Korean J. Soil Sci. Fert. **39**(1), -(2006)

Article

Nitrate Movement in the Root Zone of Corn Fields with Different Tillage Systems

Won-Il Kim*, Goo-Bok Jung, Jong-Sik Lee, Jin-Ho Kim, and Jeong-Taek Lee

Agricultural Environment and Ecology Division, National Institute of Agricultural Science and Technology, Suwon, 441-707, Korea

Movement of nitrate (NO_3-N) through a soil profile under no tillage (NT) or conventional tillage (CT) practices was monitored to identify the effects of tillage systems on nitrate leaching and retention in the soil profile at two commercial farms in central Illinois from 1993 through 1994. Anhydrous ammonia was applied in the 1993 growing seasons, while a mixture of urea and ammonium nitrate solution (URAN) was applied in three separate applications during the spring and early summer of the 1994 season. NO_3-N of each plot through a 100 cm soil depth was found to be significantly high around 20 mg kg^{-1} soil in the early 1993 season. However, downward movement of NO_3-N occurred during the growing season. At the end of growing season, Flanagan and Ipava soils generally retained more NO_3-N through the soil profile for both the CT plots and the NT plots than the Saybrook and Catlin soils. However, there was no significant difference between the nitrate content of the two soil types in each year. NO_3-N content in NT fields were slightly higher than that observed in CT fields throughout the season before harvest. It means that NT plots may reduce the nitrate leaching to the ground water.

Key words : No tillage, Nitrate movement, Soil types

Introduction

Many recent studies (Ismail et al., 1994; Kitur et al., 1994; Lal, et al., 1994) have investigated tillage effects on soil physical, chemical, and microbiological properties of the surface plow layer as well as subsoil. Minimizing tillage practices can be a benefit to soil and water conservation and help avoiding environmental hazards. It means that no tillage (NT) systems can reduce soil losses by protecting the soil surface from wind and rainfall erosion, and increase yield by improving water conservation through decreased evaporation losses.

Tillage systems affect the fate of soil N, its utilization efficiency, and subsequent potential N losses through nitrate leaching and denitrification. Many studies (Stinner et al., 1983; Rao and Dao, 1992; Angle et al., 1993) have investigated the effects of tillage, manure, and fertilizer application on soil NO_3-N concentrations under corn. They concluded that NT or reduced tillage systems result in less available N. Soil nitrate concentrations in NT plots were consistently lower than those found in CT systems, and this difference was greatest at the highest N fertilizer rates. Rao and Dao (1992) pointed out that much of the lower N availability could be attributed to a combination of lower rates of organic N mineralization, higher N immobilization, higher denitrification and higher nitrate leaching.

Several techniques are generally used to estimate the fate of N, especially nitrate leaching, in the field. Soil-core sampling is a commonly used test in the USA. Soil cores are collected periodically from various subsoil depths and analyzed for NO3-N concentration. Kanwar et al. (1985) determined nitrate movement through measurements of soil water content and NO_3-N concentration to a depth of 150 cm, comparing concentrations before and after rainfall. Angle et al. (1993) used the same technique to find combination effects of tillage, manure, and inorganic fertilizer on nitrate leaching from the corn root zone. Some N balance sheet studies (Hauck, 1982: Harris, et al., 1994) using 15N have shown that from 30 to 40 % of the fertilizer N applied is usually lost by leaching or denitrification. Kundler (1970) reported results from a 10-year international study with 15N fertilizer which showed that 10 to 30 % of applied N was lost from the system.

Therefore, to find optimal N management practices for use with the different tillage systems and to minimize nitrate leaching losses, one must understand the fate of

---

Received : October 16. 2005 Accepted : January 20. 2006

*Corresponding author: Phone : +82312900220,
Fax: +82312900206, E-mail : wikim@rda.go.kr

various N forms in soil, and how N availability to plants affects numerous parameters, especially soil water uptake. The objectives of this study were to monitor changes of soil water content, and nitrate concentrations under different tillage systems on commercial farms in Central Illinois, and to identify the effects of fertilizer, soil type, and tillage systems on nitrate leaching in soils following inorganic N fertilizer application, with a view to estimating optimal N fertilizer application rates and timing to minimize environmental hazards.

Materials and Methods

A field study was initiated in the spring of 1993 and continued for two growing seasons. The study was conducted in cooperation with two privately-owned commercial farms located in central Illinois near the city of Bloomington. The study was begun on farm A in 1993 and on farm B in 1994. The soil series in farm A consisted of (a) Flanagan silt loam (a fine, montmorillonitic, mesic, *Aquic Argiudoll*) and (b) Saybrook silt loam (a fine silty, mixed, mesic *Typic Argiudoll*). In case of farm B, these soil series were (a) Ipava silt loam (a fine, montmorillonitic, mesic, *Typic Hapludalf*) in the flat plot (less than 0.5 % slope) and (b) Catlin silt loam (a fine-silty, mixed, mesic, Typic *Argiudoll*) in the more sloping plot (Illinois Soil Survey, series 1900-1996)

Two tillage systems, conventional tillage (CT) and no tillage (NT), were used in this study. CT involved chisel-plowing, leaving residue on the soil surface, while in the NT system, the soil surface was left undisturbed from one harvest to next. About 225 kg ha^{-1} of anhydrous ammonia was fall-applied with a nitrification inhibitor, N-Serve (nitrapyrin), in the October preceding the 1993 growing seasons on the NT plots. Seeds were planted in early spring, directly above the slit left by the anhydrous ammonia applicator knife. An equivalent amount (225 kg ha^{-1}) of anhydrous ammonia was spring-applied on CT plots in 1993, just after chisel-plowing, but before planting. The fertilizer material used during the 1994 season was URAN (a mixture of urea and ammonium nitrate in aqueous solution), applied in three separate spring applications. The first application of 55 kg ha^{-1} was made just before planting, with two subsequent applications of about 30 kg ha^{-1} each, side-dressed between rows before the corn plants height exceeded the ground-clearance of the applicator machinery (about 1 m).

In the experiments, soil samples with 3 or 4 replications were collected to a depth of 120 cm with a hydraulic core-sampling machine at periodic intervals for analysis. Soil core samples were systematically collected at the sampling sites within each plot : halfway between adjacent plant rows, and directly in the row to estimate spatial variability as a function of distance from path of the applicator knife.

Immediately after collection of soil cores in a plastic sleeve, the ends of the sleeve were capped to preserve soil moisture during transport to the laboratory, where each tube was cut into 15 cm (or 7.5 cm depth increments near the soil surface) samples for analysis. Each soil core sample was sectioned, sub-sampled, and weighed before drying, and then re-weighed after 24 hr. oven-drying at 105℃.

Soil sample from each core section was extracted for nitrate assay by shaking for 1 h with 2 M KCl (3 g soil /30 ml KCl solution) in a 50 ml glass tube, and then allowed to settle in the refrigerator overnight. For nitrate analysis, nitrate in the soil supernatant was first converted to NH_4-N by adding 200 μl of soil extract into microplates containing 20 to 30 mg of Devardas alloy (mesh size = 0.05-0.2 mm, EM Science, Gibbstown, NJ). To avoid NH_4-N volatilization, 25 μl of 0.2 N sulfuric acid was added to samples before analysis for NH_4-N concentration. Chelating agent (25 μl of citrate reagent), to complex interfering divalent cations, and 50 μl of Salicylate-nitroprusside reagent were added to the wells, followed by 25 μl of hydrochlorite buffer for color development. The final volume was adjusted to 275 μl with NH_4-N free water. After 45 min. to 1 hr, spectrophotometric determinations were made at 660 nm using a BIOTEK1 microplate reader (Sims et al., 1995).

Data reduction for statistical analysis of the nitrate concentration was done with the SAS system (SAS Institute, 1985) and Super ANOVA (Gagnon, et al., 1989). Separated analyses of variance for nitrate concentration were performed for each year.

Results and Discussion

Nitrate concentration (expressed as mg kg^{-1} of dry soil) in soil core-samples collected at the two different soil types and two tillage systems in the early 1993 growing season (Fig. 1 and Fig. 2). In Feb, 2 data, NO_3-N of each plot through a 100 cm soil depth was found to be significantly high around 20 mg kg^{-1} soil in the early

1993 season. However, downward movement of NO_3-N occurred during the growing season. Although higher nitrate concentration would be expected by less nitrate leaching followed by much dryer 1992 growing season than normal, these figures also showed more NO_3-N accumulated in the NT plot surface soil of Saybrook while less in the Flanagan compared to each CT plot. However, comparison may not be valid because of different fertilization period. Anhydrous ammonium was fall-applied on no-tilled plots right after 1992 harvest and spring-applied on CT plots in 1993, just after chisel-plowing. However, statistical analysis (Table 1) shows that there is a difference between the two tillage systems for the NO_3-N concentrations (0.005 probability value) and NO_3-N in the CT plots was a slightly higher than that in the NT plots above 90 cm soil depth. One explanation of this result is that NO_3-N moved down more rapidly in the NT plots than that in CT plots. Eck and Jones (1992) noted that more NO_3-N accumulates under stubble mulch when CT plots were compared with NT plots, but the reasons for greater N accumulation were not always well defined.

Scientists generally agree that NT plots or reduced-tillage systems have lower N availability (Stinner et al., 1983; Timmons, 1984; Kanwar, 1985; Rice et al., 1986; Angle et al., 1993). However, there are two different

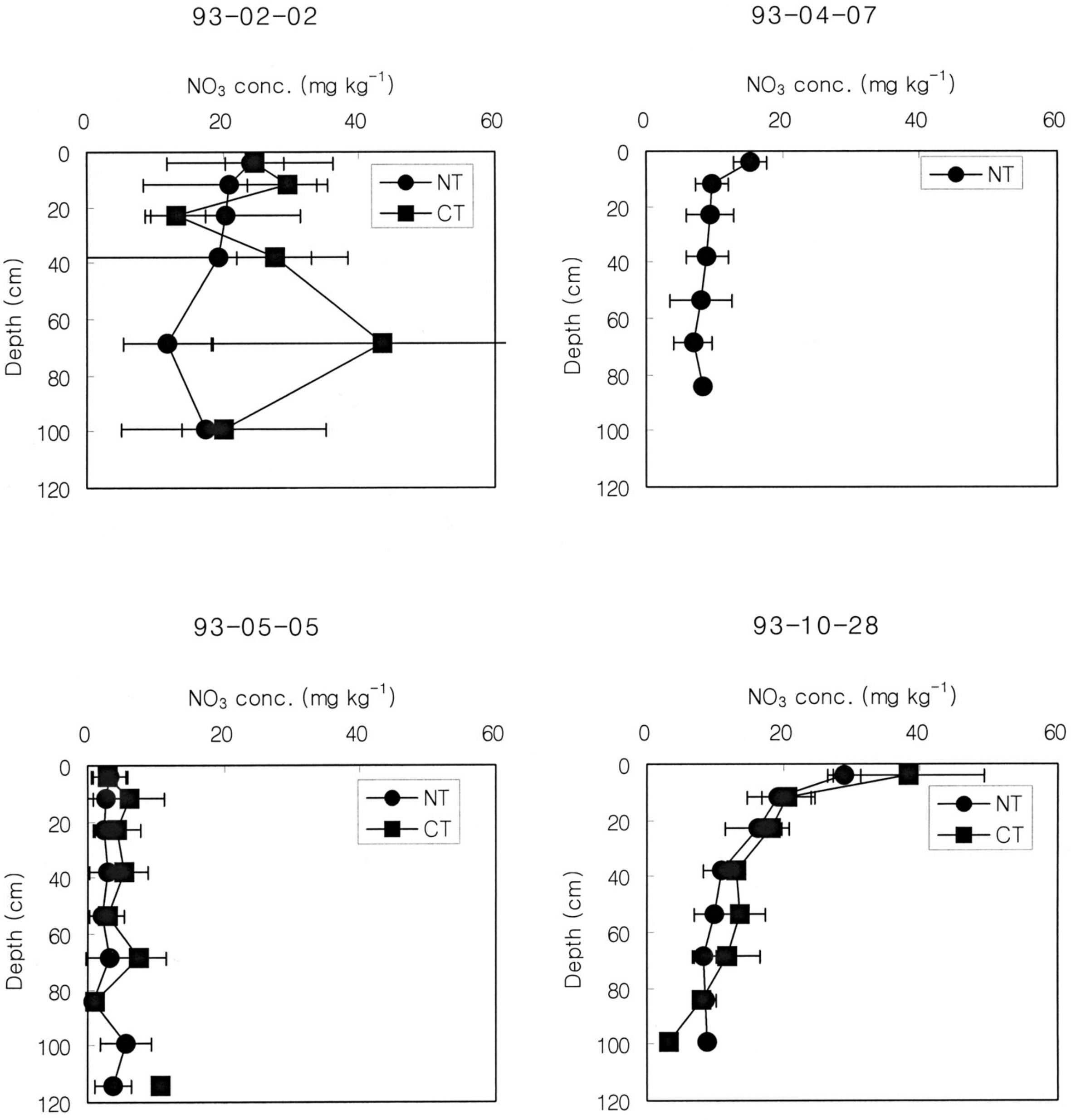


Fig. 1. NO_3-N concentration of soil core samples collected on during 1993 season from Flanagan soil in farm A located in central Illinois, USA under two tillage systems. CT soil in Apr. 7 was not collected by technical problem.

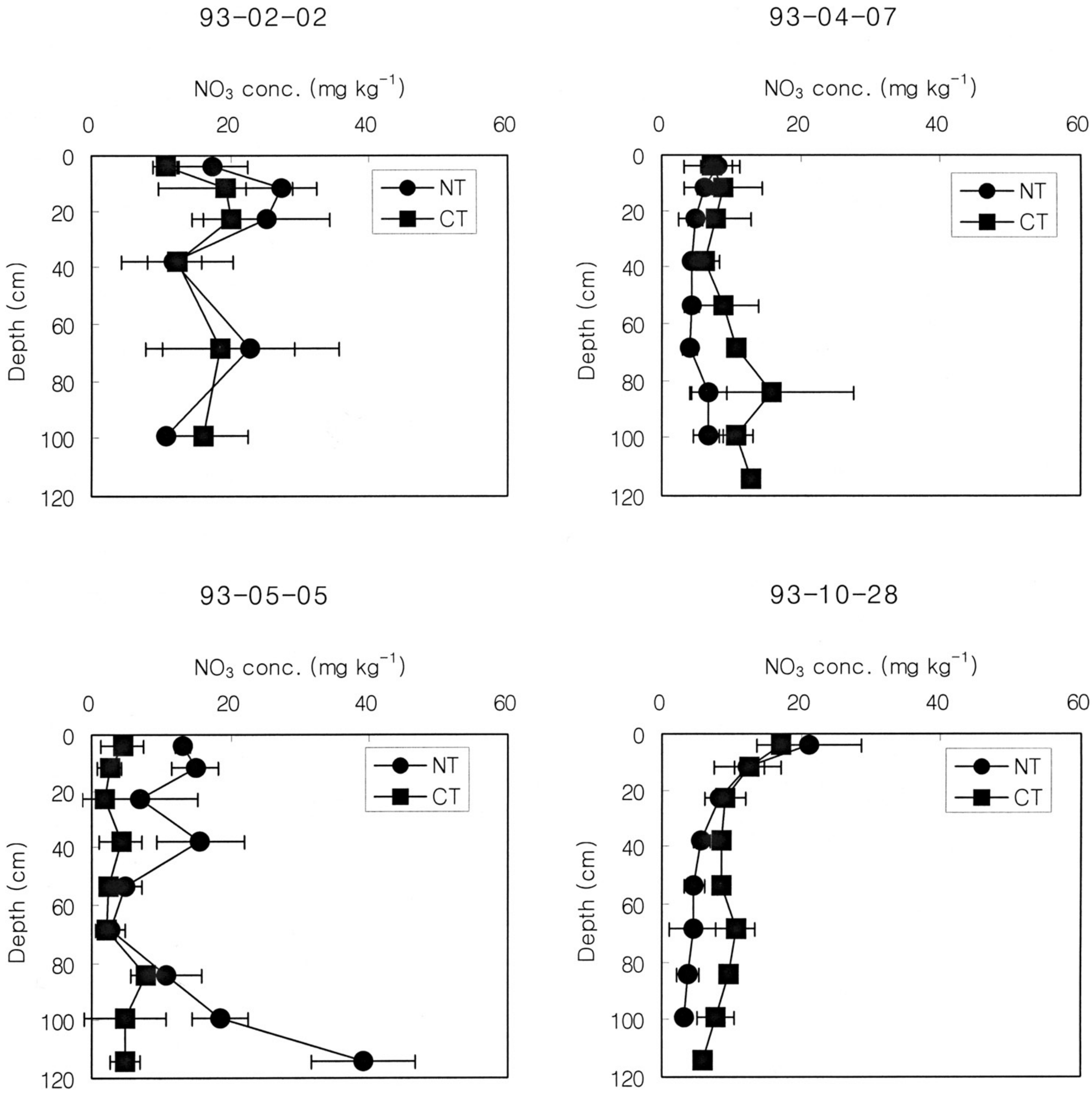


Fig. 2. NO_3-N concentration of soil core samples collected on during 1993 season from Saybrook soil in farm A located in central Illinois, USA under two tillage systems.

aspects of the tillage effect on N availability related to nitrate leaching. One group (Timmons, 1984; Kanwar, 1985; Rice et al., 1986) suggested that the lower availability on NT soils is a transient effect, resulting from translocation of NO_3-N downward in the soil profile. Without tillage, these soils show an increase in the number of macropores, which contributes to water conductivity in rapid preferential flow patterns. Because NO_3-N is quite water soluble and nitrate leaching is closely related to water movement, enhanced rainfall infiltration into NT soils, coupled with higher fertilizer rates, may create a situation in which more nitrate leaching can occur.

However, other researchers have a different viewpoint. Stinner et al. (1983) observed that N immobilization is enhanced and nitrification rates are diminished under NT when compared with CT. This often results in less nitrate leaching in NT systems. Angle et al. (1993) reported that soil NO_3-N concentrations were consistently lower under NT when compared with CT. Their results indicate that use of NT may reduce nitrate leaching below the crop root zone.

NO_3-N concentration was also affected by soil type in the October 28 sampling (Fig. 1 and Fig. 2). The Flanagan soil generally retained more NO_3-N through the soil profile for both the CT plots and the NT plots than the Saybrook soil. This may be attribute to a higher soil organic matter (SOM) content in the Flanagan soil. SOM acts as a nutrient reservoir, preventing nitrate leaching because of increased water holding capacity. Gaines and Gaines (1994) reported that soil organic matter can retain more NO_3-N compared with mineral soil components even clay. Therefore, with other things being equal, the more SOM content, the more water content in the soil. With a larger volume of water available to dissolve nitrate ions, more NO_3-N can be retained in the soil.

Fig. 3 also shows the NO_3-N concentration of soil core-samples to a depth of 120 cm for the two soil types and two tillage systems of farm B in 1994. As with 1993, the Ipava soil type retained more nitrate through the whole soil profile than the Catlin plots. Ipava soil type has a similar soil characteristic with Flanagan soil type whereas Catlin with Saybrook in 1993. In case of tillage systems, there was also significant difference between the NT and CT plots with 0.002 probability value (Table 1). Differently with 1993 data, NT plots accumulated more NO_3-N than CT plots at the end of growing season, especially surface soil, perhaps because NT plots had a higher N mineralization rate than CT plots and dryness in 1994 may reduced nitrate leaching.

In addition, nitrate concentration below a depth of 15 cm for all treatments in the end of 1993 growing season was 20 mg kg^{-1} and more while that in 1994 was about 10 mg kg^{-1} except no-till plot of Ipava soil. This result was similar to the high nitrate concentration of February data without N fertilization as mentioned above. It clearly demonstrated that about 225 kg N ha^{-1} of anhydrous ammonia application were exceed the crops requirement. Therefore, application of fertilizer to corn fields should be optimized in order to minimize potential N loss to the environment.

Throughout these two N experiments, there were several technical problems in estimating nitrate leaching and N fate. Soil core samples could not be collected periodically because the tractor with sampling equipment would have caused damage to growing crops. Large spatial variability in sampling for NO3-N concentration was another problem.

Soil water is another significant factor affecting the fate of fertilizer N. The rate and direction of water movement must be known to estimate potential plant uptake by mass flow and diffusion, as well as to estimate nitrate leaching. NO_3-N is the dominant form in which soil inorganic N leaches into groundwater because of its high water solubility. Bauder and Schneider (1979) reported that the quantity of nitrates leaching from soil was directly related to the quantity of water percolating through the soil profile. Therefore, differences in NO_3-N concentrations between NT and CT plots might also be related to soil water movement

Instead of soil core sampling, tests of water from tiles is generally used to predict the fate of N, especially nitrate leaching, in the field. NO_3-N concentration in the tile drainage reflects N losses below the crop root zone and potentially to groundwater. Randall and Iragavarapu (1995) used this technique to evaluate the effect of long-term tillage systems for continuous corn on nitrate leaching. Kanwar et al. (1988) found higher drainage flow and nitrate leaching in NT plots than CT plots. Significant amounts of NO_3-N were detected (data not shown here) in the tile drainage of both Flanagan and Saybrook soil type throughout the 1993 season at Farm A because of higher frequent precipitation than average. However, no drainage water was recorded during 1994 at Farm B because of extreme dryness during the growing season.

In summary, tillage and fertilizer application practices represent a major source of N for surface runoff and groundwater in agricultural areas. This experiment represents a cooperative effort between ARS personnel and operational commercial farms using practices typical of those in the central corn belt. The cooperating farmers allowed USDA scientists unrestricted access to representative fields over the three-year experimental period reported in this study; the measurements reported here were designed to monitor the soil water balance and the fate of nutrients applied to the soil with a view to evaluating the contribution of typical farmers practices to environmental contamination.

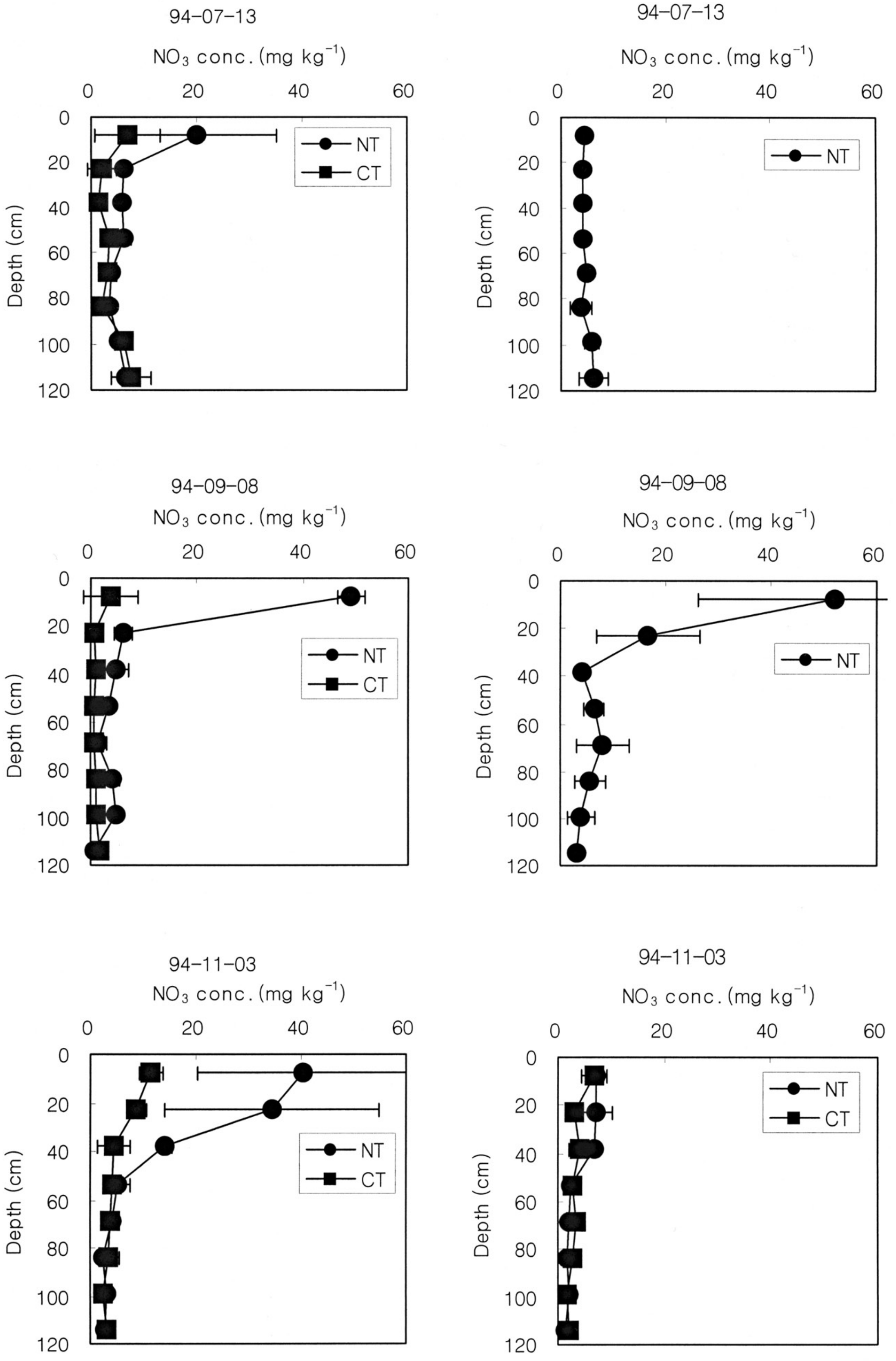
Major differences in N-levels in the soil profile throughout the growing season were noted between the two farms involved in this study. Conventional fields

Table 1. Probability value for nitrate concentration over soil depth increments with different soil types and tillage systems on farm A in 1993 and on farm B in 1994 growing season.

Source of Variance	Probability for nitrate concentration (df)	
Year	1993	1994
Soil type	0.051n.s. (1)	0.411n.s. (1)
Tillage	0.005** (1)	0.002** (1)
Date	0.001*** (5)	0.678n.s. (2)
Depth	0.989n.s. (8)	0.001*** (7)

, and * mean a significantly different from the mean at the 0.01, and 0.001 probability level, respectively.

n.s. means not significantly different from the mean.



<Ipava soil type> <Catlin soil type>

Fig. 3. NO$_3$-N concentration of soil core samples collected on during 1994 season from Ipava and Catlin soil in farm B under two tillage systems. CT soil of Catlin soil type in Jul. 13 and Sep. 8 were not collected by technical problem.

generally had more runoff following rainfall events and a lower water infiltration rate than fields cultivated with conservation NT practices, but the form of applied N and the timing of fertilizer application had a much larger effect upon the residual N remaining in the soil profile at the end of the growing season and thus the possibility for subsequent groundwater contamination.

References

Angle, J. S., C. M. Gross, R. L. Hill, and M. S. McIntosh. 1993. Soil nitrate concentrations under corn as affected by tillage, manure, and fertilizer applications. J. Environ. Qual. 22: 141-147.

Bauder, J. W., and R. P. Schneider. 1979. Nitrate-nitrogen leaching following urea fertilization and irrigation. Soil Sci. Soc. Am. J. 43: 348-352.

Eck, H. V., and O. R. Jones. 1992. Soil nitrogen status as affected by tillage, crops, and crop sequences. Agron. J. 84: 660-668.

Gagnon, J., K. A. Haycock, J. M. Roth, D. S. Feldman, Jr. W. F. Finzer, R. Hoffman, and J. Simpson. 1989. SuperANOVA accessible general linear modeling. Abacus Concepts Inc. CA.

Gaines, T. P., and S. T. Gaines. 1994. Soil texture effect on nitrate leaching in soil percolates. Commun. Soil Sci. Plant Anal. 25 (13 & 14): 2561-2570.

Harris, G. H., O. B. Hesterman, E. A. Paul, S. E. Peters, and R. R. Janke. 1994. Fate of legume and fertilizer nitrogen-15 in a long-term cropping system experiment. Agron. J. 86: 910-915.

Hauck, R. D. 1982. Nitrogen-isotope-ratio analysis. p 735-779 *In* Methods of soil analysis. part 2. (2nd ed.) Agronomy. ASA, Madison, WI.

Illinois Soil Survey. series 1900-1996. University of Illinois at Urbana-Champaign, College of Agriculture, Cooperative Extension Service.

Ismail, I., R. L. Blevins, and W. W. Frye. 1994. Long-term no-tillage effects on soil properties and continuous corn yields. Soil Sci. Soc. Am. J. 58: 193-198.

Kanwar , R. S., J. L. Baker, J. M. Laflen. 1985. Nitrate movement through the soil profile in relation to tillage system and fertilizer application method. Transactions of the ASAE. 28(6): 1802-1807.

Kitur, B. K., S. R. Phillips, K. R. Olson, and S. A. Ebelhar. 1994. Tillage effects on selected chemical properties of Grantsburg silt loam. Commun. Soil Sci. Plant Anal. 25(3&4): 225-246.

Kundler, P. 1970. Utilization, fixation, and loss of fertilizer nitrogen (review of international results of the last 10 years of basic research). Albrecht-Thaer-Arch. 14: 191-210.

Lal, R., A. A. Mahboubi, and N. R. Fausey. 1994. Long-term tillage and rotation effects on properties of a central Ohio soil. Soil Sci. Soc. Am. J. 58: 517-522.

Randall, G. W., and T. K. Iragavarapu. 1995. Impact of long-term tillage systems for continuous corn on nitrate leaching to tile drainage. J. Environ. Qual. 24: 360-366.

Rao, S. C., and T. H. Dao. 1992. Fertilizer placement and tillage effects of nitrogen assimilation by wheat. Agron. J. 84: 1028-1032.

Rice, C. W., M. S. Smith, and R. L. Blevins. 1986. Soil nitrogen availability after long-term continuous no-tillage and conventional tillage corn production. Soil Sci. Soc. Am. J. 50: 1206-1210.

SAS Institute. 1985. SAS procedures guide for personal computers. Version 6 edition. SAS Institute Inc. NC.

Sims, G. K., T. R. Ellsworth, and R. L. Mulvaney. 1995. Microscale determination of inorganic nitrogen in water and soil extracts. Commun. Soil Sci. Plant Anal. 26(1&2): 303-316.

Stinner, B. R., G. D. Hoyt, and R. L. Todd. 1983. Changes in soil chemical properties following a 12-year fallow: A 2-year comparison of conventional tillage and no-tillage agroecosystems. Soil Tillage Res. 3: 277-290.

Timmons, D. R. 1984. Nitrate leaching as influenced by water application level and nitrification inhibitors. J. Environ. Qual. 13: 305-309.

Tisdale, S. L., W. L. Nelson, and J. D. Beaton. 1985. Soil fertility and fertilizers. Macmillan Publishing Company, New York.

Wallace, A. 1994. Soil organic matter is essential to solving soil and environmental problems. Commun. Soil Sci. Plant Anal. 25(1&2): 15-28.

경운에 따른 옥수수 근권에서의 질산태질소의 이동양상

김원일[*] · 정구복 · 이종식 · 김진호 · 이정택

농업과학기술원 환경생태과

질산태 질소의 이동에 대한 토양 특성과 경운의 영향을 구명하기 위하여 1993년부터 1994년까지 2년 동안 미국 일리노이주 중부지방의 몇 개 토양통이 다른 옥수수 포장에서 질산태 질소의 함량을 조사하였다. 1993년 포장에는 무수암모니아 225 kg ha^{-1}을, 1994년 포장에는 URAN 115 kg ha^{-1}을 시용하였다. 1993년 초기 포장에 질산태질소의 함량은 토양 깊이 100 cm 까지 20 mg kg^{-1} 정도의 농도를 보였으나, 시용후 옥수수 재배 초기에는 질산태질소의 하향이동을 확인할 수 있었다. 또한 수확 후 토양중의 질산태질소의 함량은 유기물 함량이 보다 많은 Flanagan 및 Ipava 토양통에서 Saybrook 및 Catlin 토양통에 비해 높은 경향을 보였으나 유의적인 차이는 없었고, 무경운 포장에서 경운 포장에 비하여 질산태질소의 함량이 높게 나타났다. 이는 무경운에 의한 질산태질소의 지하수로의 용탈 감소를 의미한다.