Tillage and Nitrogen Management Effects on Nitrate-Nitrogen in the Soil Profile

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Abstract
A field study was conducted on Nicollet loam soils to determine the effects of tillage and nitrogen (N) management on the residual nitrate-nitrogen (NO3-N) in the soil profile. Two replications of two tillage systems (no-till and moldboard plow) and two N management practices (single application of N at the rate of 175 kg/ha and three applications totaling 125 kg/ha) were used for continuous-corn production. Soil samples were taken periodically each year to a depth of 150 cm at three locations within each of the six experimental plots (9 m apart, one along and two on either side of a tile drain running down the center of the plot). No-till and three N applications with a lower total application rate reduced the residual NO3-N in the soil profile. Regression analysis of the data showed less residual NO3-N under no-till system having a definite decreasing trend with depth. Eight years (1984-1991) of data indicate that corn yields were not affected by tillage or N management practices.

Keywords
Tillage, Nitrogen, Fertilizer, Nutrients, Management, Corn, Soil samples

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Soil Science

Comments
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ABSTRACT. A field study was conducted on Nicollet loam soils to determine the effects of tillage and nitrogen (N) management on the residual nitrate-nitrogen (NO$_3$-N) in the soil profile. Two replications of two tillage systems (no-till and moldboard plow) and two N management practices (single application of N at the rate of 175 kg/ha and three applications totaling 125 kg/ha) were used for continuous-corn production. Soil samples were taken periodically each year to a depth of 150 cm at three locations within each of the six experimental plots (9 m apart, one along and two on either side of a tile drain running down the center of the plot). No-till and three N applications with a lower total application rate reduced the residual NO$_3$-N in the soil profile. Regression analysis of the data showed less residual NO$_3$-N under no-till system having a definite decreasing trend with depth. Eight years (1984-1991) of data indicate that corn yields were not affected by tillage or N management practices.

Keywords: Tillage, Nitrogen, Fertilizer, Nutrients, Management, Corn, Soil samples.

Increased nitrate-nitrogen (NO$_3$-N) concentrations in tile drainage water and in deeper groundwater sources, as a result of higher application rates of nitrogen (N) fertilizer, have been documented in several studies (Baker and Johnson, 1981; Gast et al., 1978; Kanwar et al., 1988; Kanwar and Baker, 1991; Schepers et al., 1986). Tillage is one of the major agricultural activities affecting the transport of NO$_3$-N to groundwater. It directly affects soil water properties of the surface as well as subsurface soil and therefore leaching characteristics. Tillage disturbs the network of macropores thus potentially reducing preferential flow. Timing and rates of N-fertilizer applications can affect both the availability of N for crop growth and the amount of NO$_3$-N remaining in the soil profile (Gast et al., 1978; James, 1978; Jokela, 1992; Kanwar et al., 1985).

The amount and distribution of inorganic N, primarily NO$_3$-N, remaining in the soil profile at the end of the growing season (residual N) is greatly affected by fertilizer management as well as by the soil moisture regime. Application rates of N greater than those needed for optimum crop yields can cause an accumulation of large amounts of NO$_3$-N in the soil profile and, in some cases, movement beyond the root zone (Nelson and MacGregor, 1973; Jolley and Pierre, 1977; Olsen et al., 1970). In several studies in Nebraska, N application later in the season has consistently shown larger amounts of residual N and a greater proportion near the surface than application at planting time (Herron et al., 1971; Russelle et al., 1981; Johnston and Fowler, 1991). Residual N potentially available for the following year's crop is also susceptible to loss by leaching or denitrification. A field study in Wisconsin (Olsen et al., 1970) showed greater leaching of NO$_3$-N over the winter than during the growing season.

Herron et al. (1971) conducted field experiments to study the residual mineral N accumulation in soil and its utilization by irrigated corn. Delayed fertilizer application resulted in greater crop use efficiency and more residual N than with preplant application, suggesting greater losses through leaching and gaseous evolution with the preplant application in early spring months when there are no active crop roots for rapid uptake of N.

As part of this study, field experiments were conducted by Kanwar et al. (1988) to study the effects of no-till and conventional tillage, and single and multiple N applications, on the leaching of NO$_3$-N with subsurface drainage water below the root zone of continuous corn. Comparisons were made between conventional and no-till with a single N application of 175 kg/ha at the time of planting, and between a single application of 175 kg/ha and three N applications at a total of 125 kg/ha with the no-till system. No significant effects of tillage and N management were observed in the first year of the experiments. However, in the third year a significant reduction of NO$_3$-N in subsurface drainage water with no-till relative to conventional tillage was observed. Also with no-till, three N applications at a lower total rate reduced NO$_3$-N concentrations in drainage water compared with the single, higher rate of application.

Nyborg and Malhi (1989) conducted field experiments in north-central Alberta to compare the effect of no-till versus conventional tillage on soil NO$_3$-N content, soil water content, and soil temperature on two soils with two...
tillage treatments and two rates of applied N. The first crop did not show much of a response to applied N and yields were similar among treatments, but by the third crop, no-till plots without N produced significantly less yield than conventional tillage. However, yields on the no-till plots approached those of the conventional tilled plots when N was added. Since NO$_3$-N is subject to losses by denitrification and leaching, lower N mineralization rates under no tillage may reduce potential for NO$_3$-N loss.

Jokela and Randall (1989) found that, about one year after application, less than 3% of the applied N remained in the soil profile and 95% of that was found in the organic N pool. An average of 20% of the applied N was present in the soil profile and 2- and 4-year cropping systems. Considerable amounts of fertilizer N have been found in the soil organic N fraction. Kitur et al. (1984) reported that 28 to 42% of the fertilizer N applied to corn remained in the soil, depending on the N rate and tillage. The objective of this research was to determine the effect of two tillage practices (namely, moldboard plowing and no-till) and two fertilizer management practices (single and three N applications, with the three applications at a lower total rate) on the residual soil profile NO$_3$-N and corn yield.

**EXPERIMENTAL DESIGN**

A field study was conducted from 1984 to 1991 at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa. Soils at the experimental site are from the Canisteo-Clarion-Nicollet association formed under glacial till and are characterized by gentle rolling surface moraine with an average slope less than 3%. Surface drainage is poorly developed due to the undulating surface. Subsurface drainage is related to soil type (Canisteo soils are poorly drained, Clarion soils are well-drained, and Nicollet soils are somewhat poorly drained), and permeability is moderate. Selected soil properties at the experimental site are given in Kanwar et al. (1988).

Six plots, each drained with a single subsurface drain at a depth of 122 cm, were sampled for residual soil NO$_3$-N beginning in 1984. This experimental area was planted to oats during the 1983 growing season. Table 1 gives the dates of planting, harvesting, and N application and plant populations (corn variety Pioneer No. 3475). Plant populations are an average of five measurements per plot.

**EXPERIMENTAL VARIABLES**

Two replications of two tillage systems (no-till and conventional) and one N management practice (single application of 175 kg/ha) were used for continuous corn production requiring four of the six plots. The conventionally tilled plots were moldboard plowed each fall. The remaining two plots were also cropped to corn using no-tillage, but three N applications totaling 125 kg/ha were made. The first application of 25 kg/ha was made shortly after planting, a second application of 50 kg/ha was made in June, and the third application of 50 kg/ha was applied in late June or early July (table 1). The decision to reduce the total application by 50 kg/ha was made to determine if the potential of improved timing with three applications could overcome this reduction relative to corn yield. The recommended N rate for continuous corn on these soils would be 196 kg/ha. The N was point-injected to a depth of 10 cm (Baker et al., 1989) in liquid form (containing 28% N as urea/ammonium nitrate).

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### Table 1. Date of planting, harvesting, and fertilizer application and plant populations

<table>
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<td>7 May</td>
<td>1 May</td>
<td>6 May</td>
<td>10 May</td>
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<td>Plant population</td>
<td>11 Jun</td>
<td>29 May</td>
<td>29 May</td>
<td>1/2 Jun</td>
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<td>25 May</td>
<td>27 May</td>
<td>5 Jun</td>
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<td>Plant population (plants / acre)</td>
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<td>27,723</td>
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<td>27,509</td>
<td>25,140</td>
<td>26,140</td>
<td>22,600</td>
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<td>N-application</td>
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<td>23 May</td>
<td>2 May</td>
<td>20 May</td>
<td>15 May</td>
<td>20 May</td>
<td>15 May</td>
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<tr>
<td>Three applications (125 kg / ha)</td>
<td>(125 kg / ha)</td>
<td>1st</td>
<td>23 May</td>
<td>17 May</td>
<td>15 May</td>
<td>20 May</td>
<td>31 May</td>
<td>8 May</td>
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<tr>
<td></td>
<td>(50 kg / ha)</td>
<td>2nd</td>
<td>26 Jun</td>
<td>5 Jun</td>
<td>25 Jun</td>
<td>16 Jun</td>
<td>3 Jun</td>
<td>3 Jun</td>
</tr>
<tr>
<td></td>
<td>(50 kg / ha)</td>
<td>3rd</td>
<td>3 Jul</td>
<td>24 Jun</td>
<td>15 Jul</td>
<td>1 Jul</td>
<td>23 Jun</td>
<td>6 Jul</td>
</tr>
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</table>

* Rainfall prevented earlier application.

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**Figure 1**—Annual precipitation for Ames (1984-1991); long-term average is 81 cm.
Figure 2—Tillage effects on the average soil NO$_3$-N amounts as a function of depth for various years (means with the same letter represent no significant difference; CTS = conv. tillage single; NTS = no-till single).

**SAMPLING PROCEDURE**

A 3.2-cm-diameter x 45.7-cm-long soil probe with an open faced style sampling tube was used to collect soil samples from the field sites. Samples were taken to a depth of 150 cm at three locations within a plot, one along and two on either side of the tile line, one-fourth the distance (9 m) between the tile lines and 30 m from the bottom plot boundary. For the top 30 cm, two samples were taken in 15-cm increments; samples were then taken to 150 cm in 30-cm increments. Samples were placed into prelabeled 1-L freeze bags and sealed. The probe was cleaned after each sampling before proceeding to the next depth. The bagged soil samples were stored in large coolers in the field to limit loss of moisture and N during transport to the laboratory for moisture and NO$_3$-N analysis. The soil samples were then stored for no more than 60 d at 1° C until extractions were completed.
SAMPLE ANALYSIS
A 2-N potassium chloride extraction solution was used to extract NO$_3$-N from soil samples (Keeney and Nelson, 1982). Soil moisture was determined gravimetrically. Soil solution extracts were analyzed for NO$_3$-N by the cadmium-reduction method using a Technicon Analyzer II system (Kanwar et al., 1988).

STATISTICAL ANALYSIS
Statistical analyses of the NO$_3$-N amounts in the soil profile at each depth and with time were performed to determine significant differences in means by using the analysis of variance procedure (ANOVA) with SAS (SAS Institute, 1985). All analyses were performed at the 95% probability level. Analyses were broken into two parts:
- Conventional tillage versus no-till at the same rate of N application (175 kg/ha) to evaluate the effect of tillage on soil profile residual NO$_3$-N.
Single versus three applications of N fertilizer for the no-till system to evaluate the effect of N management on residual NO₃-N in the soil profile.

Moreover, the data were analyzed by depth for each sampling date and location and between years. Comparisons were not made from one growing season to the other, due to the lack of a uniform and balanced data set and large differences in rainfall during the growing seasons. Regression analysis of the data was done to obtain a trend of residual NO₃-N variation in the soil profile with depth.

**RESULTS AND DISCUSSION**

Figure 1 shows the annual precipitation at the experimental site for the eight-year study period; the long-term average is 81 cm. Figure 2 shows the effect of tillage on average soil NO₃-N amounts as a function of depth. The amounts of NO₃-N present in the soil profile for 1984, the beginning year of the study, were similar at each depth for the two tillage systems, but show a decreasing trend as a function of depth. At the time of harvesting in 1984, there was more NO₃-N in the soil profile of no-till plots compared to conventional tillage plots. In 1985, a dry year, the trend changed. Three applications had more NO₃-N in the soil profile than the single application. In 1986, the expected trend of lower NO₃-N levels in some layers of the soil profile was observed, and NO₃-N from the upper soil profile moved down to the tile drain depth due to significant amount of rainfall. In 1987, again a relatively wet year, concentrations remained low apparently because most of the NO₃-N was either leached out of the root zone or denitrified as also occurred in the conventional tillage plots which received a single application of N (fig. 2). A considerable difference in NO₃-N amounts was observed in 1988, a dry year. More NO₃-N accumulated in the upper 15 cm and gradually decreased with depth. No-till plots receiving three applications of N resulted in considerably less NO₃-N than the single application. In 1986, the expected trend of lower NO₃-N levels in some layers of the soil profile for three applications was observed, and NO₃-N from the upper soil profile moved down to the tile drain depth due to significant amount of rainfall. In 1987, again a relatively wet year, concentrations remained low apparently because most of the NO₃-N was either leached out of the root zone or denitrified as also occurred in the conventional tillage plots which received a single application of N (fig. 2). A considerable difference in NO₃-N amounts was observed in 1988, a dry year. More NO₃-N accumulated in the upper 15 cm and gradually decreased with depth. No-till plots receiving three applications of N resulted in considerably less NO₃-N than the single higher-rate application, but statistically there were no differences (these values represent only two sampling times, before planting and after harvesting). In 1985, a dry year, the trend changed. Three applications had more NO₃-N in the soil profile than the single application. In 1986, the expected trend of lower NO₃-N levels in some layers of the soil profile for three applications was observed, and NO₃-N from the upper soil profile moved down to the tile drain depth due to significant amount of rainfall. In 1987, again a relatively wet year, concentrations remained low apparently because most of the NO₃-N was either leached out of the root zone or denitrified as also occurred in the conventional tillage plots which received a single application of N (fig. 2). A considerable difference in NO₃-N amounts was observed in 1988, a dry year. More NO₃-N accumulated in the upper 15 cm and gradually decreased with depth. No-till plots receiving three applications of N resulted in considerably less NO₃-N than the single higher-rate application. The data in figure 4 for 1988 show an increasing trend with time possibly due to greater mineralization, although the increase is less for the three application plots. Similar trends were observed in 1989. Due to the smaller number of observations in 1989 and 1990, the least significant difference obtained was higher for some years and at certain depths.

Figure 4 shows the average total residual NO₃-N distribution in the soil profile under all tillage treatments for the fall and corresponding spring seasons at their respective sampling dates. This figure shows that the no-till system resulted in less residual NO₃-N in the soil profile than conventional tillage. Also, the NO₃-N levels were much lower in wet years of 1986 and 1987 possibly...
indicating the effects of denitrification and/or increased leaching of NO₃-N to groundwater.

Figures 5 and 6 show the overall effects of tillage treatments and N management on NO₃-N contents in the soil profile. These figures show the mean NO₃-N amounts for each depth for all years. Significant differences in the NO₃-N amounts were observed at several depths in the soil profile. Under conventional tillage, more NO₃-N accumulated in the upper soil layers where most of the macropores were destroyed due to tillage activity, while the soil structure below the 60-cm depth remains undisturbed. In the no-till system, where macropores are allowed to develop and persist, the structure at the soil surface could be markedly different, but may be similar to that in conventional tillage at greater depths. The no-till system under both N management practices indicates significantly lower NO₃-N amounts in the upper soil layers than conventional tillage. In years where fewer soil samples could be collected, 1984, 1987, and 1988 where at least five sets of soil samples were collected. The NO₃-N trend was markedly influenced by climatic conditions for all the tillage treatments. In wet years (1986 or 1987) lower amounts of NO₃-N were observed in the soil profile under all the three treatments indicating increased leaching to groundwater and/or denitrification. Also, higher corn yields of 1986 and 1987 suggest increased N uptake by the plants leaving less NO₃-N in the soil profile.

Figures 7 and 8 show the cumulative amounts of NO₃-N in the soil profile for the three treatments for all years. Cumulative soil NO₃-N amounts (profile totals of all five depths in kg/ha) were used to evaluate the effect of tillage and N management practice on soil NO₃-N. Figure 7 compares the tillage treatments at the single N application rate of 175 kg/ha. Except for the first year, 1984, no-till resulted in, on the average, less residual NO₃-N in the profile than conventional tillage. In years where fewer soil samples could be collected, 1984, 1989, and 1990, the least significant difference values were considerably higher than for years 1985, 1986, 1987, and 1988 where at least five sets of soil samples were collected. The NO₃-N trend was markedly influenced by climatic conditions for all the tillage treatments. In wet years (1986 or 1987) lower amounts of NO₃-N were observed in the soil profile under all the three treatments indicating increased leaching to groundwater and/or denitrification. Also, higher corn yields of 1986 and 1987 suggest increased N uptake by the plants leaving less NO₃-N in the soil profile.

Figure 9 shows the quadratic regression models giving NO₃-N levels in the soil profile as a function of depth for the three N management/tillage treatments. Regression equations and their R² values are also shown. The observed cumulative NO₃-N amounts in conventional tillage single, no-till single and no-till three were 116.4, 79.6, and 65.9 kg/ha, respectively. These results indicate that conventional and no-till single treatments have more NO₃-N than no-till three treatment, throughout the profile which accounts for low risk of potential groundwater contamination. The results are in accordance with the reported findings of Kanwar et al. (1988).

Figure 10 shows average corn yields as a function of tillage and N-fertilizer application rate (single application

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**Figure 6**—Overall effect of N management on soil NO₃-N amounts by depth under no-till system (means with different letters represent significant difference; NTS = no-till single; NTT = no-till three).

**Figure 7**—Annual average cumulative NO₃-N amounts in the soil profile as a function of tillage and year (means with the same letter represent no significant difference; n = no. of samplings / yr; CTS = conv. tillage single; NTS = no-till single).

**Figure 8**—Effect of single vs. three N applications on annual average cumulative NO₃-N under no-till system (NTS = no-till single; NTT = no-till three).

**Figure 9**—Regression models predicting the average NO₃-N levels in the soil profile as a function of depth, tillage, and method of N application.


Figure 10—Comparison of corn yield under the two tillage treatments.

of 175 kg/ha and three applications totaling 125 kg/ha). Statistically, no significant differences were found either between tillage or between N management practices. This figure also shows that higher corn yields were obtained in wet years of 1986, 1987, 1990, and 1991. Yields peaked near 11.2 Mg/ha in 1986, 9.5 Mg/ha in 1987 and 9.7 Mg/ha in 1990. However, yields were considerably reduced in 1988 due to extremely dry conditions resulting in higher amounts of NO3-N remaining in the soil profile. The yield for three applications, however, was equal to that obtained from the single application.

SUMMARY AND CONCLUSIONS

A field study was conducted to determine the effects of tillage and N management practices on the residual NO3-N in the soil profile. This study supports the following conclusions:

- No-till with three split N applications totaling 125 kg/ha resulted in lower amounts of residual NO3-N in the soil profile in comparison to a single N application of 175 kg/ha. Corn yields obtained from three split applications were not significantly different from the single higher N application rate under either tillage system. This result indicates that farmers can sometimes apply less N fertilizer without reducing corn yields with possible benefits of reducing the potential for NO3-N leaching to groundwater.

- Under conventional tillage system, more residual N accumulated in the top 60 cm of the soil profile than under no-till system. This possibly was due to higher rates of mineralization and less leaching to the groundwater.