Nitrogen Fertilizer Movement in the Soil as Influenced by Nitrogen Rate and Timing in Wheat Production, 1992

M. J. Ottman and N. Vigorito

Abstract

Durum wheat was grown with deficient, adequate, and excessive rates of ^{15}N*-labeled nitrogen fertilizer in order to document fertilizer nitrogen movement in the soil with differing nitrogen management. Crop water use increased with nitrogen rate due to increased vegetative growth. The amount of excess water applied increased with a decrease in nitrogen rate. Soil bromide concentrations at harvest suggest that the maximum potential depth of leaching was 3 to 6 feet. Most of the fertilizer applied in this study was recovered in the top 2 to 3 feet of soil. Fertilizer nitrogen rate and timing resulted in some differences in recovery of labeled fertilizer in the soil and plant, but did not contribute significantly to the depth of fertilizer nitrogen leaching.*

Introduction

Nitrate pollution of the groundwater is a public concern. High nitrates in drinking water causes blue baby syndrome in infants. The purpose of this investigation is to examine the effect of nitrogen rate and timing on nitrogen fertilizer movement in the soil.

Materials and Methods

Durum was grown at the Maricopa Agricultural Center during the 1991-92 growing season with deficient, adequate, and excessive levels of nitrogen fertilizer. The experiment was conducted on a Casa Grande sandy loam soil and a Trix clay loam soil.

'Aldura' durum wheat was drilled at a rate of 125 lbs seed/A on 21 November. Ammonium sulfate was applied to 12 ft. x 50 ft. plots on 22 November at deficient, adequate, and excessive rates based on a preplant soil NO_3-N value of 3 ppm in both fields. Triple super phosphate fertilizer was also applied on 22 November 91 at a rate of 75 lbs P_2O_5/A. Post-emergence fertilizer rates were based on stem nitrate concentration (Table 1). The three fertilizer rates were replicated six times in a randomized complete block design.

Labeled nitrogen fertilizer (^{15}N) was applied to 1 m x 1 m microplots within the main plot area. The microplots were covered with a plastic tray during spreading of fertilizer to the main plot area. Ammonium sulfate with a 5% enrichment of ^{15}N was used as the labeled nitrogen fertilizer and applied at a rate similar to the main plot area. Before planting, labeled nitrogen was applied to each 1 m^2 plot in a 20 x 20 grid pattern of 5 cm x 5 cm squares. Each 5 cm x 5 cm square received 1 ml of solution. Potassium bromide was included in the ^{15}N solution applied preplant at a rate of 150 lbs Br/A. After planting, the 1 ml of solution was dispensed between rows every 5 cm.

Additional microplots were established after planting in the plots receiving adequate fertilizer on the Casa Grande sandy loam soil. The purpose of these microplots was to characterize nitrogen fertilizer movement at various application times. At each of the three postplant fertilizer application times, one of these additional microplots received the adequate rate of ^{15}N fertilizer and 150 lbs Br/A. The other four microplots received non-labeled fertilizer. Each of these additional microplots received ^{15}N for one application only, and therefore, fertilizer movement from each application can be characterized by the corresponding ^{15}N microplot.

The lower portion of the wheat stem was sampled and analyzed for nitrate content before each irrigation until the flowering stage. Soil moisture was monitored using a neutron probe. On May 19, the crop was harvest ripe, and entire wheat plants were removed from a 2 ft x 2 ft area within each microplot. A plant sample was also removed outside the plot areas for background ^{15}N calculation. The plants were air-dried, weighed, the number of heads counted, and threshed for grain. The grain was weighed and kernel weight was determined for 500 kernels and yellow berry was estimated for 100 kernels. The number of kernels per head was determined arithmetically from grain yield, weight per kernel, and heads per unit area. Total nitrogen and ^{15}N content of the grain and straw from the microplots will be determined. The main plots were harvested with a small plot combine, and grain yield and test weight were determined.

Soil was sampled after harvest on May 20 and 22. A single, 2 inch diameter auger hole was dug in the center of each microplot and in one area outside the plots. The soil was sampled in 1 foot increments to a depth of 8 feet. Total nitrogen, ^{15}N content, and bromide concentration will be determined in the soil.

Results and Discussion

Irrigations

The amount of irrigation water applied to each field was distinctly different. The field with the sandy loam soil type was shorter, more level, and received less irrigation water than the clay loam field. The amount of irrigation water applied to the sandy loam soil more closely reflected crop needs.

Crop water use increased with an increase in nitrogen rate. Plants receiving higher nitrogen rates had more vegetative growth and leaf surface area for water loss compared to plants grown with lower nitrogen rates.

The plot areas grown with a deficient nitrogen rate received the most excess water at irrigation, since soil moisture content at irrigation was higher than the other treatments. Excess water is defined as the difference between the irrigation amount and the quantity of water needed to return soil moisture content to field capacity in the top 5 ft. of soil. This excess water is sometimes referred to as leaching volume. The amount of leaching that actually occurs is related to the leaching volume, concentration of species in the soil available for leaching, and other factors.

Yield and Yield Components

Grain yields were highest at the adequate and excessive rates for the sandy loam soil and at the excessive rate for the clay loam soil (Table 3). Total plant yield was greatest at the excessive rate due to increased vegetative growth with high nitrogen fertility. The harvest index, or proportion of grain to total plant yield, was highest for the adequate nitrogen treatments. Kernel weight was low for the deficient nitrogen treatments since low nitrogen fertility causes premature plant senescence and shortens the grain fill period. The number of heads per unit area increased with nitrogen fertility rate on the clay loam soil due to increased tillering associated with higher nitrogen status. The excessive nitrogen rate resulted in more heads per unit area. Grain yellow berry, a negative quality factor, was lowest at the excessive nitrogen rate.

Soil Bromide and Nitrate

Bromide and nitrate concentrations in the soil at harvest are presented in Tables 4-6. The depth of movement of bromide applied at the beginning of the season represents a worst case scenario for nitrate movement. In these studies, soil bromide concentrations were greatest at a depths of 3 to 6 feet on average. However, strong bromide peaks were not found at all on some plots which is disguised by presenting the data as an average of six replications. Bromide distribution in the soil profile was deepest for the low nitrogen rates due to lower water use. Most of the nitrate was found in the surface soil, but the nitrate levels were so low that this result is not noteworthy. Bromide moved deeper in the soil if applied earlier in the season compared to later as expected.

Recovery of Labeled Fertilizer in the Soil and Plant

Most of the applied nitrogen fertilizer did not move past the top 2 to 3 feet of soil (Tables 7 and 8). A higher percentage of applied nitrogen was found in the soil in the low nitrogen rate compared to adequate and excessive nitrogen rates on the clay loam soil, but on the sandy loam soil, this difference was not significant. Total plant yields were low for this treatment, and therefore, plant uptake of nitrogen was limited allowing nitrogen to accumulate in the surface soil. The absolute amount of fertilizer nitrogen remaining in the soil after harvest differs according to nitrogen rate of course, as opposed to recovery, which is a percentage of fertilizer applied. Recovery of labeled nitrogen in the grain was highest for the high nitrogen rate on the clay loam soil. On the sandy loam soil, nitrogen rate had no effect on recovery of applied fertilizer in the grain and total plant. Nitrogen accumulated in the straw in the high nitrogen rates. The differences in recovery of nitrogen fertilizer by the plant can be explained by the fact that potential for nitrogen accumulation in the grain is finite, and the straw can accumulate excess nitrogen. The total amount of labeled fertilizer accounted for in the soil and plant ranged from 53 to 78% in the nitrogen rate study. Nitrogen fertilizer could have been lost as gases from the plant or from the soil due to volatilization or denitrification. Some nitrogen fertilizer is undoubtedly contained in the crowns, which were not sampled.

Fertilizer application timing resulted in some differences in fertilizer recovery although fertilizer movement below 2 to 3 feet in the soil was minimal. Later applications resulted in greater recovery of ^{15}N in the plant, especially the application near anthesis.

Acknowledgements

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Table 1. Schedule of irrigation and ^{15}N fertilizer application.

Soil Type	Date	Growth Stage	Irrigation	Nitrogen Rate Deficient	Adequate	Excess
			inches	(lbs N/A)		
Trix	Nov 22	Planting	5.5	20	50	65
Clay	Jan 31	6-leaf	5.1	0	25	50
Loam	Feb 28	3 nodes	5.4	25	50	75
	Mar 26	Anthesis	4.6	20	40	60
	Apr 16	S. Dough	4.6	0	0	0
	Apr 30	Dough	3.4	0	0	0
		SUM	28.6	65	165	250
Casa	Nov 22	Planting	6.4	30	70	90
Grande	Jan 31	6-leaf	4.1	25	25	50
Sandy	Feb 28	3 nodes	4.4	35	75	110
Loam	Mar 26	Anthesis	3.8	0	30	45
	Apr 16	S. Dough	4.2	0	0	0
	Apr 30	Dough	4.1	0	0	0
		SUM	27.0	90	200	295

'able 2. Stem nitrate concentration.

Stage	Trix Clay Loam Nitrogen Rate Deficient	Adequate	Excess	Casa Grande Sandy Loam Deficient	Adequate	Excess
	Stem nitrate (ppm NO_3-N)					
3-4 leaf	1486	3544	4014	527	3503	4704
Jointing	930	1211	2442	360	480	2345
Boot	388	707	1251	478	939	2138

Table 3. Yield and yield components as influenced by nitrogen rate.

Nitrogen Rate	Grain Yield	Total Yield	Harvest Index	Kernel Weight	Kernels per head	Heads per square foot	Yellow Berry
	(T/acre)	(T/acre)	(%)	(mg)			(%)
			Trix clay loam				
Deficient	2.2	5.3	41.8	48.5	30.1	31.5	58
Adequate	3.3	7.2	45.6	49.1	32.5	42.8	24
Excess	3.8	9.0	42.8	49.7	34.2	47.2	1
LSD(.05)*	0.31	0.96	2.69	NS	3.06	6.32	6.5
			Casa Grande Sandy Loam				
Deficient	2.3	5.3	42.9	46.4	33.2	30.9	91
Adequate	3.3	7.4	44.0	50.3	33.7	40.1	10
Excess	3.5	8.5	41.8	48.3	32.2	47.6	1
LSD(.05)	0.36	0.67	NS	1.96	NS	4.35	5.2

* LSD(.05) = least significant difference at the 5% level, NS = not significant at the 5% significance level.

Table 4. Soil bromide concentration at harvest as influenced by nitrogen rate.

	Trix Clay Loam			Casa Grande Sandy Loam		
	Nitrogen Rate					
Depth	Deficient	Adequate	Excess	Deficient	Adequate	Excess
feet	ppm Br^-					
1	0.0	0.0	0.0	0.1	0.0	0.1
2	0.3	0.3	0.6	0.2	0.1	0.2
3	1.7	0.8	3.6	0.2	0.2	0.3
4	1.4	1.4	1.5	0.6	0.5	0.5
5	1.3	1.0	1.2	0.7	0.8	0.7
6	0.7	0.7	0.5	0.8	1.5	0.6
7	0.4	0.4	0.4	0.1	0.5	0.2
8	0.3	0.6	0.4	–	–	–
Avg.	0.76	0.66	1.02	0.33	0.47	0.32
			Significance of Effects[1]			
Rate		NS			NS	
Rate*Depth		**			**	

[1] NS, *, ** Not significant at P=0.05, and significant at P=0.05 and 0.01, respectively.

Table 5. Soil nitrate concentration at harvest as influenced by nitrogen rate.

	Trix Clay Loam			Casa Grande Sandy Loam		
	Nitrogen Rate					
Depth	Deficient	Adequate	Excess	Deficient	Adequate	Excess
feet	ppm NO_3-N					
1	3.7	2.6	2.9	0.7	1.5	1.6
2	2.1	2.0	2.2	0.7	1.3	0.9
3	1.1	0.8	0.9	0.7	0.7	0.8
4	0.4	0.5	0.4	0.7	0.6	0.8
5	0.4	0.4	0.4	1.0	0.8	0.9
6	0.7	0.7	0.7	0.8	0.8	0.9
7	1.1	1.0	1.3	0.7	0.8	1.0
8	0.7	0.6	0.8	0.4	0.5	0.7
Avg.	1.23	1.01	1.13	0.73	0.84	0.94
			Significance of Effects[1]			
Rate		NS			*	
Rate*Depth		**			**	

[1] NS, *, ** Not significant at P=0.05, and significant at P=0.05 and 0.01, respectively.

Table 6. Soil bromide concentration at harvest as influenced by timing of bromide application.

	Bromide Application Date			
Depth	22 Nov	31 Jan	28 Feb	26 Mar
feet	ppm Br^-			
1	0.1	0.1	0.1	0.1
2	0.1	0.1	0.1	0.2
3	0.2	0.3	0.3	4.1
4	0.5	0.5	0.8	6.7
5	0.7	0.7	2.5	2.3
6	1.1	1.2	3.9	1.1
7	0.5	0.4	1.2	0.4
8	–	–	–	–
Avg.	0.44	0.42	1.13	1.89
		Significance of Effects[1]		
Date		**		
Date*depth		**		

[1] NS, *, ** Not significant at P=0.05, and significant at P=0.05 and 0.01, respectively.

Table 7. Labeled nitrogen recovered in the soil and plant at harvest as influenced by nitrogen rate.

		Trix Clay Loam			C. Grande Sandy Loam		
		Nitrogen Rate					
Item	Depth	Deficient	Adequate	Excess	Deficient	Adequate	Excess
	feet	Recovery (% ^{15}N applied)					
Soil	1	31.8	12.9	12.4	16.2	11.1	12.1
	2	2.6	1.5	2.0	3.6	3.0	2.4
	3	0.8	0.8	0.8	1.1	1.1	0.7
	4	0.6	0.2	0.3	0.6	0.4	0.3
	5	0.4	0.1	0.2	0.4	0.4	0.2
	6	0.2	0.2	0.1	0.3	0.2	0.2
	7	0.5	0.3	0.2	0.2	0.2	0.5
	8	0.2	0.0	0.0	0.2	0.2	0.3
	Total	37.0	16.0	16.1	22.4	16.4	16.8
Grain		39.1	35.2	51.3	50.6	54.0	45.2
Straw		2.5	2.4	5.2	4.0	5.7	8.4
Plant		41.5	37.6	56.5	54.5	59.7	53.6
				Significance of Effects[1]			
Soil	Rate(R)		**			NS	
Soil	R*Depth		**			**	
Grain	Rate		**			NS	
Straw	Rate		*			**	
Plant	Rate		**			NS	

[1] NS,*,** Not significant at P=0.10, and significant at P=0.05 and P=0.01, respectively.

Table 8. Labeled nitrogen recovered in the soil and plant at harvest as influenced by timing of nitrogen application.

		Nitrogen Application Date				
Item	Depth	ALL	22 Nov	31 Jan	28 Feb	26 Mar
	feet	Recovery (% ^{15}N applied)				
Soil	1	11.1	16.7	15.2	8.7	17.3
	2	3.0	3.8	3.9	2.5	3.2
	3	1.1	1.3	1.3	0.8	0.8
	4	0.4	0.5	0.4	0.5	0.2
	5	0.2	0.2	0.0	0.3	0.0
	6	0.2	0.1	0.0	0.3	0.2
	7	0.2	0.1	0.1	0.3	0.1
	8	0.2	0.1	0.1	0.3	0.0
	Sum	16.4	22.8	21.2	13.7	21.7
Grain		54.0	43.7	49.5	48.3	59.6
Straw		5.7	5.7	8.8	3.6	3.9
Plant		59.7	49.4	58.2	51.9	63.5
				Significance of Effects[1]		
Soil	Time(T)			NS		
	T*Depth			**		
Grain	Time			*		
Straw	Time			*		
Plant	Time			*		

[1] NS,*,** Not significant at P=0.05 and significant at P=0.05 and P=0.01, respectively.