EFFECT OF N FERTILIZATION ON ACCUMULATION AND RELEASE OF READILY-MINERALIZABLE ORGANIC N

W.B. Stevens, R.G. Hoeft, and R.L. Mulvaney[1]

ABSTRACT

Increased nitrogen (N) fertilizer use has generated concern about groundwater contamination by nitrate (NO_3^-). The objective of this work was to determine how previous N management and cropping system affect fertilizer N use efficiency. Research plots from a long-term N rate study on a silt loam soil were used to evaluate the impact of long term N rates on immobilization and mineralization of fertilizer N. Labeled $^{15}NH_4{}^{15}NO_3$ was applied at rates of 0, 60, 120, 180, and 240 lb/acre to subplots of the N treatment plots. Approximately 40 and 30 percent of the applied N was recovered in the above ground portion of the plants in 1994 and 1995, respectively. A high percentage of the residual fertilizer N remaining in the soil was incorporated into organic N by fall. The amount of inorganic N remaining in the profile after harvest increased with increasing N application rate. More non-fertilizer-derived organic N was present in the fall at the 180 and 240 lb N/acre rates than at lower rates suggesting that more organic N was mineralized in these plots.

INTRODUCTION

Efficiency of fertilizer N use is increasingly important in modern corn production. The increasing cost of N fertilizer and concern about nitrate contamination of ground and surface water supplies have increased efforts to improve N management. Because it is commonly perceived that N fertilizer is over applied, one of the major thrusts has been to reduce application rates. However, if farmers are to reduce fertilizer inputs without significantly reducing yields, they have need for site specific input information. This statement is supported by recent work which showed highly variable responses to N fertilization at 77 sites across the state of Illinois. In particular, thirteen of the 77 sites did not respond to N fertilizer when applied at rates recommended by three different recommendation procedures (Brown et al., 1993). Some of these sites had high P and K test levels suggesting the possibility of manure or heavy fertilizer applications in the more distant past. However, Motavalli et al. (1992) reported that a Wisconsin silt loam soil which had been subjected to high rates of inorganic N for 25 years, also showed high levels of P and K.

Several studies have shown that applying high rates of inorganic N on a long-term basis can affect subsequent N response (Motavalli et al., 1992; Jenkinson, 1991; Odell et al., 1982). El-Harris et al. (1983) showed that higher rates of inorganic-N fertilization lead to higher

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[1]R.G. Hoeft and R.L Mulvaney are professors in the Dept. of Crop Sciences and the Dept. of Natural Resources and Environmental Sciences, respectively and W.B. Stevens is a Jonathan Baldwin Turner Fellow in the Dept. of Crop Sciences, Univ. of Illinois.

mineralization potentials, and Shen et al. (1989) showed that recently formed organic N is mineralized 7 times faster than older organic N forms. Thus, it is possible that the lack of response on at least some of the 13 sites mentioned in the study by Brown et al. (1993) is a result of long-term N fertilization and the maintenance of an easily-mineralizable organic-N pool.

The objectives of this work were to determine the effect of long-term applications of (N) fertilizer at various rates on organic nitrogen formation and mineralization in Illinois soils, and on crop yield.

MATERIALS AND METHODS

Research plots located near Monmouth, IL at the University of Illinois Northwest Research Center on a Muscatine silt loam were used to evaluate the impact of long term N rates on the fate of applied fertilizer N. The design was a randomized complete block with 5 N rates (0, 60, 120, 180, and 240 lb N/acre) and three replications. The plots were established in 1982 and hybrid corn has been grown continually since initiation of the experiment. A 7.5 x 10 foot microplot was set aside each year (1994 and 1995) within each N treatment plot and treated with ^{15}N-labeled NH_4NO_3. The microplot area used in 1995 had not received ^{15}N in 1994. The area that received ^{15}N in 1994 received unlabeled ammonium nitrate in 1995. This facilitated the evaluation of the recovery of fertilizer N by crops in the year of application and the recovery of residual N from fertilizer applied the prior year.

Double-labeled ammonium nitrate ($^{15}NH_4{}^{15}NO_3$, 10 atom % ^{15}N) was diluted with unlabeled ammonium nitrate (NH_4NO_3, 0.3663 atom % ^{15}N) and dissolved in 2 L distilled water. The ^{15}N content of the fertilizer applied was 3 atom %.

Corn was planted and ^{15}N-labeled NH_4NO_3 was applied May 9, 1994 and May 21, 1995. The labeled fertilizer was applied in 2 L of water using a CO_2-pressurized spray applicator to obtain uniform coverage. Dry NH_4NO_3 fertilizer was applied by hand on the remaining plot areas. Germination counts were taken and harvest areas thinned to 27000 plants/acre on June 16, 1994 and on June 20, 1995.

Ear leaf samples were collected at tasseling and analyzed for N, P, and K. At physiological maturity, whole plants were harvested from the microplot areas, weighed and sampled for ^{15}N and total N analysis. Grain, cobs, and stalks were analyzed separately. Main plots were harvested for yield on Oct. 4, 1994 and Oct. 17, 1995. Soil samples were taken from all plots in early spring and after harvest in 1994 and 1995 to a depth of four feet and analyzed for inorganic N and total N including ^{15}N by depth (0-6", 6-12", 12-24", 24-36", and 36-48" increments).

RESULTS AND DISCUSSION

Over the first 11 years of the study, an average optimum yield of 148 bushels per acre was obtained with an average application of 170 lb N/acre for an efficiency of 1.27 lb N/bushel of corn produced (Fig. 1). The optimum N rate varied from a low of 116 in 1991 to a high of 240 lb N/acre in 1992, 1994, and 1995 (Table 1). The high N requirement in 1994 was associated with the highest yield of the study. However, the high N requirement observed in 1992 and 1995 was associated with some of the lowest yields observed in the study period. In both 1990 and 1991, the amount of N required per bushel of corn produced was well below the average for the other years. This might have been due to the fact that the two previous years, 1988 and 1989, had poor growing conditions which resulted in abnormally low yields and thus more N may have been retained in the profile for succeeding crops.

Increasing N rate resulted in increased N concentration in the ear leaf samples in 1994 and 1995 (Table 2). In 1994, the N concentration at rates of 180 lb N/acre or less was at levels below those deemed necessary (2.9%) for optimum crop production, although there was no significant difference in N concentration between plants grown on the 180 and 240 lb N/acre rates. In 1995, the N concentrations of both the 180 and 240 lb N/acre rates exceeded 2.9% while those of the 0, 60 and 120 lb N/acre rates fell considerably short of the optimum. Changes in N rates did not significantly or consistently affect either P or K concentration of the ear leaf. This was not surprising as the soil test levels for both P and K are high at this location (Table 3).

Three techniques were used to measure the efficiency of utilization of applied fertilizer (Table 4). Percent of total uptake as fertilizer and percent of fertilizer N recovered in the above ground portion were determined based on the ^{15}N analysis of the total above ground portion of the plant. The third measure of efficiency of fertilizer N uptake (Diff. Method) assumed that if the amount of N contained in the above ground portion of the crop on the unfertilized plot represented the amount of soil N uptake for all plots then the difference in uptake between the control and the N treated plots would provide a measure of N fertilizer use efficiency. Using that assumption, efficiency of fertilizer N uptake was calculated using the equation:

$$\frac{\text{N uptake (N-treated plot) - N uptake (non N treated plot) *100}}{\text{fertilizer N applied}}$$

The proportion of the total N in the plant coming from fertilizer increased with increasing rate of application in both years and was relatively constant from year to year. While the fertilizer accounted for a higher percentage of the total uptake with increasing N rate, the percent of fertilizer N taken up by plants remained relatively constant across all N rates. The lower recovery of fertilizer N in 1995 than 1994 was probably due to the poor crop growth associated with the hot, dry growing season and/or the cool, wet spring of 1995.

Corn grown in 1995 on the area that had received the ^{15}N fertilizer in 1994 recovered 8 to 12 % of the residual fertilizer N that had been applied in 1994 (Table 5). The recovery of the residual N was relatively consistent across all N rates, but as an absolute, was higher with the higher rates of N application. Recovery of total nonlabeled N from the 1994 microplot areas ranged from 1.1 to 1.8% of the soil organic N content to a depth of 12 in. Using these data as an estimate of mineralization, the percent of residual fertilizer N mineralized was 6 to 7 times greater than the percent of nonfertilizer N mineralized.

Results obtained using the difference method showed a decreasing recovery of applied N with increasing N rate (Table 4). Recovery values obtained with this method were considerably higher in 1994, but similar in 1995 when compared to those calculated using ^{15}N. This differential in recovery observed in 1994 may be somewhat an artifact of the techniques. In the case of the difference method, it is possible that mineralization may be lower in the unfertilized plots in comparison to the fertilized plots due to the long-term nature of the treatments thus giving the appearance of greater fertilizer recovery in the treated plots. Additionally, it is possible that the plants grown on the unfertilized plots may have had restricted root growth that inhibited the amount of soil N they were able to recover. The poor growing conditions observed in 1995 likely resulted in reduced root growth and reduced mineralization rates on all plots.

There were no significant differences in soil inorganic N content across N treatments in the spring of 1994. As a result, all values for a given depth increment were averaged (Fig. 2). This lack of treatment effect on spring inorganic N content may have been the result of exceptionally high leaching during the wet 1993 season. Results in the spring of 1995 and 1996 were similar to those observed in 1994, but did show slightly more inorganic N in the lower portion of the horizon of the higher N rate treatments (Figure 3).

From 70 to 80% of the fertilizer N was recovered in the plant-soil system in 1994, but a lesser amount (57 to 64%) was recovered in 1995 (Table 6). Fertilizer unaccounted for in this analysis was most likely lost from the plant-soil system through leaching and/or denitrification. The differential in recovery between the two years may have been due to enhanced denitrification that might have occurred in the wet spring of 1995. At N rates at or less than the optimum, the majority of the fertilizer N remaining in the soil in the fall of the year (more than 75%) was in an organic form in both years. Even at the highest N rate, 65% or more of the fertilizer N remaining in the soil was present in the organic form.

In 1994, none of the fertilizer N was detected below the 2 foot level in the soil in the fall of the year (Table 7). Whereas in 1995, although the levels were low, fertilizer N was detected to a depth of 4 feet at all rates of application. The differential between the two years was likely the result of excess precipitation early in the growing season in 1995. The leaching rains likely occurred early enough to move the fertilizer through the profile before it had an opportunity to convert to an organic from. As would be expected, the fertilizer-derived inorganic N was deeper in the soil profile as N application rate increased. These results underscore the decreasing efficiency of N fertilizer use as application rate increases.

Even though the fertilizer-derived inorganic N was relatively low in the fall of the year, the total inorganic N was relatively high (Table 8). This was especially true for the highest N rates which had over 80 lb N/acre present as NO_3^--N in the fall of the year. Since much of this was not derived from fertilizer, it must have been the result of mineralization of organic N. While this was undoubtedly true, the organic N content was generally not affected by N treatment. These data support the theory that long-term application of high rates of N fertilizers may lead to the buildup of an easily-mineralizable organic N pool.

The fall inorganic N content increased with increased N rate at all soil depth intervals. The depth to which inorganic N moved in the profile also increased as higher N rates were applied. This confirms that higher N rates increase the risk of N loss through leaching. It is important to realize that growing conditions and thus plant N uptake were near optimum in 1994, but much less than optimum in 1995. Therefore it might be reasonable to expect the higher levels of inorganic N that were observed in the lower profile in 1995 than in 1994.

SUMMARY

Hybrid corn yield increased throughout the range of fertilizer N rates in 1994 and 1995, but the 11 year average shows a yield plateau at about 170 lb N/acre. The corn plants recovered approximately 40% of the applied N in a very favorable growing season (1994) and approximately 25 to 30% in a relatively poor growing season (1995). A high percentage of the fertilizer N remaining in the soil profile after harvest was incorporated into organic N forms by fall. The amount of inorganic N remaining in the profile after harvest also increased with increasing N application rate. Finally, more non-fertilizer-derived organic N was present in the fall at the 180 and 240 lb N/acre rates than at lower rates suggesting that more organic N was mineralized in these plots. This despite the fact that organic N content did not differ appreciably among plots.

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Table 1. Variation in optimum yield and N rate over time.

Year	Optimum Yield bu/acre	Optimum N rate lb N/acre	Optimum N rate lb N/bushel
1983	146	126	0.86
1984	171	194	1.13
1985	180	188	1.05
1986	173	177	1.02
1987	166	160	0.96
1988	70	138	1.97
1989	108	124	1.16
1990	179	136	0.76
1991	130	116	0.88
1992	99	240	2.42
1993	133	137	1.03
1994	197	240	1.22
1995	118	240	2.03
Avg.	144	170	1.27

Table 2. Ear leaf nutrient concentrations (%) at silking. 1994 and 1995.

N, lb/acre	N	P	K
		1994	
0	1.20 c	0.31 a	2.01 a
60	2.45 b	0.31 a	1.78 cd
120	2.50 b	0.30 a	1.75 d
180	2.86 a	0.30 a	1.89 bc
240	3.04 a	0.32 a	1.90 ab
		1995	
0	1.67 c	0.41 a	1.89 a
60	1.82 bc	0.30 bc	1.86 a
120	2.10 b	0.27 c	1.83 a
180	2.95 a	0.32 b	1.81 a
240	3.23 a	0.33 b	1.78 a

Table 3. Effect of long-term N rate on soil test P and K and soil pH in the surface 6 inches at Monmouth, IL. Samples were taken April 25, 1994.

N Rate	pH	P	K
(lb/acre)		lb/acre	
0	6.7 a	230 a	439 a
60	6.6 a	189 a	468 a
120	6.4 b	118 b	344 b
180	6.0 c	107 b	342 b
240	5.9 c	100 b	300 b

Table 4. Efficiency of fertilizer uptake as influenced by rate of N application.

N rate lb/acre	Fertilizer N Efficiency: % of Total Uptake from fertilizer	% of fertilizer N recovered (^{15}N)	% of fertilizer N recovered (Diff. Method)
		1994	
60	18 a	38 a	78
120	29 b	40 a	73
180	38 c	41 a	65
240	47 d	40 a	55
		1995	
60	14 d	22 c	25
120	26 c	25 bc	21
180	37 b	32 a	22
240	47 a	31 ab	18

Table 5. Recovery of residual fertilizer N from soil in the cropping season one-year after initial application.

Initial N Rate	Residual Soil Fertilizer N[§]	Crop Uptake of Residual Fertilizer N	Recovery of Residual Fertilizer N
lb/acre	lb N/acre	lb N/acre	%
60	24 (23)	2 b	8
120	40 (38)	3 b	8
180	50 (39)	6 a	12
240	67 (43)	6 a	9

[§] Values in parentheses show the amount (lb N/acre) of the residual soil fertilizer N that was present in the organic form.

Table 6. Fate of ^{15}N-labeled fertilizer N as affected by N rate.

N rate (lb/acre)	Plant Uptake	Inorganic Soil N	Organic Soil N	Total
	Fraction of Plant-Soil System			
	Percent of applied N			
	1994			
60	38	2	40	80
120	40	2	32	74
180	41	6	22	69
240	40	10	18	68
	1995			
60	22	7	35	64
120	25	3	28	56
180	32	6	21	59
240	31	8	18	57

Table 7. Effect of N rate on fertilizer derived soil inorganic N with depth.

	N rate (lb/acre)			
depth (in)	60	120	180	240
	Inorganic N (lb/acre)			
	1994			
0-6	1	1	4	7
6-12	0	0	3	7
12-24	0	0	4	10
24-36	0	0	0	0
36-48	0	0	0	0
Total	1	1	11	24
	1995			
0-6	1	2	4	6
6-12	0	0	2	3
12-24	2	1	1	5
24-36	1	1	2	4
36-48	4	0	1	2
Total	8	4	10	20

Table 8. Effect of N rate on soil inorganic N with depth.

	N rate (lb/acre)				
depth (in)	0	60	120	180	240
			Inorganic N (lb/acre)		
			1994		
0-6	16	17	22	24	28
6-12	9	13	13	23	30
12-24	10	11	14	30	38
24-36	0	0	1	6	5
36-48	0	0	0	1	3
total	35	41	50	84	104
			1995		
0-6	11	21	20	35	40
6-12	4	5	7	15	23
12-24	5	8	7	12	20
24-36	5	6	4	9	17
36-48	2	9	6	22	10
total	27	49	44	93	110

Figure 1. Effect of N rate on hybrid corn grain yield at Monmouth, IL.

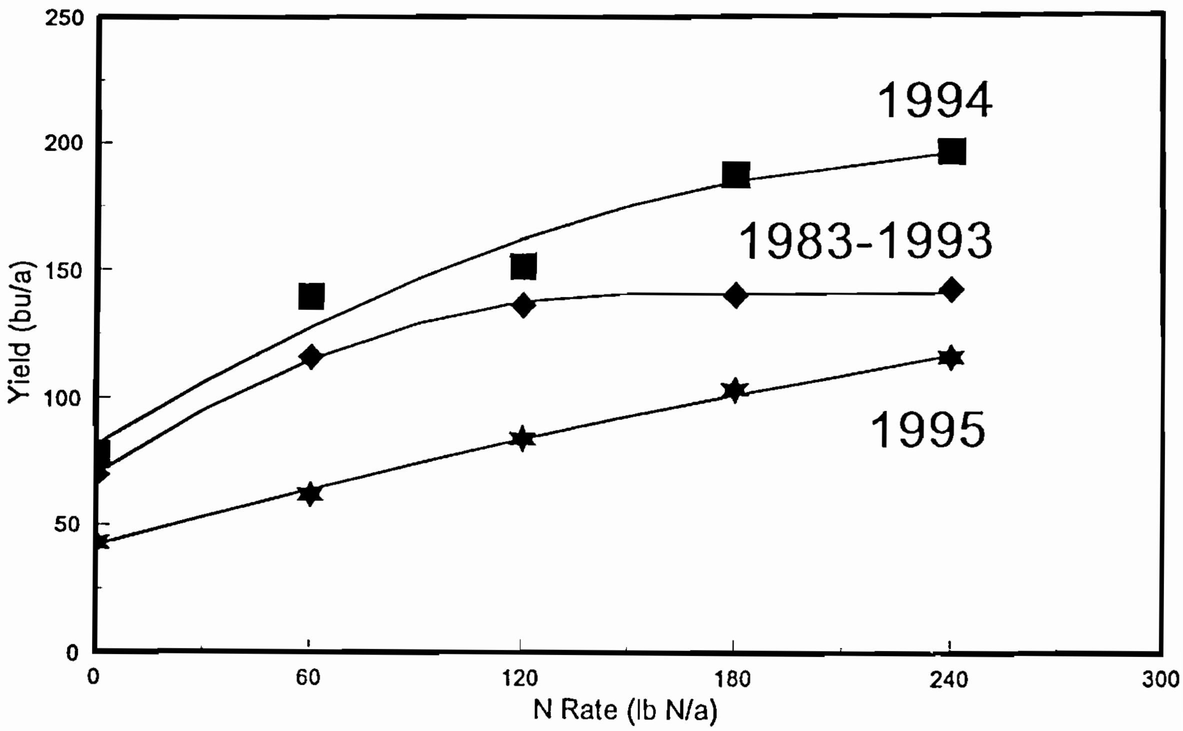
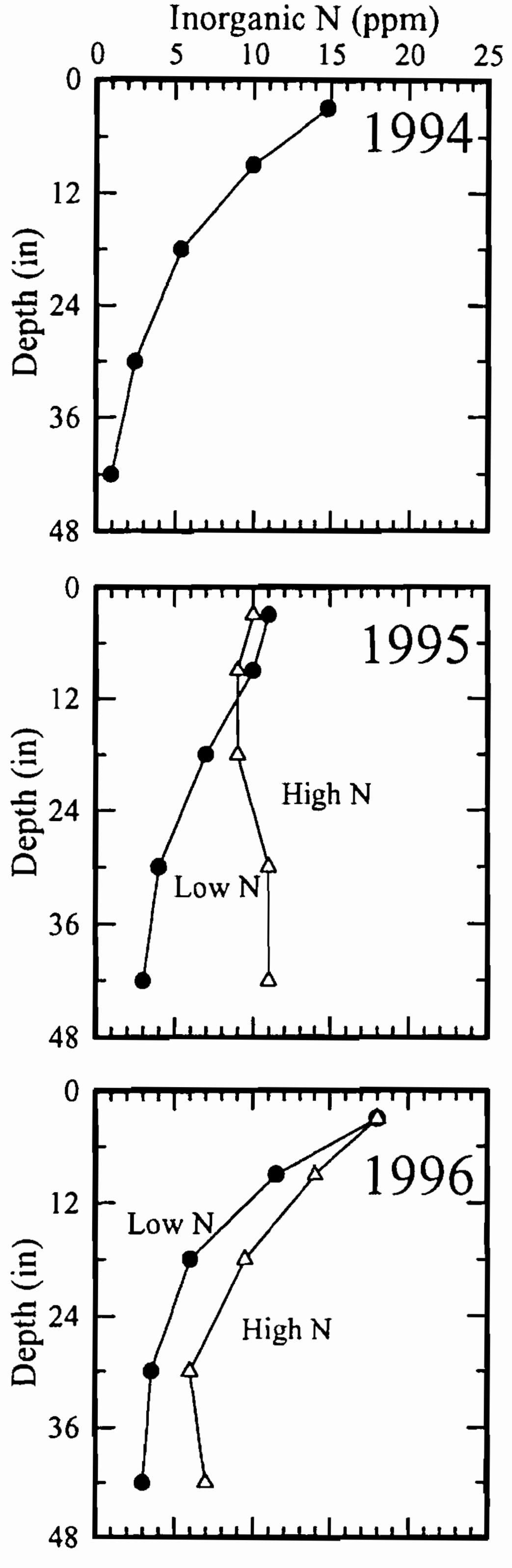


Figure 2. Spring inorganic N content at Monmouth, IL. Samples were taken April, 25 in 1994 and 1995, and April 18, 1996. High N refers to the 180 and 240 lb N/ acre rates and low N to the 0, 60, and 120 lb N/acre rates.



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Dr. Peter Scharf
University of Missouri
Dept. of Agronomy
Columbia, MO 65211