Nitrogen Fertilizer Movement in Wheat Production, Yuma

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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 relate best management practices and nitrogen fertilizer movement in a commercial wheat field.

Materials and Methods

A commerial wheat field in the Yuma Valley was monitored during the 1990-91 wheat growing season. The soil type of the field was a Gadsden clay consisting of a 4 foot layer of clay to silty clay loam on top of sand. The chemical properties of the soil are: pH=7.9, electrical conductivity (ECe)=5.0 mmhos/cm, Na=24.4 meq/L, Ca+Mg=29.2 meq/L, sodium adsorption ratio (SAR)=6.4, exchangeable sodium percentage (ESP)=7.4, NO_3-N=39 ppm, P=4 ppm, K=500 ppm. The soil chemical analysis indicate that yields are not expected to be limited by excess salt or sodium and that preplant applications of nitrogen or phosphorus fertilizer are not required. The soil holds approximate 8 inches of plant available water in the top 5 feet of soil. The nitrate level in the top 8 inches of soil at the beginning of the season was 39 ppm NO_3-N. Irrigation water was applied in level basins.

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The hard red spring or bread wheat cultivar 'WestBred 911' was drilled in dry soil and irrigated on 22 December 90. The seeding rate was 150 lbs seed/A and the row spacing was 6 inches. A summary of the irrigation and fertilization records is presented in Table 1. Approximately 5 to 6 inches of water was applied each irrigation. Nitrogen was injected in the soil preplant or applied in the irrigation water postplant as anhydrous ammonia. Phosphorus fertilizer was applied preplant at a rate of 52 lbs. P_2O_5/A as 11-52-0.

Labeled nitrogen fertilizer (^{15}N) was applied at rate of approximately 5% of the intended grower fertilizer rate preplant and before each fertigation. Nine 1 meter x 1 meter plots were established in an 8 acre level basin. Ammonium sulfate with a 99% enrichment of ^{15}N was used as the labeled nitrogen fertilizer. Before planting, labeled nitrogen was applied to each 1 m2 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. The rate of ^{15}N for each fertilization is presented in Table 1.

The lower portion of the wheat stem was sampled and analyzed for nitrate content before each irrigation until the watery kernel stage. Soil moisture was monitored using a neutron probe. On May 29, the crop was near physiological maturity, and entire wheat plants were removed from a 2 ft x 2 ft area within each of the nine microplots. A plant sample was also removed outside the plot areas for background ^{15}N calculation. The plants were air-dried, weighed, and threshed for grain. The grain was weighed and kernel weight and yellow berry were determined. Total nitrogen and ^{15}N content of the grain and straw will be determined.

Soil was sampled near the harvest ripe stage on 12 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 13 feet. Total nitrogen, ^{15}N content, and bromide concentration will be determined in the soil.

Results and Discussion

Nitrogen Fertilizer Management

The nitrogen fertility program of the grower resulted in stem nitrate concentrations in the adequate, but not excessive range (Fig. 1). However, actual nitrogen rates were usually higher than recommended by soil and plant tissue analysis. At the preplant soil nitrate concentration of 39 ppm, preplant fertilizer nitrogen is not required according to soil test guidelines, and 134 lbs N/A were applied. Excess nitrogen may have been applied near the 6 leaf and 2 node kernel stages (Table 2). Current stem test guidelines are based on irrigation and fertilization at the 6 leaf, boot, and flower stages. If additional irrigations are applied during this time period, application of nitrogen with these irrigations may be required to maintain crop yields.

Nitrogen management in this field was difficult due to soil heterogeneity, which is reflected in the variation in stem nitrate concentrations among plots. Nitrogen rates optimum for one section of the field could result in yield losses in another portion of the field. The nitrogen rates applied resulted in optimum or slightly above optimum nitrogen fertility status in the plant. However, nitrogen management may be improved in this case by reducing preplant and post-heading nitrogen fertilizer rates.

Irigation Management

The amount of water applied exceeded the capacity of the soil to retain the irrigation water in the top 5 ft., with the exception of the irrigation at planting and possibly the irrigation on 4 May (Table 3). "Excess" water or leaching volume contributes to leaching potential. The actual amount of nitrogen leached will be influenced by leaching volume and the concentration of nitrate available for leaching, among other factors.

The maximum allowable depletion of soil water before yield loss occurs is approximately 4 inches for this soil type most of the season. The grower applied 5 to 6 inches of water in each of 8 irrigations, and 8 to 16 inches of water were "excess" and potentially leached below 5 ft. The irrigations applied generally reflected crop water requirements with a few minor exceptions: the irrigation on 31 Jan was early but necessary to avoid soil cracking, the irrigation on 04 May may have been too late, the irrigation on 14 May may have been too early. The irrigation management in this field is considered very good. Major improvements in irrigation efficiency are possible only by decreasing the amount of water applied each irrigation, which is limited by irrigation system itself.

Yield

The average grain yield for the entire field was 4 T/A. The grain yield averaged over the nine microplots was also 4 T/A (Table 4). This extremely high grain yield can be credited to the skill level of the grower and the favorable growing season. The total plant yield averaged 8.6 T/A and straw yield was 4.6 T/A. The average harvest index of 46.5% is considered normal. The kernel weights are high for this cultivar and can be attributed to the relatively cool grain filling period. The late season nitrogen applications are probably responsible for the low yellow berry percentage in this test.

Nitrogen Fertilizer Movement

Bromide, nitrate, and ^{15}N amounts in the soil and plant at harvest are presented in Tables 5-8. Bromide was applied before the first irrigation and ^{15}N was applied at each fertilization.

Soil bromide concentration was usually greatest at 2 to 3 feet and was often not detectable below 6 feet (Table 5). However, bromide concentration was very low on several plots. Bromide was very low or not detectable on plots 2 and 5, and may have been detected below 13 feet if we had sampled deeper. On plot 9, significant amounts of bromide were detected at depths of 12 to 13 feet. Bromide was detected at depths of 10 feet on plots 6 and 8.
For most plots, however, the bulk of the bromide was detected at depths less than 8 feet.

The nitrate concentration in the soil profile at harvest averaged less than 3 or 4 ppm, although some individual plots contained much higher levels than this (Table 6). The nitrate levels are considered very low. Appreciable nitrate was detected on two plots only, plots 7 and 8, between 5 and 10 feet below the surface. The nitrate levels at harvest are difficult to assess by themselves, since the initial nitrate values at the beginning of the season are not available for comparison.

Most of the ^{15}N detected in the soil was found in the top 2 feet (Table 7) in non-nitrate form. Approximately 26% of the ^{15}N was found in the top 2 feet of soil, while depths below 3 feet averaged 0.5% recovery. The amount of ^{15}N detected at these lower depths is small and near natural abundance of ^{15}N.

The amount of ^{15}N recovered in the plant averaged 37%, 9% in the straw and 28% in the grain (Table 8). Our plant and soil analyses have accounted for approximately 70% of the applied labeled nitrogen. Some ^{15}N was undoubtedly recovered in the plant crowns, which were not sampled. The applied ^{15}N could also have been lost in the gaseous form due to ammonia volatilization, denitrification, or evolution from the plant.

The soil ^{15}N values provide a different perspective on fertilizer nitrogen leaching compared to the bromide concentrations. The bromide data indicates a worst case scenario, does not account for plant uptake, and assumes the mobile form and method of application of bromide is similar to that of the fertilizer. The ^{15}N approach also assumes that the form and method of application of ^{15}N is similar to the fertilizer applied in the field, which is a good assumption in this case since the grower applied nitrogen as anhydrous ammonia. Use of ^{15}N has the added advantage that the tracer is transformed in the soil and taken up by the plant similar to ^{14}N.

Lack of movement of ^{15}N in this study is probably related to the fact that the ^{15}N was applied in the ammonium form, which adhers to soil particles. Any ammonium nitrogen converted to nitrate must have been absorbed by the plant before being potentially leached during subsequent irrigations. At harvest, most of the ^{15}N was in non-nitrate form, such as ammonium or organic constituents, which are not readily leached. The ^{15}N remaining in the soil at harvest could possibly be transformed to nitrate, provided that moisture is supplied to the dry soil, and potentially leached by the first irrigation for the next crop. The potential depth of leaching of this residual nitrogen in the succeeding crop may be similar to that indicated by the bromide data. However, plant uptake of nitrogen could minimize leaching potential.

Summary

This field was managed in such a way that high yields and quality grain were produced. Nitrogen management could be refined somewhat, particularly for preplant applications. The main improvement in irrigation efficiency is the amount of water applied each irrigation, which is limited by the irrigation system. Most of the ^{15}N in the soil at harvest was contained in the top 2 feet and is probably indicative of the depth of movement of the fertilizer applied by the grower. Bromide was contained in the top 8 feet on average and may represent, or exaggerate, potential depth of leaching of any residual nitrogen.

Acknowledgements

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

Date	Stage	Irrigation	Fertilization	^{15}N Application
		(inches)	(lbs N/acre)	(lbs N/acre)
05 Dec	Preplant	—	134	—
21 Dec	Preplant	—	—	6.1
22 Dec	Planting	5-6	—	—
31 Jan	3 leaf	5-6	—	—
22 Feb	6 leaf	—	—	2.5
01 Mar	—	5-6	41	—
14 Mar	2 nodes	—	—	2.1
22 Mar	—	5-6	41	—
03 Apr	Boot	—	—	1.9
08 Apr	—	5-6	41	—
19 Apr	Kernel watery	5-6	41	2.1
04 May	—	5-6	—	—
14 May	—	5-6	—	—
ALL		40-48	298	14.7

Table 2. Stem nitrate concentrations.

Plot	Date/Stage 30 Jan 3 leaf	22 Feb 6 leaf	14 Mar 2 nodes	03 Apr Boot	19 Apr Water
	Stem nitrate (ppm NO_3-N)				
1	5169	3400	1232	577	742
2	4230	2340	956	1079	843
3	5005	2670	715	264	471
4	4739	4775	2175	741	1143
5	5153	3565	2349	1937	1916
6	5282	5296	2806	1074	1170
7	4172	7134	2733	1110	1197
8	4833	4378	2177	745	660
9	4955	1514	1519	1014	1017
AVG	4838	3897	1851	949	1018
Recommended N rate (lbs/A)	0-20	0-20	0-20	30	30-60
Actual N rate (lbs/A)	0	41	41	41	41

Table 3. Irrigation amounts, rainfall and estimated crop water use since the previous irrigation, and excess irrigation water applied to the top 5 ft. of soil.

Date	Irrigation Amount	Rainfall	Water Use	Excess Irrigation
	inches			
22 Dec	5-6	--	--	0
31 Jan	5-6	0.60	1.84	0.36 - 2.36
01 Mar	5-6	0.56	2.81	2.75 - 3.75
22 Mar	5-6	0.13	4.13	1.00 - 2.00
08 Apr	5-6	0.39	4.73	0.66 - 1.66
19 Apr	5-6	0	3.59	1.41 - 2.41
04 May	5-6	0	5.29	0 - 0.71
14 May	5-6	0	2.49	2.22 - 3.51
12 Jun	---	0	3.60	---

Table 4. Yield and kernel characteristics.

Plot	Total Yield	Grain Yield	Harvest Index	Kernel Weight	Yellow Berry
	(T/acre)	(T/acre)	(%)	(g/1000)	(%)
1	9.0	4.1	45.1	45.2	2
2	10.4	4.6	44.2	44.4	1
3	7.1	3.3	47.0	45.2	4
4	9.2	4.4	47.6	45.0	1
5	8.4	3.8	44.7	45.2	1
6	8.9	4.0	44.9	44.6	1
7	8.3	4.1	49.5	45.6	0
8	8.4	4.1	49.4	45.4	0
9	7.8	3.8	48.4	45.2	1
AVG	8.6	4.0	46.5	45.0	1.3

Table 5. Bromide concentration (ppm Br^-) in the soil at harvest. Values <0.5 ppm are below the analytical detection limits

Depth	Plot									
	1	2	3	4	5	6	7	8	9	Avg[1]
ft	Bromide (ppm Br^-)									
1	0.9	0.8	1.3	1.2	<0.5	0.8	5.5	6.5	0.8	2.0
2	2.3	0.7	3.5	2.1	<0.5	1.0	10.6	8.5	1.0	3.3
3	2.1	<0.5	1.5	2.3	<0.5	1.6	5.2	4.2	<0.5	2.0
4	2.1	<0.5	2.4	1.8	<0.5	1.7	1.0	1.2	<0.5	1.2
5	1.2	<0.5	1.2	0.5	<0.5	0.8	0.8	0.8	<0.5	0.7
6	<0.5	<0.5	<0.5	<0.5	<0.5	0.9	0.9	0.8	<0.5	0.4
7	<0.5	<0.5	0.6	<0.5	<0.5	1.2	1.0	0.5	<0.5	0.5
8	<0.5	<0.5	<0.5	<0.5	<0.5	1.8	0.9	0.6	<0.5	0.6
9	<0.5	<0.5	<0.5	<0.5	<0.5	1.8	<0.5	0.8	<0.5	0.5
10	<0.5	<0.5	<0.5	<0.5	<0.5	0.9	<0.5	1.6	<0.5	0.5
11	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	0.8	0.3
12	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	2.9	0.6
13	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2.6	0.6

[1] The average was calculated by setting values <0.50 ppm to 0.25 ppm

Table 6. Nitrate concentration (ppm NO_3-N) in the soil at harvest. Values <0.3 ppm are below the analytical detection limit.

Depth	Plot 1	2	3	4	5	6	7	8	9	Avg[1]
ft	Nitrate (ppm NO_3-N)									
1	1.7	2.2	1.2	3.0	2.5	2.4	2.3	2.8	1.7	2.2
2	1.2	1.0	1.0	1.6	3.7	1.3	1.0	1.3	1.3	1.5
3	0.5	0.6	0.3	0.6	3.6	0.5	0.5	0.5	1.8	1.0
4	0.3	1.2	<0.3	0.7	0.7	0.6	3.0	6.4	1.6	1.6
5	<0.3	1.6	0.4	1.4	0.5	<0.3	7.6	14.0	0.4	2.9
6	<0.3	0.8	2.2	2.2	0.4	<0.3	10.6	6.7	0.3	2.6
7	0.7	1.1	3.6	1.2	0.3	<0.3	16.6	5.0	0.3	3.2
8	1.8	1.0	2.6	0.8	0.4	<0.3	20.6	7.4	0.4	3.9
9	2.6	1.1	3.3	1.6	0.7	<0.3	9.9	12.4	<0.3	3.6
10	3.5	0.7	2.7	0.9	1.3	0.9	12.9	13.0	<0.3	4.0
11	2.3	0.4	1.7	0.9	1.4	0.7	9.5	8.0	<0.3	2.8
12	2.8	0.4	1.4	1.0	2.0	1.3	7.8	6.8	0.6	2.7
13	1.8	4.9	1.9	1.4	2.2	1.9	6.1	5.4	1.4	3.0

[1]The average was calculated by setting values <0.3 ppm to 0.17 ppm.

Table 7. Labeled nitrogen in the soil at harvest. The symbol 'nd' indicates that the nitrogen level in the soil was too low for ^{15}N analysis.

Depth	Plot 1	2	3	4	5	6	7	8	9	Avg
ft	Soil ^{15}N (% of ^{15}N applied)									
1	14.7	26.9	11.6	45.5	17.1	16.6	6.7	29.5	23.9	20.8
2	5.7	2.8	4.6	14.4	7.6	3.5	2.5	5.1	4.4	5.6
3	0.9	0.5	nd	6.8	0.8	1.2	0.7	2.6	0.6	1.6
4	0.4	0.2	0.1	nd	0.1	1.4	-0.3	0.3	0.4	0.3
5	0.3	0.1	nd	nd	0.4	0.6	-0.4	0.1	nd	0.2
6	0.9	nd	0.3	nd	0.5	0.2	0.2	3.7	0.1	0.7
7	0.1	nd	0.1	nd	nd	0.3	0.8	2.6	nd	0.7
8	nd	nd	0.0	nd	0.4	nd	0.3	1.7	nd	0.6
9	0.3	0.2	0.2	nd	nd	nd	0.2	1.8	nd	0.5
10	0.3	0.2	nd	nd	0.9	1.3	0.5	2.1	nd	0.9
11	nd	nd	nd	nd	0.8	nd	0.2	0.5	nd	0.5
12	0.3	nd	nd	nd	nd	nd	0.0	0.5	nd	0.3
13	0.2	nd	nd	nd	0.6	0.3	0.1	0.2	nd	0.3

Table 8. Labeled nitrogen in the grain and straw at harvest.

Plant Part	Plot 1	2	3	4	5	6	7	8	9	Avg
	(% of ^{15}N applied)									
Grain	23.5	25.7	22.5	40.2	28.8	24.0	—	29.4	27.8	27.7
Straw	10.4	12.5	7.4	9.94	10.1	11.3	7.1	7.2	6.6	9.2