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# EFFECT OF MOISTURE REGIME ON RECOVERY AND UTILIZATION OF FERTILIZER N APPLIED TO CORN

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***ABSTRACT:*** Environmental and economic concerns have resulted in renewed interest in the potential for N loss under various climatic conditions. Experiments were conducted over a three-year period at three locations in Illinois to evaluate the effects of soil type and soil moisture conditions on the fate of fertilizer N during the growing season. At each location, a factorial arrangement of four N rates (0, 100, 150, and 200 lb N/acre) and three soil moisture levels (ambient, ambient + 4 in. over a 3-d period, and ambient + 6 in. over an 8-d period) was established with corn (*Zea mays* L.). Isotopic $^{15}N$ was used for the 150 lb N/acre plots. After the moisture treatments had been imposed, moisture levels were allowed to return to conditions drier than 0.33 bar and plots were split with one half receiving a supplemental application of 50 lb N/acre. Regression equations relating total recovered N and plant N uptake to soil moisture condition and N application were developed for each site. Fertilizer N recovery on a Drummer sicl (fine-silty, mixed, mesic Typic Haplaquoll) averaged 50 and 44% at the end of the growing season with the application of 4- and 6-in. excess water, respectively, compared to 83% with the ambient treatment. Fertilizer N recoveries of 61% with excess water application compared to 88% with ambient moisture were observed on a Cisne sil (fine, montmorillonitic, mesic Mollic Albaqualf). Excessive losses of fertilizer N were observed on a Plainfield soil (mixed, mesic Typic Udipsamment). Less than 25% of the N was recovered with the ambient treatment, with

even lower recoveries (8-13%) associated with the application of excess water. Denitrification appeared to be the primary loss mechanism on the Cisne and Drummer soils, whereas leaching was the primary loss mechanism on the Plainfield soil.

## INTRODUCTION

During the 1970s, world demand led to high grain prices, which encouraged farmers to maximize production. Since then, favorable world climates along with more intensive farming practices in other countries have resulted in increased production of grain world-wide with associated lower commodity prices for U.S. production. These lower prices plus an awareness that fertilizers may be contributing to contamination of surface and ground water supplies have provided an incentive to improve N management programs (1,2,3).

Farmers have recognized that since N loss from soil is dependent on climatic conditions it will not occur on every field in every year. However, lacking a reliable technique to predict the magnitude of loss in any given year, they frequently add sufficient N to accommodate an average loss. This approach leads to an overapplication of fertilizer N in some cases and an underapplication in others. These errors could be reduced if losses could be estimated early enough in the growing season to allow farmers to reapply N to maintain optimum yield.

The magnitude of N loss from denitrification is dependent on temperature, soil texture, soil organic matter, and moisture status of the soil (4). At soil temperatures typically found during the growing season, the rate of denitrification increases from 1.5 to 2.1 times with an 18°F increase in temperature (5). Denitrification occurs at soil moisture tensions near saturation, with rapid changes in the rate of gaseous N emissions during wetting and drying cycles (6,7,8). Smith and Tiedje (9) found rapid increases in denitrification within 6 h of water application, while Sexstone et al. (10) found that denitrification occurred in bursts in response to rainfall and that both the time of initiation and the duration of denitrification depended on soil type. They found that 38 to 55% of the total N loss occurred within 48 h of rainfall events greater than 0.4 in. during late spring.

Leaching of $NO_3$ can occur from any soil whenever precipitation exceeds evapotranspiration and the soil is not frozen (11), but the loss is generally greater in coarse-textured soils. The amount of N leached is directly related to the rate of water movement through soil, increasing as infiltration and percolation increase and as the water-holding capacity of soil decreases (12). In the corn belt, these conditions often occur in the spring before vigorous plant growth increases the evapotranspiration rate above the rate of precipitation or in the fall and winter when crops are not growing.

In the midwest, rainfall events which create saturated soil conditions are common in the spring of the year. A serious loss of N can result, because temperatures are usually adequate for rapid nitrification of ammoniacal N, and the $NO_3$ formed is readily removed either by denitrification in poorly drained soils or by movement through the profile in well-drained soils (11). The objective of this study was to determine the effect of excess moisture conditions on the fate of fertilizer N applied to corn on three different soil types.

## MATERIALS AND METHODS

Field experiments were established at Brownstown, DeKalb, and Havana, IL, on a Cisne soil, a Drummer soil, and a Plainfield soil, respectively. The experiments were conducted from 1985 through 1988.

Nitrogen loss problems have been observed in each of these major Illinois soil types. A relatively impermeable claypan in the Cisne soil at Brownstown frequently results in the persistence of excess soil moisture for extended periods in spring and early summer, and thus these soils have a high potential for denitrification. The same difficulty arises with the Drummer soil at DeKalb due to low internal permeability. Leaching of mobile nutrients such as $NO_3$ is a major problem on the excessively well drained Plainfield soil at Havana.

Applications of 0, 100, 150, and 200 lb N/acre were made in factorial combination with two moisture levels of ambient: ambient plus 4 in. of water evenly distributed over a 3-d period, and ambient plus 6 in. of water evenly distributed over an 8-d period. These treatments simulate rainfall events that occasionally occur in Illinois.

Corn was planted in early to mid-May and N applications were made at the V1 to V3 growth stage. To insure that a substantial portion of the N was present as $NO_3$, N was broadcast as $NH_4NO_3$ in 1985 and 1986, and as $KNO_3$ in 1987 and 1988 on plots measuring 15 × 50 feet (ft.) on the Cisne and Drummer soils and 15 × 35 ft. on the Plainfield soil. In 1986, 1987, and 1988, N was broadcast over all but a 7.5 × 12 ft. microplot area in the center of the 150 lb N/acre plot area. To this area, arranged to include four rows of corn, $^{15}N$-labeled fertilizer was applied as uniformly as possible, using a compressed air sprayer. In 1986, $NH_4NO_3$ (doubly labeled with 0.01 atom % $^{15}N$) was applied at all locations. In 1987 and 1988, $^{15}N$-enriched $KNO_3$ was applied; the $^{15}N$ content was 2.79 atom % $^{15}N$ for the Drummer and Cisne and 2.29 atom % $^{15}N$ for the Plainfield.

Following N application, sufficient water was applied to the entire plot area to bring soil moisture tension to approximately 0.33 bar at a depth of 6 in. Once that moisture level was obtained, the moisture regimes were established using a solid set sprinkler system on the Drummer and Cisne and a traveling gun on the Plainfield. Border rows were placed between the moisture treatments. The 4 and 6 in. water applications were target values for the excess water treatments; actual application rates are given in Table 1.

Tensiometers were installed on the Drummer and Cisne in 1987 and 1988 to monitor soil moisture tension at the 6-in. depth. The percent moisture of the soil and the number of days of soil moisture tension below 0.33 bar were calculated from the tensiometer data using laboratory-derived moisture curves (13). Total rainfall + irrigation during the growing season for each soil are given in Table 1. Bulk density was determined from intact soil samples taken at 1-ft. increments to a depth of 4-ft. for calculation of fertilizer N recovery.

Table 1. Monthly Total Rainfall and Irrigation for the Growing Season†.

| Month | 1986 Rain | 1986 Irrig‡ | 1987 Rain | 1987 Irrig‡ | 1988 Rain | 1988 Irrig‡ |
|---|---|---|---|---|---|---|
| | inches | | | | | |
| | | | Cisne | | | |
| Total | 15.6 | 1.6 | 11.6 | 1.1 | 8.5 | 9.1 |
| Excess§ | | | | | | |
| 3 day | | 4.0 | | 4.0 | | 2.9 |
| 8 day | | 6.0 | | 6.2 | | 5.2 |
| | | | Drummer | | | |
| Total | 21.4 | 0 | 30.1 | 0 | 14.3 | 0 |
| Excess§ | | | | | | |
| 3 day | | 4.0 | | 4.3 | | 3.9 |
| 8 day | | 5.8 | | 6.1 | | 5.9 |
| | | | Plainfield | | | |
| Total | 17.0 | 12.0 | 9.6 | 13.0 | 8.8 | 20.7 |
| Excess§ | | | | | | |
| 3 day | | 3.0 | | 3.2 | | 3.9 |
| 8 day | | 7.6 | | 5.8 | | 6.9 |

† Monthly totals of rainfall are for periods between planting and harvest only.

‡ Values reported represent water applied to all plots for corn production or for adjustment of soil moisture tension (0.33 bar) prior to establishment of water regimes. No application (other than excess moisture treatments) were made to Drummer soil, as irrigation facilities were limited, and rainfall was adequate to reduce soil moisture tension to $< 0.33$ bar before moisture treatment application.

§ Excess water application was initiated at V6 - V8. Values represent actual application achieved for the 3 and 8 day excess water treatments.

The application of excess water on the Cisne soil resulted in soil moisture tension at the 6-in. depth of less than 0.33 bar for 2 days with the 4-in. water treatment, and for 3 and 7 days following the 6-in. water treatment for 1987 and 1988, respectively. With the Drummer, tensiometer readings indicated 2 and 4 days of less than 0.33 bar with the 4-in. water treatment and 3 and 5 days with the 6-in. water treatment, for 1987 and 1988, respectively.

After the water treatments were imposed and soil moisture content was no longer at saturation (approximately 7 days after completion of excess water treatments), supplemental N was applied to one-half of each plot at the rate of 50 lb N/acre as $NH_4NO_3$. Additional water was applied as needed to prevent water stress during the growing season on the Cisne and Plainfield soils.

At harvest, plant samples were collected from a 5 × 5 ft. area in the center of all but the 150 lb N/acre plots where samples were collected from a 5-ft. section of the inside two rows in the micro-plot area. The samples were dried, weighed, ground, and analyzed for N concentration using a salicylic acid-thiosulfate modification of the semimicro-Kjeldahl method described by Bremner and Mulvaney (14).

Soil samples were collected at 1-ft. increments down to 4 ft. at silking and harvest. Immediately after collection, the soil samples were frozen until analyzed for $NO_3$-N and total N. Soil samples were wet-sieved, and inorganic N concentration was determined by steam distillation of 2 M KCl extracts with MgO and Devarda's alloy as described by Keeney and Nelson (15). Total N analysis of soil samples were performed using a permanganate-reduced iron modification of a semimicro-Kjeldahl method (14).

Distillates from total and inorganic N analysis were retained for $^{15}N$ analysis with an automated mass spectrometer (16). Total recovered fertilizer N was calculated by summing the soil (4-ft. depth) and plant fertilizer N contents. Fertilizer N in organic forms was calculated from the difference between total N and inorganic N content. Fertilizer N loss was calculated by subtracting total recovered fertilizer N from the amount of fertilizer applied. Experimental design was a split block with three replications with moisture treatment as the main block. Significance of treatment effects was determined by least significant differences.

Calculation of total N recovery for the regression analysis was made by the difference method, using the equation: total recovered N = $(NP_t + NS_t) - (NP_c + NS_c)$, where $NP_t$ is treatment plant N, $NS_t$ is treatment inorganic soil N ($NO_3$ + $NH_4$ to 4 ft.), $NP_c$ is the unfertilized plant N, and $NS_c$ is unfertilized inorganic soil N. Soil and plant N data were pooled for 1987 and 1988 for the Cisne and

Drummer soils. Data from 1985 was also included for the Plainfield soil, but data from 1988 was dropped from this location because production problems prevented accurate measurements. Two measures of soil moisture condition were evaluated to determine which could best explain plant N uptake and total recovered N response to moisture treatment: total rainfall plus irrigation in May and June and number of days in May and June with a soil moisture tension below 0.33 bar. Both of these are easily determined measures of soil moisture that could be obtained and used by farmers and/or their advisors.

Quadratic and interaction terms of the independent variables were considered in the model. Multiple regression equations were developed using stepwise and backward elimination procedures (17). The $R^2$ statistic and $C_p$ criteria were used to select the best fit regression equation as described by Neter and Wasserman (18). The best fit multiple regression equations were used to develop response curves for each soil type. The curves were developed by solving the equations for arbitrary values of the independent variables within the range measured in the study.

## RESULTS AND DISCUSSION

*Cisne:* Application of 6 in. of excess water in 1987 and with both 4 and 6 in. of excess water in 1988 resulted in a significant decrease in the amount of fertilizer N recovered (Table 2). While not significant, the same trends were observed in 1986. In 1986 and 1987, 33% of the total fertilizer N was unaccounted for in the plant-soil system with the ambient treatment compared to only 5% for the same treatment in 1988 (Table 2). The high recovery observed in 1988 was probably the result of very low rainfall throughout the growing season (Table 1) and thus a low potential for N loss from denitrification.

Most of the fertilizer N remaining at harvest was found in the top foot of soil (Table 3). Small amounts of fertilizer N were found in the 1-2 ft. zone in both 1987 and 1988, but at greater depths, the fertilizer $^{15}N$ was undetectable. Although distribution of soil N seemed to be independent of moisture treatment,

Table 2. Effect of Excess Moisture on Fate of Fertilizer N (lb/acre) on a Cisne, a Drummer, and a Plainfield Soil, Calculated from $^{15}N$ Data.

| Year | Cisne Soil Moisture Level | | | Drummer Soil Moisture level | | | Plainfield Soil Moisture Level | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| | Fertilizer N loss (lb/acre) | | | | | | | | |
| 1986 | 48.0 a | 74.3 a | 66.3 a | 25.3 a | 61.1 ab | 95.0 b | 112.6 a | 130.9 b | 131.1 b |
| 1987 | 51.7 a | 54.0 ab | 74.7 b | 29.8 a | 77.5 b | 85.3 b | 123.6 a | 137.3 a | 137.6 a |
| 1988 | 7.7 a | 42.4 ab | 49.4 ab | 18.4 a | 59.4 b | 70.4 b | 45.6 a | 129.9 b | 138.7 b |

Fertilizer N in lb/acre, calculated by $^{15}N$ method.
Soil moisture level: 1 = ambient; 2 = ambient + 4 inches of excess water; 3 = ambient + 6 inches excess water.
Means with the same letter within years and soil type are not significantly different.

**Table 3.** Effect of Excess Moisture on Fertilizer N (lb/acre) Remaining in Soil Calculated from $^{15}$N Data for Cisne and Drummer soil†.

| Depth (in.) | Soil Moisture Level: Ambient | Ambient + 4 in. | Ambient + 6 in. |
|---|---|---|---|
| | Fertilizer N (lb/acre) | | |
| | | **CISNE** | |
| | | 1986 | |
| 0 - 12 | 25.2 a | 20.1 a | 28.5 a |
| 12 - 24 | 4.8 b | 3.0 b | 4.6 b |
| 24 - 36 | 3.3 b | 3.2 b | 7.5 b |
| 36 - 48 | 3.0 b | 1.7 b | 3.4 b |
| | | 1987 | |
| 0 - 12 | 11.5 a (9.3) | 9.6 a (8.0) | 8.1 a (6.8) |
| 12 - 24 | 4.0 b | 5.3 ab | 4.3 b |
| 24 - 36 | + b | 1.1 b | + c |
| 36 - 48 | + b | + b | + c |
| | | 1988 | |
| 0 - 12 | 29.5 a (22.5) | 25.2 a (17.8) | 20.0 a (18.8) |
| 12 - 24 | 13.5 b | 8.3 b | 5.6 b |
| 24 - 36 | 1.2 c | + b | + b |
| 36 - 48 | + c | 0 b | 0 b |
| | | **DRUMMER** | |
| | | 1986 | |
| 0 - 12 | 40.4 a | 20.5 a | 10.1 a |
| 12 - 24 | 7.5 b | 6.0 b | 1.8 b |
| 24 - 36 | 15.1 b | 9.8 b | 8.0 ab |
| 36 - 48 | 7.6 b | 7.3 b | 4.7 ab |
| | | 1987 | |
| 0 - 12 | 45.6 a (45.0) | 27.6 a (27.2) | 15.9 a (15.6) |
| 12 - 24 | 8.3 b | 7.5 b | + b |
| 24 - 36 | 1.5 b | 1.5 b | 1.8 b |
| 36 - 48 | + b | + b | 1.3b |
| | | 1988 | |
| 0 - 12 | 59.1 a (21.8) | 27.4 a (26.3) | 23.1 a (19.3) |
| 12 - 24 | 8.5 b | 5.8 b | 2.7 b |
| 24 - 36 | 2.9 b | 2.7 b | 1.9 b |
| 36 - 48 | 1.1 b | + b | + b |

†Values represent means of 3 replicates. Values in the same row within the same year and sampling period followed by the same letter do not differ significantly (0.05 level). A + indicates trace amounts of fertilizer N, ( ) designates fertilizer N in the organic form, calculated as total N - inorganic N.

small amounts of fertilizer N were detected down to 4 ft. in 1986, indicating that some downward movement of $NO_3$ had occurred on this soil. Since only trace amounts of fertilizer N were found at the lower depths in 1987 and 1988 (when detection was improved by use of $^{15}N$ enrich ertilizer), N loss through leaching was negligible on this soil. This is to be expected since the impermeable claypan on this soil limits water movement and creates saturated conditions, restricting the leaching of $NO_3$ below the rooting zone (11).

Data collected in 1987 and 1988 indicated that a substantial portion of the fertilizer N remaining in the top foot of soil was present as organic N, irrespective of water treatment (Table 3). This would help to preserve N from loss during the winter and early spring.

The best fit regression equations for prediction of total recovered N (RN) and plant N uptake (PN) for the Cisne were: RN (lb/acre) = $-2.8435 + 1.2078\ N + 0.7007\ Ns - 0.00155\ N^2 - 0.019\ N \times M$; ($R^2 = 0.75$), PN (lb/acre) = $61.3357 + 1.1266\ N + 0.8086\ N_s - 0.0027\ N^2 - 0.0032\ N \times N_s$ ($R^2 = 0.75$), respectively. In both equations, N represents applied N (lb/acre), $N_s$ is supplemental N (lb/acre), and M represents the number of days when soil moisture tension was below 0.33 bar. Based on the RN equation, N recovery at the 150 lb N/acre rate was 86% with 5 days of soil moisture tension below 0.33 bar, as compared to 96% recovery when soil moisture tension was never below 0.33 bar (Figure 1).

***Drummer:*** Loss of fertilizer N from the plant-soil system for the ambient, 4-, and 6-in. water regimes averaged 17, 44, and 56%, respectively, for the three-year period (Table 2). Consistent with the Cisne soil, smaller fertilizer N losses occurred in the drought year of 1988 compared to the other two years.

Most of the N remaining in the soil was found in the surface foot of the profile in all three years (Table 3). Small amounts of fertilizer N were found at depths down to 4 ft., indicating that some downward movement of fertilizer N occurred on this soil. However, as was seen with the Cisne, the amount of fertilizer N found at the 3-4 ft. depth was small and seemed to be independent of

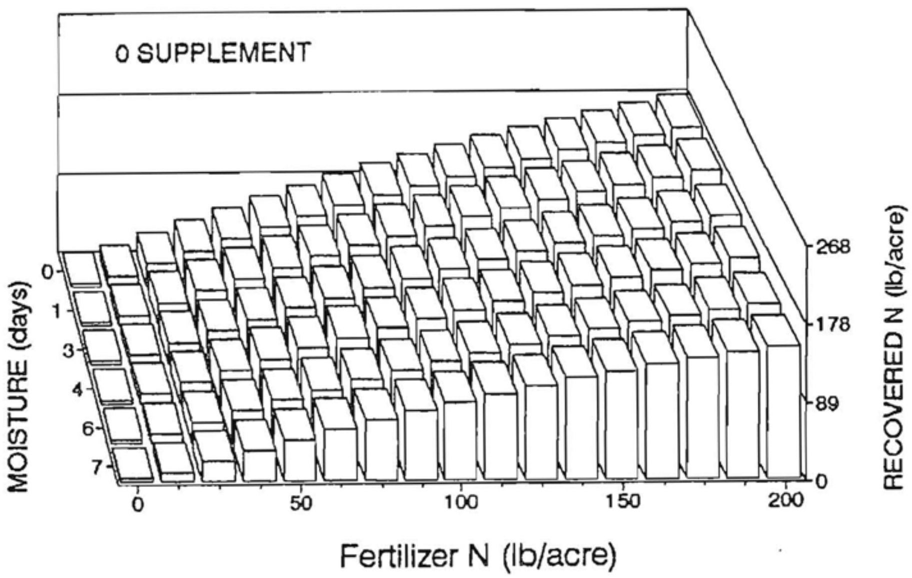


FIGURE 1. Predicted Effects on Fertilizer N Recovery with Fertilizer N Application and Soil Moisture Condition in Days of Soil Moisture Tension Below 0.33 Bars on a Cisne soil with No Supplemental N Application.

the excess moisture treatments. This would indicate that only small amounts of fertilizer N loss could be attributed to leaching.

With the ambient treatment, over 98% of the applied fertilizer N remaining in the soil at harvest in 1987 was in the organic fraction (Table 3), but in 1988, less than 40% was present in organic forms. The difference may be attributed to the heavy rainfall in August of 1987, which would have reduced inorganic N concentrations through denitrification, and to the drought in 1988 that would have reduced the incorporation of fertilizer N into organic forms, as immobilization of N is reduced under water stress (19). The latter finding indicates that the potential for leaching may be increased in soils under drought conditions if soil moisture levels exceed water-holding capacity prior to the next period of crop N use.

The best fit regression equations for prediction of total recovered N and plant N for the Drummer soil were: RN (lb N/acre) = 6.0505 + 0.6668 N + 0.4833

$N_s$ - 0.0379 N × M; ($R^2$ = 0.74) and PN = 69.8776 + 0.7133 N + 0.6751 $N_s$ - 0.0007 $N^2$ - 0.0399 N × M - 0.00214 N × $N_s$ ($R^2$ = 0.74), respectively. The negative N by moisture interaction in the PN equation indicates that additional days of soil moisture tension below 0.33 bar progressively decreased N uptake as the rate of initial N was increased. The kinetics of denitrification have been described as a second-order reaction, dependent on both $NO_3$ level and soluble organic carbon (20). Therefore, higher N application would lead to higher denitrification rates. Consequently uptake of the $NO_3$ remaining in the soil would also be proportionally reduced with the higher N rates.

Based on the RN equation, N recovery with an initial application of 150 lb N/acre was 52% assuming 5 days with soil moisture tension below 0.33 bar, compared to 70% when soil moisture tension was never below 0.33 bar (Figure 2).

Mulvaney and Kurtz (8) found that denitrification occurred only if soil moisture tension was less than 0.33 bar. Because the best fit regression equation was found using the number of days below 0.33 bar, and because examination of fertilizer N content in the soil by depth did not indicate significant movement of $NO_3$ below the 24-in. depth on either the Drummer or the Cisne (Table 3), the N deficits observed for these soils (Table 2) were due largely to denitrification. Application of excess water led to larger losses of fertilizer N for the Drummer than for the Cisne. The difference can be attributed to the higher organic matter content of the Drummer, since the rate of denitrification depends upon the availability of soluble organic carbon in the soil (20).

***Plainfield:*** Addition of excess moisture treatments significantly increased fertilizer N loss compared to the ambient treatment in 1986 and 1988 (Table 2), with very low recovery of fertilizer N observed in the plant-soil system at all moisture levels. In 1987, extensive fertilizer N losses from the plant-soil system with all moisture treatments resulted in no significant difference between treatments. In the three-year period, application of excess water resulted in 87 to 92% of the fertilizer N application being lost.

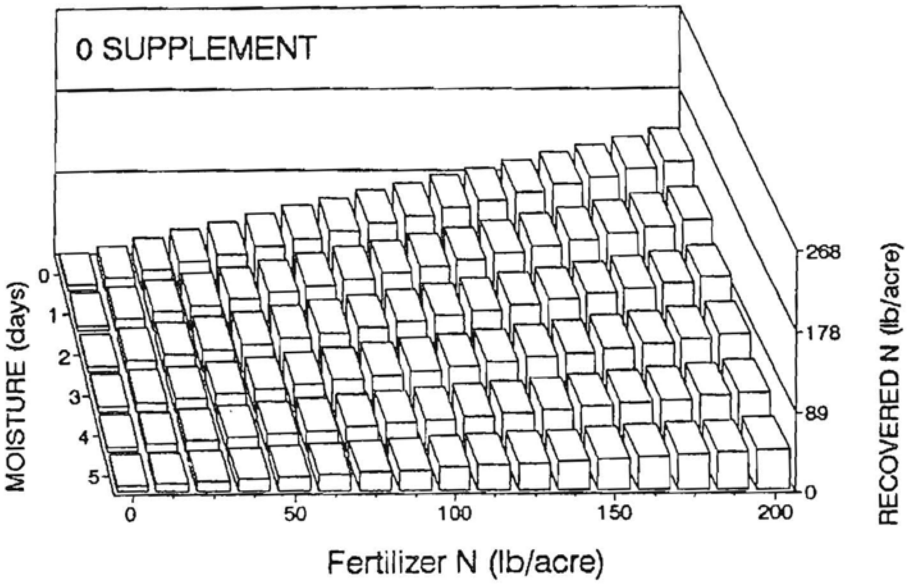


FIGURE 2. Predicted Effects on Fertilizer N Recovery with Fertilizer N Application and Soil Moisture Condition in Days of Soil Moisture Tension Below 0.33 Bars on a Drummer Soil with No Supplemental N application.

In 1986 and 1988, relative large amounts of fertilizer N were found below the 1 ft. depth at midseason, indicating that large amounts of fertilizer N had moved in the soil profile (Table 4). In addition, smaller amounts of fertilizer N were recovered with the application of excess moisture compared to the ambient treatment, indicating that leaching was the main source of N loss on this soil. By the end of the growing season, most of the fertilizer N was lost from the soil profile in both years. Soil data for 1987 was consistent with that found in the other two years, except that most of the fertilizer N was lost from the soil profile by midseason even with the ambient moisture treatment. Similar results have been reported for lysimeter studies with very sandy soils, where the losses were caused by leaching (21). Results obtained in the present study provide further evidence of the potential contamination of groundwater by $NO_3$ derived from fertilizer applied to a Plainfield sand, even with normal rainfall and irrigation practices.

**Table 4.** Effect of Excess Moisture on Fertilizer N (lb/acre) Remaining in Soil on a Plainfield soil, Calculated from $^{15}N$ Data†.

| Depth (in.) | Soil Moisture Level: Ambient | Ambient + 4 in. | Ambient + 6 in. |
|---|---|---|---|
| | Fertilizer N (lb/acre) | | |
| **1986** | Silking | | |
| 0 - 12 | 30.0 a | 21.5 a | 9.2 a |
| 12 - 24 | 5.6 b | 3.1 b | 2.9 b |
| 24 - 36 | 4.5 b | 2.8 b | 1.5 b |
| 36 - 48 | 5.7 b | 5.1 b | 3.5 b |
| | Harvest | | |
| 0 - 12 | 8.8 a | 8.7 a | 10.7 a |
| 12 - 24 | 2.5 b | + b | + b |
| 24 - 36 | 1.1 b | + b | 1.2 b |
| 36 - 48 | 1.3 b | 1.1 b | 3.4 b |
| **1987** | Silking | | |
| 0 - 12 | 2.1 a | 1.2 a | + a |
| 12 - 24 | 0 b | 0 a | 0 a |
| 24 - 36 | 1.3 b | + a | + a |
| 36 - 48 | + b | + a | 0 a |
| | Harvest | | |
| 0 - 12 | 2.0 ab (1.4) | 3.0 a (2.8) | 0.9 b (0.5) |
| 12 - 24 | 0 b | 0 b | 0 b |
| 24 - 36 | + b | + b | 0 b |
| 36 - 48 | + b | + b | 1.5 a |
| **1988** | Silking | | |
| 0 - 12 | 16.2 a | 2.1 b | 0.9 a |
| 12 - 24 | 8.2 a | + b | 0 a |
| 24 - 36 | 31.8 a | 8.7 ab | 4.9 a |
| 36 - 48 | 29.1 a | 16.6 a | 5.0 a |
| | Harvest | | |
| 0 - 12 | 5.8 a (5.3) | 2.3 a (2.2) | + a |
| 12 - 24 | 1.3 b | 0 b | 0 a |
| 24 - 36 | 1.7 b | + b | 0 a |
| 36 - 48 | + b | 0 b | 3.1 a |

† Values in the same row within the same year and sampling period followed by the same letter do not differ significantly (0.05 level). A + indicates trace amounts of fertilizer N, ( ) designates fertilizer N in the organic form, calculated as total N - inorganic N.

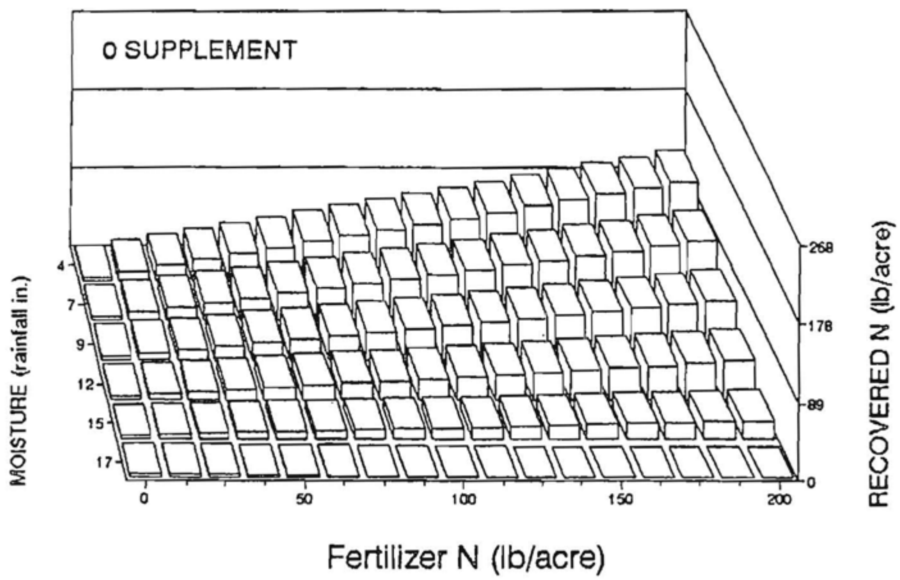


FIGURE 3. Predicted Effects on Fertilizer N Recovery with Fertilizer N Application and Soil Moisture Condition in Total Rainfall + Irrigation in May and June on a Plainfield Soil with No Supplemental N Application.

The best fit regression equations for total N recovered and plant N uptake for the Plainfield soil were: RN (lb/acre) = 4.765 + 0.735 N + 0.468 $N_s$ - 0.0447 N × RI; ($R^2$ = 0.77) and PN = 52.095 +0.5936 N + 0.4928 $N_s$ - 6.5272 RI + 0.2457 $RI^2$ - 0.03429 N × RI ($R^2$ = 0.67), respectively, In these equations, RI represents total rainfall + irrigation in May and June.

Unlike the heavier textured soils, the regression analysis for N uptake by corn on the Plainfield did not include a negative N x $N_s$ interaction, indicating that N was limiting even with the addition of 50 lb N/acre at all initial N application rates. On this soil, N recovery increased linearly with both initial N and supplemental N application (Figure 3). Nitrogen recovery of 58% would be predicted with the lowest rainfall plus irrigation level recorded during the study, compared to 20% with the highest moisture treatment used. This indicates that excessive N losses could occur with above-average rainfall in May and June.

Since this soil is usually irrigated, N application through the irrigation system could be made at periods of high plant N uptake and increase the efficiency of N fertilizer use (22).

## CONCLUSIONS

Nitrogen fertilizer management is difficult because the fate of N is dependent upon the weather, especially rainfall, and soil type. In many cases, if the magnitude of N loss resulting from large rainfall events could be predicted and an application of supplemental N could be made if needed, the initial rate of fertilizer N application could be reduced. The results indicated that, of the soil moisture regimes evaluated, number of days of soil moisture tension below 0.33 bar provided the best prediction of total N recovery for the Cisne soil and the Drummer soil. Rainfall plus irrigation in May and June provided the best prediction for N recovery for the Plainfield soil. With the higher organic matter Drummer soil, saturation of soil for 5 days would result in losses approaching 50%, whereas saturation for the same period would result in losses of only 10 to 12% with the Cisne soil. On the Plainfield soil, excessive N losses could occur with above-average rainfall in May and June, indicating the need for split application of N. The predictive equations developed in this study could be used to predict N losses experienced with large rainfall events and assist in management decisions of whether supplemental N applications are needed.

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