Effect of Strip Tillage on Corn Nitrogen Uptake and Residual Soil Nitrate Accumulation Compared with No-Tillage and Chisel Plow

Mahdi Al-Kaisi* and Mark A. Licht

ABSTRACT

Tillage and N management systems can have a significant effect on N use by corn (*Zea mays* L.) and nitrate (NO_3–N) movement through the soil profile. Potential water quality and NO_3–N loss problems associated with conventional tillage and fall-applied N have prompted this study. The objective is to evaluate strip tillage effect on corn N uptake and NO_3–N movement through the soil profile compared with chisel plow and no-tillage systems. The three tillage systems implemented in this study were strip tillage, no-tillage, and chisel plow along with two N application timings (fall and spring) of 170 kg N ha^{-1} for corn in a corn–soybean [*Glycine max* (L.) Merr.] rotation on two Iowa fields in 2001 and 2002. The three tillage systems were implemented every year for both crops (corn and soybean). Crop response, N uptake, and other soil NO_3–N measurements were conducted on a randomized complete block design experiment. Grain yields and grain N uptake showed no significant improvement under strip tillage compared with no-tillage or chisel plow systems. Tillage and N treatments caused no significant differences in NO_3–N accumulation at the lower depths of the root zone (1.2 m). Strip tillage and no-tillage resulted in lower residual soil NO_3–N buildup than chisel plow in the 0- to 1.2-m soil profile after 2 yr of tillage implementation. Tillage and N treatments did not cause significant differences in NO_3–N concentration in water leachate collected at the 1.2-m depth.

THE INTEGRATION of tillage and N management (i.e., type of tillage system, timing of tillage system, timing of N application, and N rate) present significant challenges for producing corn, sustaining soil productivity, and improving water quality. The susceptibility of N to leaching, denitrification, volatilization, and immobilization is highly related to the timing of N application, which can increase due to fall N application compared with spring application (Dinnes et al., 2002). Fall N application can lead to significant N losses, rendering it less effective for plant uptake. Delaying N application until spring can reduce NO_3–N losses due to leaching and surface water runoff (Malhi and Nyborg, 1983; Carefoot and Janzen, 1997). The timing of N fertilizer application is one of many causes of nutrient losses into the nation's lakes and streams (Gast et al., 1978; Power and Schepers, 1989), hypoxia in the Gulf of Mexico (Dinnes et al., 2002), and adverse health effects such as methemoglobinemia (Fletcher, 1991; Keeney and Follett, 1991). In southern Minnesota, NO_3–N losses into tile drains were reduced by 36% with spring N application compared with fall N application (Randall, 1997). Nitrogen losses can create conditions where N becomes deficient and crop productivity can decline rapidly (Welch et al., 1971; Kucey and Schaalje, 1986; Reeves et al., 1993; Randall et al., 1997; Torbert et al., 2001).

Many soil and water quality problems are associated with conventional tillage, along with other problems that affect water resources (Baker and Laflen, 1983; Mickelson et al., 2001; Zalidis et al., 2002). Tillage systems have a significant effect on N dynamics by affecting N pools in the soil system. Soil disturbance during the tillage process and the incorporation of surface residue increases soil aeration, which can increase the rate of residue decomposition (McCarthy et al., 1995). This process impacts soil organic N mineralization whereby readily available N for plant use is increased (Dinnes et al., 2002). Therefore, the type of tillage system and N fertilization timing can influence the amount of N available for loss in the soil profile. Deep accumulation of NO_3–N in the soil profile represents a potential for NO_3–N leaching into shallow water tables (Keeney and Follett, 1991). Halvorson et al. (2001) found that conventional and conservation tillage systems accumulated more soil NO_3–N down to 150 cm compared with a no-tillage system in a spring wheat (*Triticum aestivum* L.)–fallow cropping study in North Dakota. They concluded that conventional and conservation tillage systems mineralized more N at the soil surface due to soil disturbance than their no-tillage system. Similarly, Sainju and Singh (2001) found evidence that more intensive tillage systems caused greater NO_3–N accumulation in the soil profile than no-tillage using corn and a cover crop. In a 3-yr study on tillage and N management in a corn–soybean rotation, it was found that moldboard plowing reduced tile flow by an average of 2 cm of water depth compared with no-tillage (Weed and Kanwar, 1996). In the same study, the 3-yr average NO_3–N concentration of the tile water of no-tillage was lower (21.9 mg L^{-1}) than that of moldboard plowing (36.9 mg L^{-1}), and the average NO_3–N loss from the no-tillage system was 74 kg ha^{-1} less than the moldboard plow system (Weed and Kanwar, 1996). Randall and Iragavarapu (1995) found similar trends under continuous corn from an 11-yr study in southern Minnesota where the 11-yr average of NO_3–N losses for moldboard plowing were 43 kg ha^{-1} compared with 41 kg ha^{-1} for no-tillage losses. The narrow difference in NO_3–N loss between the two systems was attributed to the greater length of the study, which caused greater variability in the soil and environmental conditions.

Total grain N content is often found to be greater under no-tillage system due to greater N use efficiency in no-tillage crops than crops grown in conventional tillage

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Published in Agron. J. 96:1164–1171 (2004).
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Abbreviations: DOY, day of year; FCP-FF, fall chisel plow with fall N fertilizer application; FST-FF, fall strip tillage with fall N fertilizer application; FST-SF, fall strip tillage with spring N fertilizer application; NT-FF, no-tillage with fall N fertilizer application; SST-SF, spring strip tillage with spring N fertilizer application.

systems (Angle et al., 1993). Several studies have found that no-tillage increased total grain N uptake slightly compared with conventional tillage and generally equaled that of conservation tillage (Angle et al., 1993; Halvorson et al., 2001; Sainju and Singh, 2001). On the other hand, some studies found N deficiencies are more common in no-tillage than conventional tillage systems (Olson and Kurtz, 1982; Mehdi et al., 1999), translating into less grain N uptake.

No-tillage can be associated with delayed planting and emergence in poorly drained Midwest soils. A new alternative tillage system, strip tillage, has been proposed and studied during the past decade. Strip tillage results in a disturbed narrow zone of 15 to 20 cm wide and 15 to 20 cm deep in the previous crop's row, whereas the interrow area is left undisturbed. Strip tillage offers an opportunity to apply nutrients and prepare a seedbed in one tillage operation. Granular P and K with granular, liquid, or gaseous N can be applied during the time of tillage operation (Al-Kaisi and Hanna, 2002). This tillage system may provide a potential solution to some of the nutrient and water quality problems associated with conventional tillage and, to a certain extent, with no-tillage, namely, nutrient use efficiency, surface water runoff, and deep NO_3–N leaching. It is well known that conventional tillage can contribute to significant surface water problems due to surface runoff of P- and N-laden sediment transport to river and streams. On the other hand, N use efficiency may be affected under no-tillage systems due to improved infiltration and consequently increased N leaching (Drees et al., 1994; Roseberg and McCoy, 1992; Kladivko et al., 1991; Tyler and Thomas, 1977). The benefit of strip tillage as a tillage system in providing a warmer seedbed especially in poorly drained wet soils and the banding of fertilizers in close proximity of the root system can provide advantages over no-tillage in improving N use efficiency. The timing of N application under strip tillage has not been fully investigated, and there is a need to evaluate the effect of such a system on N uptake by crops and potential N loss compared with no-tillage and other conservation tillage systems. The objectives of this study were to (i) evaluate corn yield response and N use using strip tillage compared with no-tillage and fall chisel plow treatments and (ii) compare NO_3–N movement using fall vs. spring N applications within strip tillage, no-tillage, and fall chisel plow systems.

MATERIALS AND METHODS

Site Description

The study was conducted on two Iowa State University research and demonstration farms in 2001 and 2002. One site was located at the Marsden research farm near Ames, IA, where the soils were Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludolls) and Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls). Each tillage treatment's main plot was split into two equal halves having the same tillage system. The first half was planted to corn, and the second half was planted to soybean. On 10 May 2001, corn (Fontenelle '4741' hybrid)[1] was planted to the first half with seed drop populations of 74 600 plants ha^{-1}, and soybean was planted to the second half at 120 000 plants ha^{-1}. On 6 May 2002, the previous-year soybean half plot was planted to corn (Fontenelle 4741 hybrid) with seed drop populations of 79 000 plants ha^{-1}, and the previous-year corn half plot was planted to soybean at 120 000 plants ha^{-1}, using a four-row planter at 5-cm planting depth and 76-cm row spacing for both crops. Seasonal precipitation (October through September) was 766 and 713 mm for 2001 and 2002, respectively, with a normal precipitation of 813 mm. The second site was at the Northeast Research and Demonstration Farm near Nashua, IA. Soils at this site were Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls) and Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls). Each tillage treatment's main plot was split into two equal halves having the same tillage system. The first half was planted to corn, and the second half was planted to soybean. At the Nashua site, corn (Dekalb '533-2BT' hybrid) was planted on 12 May 2001 and 5 May 2002 with seed drop populations of 80 300 plants ha^{-1} for both years, using a six-row planter at 5-cm planting depth and 76-cm row spacing. The second year of corn was planted into soybean residue from the first year. The soybean was planted on 12 May 2001 and 15 May 2002 with a seed drop population of 196 400 plants ha^{-1} both years. The seasonal precipitation was 832 and 711 mm in 2001 and 2002, respectively, with a normal precipitation of 864 mm. At both sites, the tillage and N application field operations were conducted in the middle of November for the fall treatments and at the end of April for the spring treatments. Before this study, both locations were in a corn–soybean rotation with soybean planted in 2000. The Ames site had previously been in a no-tillage corn–soybean rotation, whereas the Nashua site was previously in a chisel plow tillage system with a corn–soybean rotation.

Experimental Design and Management

The study consists of five treatments. There were three tillage systems (no-tillage, strip tillage, and fall chisel plow) and two timings of N application and strip tillage (fall and spring). The timing of N application for no-tillage and chisel plow was in the fall during the tillage operation. The strip tillage treatments consisted of fall and spring tillage and N fertilizer applications. These treatments were identified as follows: fall strip tillage with fall N fertilizer application (FST-FF), fall strip tillage with spring N fertilizer application (FST-SF), and spring strip tillage with spring N fertilizer application (SST-SF). The other two treatments were fall chisel plow with fall N fertilizer application (FCP-FF) and no-tillage with fall N fertilizer application (NT-FF). The experimental design used in this study was a randomized complete block design with four replications at each location. Plot dimensions were 36.5 m in length and 27.4 m in width. Each treatment plot was split into two halves. One half was planted to corn and the other half to soybean to establish a corn–soybean rotation sequence in 2001. In 2002, the previous-year soybean half plots were planted to corn, and the corn half plots were planted to soybean under the same tillage system for both crops.

On the fall chisel plow plots, primary tillage consisted of fall chisel plowing followed by field cultivation as the secondary tillage in the spring. Strip tillage was implemented using a four-row rototiller at the Ames site and a modified four-row fertilizer injector with mole knives followed by 51-cm hiller disks at the Nashua site. The mole knife consisted of a

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[1] Trade names and product lines are used for the benefit of readers and do not imply endorsement by Iowa State University over comparable products.

shank of 43 cm in length by 1.6 cm in width and a mole of 4.5 cm in width by 9 cm in length. Strip tillage at both sites resulted in a disturbed soil zone or strip of 20 cm in width and 10 to 15 cm in depth, leaving a berm 7 to 10 cm in height. Under no-tillage, the only field operation conducted was seed planting and N fertilizer application.

For all tillage treatments, N was injected at a 15-cm soil depth at a rate of 170 kg N ha^{-1} in the row zone, resulting in minimal soil and residue disturbance. At the Ames site, a urea ammonium nitrate solution was applied using a spoke point injector (Baker et al., 1989). At the Nashua site, anhydrous ammonia was injected at a 15-cm depth by using mole knives on the conventional tillage and strip tillage plots. For the no-tillage plots, an applicator with 1.25-cm-wide shanks with a 3.5-cm-wide shovel was used to apply anhydrous ammonia at 15-cm soil depth. The N applicator used on the no-tillage plots caused minimum soil and residue disturbance. Weeds were controlled using pre- and postemergence herbicides that are typically used in corn production for central and northeastern Iowa.

Soil Nitrogen Measurements

Before establishing the study, soil samples were taken in fall 2000 for each site before tillage or N application was implemented. For each subsequent year (2001 and 2002), soil samples were taken immediately after harvest (approximately 15 October). The soil samples were taken from each individual plot to a depth of 1.2 m in increments of 0 to 15, 15 to 30, 30 to 60, 60 to 90, and 90 to 120 cm. Soil sample for each depth consisted of 10 to 12 soil cores diagonally across the rows, which includes samples from both in and between the rows. Soil samples were kept in plastic-lined paper bags and placed in a cooler for transport. Samples were immediately air-dried and analyzed for total N (for the 0- to 15-cm depth) by dry combustion with a LECO CHN-2000 C-N analyzer (LECO Corp., St. Joseph, MI) and for NO_3–N (for the 0- to 120-cm soil depth increments) with a Lachat QuickChem 4 in 2000 and 2001 and a Lachat QuickChem 8000 (Lachat Instruments, Milwaukee, WI) in 2002. There was a N misapplication at the Nashua site only due to equipment calibration resulting in N overapplication (approximately 335 kg ha^{-1}), which exceeded the designed N application rate of 170 kg ha^{-1} for FST-SF and SST-SF in 2002. These plots were utilized for yield calculation and N uptake only. Soil samples from those plots were not included due to the overapplication of N fertilizer.

Nitrate Leaching Measurements

Soil water samples were collected to measure NO_3–N leached 24 h after rain events at a 1.2-m soil depth by using suction lysimeters consisting of a porous ceramic cup connected to a 1.2-m-long PVC tube (3 cm inner diameter). One lysimeter per plot was installed in a corn row of each treatment. To install the lysimeters, a soil core 7.5 cm in diameter was removed. The soil core was then mixed with water to make a soil slurry that was poured into the hole around the ceramic cup. The soil slurry provided contact between the ceramic cup of the lysimeter and the surrounding soil medium. After the suction lysimeter was placed in the hole, the remaining soil was backfilled and packed consistently in 6- to 10-cm layers around the lysimeter to prevent potential preferential flow. The slurry was allowed to reach equilibrium with the soil water before a vacuum was applied.

Before applying a vacuum, the suction tubes were emptied of any free-standing water. To collect water samples, a vacuum of 0.59 MPa was applied to the lysimeters by using a battery-operated pump supplied by SoilMoisture Equipment Corporation (Goleta, CA) 24 h after a rainfall event that was equal to or greater than 10 mm. The water or leachate samples were collected 24 h after the vacuum was established, stored in plastic nalgene bottles, and placed in a cooler for transport. The water samples were frozen if NO_3–N analysis was not done immediately. The water samples were thawed to room temperature before NO_3–N analysis by using a Lachat QuickChem 4 (Lachat Instruments, Milwaukee, WI).

Crop Measurements

Corn yields were determined by hand-harvesting the center two rows, 5.3 m in length, of each plot. All corn ears were shelled to determine the corn yield. Corn grain yields were adjusted to 155 g kg^{-1} moisture. The grain samples were dried in a forced-air oven at 65°C for 7 d. The dried grain samples were analyzed for total N by dry combustion by using a LECO CHN-2000 C-N analyzer. Grain N uptake was calculated based on the total dry mass multiplied by the respective total N concentration.

Statistical Analysis

Data were analyzed using the SAS statistical software package (SAS Inst., 2001). The GLM procedure was used to perform the analysis of variance that was appropriate for a randomized complete block design for residual soil NO_3–N, soil NO_3–N profile, soil water NO_3–N, grain N uptake, and grain yield. Means were separated using Fisher's protected and unprotected least significant difference (LSD) test at statistical significance of $P \leq 0.05$.

RESULTS AND DISCUSSION

Yield Response and Grain Nitrogen Uptake

Effects of tillage systems and timing of N application treatments on corn yield were not statistically significant in either 2001 or 2002 at the Ames site (Table 1). Similarly, there was no significant difference in grain N uptake among the five treatments in either year. At the Nashua site, yields were statistically identical among the five treatments in 2001 (Table 1). But in 2002, FST-FF and FCP-FF resulted in greater yields than the other three treatments. Grain N uptake showed no significant differences among the five treatments in 2001. However, NT-FF had significantly lower grain N uptake than the other four treatments (Table 1).

Table 1. Tillage and N fertilizer timing effects on corn grain yield and grain N uptake in 2001 and 2002.

	Corn yield				Grain N uptake			
	Ames		Nashua		Ames		Nashua	
Treatment†	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
	Mg ha^{-1}				kg ha^{-1}			
FST-FF	**11.4a‡**	**14.2a**	**13.9a**	**15.0a**	**130.1a**	**164.6a**	**161.6a**	**174.0a**
FST-SF	**11.2a**	**13.8a**	**13.4a**	**13.4b**	**135.7a**	**160.8a**	**144.0a**	**178.6a**
SST-SF	**11.3a**	**14.7a**	**13.3a**	**13.3b**	**141.0a**	**172.5a**	**147.8a**	**185.2a**
FCP-FF	**12.1a**	**14.8a**	**13.3a**	**14.9a**	**156.4a**	**159.0a**	**160.0a**	**173.5a**
NT-FF	**11.5a**	**14.1a**	**14.5a**	**13.1b**	**142.3a**	**158.2a**	**147.3a**	**147.0b**

† FST-FF, fall strip tillage with fall N fertilizer application; FST-SF, fall strip tillage with spring N fertilizer application; SST-SF, spring strip tillage with spring N fertilizer application; FCP-FF, fall chisel plow with fall N fertilizer application; NT-FF, no-tillage with fall N fertilizer application.

‡ Means within the same column followed by the same letter are not significantly different according to a protected Fisher's LSD(0.05).

Residual Soil Nitrate Nitrogen in the Root Zone

Differences in residual soil NO_3–N buildup between treatments were not significant except at the 15-cm soil depth after 2 yr of management at the Ames site (Fig. 1). At the top 15-cm soil depth, FST-FF resulted in significantly greater residual soil NO_3–N content than that of NT-FF. The increase in residual soil NO_3–N under FST-FF at the top 15-cm soil depth, where the soil disturbance took place in fall strip tillage management, might be attributed to the increased N mineralization compared with no-tillage. Strip tillage treatments with different timings of tillage and N application (FST-FF, FST-SF, and SST-SF) did not show significant differences in residual soil NO_3–N content in the root zone, indicating that there was no effect on residual soil NO_3–N due to different timing of strip tillage operation or N application under strip tillage.

At the Nashua site, significant treatment effects on residual soil NO_3–N were observed at the 0- to 15-, 15- to 30-, and 30- to 60-cm depths (Fig. 1). Residual soil NO_3–N was significantly higher for FST-FF at the 15- to 30- and 30- to 60-cm soil depths compared with NT-FF. Treatment FCP-FF resulted in greater residual soil NO_3–N at the 0- to 15-, 15- to 30-, and 30- to 60-cm soil intervals than NT-FF. The lower soil NO_3–N at the above-mentioned soil depths associated with no-tillage may be attributed to a greater water infiltration rate and NO_3–N distribution to lower depths in the soil profile or drainage system (Kladivko et al., 1991; Tyler and Thomas, 1977)

At the Ames site, total residual soil NO_3–N content at the top 1.2-m soil depth after harvest did not differ among the five treatments in 2001 (Table 2). In 2002, however, FCP-FF resulted in greater total residual soil NO_3–N content than FST-SF and NT-FF. Compared with residual soil NO_3–N content before the initiation of this study in 2000, there had been substantial NO_3–N loss of 20.0 kg ha^{-1} under FST-FF treatment during the 2001 season (Table 2). However, the changes of total residual soil NO_3–N contents were small under the other treatments. Results of 2002 showed a substantial increase in total residual soil NO_3–N content at the top 1.2 m under strip tillage and chisel plow tillage treatments but slight increase under no-tillage as compared with residual soil NO_3–N content before the initiation of this study in 2000. These findings may suggest better water movement causing soil NO_3–N leaching below 1.2-m soil depth under no-tillage (Kladivko et al., 1991; Tyler and Thomas, 1977).

Table 2. After-harvest total residual soil NO_3–N in the top 1.2-m soil depth for 2000, 2001, and 2002 growing seasons.

	Ames			Nashua‡		
Treatment†	2000	2001	2002	2000	2001	2002
	kg ha^{-1}					
FST-FF	33.8a§	13.8a	43.6ab	21.0a	109.0a	101.9ab
FST-SF	25.2a	22.7a	37.1b	23.8a	77.0b	–
SST-SF	30.2a	32.2a	44.0ab	28.4a	138.1a	–
FCP-FF	30.2a	28.5a	60.4a	22.5a	156.3a	127.0a
NT-FF	32.5a	30.3a	27.3b	42.3a	121.1a	54.2b

† FST-FF, fall strip tillage with fall N fertilizer application; FST-SF, fall strip tillage with spring N fertilizer application; SST-SF, spring strip tillage with spring N fertilizer application; FCP-FF, fall chisel plow with fall N fertilizer application; NT-FF, no-tillage with fall N fertilizer application.

‡ Soil NO_3–N data for treatments FST-SF of 2001 and FST-SF and SST-SF of 2002 at Nashua site were not collected due to N overapplication on these plots.

§ Means within the same column followed by the same letter are not significantly different according to a protected Fisher's LSD(0.05).

At the Nashua site in 2001, FST-SF had significantly lower residual soil NO_3–N content compared with the other treatments (Table 2). However, in 2002, FCP-FF treatments had significantly greater residual soil NO_3–N content in the top 1.2 m than NT-FF treatment. These findings generally agree with others where greater N accumulation occurred under conventional tillage systems (Sainju and Singh, 2001). Unlike the Ames site, residual soil NO_3–N content increased tremendously regardless of treatment during 2001, but such increases were not observed in 2002.

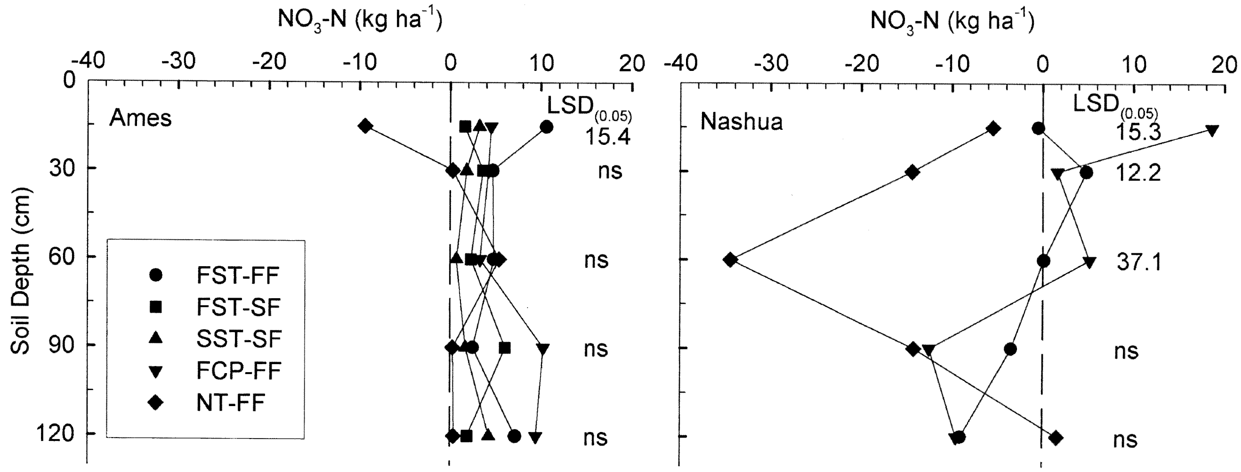

Fig. 1. Residual soil NO_3–N content at different soil depths in the root zone after 2 yr (NO_3–N kg ha^{-1} was estimated as a difference between year 2002 and 2000 soil NO_3–N content at different soil depths) for the Ames and Nashua sites. The least significant differences are according to unprotected Fisher's LSD$_{(0.05)}$ test. FST-FF, fall strip tillage with fall N fertilizer application; FST-SF, fall strip tillage with spring N fertilizer application; SST-SF, spring strip tillage with spring N fertilizer application; FCP-FF, fall chisel plow with fall N fertilizer application; NT-FF, no-tillage with fall N fertilizer application.

Soil Nitrate Nitrogen Movement in the Root Zone

The soil NO_3–N distribution was influenced by both tillage system and timing of N application. At the Ames site, the initial soil NO_3–N content distribution in the soil profile during the fall of 2000, before imposing tillage and N treatments, showed no significant differences except at depth intervals of 15 to 30 and 90 to 120 cm (Fig. 2). In 2001, the soil NO_3–N content of all the treatments was similar at all depth intervals except 0 to 15 cm. In contrast, soil NO_3–N content differed among the treatments at each depth in 2002. Significantly greater amounts of NO_3–N were observed at 60- to 90- and 90- to 120-cm soil depths under FCP-FF tillage treatment compared with the other tillage treatments. Generally, after 2 yr, NT-FF had lower soil NO_3–N content at all depths than that for strip tillage and chisel plow treatments.

The overall trend of nitrate movement within the soil profile revealed a progressive increase in NO_3–N content over time with considerable accumulation of NO_3–N, particularly at the lower depths for all tillage systems at the Ames site (Fig. 2). Treatments FCP-FF and SST-SF show greater NO_3–N accumulation than no-tillage. Dif-

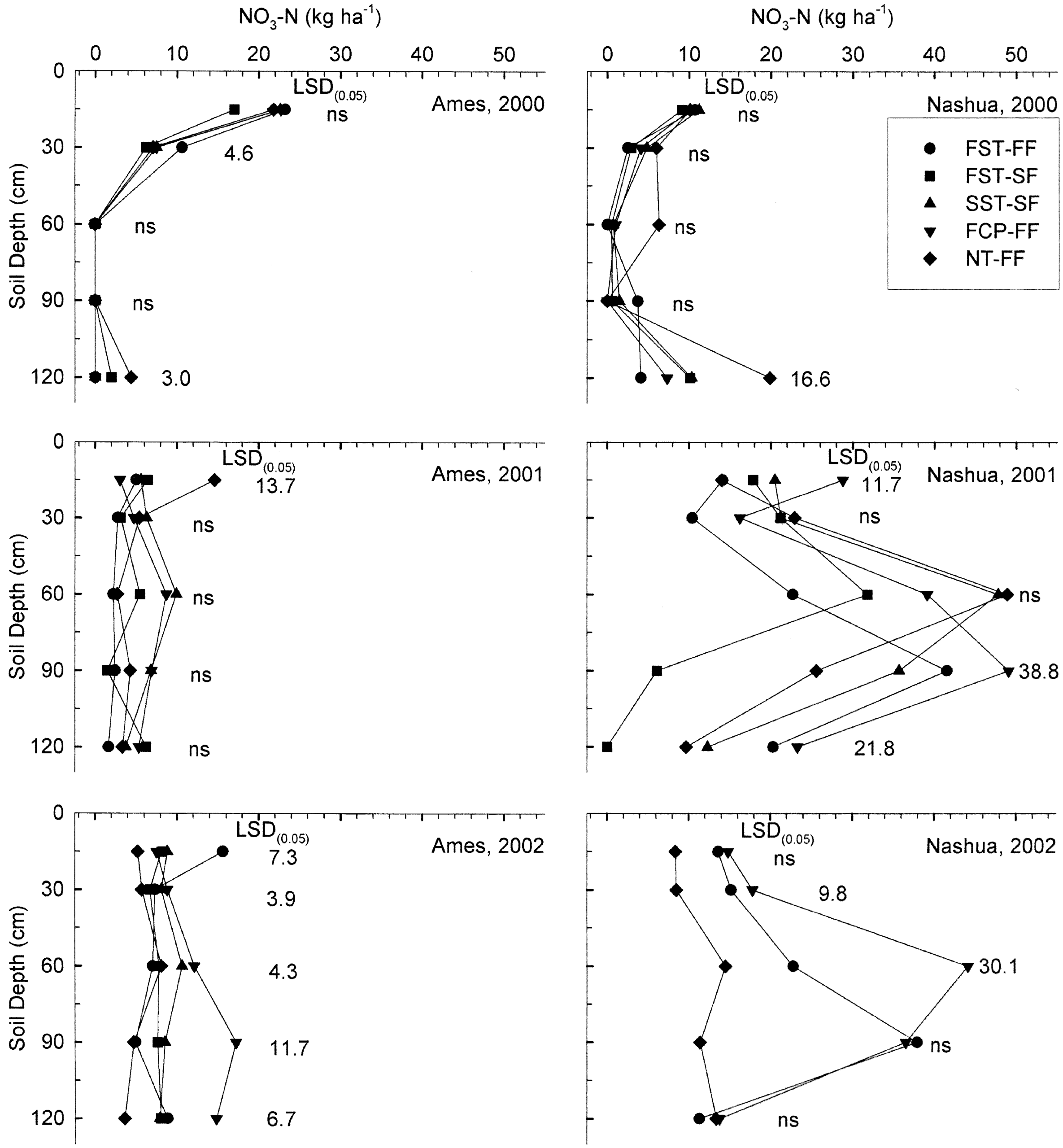

Fig. 2. After harvest, soil NO_3–N distribution profile of different tillage systems and timing of N application during 2000 (before treatment application), 2001, and 2002 (after treatments application) for Ames and Nashua sites. The least significant differences are according to unprotected Fisher's $LSD_{(0.05)}$ test. FST-FF, fall strip tillage with fall N fertilizer application; FST-SF, fall strip tillage with spring N fertilizer application; SST-SF, spring strip tillage with spring N fertilizer application; FCP-FF, fall chisel plow with fall N fertilizer application; NT-FF, no-tillage with fall N fertilizer application.

ferent timings of N applications under strip tillage had no significant effect on NO_3–N movement to lower depths within the soil profile. These findings are consistent with other research findings by Sainju and Singh (2001), particularly for chisel and no-tillage systems.

At the Nashua site in 2000, before imposing tillage and N treatments, the residual NO_3–N content was similar among the treatments except the 90- to 120-cm soil depth interval (Fig. 2). In 2001, significant differences were observed among the treatments at the 0- to 15-, 60- to 90-, and 90- to 120-cm soil depths. Compared with the initial residual soil NO_3–N content before the initiation of this study in 2000, treatments FST-FF, SST-SF, FCP-FF, and NT-FF showed considerable increase in NO_3–N at all depths in the top 1.2 m, with greater increases in NO_3–N content at the 60- to 90- and 90- to 120-cm soil depths compared with other depths (Fig. 2). In 2002 (no data were available for FST-SF and SST-SF treatments), however, the NO_3–N content differed significantly among treatments only at depth intervals of 15 to 30 and 30 to 60 cm. The NT-FF treatment had the lowest NO_3–N accumulation for all depths

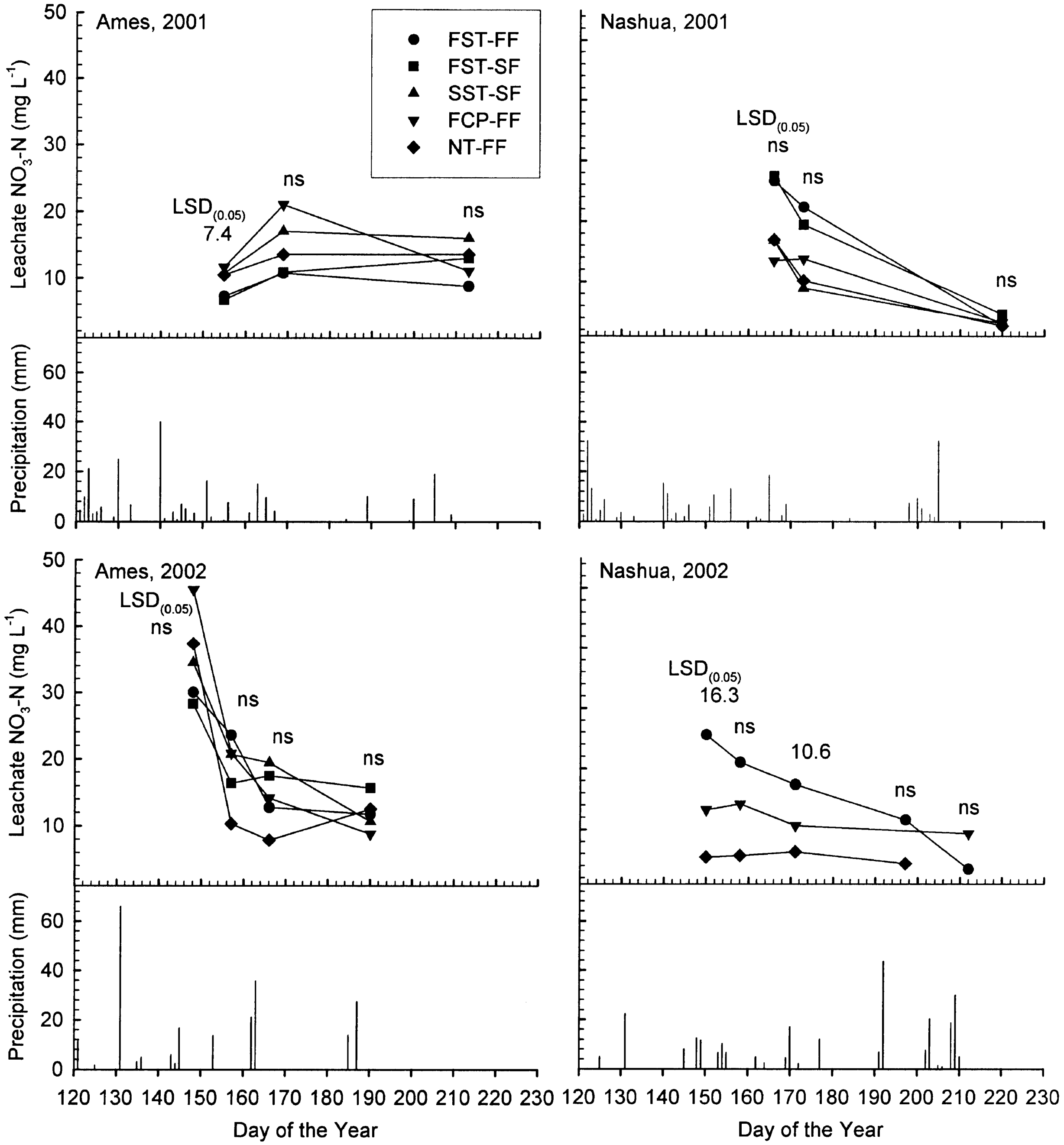

Fig. 3. **Precipitation and water NO_3–N concentration of leachate collected at 1.2-m soil depth in lysimeters after rainfall events for the Ames and Nashua sites in 2001 and 2002. The least significant differences are according to unprotected Fisher's $LSD_{(0.05)}$ test. FST-FF, fall strip tillage with fall N fertilizer application; FST-SF, fall strip tillage with spring N fertilizer application; SST-SF, spring strip tillage with spring N fertilizer application; FCP-FF, fall chisel plow with fall N fertilizer application; NT-FF, no-tillage with fall N fertilizer application.**

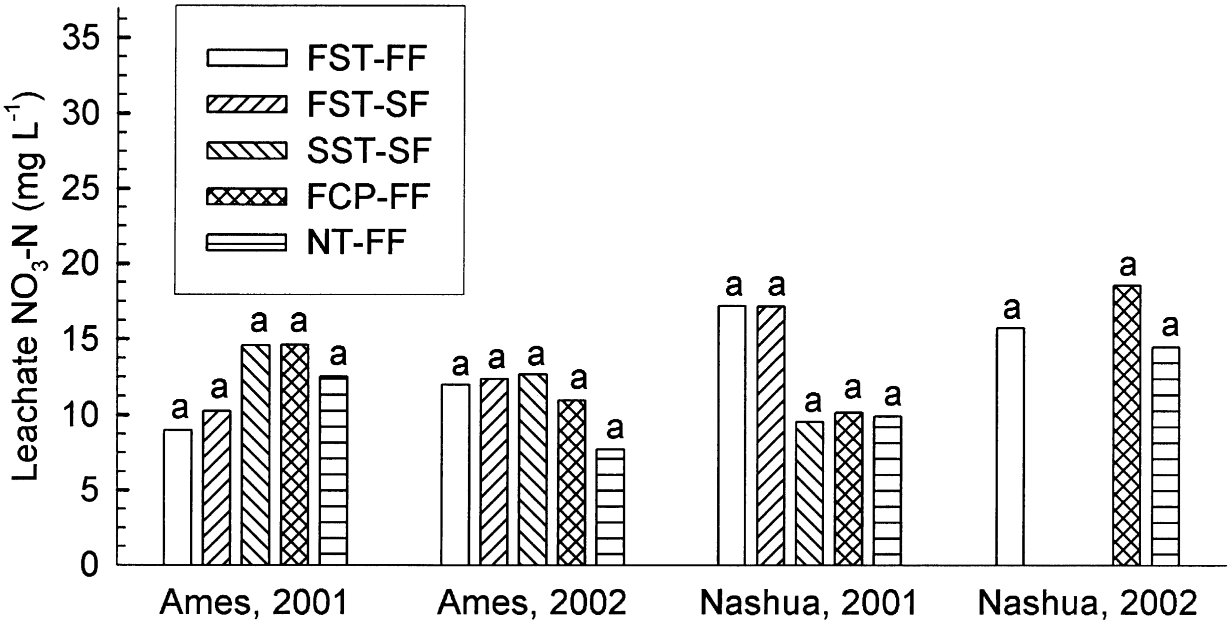

Fig. 4. Overall average of water NO_3–N concentration leachate collected after many rainfall events during the growing season at a 1.2-m soil depth lysimeters for the Ames and Nashua sites in 2001 and 2002. The mean separations are based on least significant differences according to unprotected Fisher's $LSD_{(0.05)}$ test. FST-FF, fall strip tillage with fall N fertilizer application; FST-SF, fall strip tillage with spring N fertilizer application; SST-SF, spring strip tillage with spring N fertilizer application; FCP-FF, fall chisel plow with fall N fertilizer application; NT-FF, no-tillage with fall N fertilizer application.

compared with strip tillage and chisel plow treatments. The NO_3–N distribution within the top 1.2 m of both sites showed similar trends, with greater magnitude in NO_3–N accumulation at the lower depths (60–90 cm) of the strip tillage and chisel plow.

Soil Nitrate Nitrogen Leaching

At the Ames site, the leachate NO_3–N concentration of all tillage treatments was generally not significantly different in 2001 or 2002 (Fig. 3). In 2001, leachate NO_3–N concentrations showed little change throughout the growing season, whereas in 2002, the NO_3–N concentration decreased significantly after day of year (DOY) 140 when rain events were very limited. The increase of NO_3–N movement through the soil profile in both years was affected by the amount of rainfall received, especially in 2002, where the NO_3–N concentration was much greater after the site received greater rainfall amounts compared with later rainfall events.

At the Nashua site in 2001, there were no significant differences among all treatments in leachate NO_3–N concentrations during all sampling periods, with an overall decrease in NO_3–N concentration as the growing season progressed. In 2002, leachate NO_3–N concentration under FST-FF was significantly greater than that of the NT-FF treatment at the rain events of DOYs 150 and 171. The leachate NO_3–N concentration for FST-FF and NT-FF decreased as the season progressed, whereas leachate NO_3–N concentration for FCP-FF treatment increased after DOY 190 as the rainfall amount increased.

Although the average leachate NO_3–N concentration did not show statistically significant differences between tillage treatments and N application timings for either location in 2001 or 2002 (Fig. 4), the results of this study seemed to show that no-tillage results in less leachate of NO_3–N concentration. Two main factors seem to affect NO_3–N leachate concentration at both sites: the amount of rain that was received at each site and N dynamics at each site due to tillage system and N management effects. Perhaps, no-tillage may cause a greater amount of NO_3–N leaching below the depth of the lysimeter compared with the effect of the other two tillage systems and the method of N application, especially with strip tillage where N was banded in the row and the positions of the lysimeters were located in the row for all tillage systems. These two factors may have led to greater accumulation of NO_3–N concentrations due to leaching under both strip tillage and chisel plow compared with no-tillage treatment.

CONCLUSION

Strip tillage had no significant impact on increasing corn yields compared with other tillage systems in this study in three of four site-years. However, one site-year, fall strip tillage with fall N fertilizer was very comparable to fall chisel plow; both generally produced greater yields than no-tillage and the other strip tillage treatments. Grain N uptake was not significantly improved by using strip tillage over no-tillage and fall chisel plow in three of four site-years. The findings of this study suggest that residual soil NO_3–N in the root zone varies from year to year, depending on climatic conditions. However, at both Ames and Nashua sites, no-tillage and strip tillage trends indicated a lower residual soil NO_3–N buildup than chisel plow at the top 1.2 m after 2 yr. Spring strip tillage and N application had a relatively insignificant effect on residual soil NO_3–N buildup.

It was also observed that NO_3–N accumulation at the lower depths was greater under strip tillage and fall chisel plow than no-tillage. The leachate NO_3–N concentration decreased as the growing season progressed due to a decrease in the amount of rainfall late in the season and a lower potential of NO_3–N leaching. The nitrate concentration of the leachate collected below the root zone at a 1.2-m soil depth for FST-FF and FST-SF treatments was greater initially in the season than that of other tillage treatments (NT-FF and FCP-FF).

ACKNOWLEDGMENTS

We acknowledge the contribution of Jon Bahrenfus, Mike Fiscus, Ken Pecinovsky (research farms managers at Ames and Nashua, IA) for plot preparation, maintenance, and harvest.

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