%, 13-13.9% and below 13%, respectively.

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