Fate of Fertilizer Nitrogen Applied to Two Indiana Soils Cropped to Corn

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Introduction

Nitrogen is the plant nutrient applied in the largest quantities for crop production in the United States. On the average, Indiana corn producers apply higher amounts of N per unit area (130 kg/hectare/year) than farmers in other corn belt states. Corn yields typically increase with increasing N application rates up to about 200 kg/ha/year, however, little is known about the corn yield response to rates of applied N above 300 kg/ha. There is interest in applying large amounts of N to achieve high corn silage or grain yields. Cummings (1967) observed small corn yield increases with increased rate of applied N up to 896 kg/ha. However, Powell and Webb (1972) observed that corn yields decreased at N rates above 224 kg/ha on Webster clay loam soil at Ames, Iowa and above 448 kg/ha on another site of the same soil at Kanawha, Iowa.

There is little information on the ultimate fate of that portion of applied N which is not assimilated by plants, particularly where high N application rates are used. This information is needed because of possible water quality deterioration associated with the presence of large amounts of excess NO_3^- in the soil profile at the end of the cropping season. The application of large amounts of fertilizer N results in NO_3^- accumulation in the soil profile because corn plants can efficiently utilize only moderate amounts of N. Therefore, the objectives of the study reported here were to determine: (i) the effects of several N application rates (ranging from 0 to 1344 kg/ha/yr) on the yield of corn grown on two Indiana soils, and (ii) the fate of N over a four year period in two soils treated with varying rates of fertilizer N and cropped to corn.

Materials and Methods

Two soil types located approximately 1 km apart on the Purdue University Agronomy Farm near West Lafayette were selected for the study. One soil, a Chalmers silty clay loam (Typic Argioquall), was underlain by tile drains every 20 m and had the following characteristics at the surface: cation exchange capacity (CEC), 32.5 meq/100g; organic C, 2.2%; available P, 93 μg/g; and exchangeable K, 333 μg/g. The other soil, a Fincastle silt loam (Aeric Ochraqualf), was not tile drained (a limited amount of old field tile may have been present) and had the following characteristics: CEC, 16.3 meq/100 g; organic C, 1.115%; available P, 50 μg/g; and exchangeable K, 143 μg/g.

Plots (3 x 18.3 m) were established in the spring of 1969 using a randomized complete block design with four replications. Before fertilization the NH_4^+-, NO_3^--, and total-N concentrations in composite soil samples taken from the 0-15, 15-30, 30-60, 60-90, and 90-120 cm depths in each plots were determined. Urea was broadcast at rates of 0,168,336,672, and 1344 kg N/ha in May and November 1969 and in November 1970 and 1971. Urea was incorporated by disking in May 1969 and by plowing when applied in November. The experimental areas were seeded to corn each year (Dekalb XL-45 in 1969 and Pioneer 3369A in 1970 thru 1972 in rows 76 cm apart and at a rate which resulted in an average population of 58,000 plants/ha at harvest. Weed and insect control was accomplished by common pesticides and by cultivation.

Steel access tubes 1 m in length with holes drilled near the lower end were placed in the center of each plot. Access tubes 3 m in length were placed in control plots and plots treated with 1344 kg/N/year. Samples of the free water beneath the plots were withdrawn at various intervals over the four year period by use of a hand operated vacumn pump. The water samples were subsequently analyzed for NH_4^+ and NO_3^--N by steam distillation (Bremner and Keeney, 1965).

At the end of each cropping year grain yield was determined by hand harvesting the middle 7.9 m section of the center two rows of each plot. Grain samples were dried, ground, and analyzed for total N (Nelson and Sommers, 1973). Each fall composite soil samples were taken from the 0-15, 15-30, 30-60, 60-90, and 90-120 cm depths of each plot. The samples were air-dried, crushed, and analyzed for NH_4^+- and NO_3^--N (Bremner and Keeney, 1966). At the end of the fourth cropping year, total N concentrations were also determined in each soil sample using the method of Nelson and Sommers (1972).

Nitrogen balances were calculated for the upper 1.2 m of each plot assuming a bulk density of 1.4 g/cm^3 averaged over the profile. Bulk density measurements in a few plots confirmed the applicability of this value. Furthermore, even if the value assumed for bulk density is in error, comparisons between treatments would be valid because of the homogenity in bulk density from plot to plot. Amounts of N added as fertilizer, present in the profile as NH_4^+ and NO_3^- at the start and end of the study, and removed as grain were accurately measured. Amounts of N added in rainfall and fixed by free-living microorganisms were estimated as 10 kg/ha/year. Net amounts of N mineralized during organic matter decomposition or immobilized during organic matter synthesis were estimated by changes in total N throughout the soil profile over the four year period. Nitrogen present in corn stover from the 1972 crop (this N would not be included in total N analysis of soil) was estimated from grain: stover ratios and N concentrations in stover observed in previous studies conducted on Chalmers and Fincastle soils.

All values reported are averages of four replications. All soil analysis data are expressed on a moisture-free basis and grain yields are calculated using a 15.5% moisture basis.

Results and Discussion

Table I presents data for corn yields as affected by rate of N applied to two soils over a four year period. During the first cropping year near maximum yields were obtained with application of 168 kg N/ha and yields tended to decline at higher N rates. The low yields obtained with 1344 kg N/ha may have resulted from accumulation of NH_3 or NO_2^- in soils shortly after urea application

TABLE I *Corn grain yields as affected by rates of nitrogen applied to two soils.*

Soil type*	N applied annually	Corn grain yield 1969	1970	1971	1972	Ave.
		kg/ha				
Chalmer sicl	0	7351	6423	2992	3776	5136
	168	8851	9628	11879	8649	9752
	336	8910	9697	12450	10223	10320
	672	8402	9044	12720	10029	10049
	1334	5111	9941	12695	10361	9527
Fincastle sil	0	7363	4453	1468	1555	3710
	168	7880	8950	9239	8894	8740
	336	7728	8840	10023	9897	9122
	672	5824	8222	8486	10825	8339
	1334	2562	9013	9245	11127	7987

*sicl, silty clay loam; sil, silt loam

and during seed germination. Both NH_3 and NO_2^- are phytotoxic when present in substantial amounts in the root zone. During subsequent cropping seasons maximum yields were obtained at N application rates of 168 or 336 kg/ha. The highest average yield over four years was obtained on both soil types in plots treated with 336 kg N/ha/year. On the average, N application rates higher than 336 kg/ha/year resulted in slightly decreased yields. The average yields on Chalmers and Fincastle soils obtained with 168 kg N/ha/year was 94.5% and 95.8%, respectively, of yields obtained with 336 kg N/ha/year. This finding suggests that maximum yields may have been obtained with a N application rate markedly below 336 kg N/ha/year. Other studies on these soils suggest that maximum corn yields may be obtained with from 200 to 230 kg N/ha/year.

The approximate N balance for Chalmers soil cropped to corn for a four year period is given in Table II. Net mineralization of N occurred at all N application rates except 1344 kg N/ha/year where about 1.5% of the added N

TABLE II *Approximate nitrogen balance sheet from Chalmers soil cropped to corn for four years.*

	Fertilizer N applied annually, kg/ha: 0	168	336	672	1344
	kg N/ha				
N inputs:					
fertilizer	0	672	1344	2688	5376
mineralized	681	276	344	134	0
inorg. N. in profile	283	283	283	283	283
rainfall and fixation	40	40	40	40	40
Total	1004	1271	2011	3145	5699
N recovered:					
grain and stover	323	635	686	681	656
inorg. N in profile	106	131	133	241	464
immobilized	0	0	0	0	90
Total	429	766	819	814	1210
N lost from soil	575	504	1192	2331	4489

was incorporated into soil organic N. This finding suggests that very high N fertilizer additions would be required to increase the organic N content of Chalmers soils under continuous corn culture and that under normal fertilization practices significant amounts of organic N are mineralized each year (69 kg/ha/year at an N fertilizer rate of 168 kg/ha/year). The amounts of inorganic N recovered from the soil profile after four years were lower than those initially present for all N application rates except 1344 kg N/ha/year. This finding is surprising because it was presumed that inorganic N not used by plants would, in part, accumulate in the profile. Amounts of N recovered in grain plus stover increased with increasing N addition rate up to 336 kg/ha/year and then remained relatively constant.

The total amounts of N recovered in grain plus stover and inorganic and immobilized N in the soil profile after 4 years were much less than the amounts of N added to each plot. The proportion of N inputs which were recovered after 4 years was highest in plots receiving 168 kg N/ha/year (60.3%) and decreased in the following treatment order: 0>336>672>1344 kg N/ha/year. The proportion of added N recovered from plots receiving 1344 kg N/ha/year was only 21.2%.

The amounts of N apparently lost from Chalmers soil tended to increase with increasing rate of applied N except that N lost from plots treated with 168 kg N/ha/year was lower than that lost from untreated plots. This finding suggests that moderate fertilizer applications will not increase N loss from some soils and substantiates that N losses may be large (144 kg N/ha/year) from soils where no fertilizer was applied. Very large N losses were observed in plots receiving 672 and 1344 kg N/ha/year verifying that applications of N greatly in excess of plant needs will lead to poor recoveries of added N as a result of leaching/denitrification.

Table III presents an approximate N balance in Fincastle soil for a 4 year period. Net mineralization of organic N was observed in plots receiving 0 and 168 kg N/ha/year, whereas net immobilization of added N was obtained in plots

Table III *Approximate nitrogen balance sheet for Fincastle soil cropped to corn for four years.*

	Fertilizer N applied annually, kg/ha				
	0	168	336	672	1344
	Kg N/ha				
N inputs:					
fertilizer	0	672	1344	2688	5376
mineralized	226	338	0	0	0
inorg. N in profile	206	206	206	206	206
rainfall and fixation	40	40	40	40	40
Total	472	1256	1590	2934	5622
N recovered:					
grain and stover	225	579	619	591	580
inorg. N in profile	34	66	172	596	706
immobilized	0	0	282	535	1355
Total	259	645	1073	1722	2641
N lost from soil	213	611	517	1212	2981

treated with $\geq$ 336 kg N/ha/year. This finding suggests that the organic N content of Fincastle may be increased by applications of above average (~ 300 kg/ha/year) amounts of fertilizer N. Lower amounts of (NH_4^+ + NO_3^-)-N were found after 4 years of cropping in plots receiving $\leq$ 336 kg N/ha/year as compared to amounts of inorganic N in the soil profile at the start of the study. At N addition rates of $\geq$ 672 kg/ha/year significant amounts of inorganic N accumulated in the profile. Amounts of N recovered in corn grain and fodder increased with increasing rate of fertilizer N up to 336 kg/ha/year and remained relatively constant at higher N application rates.

Total amounts of N recovered after 4 years increased with increasing rate of applied N. The proportion of added N which was recovered ranged from 67.5% in plots treated with 336 kg N/ha/year to 47% in plots receiving 1344 kg N/ha/year. Amounts of N apparently lost from the soil-plant system tended to increase with increasing rate of applied N except that higher N loss was observed in plots receiving 168 kg N/ha/year as compared to those treated with 336 kg N/ha/year. Average annual N loss ranged from 53 kg/ha for the unfertilized to 745 kg/ha for the plot receiving 1344 kg N/ha year.

It is interesting that the apparent N loss from Chalmers soil was larger than the loss from Fincastle soil at each N addition rate except 168 kg N/ha/year. This finding may result from the artificial drainage system installed in the Chalmers study area which provided a transport mechanisms for moving large amounts of NO_3^--N out of the soil profile. Determination of inorganic N in the free soil water at a depth of 1 m (approximate depth of drainage tile in Chalmers soil) provides direct evidence for NO_3^--N leaching. Fig. 1 and Fig. 2 give data for the NO_3^--N content of the soil water at the 1 m depth in Chalmers and Fincastle soils, respectively, treated with varying rates of fertilizer N. In Chalmers soils the NO_3^--N concentration in the soil water increased with N application rate at each sampling time except that data for the plots treated with 168 kg N/ha/year was similar to that of the unfertilized plot. There were large fluctuations in the NO_3^--N concentration in soil water with time in those plots treated with highest rates of N. Highest concentrations were normally measured in the winter and early spring. The fluctuations in NO_3^--N concentrations observed result from the varying amounts of water percolating through the soil profile during various seasons and the amounts of NO_3^- available for transport at the time of downward water movement.

More NO_3^--N tended to accumulate in the soil water below Fincastle plots as compared to Chalmers plots because free drainage by tiles was not provided in the Fincastle. Although the soil water from plots receiving 0 and 168 kg N/ha/year was low in NO_3^--N, the soil water from plots treated with high rates of N had high NO_3^--N concentrations several times during the study. The NO_3^--N concentration in soil water tended to increase with increasing rate of N applied. There were extreme fluctuations in NO_3^--N concentrations of soil water with time in Fincastle soil. Highest NO_3^--N concentrations were in the winter and early spring following fall application of fertilizer. Further evidence for more NO_3^- accumulation in Fincastle soil as compared to Chalmers soil is provided by NO_3^--N analysis of the soil profile at the end of 4 cropping seasons (Table II and III) and by the higher corn yields obtained on Fincastle soil the first cropping season after N fertilization ceased.

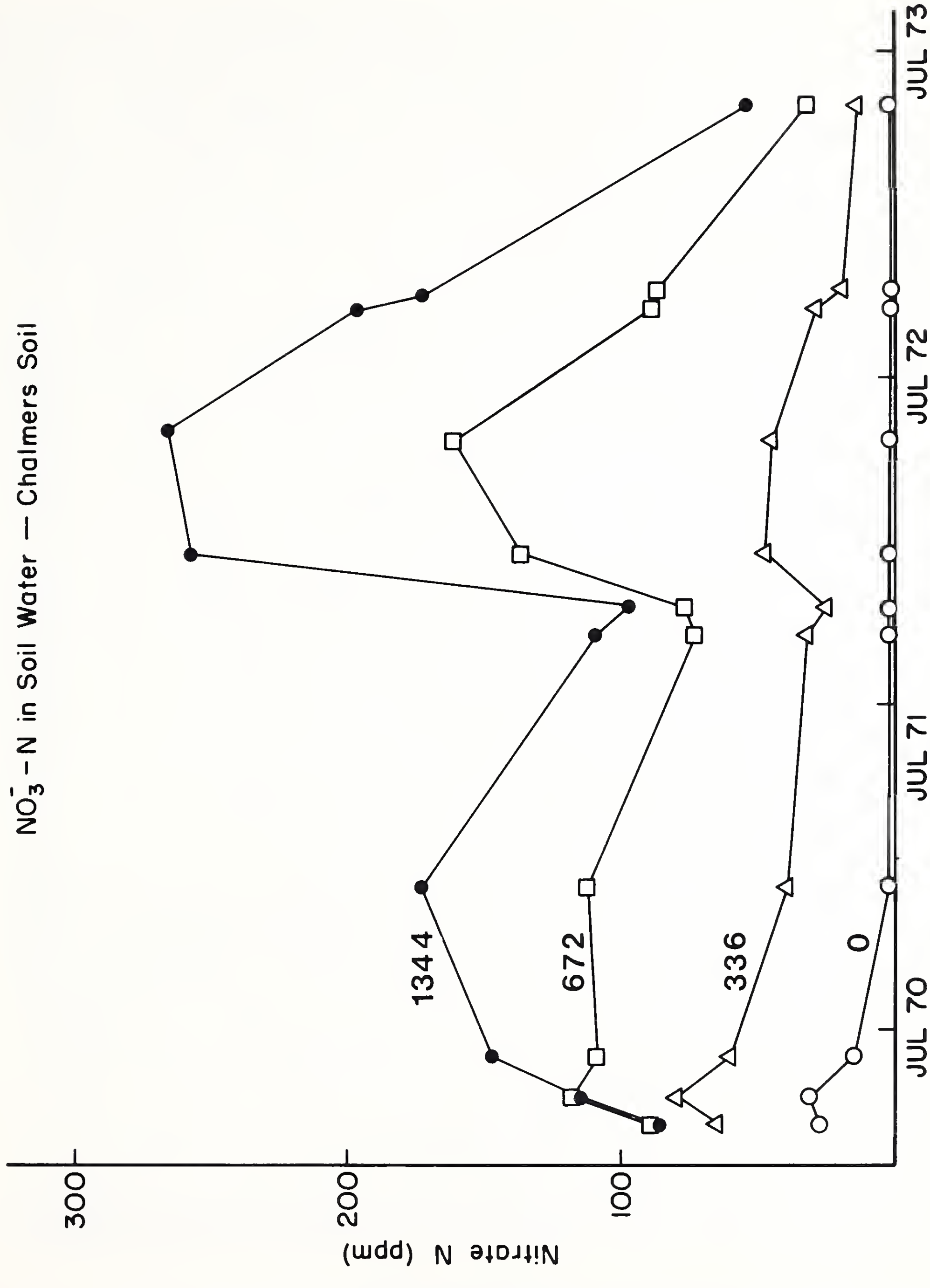

Figure 1. *Nitrate N concentration in soil water at a depth of 1 m beneath Chalmers soil treated with varying rates of fertilizer nitrogen (numerical values above lines refer to rate of N applied in kg/ha/year.)*

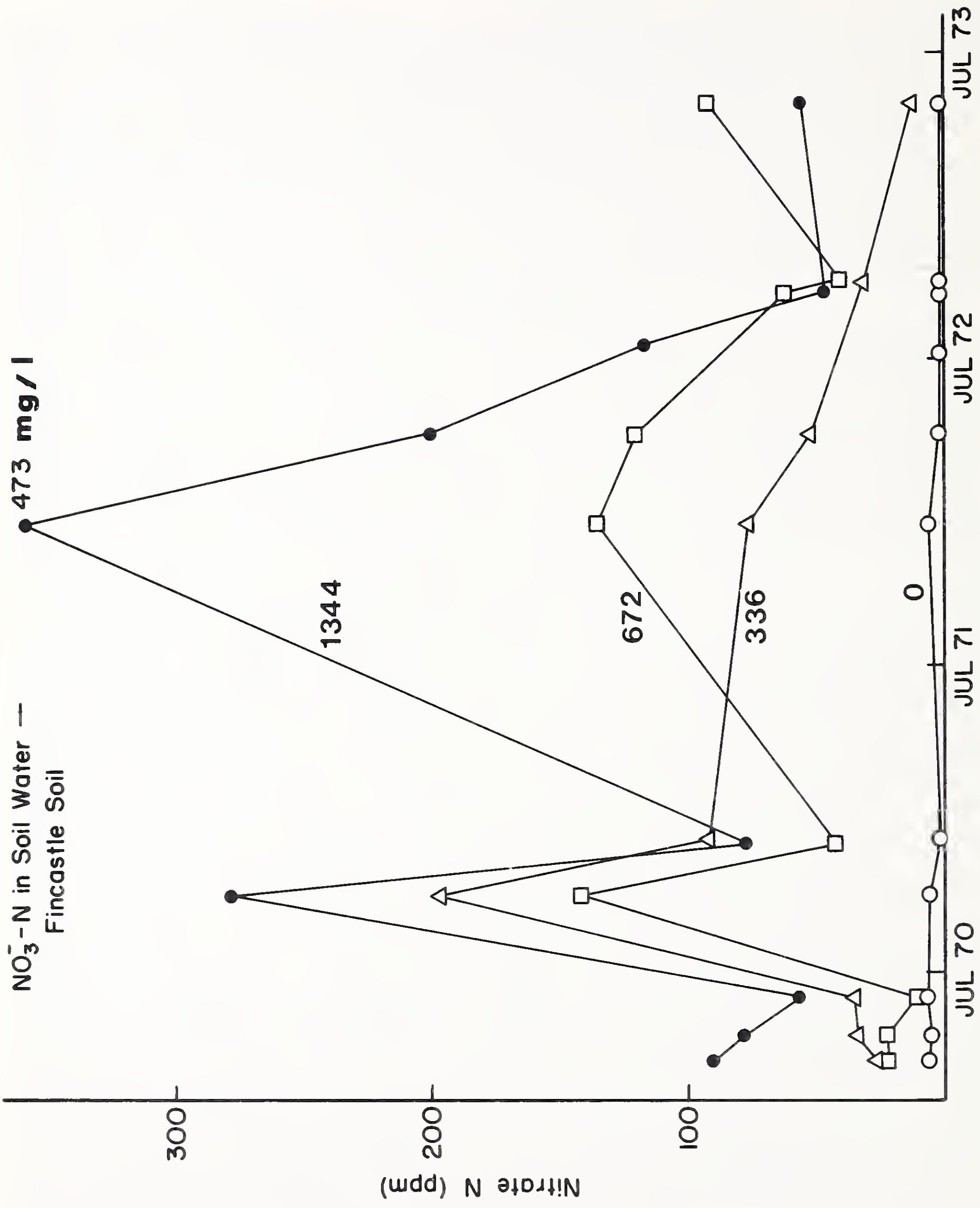

FIGURE 2. *Nitrate N concentration in soil water at a depth of 1 m beneath Fincastle soil treated with varying rates of fertilizer nitrogen (numerical values above lines refer to rate of N applied in kg/ha/year).*

Analysis of soil water from the 3 m depth established that the NO_3^--N concentration was low in plots treated with 0 or 1344 kg N/ha/yr for both soil types. This finding suggests that NO_3^--N is not being leached deep into the soil profile where the possibility for contamination of ground water supplies exist. However, it appears that water moving through tile drains is removing the excess NO_3^--N from the lower portion of the soil profile. Analysis of the tile drainage water from the system draining the Chalmers study area indicated that NO_3^--N concentrations were high (~25 mg NO_3^--N/l).

Analysis of the profile of each soil at the end of the first cropping season indicated that substantial amounts of NO_3^--N were present. However, the amounts of NO_3^--N in the profile had decreased markedly by the start of the next cropping suggesting large over winter losses of N. It is unlikely that large amounts of NO_3^--N was moved from the top of the soil profile to below 1.2 m by leaching during a 5 month period. Thus, it seems likely that denitrification in the early spring was partially responsible for NO_3^--N losses from the soils studied.

The data collected in this study establish that high rates of fertilizer N (above 336 kg/ha/year) do not improve corn yields and result in extensive loss of N from the soil-plant system. The majority of the N lost from Chalmers and Fincastle soil is transported from the upper root zone by percolating water and is eventually removed in tile drainage water. A portion of the excess NO_3^--N present in the profile at the end of the cropping season is apparently lost by denitrification in the early spring when soils are saturated.

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