Nitrogen Movement in the Soil as Influenced by Nitrogen Fertilizer Rate and Timing in Wheat Production, 1991

M. J. Ottman and N. Vigorito

Introduction

Nitrate pollution of groundwater is a growing public concern. Half of our nation's population relies on groundwater as a source of drinking water. Agriculture is being scrutinized as a source of nitrate pollution of groundwater. Nitrogen fertilizer is a potential source of groundwater pollution. Best management practices (BMP's) for nitrogen fertilizer applications have been mandated in an effort to limit nitrogen pollution of groundwater. BMP's for nitrogen management in wheat are based on soil testing, plant analysis, and efficient irrigation.

The purpose of this investigation is to document depth of fertilizer nitrogen movement in wheat grown with best management practices.

Materials and Methods

Durum was grown at the Maricopa Agricultural Center during the 1990-91 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.

Triple super phosphate fertilizer was applied on 27 November 90 at a rate of 75 lbs P_2O_5/A and incorporated with a spring tooth harrow. 'Aldura' durum wheat was drilled at a rate of 145 lbs seed/A on 28 November. Ammonium sulfate was applied to 12 ft. x 50 ft. plots on 28 November at deficient, adequate, and excessive rates based on a preplant soil NO_3-N value of 3 ppm in both fields. 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 five 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 June 4, 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 5 to 7 June. 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 (Table 2). 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.

Stem Nitrate

The stem nitrate concentrations for the deficit and excess fertilizer rates were within their expected ranges established by University guidelines for at least one growth stage (Table 3). Stem nitrate for the adequate fertilizer rate was generally in the adequate range except on the sandy loam soil at joint and flower. The nitrogen fertility status achieved by the various fertilizer rates as indicated by stem nitrate was close to desired except for the adequate treatment on the sandy loam soil, which was lower than desired at certain stages.

Yield and Yield Components

Grain yields were highest at both the adequate and excessive rates (Table 4). 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 lowest for the excess nitrogen treatments also due to increased vegetative growth associated with high nitrogen fertility. 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 due to increased tillering associated with higher nitrogen status. 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 5-7. 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 5 feet on average. However, bromide peaks were found at depths of 6 to 7 feet, or not at all, on some plots. Bromide distribution in the soil profile was deepest for the low nitrogen rates on the Trix clay loam due to lower water use and higher irrigation amounts. The nitrate distribution was deepest for the high nitrogen rate on this soil type also, presumably due to excess fertilizer application, but the nitrate levels were so low that this result is not noteworthy. The experiment conducted on the Casa Grande sandy loam soil had no nitrogen rate X depth interactions for soil bromide or nitrate at harvest presumably due to greater irrigation efficiency. Bromide moved deeper in the soil if applied earlier in the season compared to later as expected.

^{15}N Recovery in the Soil and Plant

Most of the applied nitrogen fertilizer did not move past the top 2 to 3 feet of soil (Tables 8 and 9). The recovery of fertilizer nitrogen was similar for all nitrogen rates except for the top foot of the sandy loam soil where recovery was greatest in the low nitrogen treatment. 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 lowest 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, but recovery in the straw was greatest at the high nitrogen rate. 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 60 to 75% 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.

Early season applications of labeled fertilizer resulted in greater recovery of the fertilizer in the soil, especially in the top few feet. Later applications resulted in greater recovery of ^{15}N in the plant, except the application near anthesis. Recovery of ^{15}N in the plant was greatest between the 5 leaf and boot stages, the period of most rapid plant uptake of nitrogen.

Summary

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. The adequate nitrogen rate resulted in grain yields similar to the excess nitrogen rate, even though approximately 50% more nitrogen was supplied by the excess rate. Soil bromide concentrations at harvest suggest that the maximum potential depth of leaching was 3 to 5 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.

Acknowledgements

Funding for this project was supplied by the Arizona Department of Environmental Quality.

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

Date	Stage	Irrigation	Nitrogen Rate		
			Deficient	Adequate	Excess
		(inches)	---------- lbs N/acre ----------		
		Trix clay loam			
28 Nov	Planting	5.1	32	65	98
01 Feb	5 leaf	5.9	0	0	50
27 Feb	2 nodes	5.2	38	75	75
20 Mar	Boot	4.8	0	27	27
10 Apr	Anthesis	5.8	0	30	45
25 Apr	Milk	5.3	0	0	0
07 May	Soft dough	5.3	0	0	0
SUM		37.4	70	197	295
		Casa Grande sandy loam			
28 Nov	Planting	5.1	32	65	98
01 Feb	5 leaf	3.8	0	30	50
27 Feb	2 nodes	3.9	25	50	100
20 Mar	Boot	2.8	0	35	70
10 Apr	Kernel watery	3.9	0	20	20
25 Apr	Milk	3.7	0	0	0
07 May	Soft dough	5.1	0	0	0
SUM		37.4	70	197	295

Table 2. Irrigation amounts, rainfall and crop water use since the previous irrigation date, and excess irrigation water applied to the top 5 ft. of soil to durum grown with deficient, adequate , or excess rates of nitrogen fertilizer.

Date	Irrigation Amount	Rainfall	Crop Water Use			Excess Irrigation		
			Deficient	Adequate	Excess	Deficient	Adequate	Excess
	---------- inches ----------							
				Trix clay loam				
28 Nov	5.11	--	--	--	--	--	--	--
01 Feb	5.93	1.89	1.76	1.81	1.81	2.71	2.75	2.74
27 Feb	5.15	0.24	3.87	4.14	4.08	1.95	2.94	1.79
20 Mar	4.82	1.38	3.23	3.60	3.37	2.58	2.26	2.48
10 Apr	5.79	0.71	3.89	4.24	4.12	2.83	2.30	2.45
25 Apr	5.30	0	4.40	4.75	5.09	3.32	2.66	2.88
07 May	5.35	0	3.79	4.59	4.64	1.72	1.61	1.53
04 Jun	--	0	1.82	3.43	4.42	--	--	--
SUM	37.4	4.22	22.8	26.7	27.6	15.1	14.5	13.9
				Casa Grande sandy loam				
28 Nov	5.11	--	--	--	--	--	--	--
01 Feb	3.79	1.89	1.81	1.86	1.81	0.89	0.74	0.74
27 Feb	3.87	0.24	3.70	4.04	4.07	0.32	0	0
20 Mar	2.85	1.38	3.24	3.58	3.81	0.05	0	0
10 Apr	3.92	0.71	4.58	4.99	5.40	0.52	0	0
23 Apr	3.69	0	3.22	3.88	4.35	0.37	0	0
07 May	5.14	0	3.85	5.82	6.84	2.39	0.14	0.14
04 Jun	--	0	1.47	2.12	2.73	--	--	--
SUM	28.4	4.22	21.9	26.3	29.0	4.54	0.88	0.88

Table 3. Stem nitrate concentrations.

		Trix Clay Loam			C. Grande Sandy Loam		
		Nitrogen Rate					
Date	Stage	Deficient	Adequate	Excess	Deficient	Adequate	Excess
		Stem nitrate (ppm NO_3-N)					
19 Jan	3-4 leaf	4292	4484	4609	4126	5000	4361
19 Feb	1 node	879	988	1637	554	432	4271
10 Mar	3 nodes	1331	1286	2128	1397	1546	3815
30 Mar	Heading	260	587	2875	517	362	1220

Table 4. Yield and yield components as influenced by nitrogen rate.

Nitrogen Rate	Grain Yield	Total Yield	Harvest Index	Kernel Weight	Kernel Number	Head Number	Yellow Berry
	(T/A)	(T/A)	(%)	(mg)	($head^{-1}$)	(ft^{-2})	(%)
			Trix clay loam				
Deficient	3.0	6.7	45.0	52.3	30.8	39.2	64
Adequate	3.8	8.3	45.4	56.0	31.2	45.0	10
Excess	3.7	9.7	38.2	55.5	29.2	47.2	6
LSD(.05)*	0.29	0.60	2.40	0.99	NS**	4.33	6.8
			Casa Grande sandy loam				
Deficient	1.9	4.8	39.2	50.2	26.6	28.8	59
Adequate	3.1	7.6	40.8	55.6	29.4	39.5	4
Excess	3.1	8.1	37.9	55.4	27.7	42.0	1
LSD(.05)	0.37	0.77	3.36	2.68	1.63	4.70	12.7

* LSD(.05) = least significant difference at the 5% significance level.

** NS = not significant at the 5% significance level.

Table 5. 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	1.07	0.87	1.00	0.50	0.30	0.25
2	2.21	2.27	2.98	2.79	0.49	0.37
3	2.59	2.78	4.29	4.69	5.94	3.79
4	1.53	1.13	2.33	3.08	8.55	4.53
5	1.99	1.29	1.28	1.29	3.49	2.96
6	2.11	1.69	1.28	1.72	1.76	2.15
7	1.57	1.48	0.92	1.25	0.76	1.44
8	0.89	1.23	0.51	0.51	0.43	0.60
Avg.	1.75	1.58	1.82	1.98	2.72	2.01
			Significance of Effects[1]			
Rate(R)		NS			NS	
R*Depth		**			NS	

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

Table 6. 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	1.68	0.17	0.17	1.04	0.49	0.59
2	0.24	0.22	0.17	0.36	0.21	0.28
3	0.17	0.24	0.22	0.22	0.17	0.17
4	0.27	0.17	0.23	0.30	0.17	0.33
5	0.17	0.17	0.17	1.00	1.10	0.74
6	0.19	0.17	0.28	1.05	2.79	1.40
7	0.30	0.17	0.75	1.72	2.23	1.27
8	0.49	0.25	0.94	1.25	2.31	1.50
Avg.	0.44	0.19	0.37	0.87	1.18	0.79
			Significance of Effects[1]			
Rate(R)		NS			NS	
R*Depth		**			NS	

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

Table 7. Soil bromide concentration at harvest as influenced by timing of bromide application

	Bromide Application Date				
Depth	28 Nov	01 Feb	27 Feb	20 Mar	10 Apr
feet	ppm Br^-				
1	0.25	0.25	2.69	0.89	0.25
2	0.43	0.31	6.31	3.01	0.29
3	7.73	4.66	12.18	8.05	0.54
4	5.38	4.37	1.42	3.64	0.51
5	1.85	0.25	0.58	0.58	0.25
6	0.58	0.47	0.38	0.25	0.25
7	0.25	0.69	0.25	0.25	0.25
8	0.25	0.69	0.25	0.25	0.25
Avg.	2.09	1.54	3.01	2.11	0.32
			Significance of Effects[1]		
Time(T)			*		
T*Depth			**		

[1] *,** 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 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	16.9	13.5	14.0	14.1	7.6	7.8
	2	6.6	1.9	4.7	1.9	3.4	2.2
	3	0.9	1.3	1.3	1.4	0.8	1.0
	4	0.7	0.1	0.4	0.4	0.2	0.3
	5	0.4	0.2	0.4	0.0	0.1	0.3
	6	0.5	0.1	0.8	0.0	0.1	0.1
	7	0.7	0.1	0.3	0.1	0.0	0.2
	8	0.2	0.1	0.1	0.0	0.0	0.0
	Avg.	3.4	2.2	2.7	2.2	1.5	1.5
Grain		44	42	32	37	41	40
Straw		–	–	–	4.7	5.7	8.2
Plant		--	--	--	42	47	48
				Significance of Effects[1]			
Soil	Rate(R)		NS			NS	
Soil	R*Depth		NS			*	
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 9. Labeled nitrogen recovered in the soil and plant at harvest as influenced by timing of nitrogen application.

		Nitrogen Application Date				
Item	Depth	28 Nov	01 Feb	27 Feb	20 Mar	10 Apr
	feet	Recovery (% ^{15}N applied)				
Soil	1	12.1	6.2	4.8	4.9	4.8
	2	3.6	1.4	1.6	1.0	2.9
	3	0.6	0.4	0.3	0.9	0.1
	4	0.2	0.1	0.2	0.0	0.0
	5	0.1	0.1	0.0	0.0	0.0
	6	0.0	0.1	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0
	8	0.1	0.0	0.0	0.0	0.0
	Avg.	2.1	1.0	0.9	0.9	1.0
Grain		34	46	45	55	39
Straw		6.7	8.6	7.4	4.5	2.7
Plant		40	54	52	60	42
				Significance of Effects[1]		
Soil	Time(T)			+		
Soil	T*Depth			**		
Grain	Time			**		
Straw	Time			**		
Plant	Time			**		

[1] +,** Significant at P=0.10 and P=0.01, respectively.