Comparative influence of tillage systems and nutrient timing on the soil environment and crop response in Iowa soils

by

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Signatures have been redacted for privacy

To Melea for her patience, sacrifice, and confidence.

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LIST OF ABBREVIATIONS

DOY, day of the year;

ERI, emergence rate index;

FST-FF, fall strip-tillage with fall N fertilizer application;

FST-SF, fall strip-tillage with spring N fertilizer application;

FCT-FF, fall conventional tillage with fall N fertilizer application;

N, nitrogen;

NO_3-N, nitrate nitrogen;

NT-FF, no-tillage with fall N fertilizer application;

R6, physiological maturity growth;

SST-SF, spring strip-tillage with spring N fertilizer application;

V6, 6^{th}-leaf growth stage;

V12, 12^{th}-leaf growth stage;

VT, tassel growth stage;

WUE, water use efficiency;

Y:N, corn yield to nitrogen ratio.

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ABSTRACT

Tillage systems can affect soil productivity, crop N availability and use efficiency, and seedbed conditions (soil temperature, moisture, and penetration resistance). The challenges associated with some tillage systems, namely conventional tillage and no-tillage, have prompted this study to (i) evaluate the effects of strip-tillage on corn (*Zea mays* L.) productivity as compared to conventional tillage and no-tillage (ii) identify the effect of strip-tillage and N timing on the N availability and use efficiency (iii) determine the impact of strip-tillage on soil moisture, temperature, and penetration resistance. The study was conducted at two sites in 2001 and 2002. One site was near Ames, Iowa where the soils were Nicollet (Aquic Hapludolls) and Webster (Typic Haplaquolls). The second site was near Nashua, Iowa where the soils were Kenyon (Typic Hapludolls) and Floyd (Aquic Hapludolls). The impacts of tillage treatments on crop response were determined by measuring corn emergence, dry matter, plant N uptake, and grain yield. Residual soil NO_3-N, NO_3-N movement, and water use efficiency, along with soil temperature and soil penetration resistance, were estimated for different tillage systems.

Results of this study suggest strip-tillage offers no significant advantages in improving corn production over no-tillage or conventional tillage. In this study, strip-tillage had a slight advantage early in the growing season in improving corn emergence due to improvement of soil temperature over no-tillage by 1.4-1.9°C, but this advantage did not significantly increase yields. There was no significant difference in soil moisture content between all tillage systems at any depth, but generally strip-tillage showed greater water content than conventional tillage and a similar water content to no-tillage at the lower soil depths. Strip-tillage had no significant advantages in improving plant N uptake, water use efficiency, or reducing N leaching over no-tillage regardless of the timing of tillage implementation and N fertilizer application. Soil penetration resistance of strip-tillage was often comparable with no-tillage, but greater than conventional tillage at the 0-20 cm depth. Penetration resistance and soil moisture for all treatments were inversely related throughout the soil profile, where the differences were most pronounced at the 30 and 60 cm depths.

CHAPTER 1

GENERAL INTRODUCTION

Soil and water quality are of growing concern to different interest groups across the United States. There is a realization that agricultural practices are being associated with the degradation of the nation's lakes and streams by nutrients (Gast et al., 1978; Power and Schepers, 1989), hypoxia in the Gulf of Mexico (Dinnes et al., 2002), and adverse health effects like methemoglobinemia (Fletcher, 1991; Keeney and Follett, 1991). Along with the use of N fertilizer, tillage practices can have a detrimental effect on water quality. Iowa has repeatedly led the United States in corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) production with 15% of the 62.2 million hectares nationwide in corn and soybean production (N.A.S.S., 2002). The high intensity of agricultural production led to an average of 98% of the corn cropland in Iowa receiving N fertilization at an average of 140 kg ha^{-1} (N.A.S.S., 2002). It was found that conventional tillage is often attributed with adverse effects on soil and water quality (Baker and Laflen, 1983; Mickelson et al., 2001; Zalidis et al., 2002). Therefore, tillage systems and N timing need to be evaluated to determine their impacts on soil and water resources.

In the United States conservation tillage systems account for approximately 44 million hectares or 36% of the annually planted cropland (Fawcett and Towery, 2002). In Iowa, conventional tillage, conservation tillage not including no-tillage, and no-tillage each account for approximately one-third of the corn and soybean cropland planted (I.R.M.P., 2000). Tillage systems are used for many agricultural purposes ranging from weed control to the incorporation of crop residue and amendments and ultimately to prepare the best possible seedbed for crop germination. The necessary intensity of tillage to achieve optimum soil conditions for crop production is widely disputed. However, conservation tillage systems, namely no-tillage, have been perceived by producers to impede soil temperature increases and soil drying in the spring with no reduction of soil compaction (Uri, 2000). Therefore, no-tillage in some soil and ecosystem conditions may affect the ideal seedbed conditions for plant emergence, plant growth, and root development.

In response to the factual and perceived challenges associated with no-tillage, strip-tillage emerged as a stand alone tillage operation that was traditionally adopted for fertilizer application (Al-Kaisi and Hanna, 2002; Jasa et al., 2000). In the 1990's the use of strip-tillage increased because it has the capability to apply the necessary nutrients and prepare an adequate seedbed while leaving the interrow undisturbed. Strip-tillage typically disturbs a narrow zone 15-20 cm wide by 15-20 cm deep. The promotion of spring tillage and N fertilizer application is supported because strip-tillage concurrently applies nutrients and tills the soil (Al-Kaisi and Hanna, 2002; Vyn et al., 1994). For these reasons, strip-tillage increases soil temperature and soil-water evaporation in the seedbed, as compared to no-tillage, and provides a potential solution to soil and water quality concerns associated with conventional tillage systems. Therefore, as an emerging and alternative tillage system, strip-tillage must be evaluated based on its impacts on crop response, N use efficiency, and soil seedbed properties.

The challenges associated with some tillage systems, namely conventional tillage and no-tillage, have prompted this study to (i) evaluate the effects of strip-tillage on corn response as compared to conventional tillage and no-tillage (ii) identify the effect of strip-tillage and N timing on the N availability and use efficiency (iii) determine the impacts of strip-tillage on soil moisture, temperature, and penetration resistance.

THESIS ORGANIZATION

This thesis is organized into five chapters, each addressing a specific aspect of the research project. All chapters are written using data generated from two research sites at the Agronomy Research Farm near Ames, Iowa and the Northeast Research and Demonstration Farm near Nashua, Iowa. Chapter one is a general introduction that outlines the relevance of this study. Chapter two evaluates the effect of different tillage systems and N application timing on crop response. Chapter three evaluates the effect of different tillage systems, N application timing, and strip-tillage timing on residual soil NO_3-N and N leaching. Chapter four covers tillage system effects on some soil physical and hydraulic properties. Chapter five summarizes and concludes the research project findings. This thesis has been written with the potential for chapters two, three, and four to be published in various refereed journals at a later time.

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CHAPTER 2

STRIP-TILLAGE EFFECTS ON CORN RESPONSE, N UPTAKE, AND WATER USE EFFICIENCY

INTRODUCTION

Conventional tillage, conservation tillage, and no-tillage each accounted for one-third of Iowa's corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) cropland in production according to a survey by the Iowa Residue Management Partnership Committee in 1999 (I.R.M.P., 2000). In the United States, 36% of cropland planted annually is in a conservation tillage system, accounting for approximately 44 million hectares (Fawcett and Towery, 2002). Nationwide the use of no-tillage has increased by 15.5 million hectares from 1990 to 2002, while total cropland in conservation tillage remained fairly constant (Fawcett and Towery, 2002).

Tillage systems are used for many agricultural purposes ranging from weed control to the incorporation of crop residue, as well as the preparation of a suitable seedbed for improved seed germination. One of many problems associated with conventional tillage systems is water quality, because of significant increases in chemical and soil losses into Iowa's lakes and streams. Conversely, it has been well documented that conservation tillage systems significantly reduce surface runoff due to crop residue cover (Chichester and Richardson, 1992; Fawcett and Towery, 2002; Mickelson et al., 2001). Compared to conventional tillage systems, conservation tillage also has a significant contribution in conserving soil moisture (Fortin, 1993), improving soil and water quality (Baker and Laflen, 1983; Kettler et al., 2000), lowering input costs, and reducing labor needs (Tebrugge and During, 1999). However, conservation tillage systems need to be evaluated in terms of their impacts on crop response, as well as soil and water quality.

In addition to the advantages conservation tillage systems possess, there are perceptions and factual concerns regarding conservation tillage systems, particularly no-tillage. One of the main concerns among producers is the perception that no-tillage will affect yields due to cool, wet conditions early in the spring, particularly in poorly drained soils (I.R.M.P., 2000; Uri, 2000). It is documented that no-tillage results in slower seed emergence and plant development than conventional tillage systems (Erbach et al., 1992; Fortin, 1993; Gupta et al., 1988; Kaspar et al., 1990) due to higher amounts of crop residue. The higher amounts of crop residue on the soil surface can impede the soil warming and drying process, especially for poorly drained soils (Fortin and Pierce, 1991; Kaspar et al., 1990). It has been reported that no-tillage corn yields can be reduced by as much as 35% compared to conventional tillage (Erbach et al., 1992; Hussain et al., 1999; Vyn and Raimbault, 1992; Vyn and Raimbault, 1993). Alternatively, a research study in Iowa indicated no yield reduction with no-tillage compared to conventional or reduced tillage systems (Tapela and Colvin, 2002). Many studies have examined the effect of no-tillage with in-row residue removal on corn yield (Azooz et al., 1995; Fortin, 1993; Janovicek et al., 1997; Kaspar et al., 1990; Swan et al., 1994). In these studies in-row residue removal improved yield response due to the creation of a zone in which unimpeded solar radiation warms the soil surface and increases soil moisture evaporation.

In the early 1990's the concept of a new tillage system, strip-tillage, began to increase in popularity and use. This system offers a unique opportunity to apply nutrients and prepare a seedbed in one tillage operation. This characteristic provided a solution to the potential problems associated with no-tillage systems, namely late emergence of corn due to cool and wet soil conditions, by enhancing soil evaporation and warming of the seedbed, while minimizing soil disturbance. Generally, strip-tillage disturbs a narrow zone 15-20 cm wide and 15-20 cm deep in the previous crop row, whereas the interrow area is left undisturbed. Therefore, strip-tillage can be identified as a tillage system as well as a nutrient application system in the fall, for which it was initially developed.

The timing of strip-tillage and nutrient application is crucial (Al-Kaisi and Hanna, 2002). Al-Kaisi and Hanna (2002) indicated increased soil temperatures by 1^{o}C and faster soil drying in the spring are possible benefits of strip-tillage over no-tillage for early seed emergence. Wittmuss et al. (1971) reported that strip-tillage corn yielded an average of 0.13 Mg ha^{-1} more than conventional tillage in fifteen unreplicated trials. Opoku et al. (1997) compared moldboard plow, chisel plow, disking, strip-tillage, and no-tillage in a corn-wheat (*Triticum aestivum* L.) rotation in Ontario, Canada. It was found that strip-tillage corn yields were significantly higher than no-tillage, but it was not significantly different from moldboard plowing or chisel plowing. In southern Indiana one study showed strip-tillage grain yields were equal or better than conventional tillage in well drained soils, but on poorly drained soils grain yields for strip-tillage were depressed (Griffith et al., 1973).

Traditionally, N and other nutrients are applied in the fall, particularly with a strip-tillage system. However, N application timing is becoming more critical due to the effect of NO_3-N concentrations on surface and groundwater water quality (Fletcher, 1991; Gast et al., 1978; Power and Schepers, 1989). An obvious example of nutrient effects on water quality is hypoxia in the Gulf of Mexico. The phenomena is partly caused by the Upper and Central Mississippi Basins which account for approximately 39% of the N in the Gulf of Mexico (Dinnes et al., 2002). Among other things, fall N application can lead to significant N losses, rendering it less effective for plant N uptake than spring application (Carefoot and Janzen, 1997; Malhi and Nyborg, 1983). The susceptibility of N to leaching, denitrification, volatilization, and immobilization (Dinnes et al., 2002) within the soil environment can be reduced by delaying N application until spring. This was well documented in southern Minnesota (Randall, 1997; Randall et al., 1992), where NO_3-N losses in tile drains were reduced by 36% with spring N application and N use efficiency was increased by 20% over fall N application. In Illinois, Welch et al. (1971) conducted a four year study with four N rates (56, 112, 168, and 224 kg N ha^{-1}) where corn yields were increased with spring application over fall application for all rates except 56 kg N ha^{-1}. The timing of N application can greatly improve N availability for plant growth and grain yields. However, the concept of alternative timing for strip-tillage and nutrient application with strip-tillage, other than the fall season, has not been well explored. Therefore, evaluating strip-tillage and nutrient application for fall versus spring is essential to determine the effectiveness of this tillage system.

Another aspect related to tillage systems is moisture availability and water use efficiency (WUE) by the crop. Strip-tillage is not well evaluated in terms of crop WUE. In general, conservation tillage systems are often used to manage residue to conserve soil moisture (Christenson et al., 1994; Unger, 1986; Wagger and Cassel, 1993). Wiese et al. (1998) found no-tillage increased the WUE of grain sorghum [*Sorghum bicolor* (L.)

Moench.], but not for winter wheat under irrigated conditions. Norwood (1999; 2000) conducted two separate studies in southwest Kansas using corn in various dryland wheat rotations to investigate WUE. In both studies, Norwood observed greater corn WUE under no-tillage than conventional tillage by an average of 3.24 and 0.96 kg ha^{-1} mm^{-1}.

The challenges associated with conventional tillage and no-tillage in a corn-soybean rotation prompted this research to provide an alternative tillage system that would address corn production concerns associated with no-tillage and water quality concerns associated with conventional tillage. The objectives of this study were to: (i) evaluate strip-tillage effects on corn response compared to traditional tillage systems and (ii) determine the effect of strip-tillage and N timing on corn N uptake and WUE.

MATERIALS AND METHODS

Site Description

The study was conducted on two Iowa State University research and demonstration farms in 2001 and 2002 (Table 2.1). One site was at the Marsden research farm near Ames, Iowa, where the soils were Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludolls) and Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls). This site was planted to corn (Fontenelle 4741 hybrid) on 10 May 2001 and 6 May 2002 with seed drop populations of 74,600 and 79,000 plants ha^{-1}, respectively. Seasonal precipitation (October through September) in 2001 was 766 mm and 713 mm for 2002 with a normal precipitation of 813 mm. The second site was at the Northeast Research and Demonstration Farm near Nashua, Iowa. Soils at this site were Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls) and Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls). 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. The seasonal precipitation was 832 and 711 mm in 2001 and 2002, respectively, with a normal precipitation of 864 mm. Prior to this study both locations were under a corn-soybean rotation with soybeans planted in 2000. The Ames site had previously been under a no-tillage corn soybean rotation, while the Nashua site was previously under a conservation tillage corn soybean rotation.

Experimental Design and Management

The study consisted of three tillage systems; conventional tillage, strip-tillage, and no-tillage. The strip-tillage treatments consisted of fall and spring strip-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 conventional tillage with fall N fertilizer application (FCT-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 long and 27.4 m wide. Each treatment plot was split into two halves; one half was planted to corn and the other half to soybeans to establish a corn-soybean rotation sequence.

On the conventional tillage 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 four row fertilizer injector modified with mole knives followed by 51 cm hiller disks at the Nashua site. The mole knife consisted of a shank of 43 cm long by 1.6 cm wide and a mole of 4.5 cm wide by 9 cm long. Strip-tillage at both sites resulted in soil disturbed 20 cm wide and 10-15 cm deep leaving a berm of 7-10 cm high. Under no-tillage, the only field operation completed was seed planting and N fertilizer application. For all treatments N was injected at a rate of 170 kg N ha^{-1} in the row zone, resulting in minimal soil and residue disturbance. At the Ames site 32% ammonium nitrate (NH_4NO_3) was applied using a spoked point injector. At the Nashua site anhydrous ammonia was injected at a 15 cm depth using mole knives on the conventional tillage and strip-tillage plots and a nurse applicator with 1.25 cm wide shanks with a 3.5 cm wide shovel on the no-tillage plots. The nurse applicator was utilized on the no-tillage plots to minimize soil and residue disturbance. Weeds were controlled using pre- and post-emergence herbicides. At the Ames site in 2001, 2.2 L ha^{-1} of glyphosate (Roundup) was applied pre-emergence and no post-emergence herbicide was applied. In 2002, 2.2 L ha^{-1} of glyphosate (Roundup) was applied both pre- and post-emergence. At the Nashua site in 2001, 2.5 L ha^{-1} of dimethenamid (Frontier) was applied pre-emergence and 2.5 L ha^{-1} of bentazon + atrazine (Laddock) applied post-emergence. In 2002, 1.5 L ha^{-1} of dimethenamid (Outlook) was applied pre-emergence and 3.5 L ha^{-1} of dicamba + atrazine (Marksman) was applied post-emergence.

Crop Measurements

An emergence rate index (ERI) was determined using a method outlined by Erbach (1982) in which two rows 5.3 m long were staked prior to corn emergence and monitored each day for ten consecutive days following the first emergence. ERI was calculated using the following equation (Erbach, 1982);

$$ERI = \sum_{n=first}^{last} \frac{[\%n - \%(n-1)]}{n}$$

where, %n is percentage of plants emerged on day n, %(n-1) is percentage of plants emerged on day n-1, n is number of days after planting, first is number of days after planting when the first plant emerged, and last is number of days after planting when emergence was completed.

Corn yields were determined by hand-harvesting the center two-rows 5.3 m long of each plot. All corn ears were shelled to determine the corn yield. Corn grain yields were adjusted to 155 g kg^{-1} moisture. Plant samples were collected at the 6^{th}-leaf (V6), 12^{th}-leaf (V12), tassel (VT), and physiological maturity (R6) growth stages for the determination of dry matter production and N uptake. Corn plant samples were collected as identified by Ritchie et al. (1997) from each plot for both sites in each year. The area for plant sampling consisted of one 4.6 m long row per plot. The 4.6 m length was divided into three 1.53 m sections. At the V6, V12, VT, and R6 corn growth stages one plant from each section was cut at ground level, totaling three plants per plot. Plant samples were dried in a forced air oven at 55°C for at least four days before weighing. Concentrations of total N was determined by dry combustion using a LECO CHN-2000[1] C-N analyzer (LECO Corporation, St. Joseph, MI). Plant N uptake at different growth stages was calculated based on the total dry matter mass multiplied by their respective total N concentration. A ratio of corn grain

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

yield to N uptake by the grain (hereafter referred to as Y:N ratio) was determined by dividing each treatment's yield by its respective grain N uptake.

Soil Moisture Measurements

Profile soil moisture measurements were monitored after corn emergence until the R6 growth stage, while surface soil moisture was monitored from the beginning of May until the R6 growth stage. Soil moisture was measured in only the corn plots at both sites. Soil moisture measurements were taken at five increments through the soil profile: 0-15, 15-30, 30-60, 60-90, and 90-120 cm using time domain reflectometry (TDR). An Imko TRIME-FM instrument with a TRIME-T3 tube access probe was used to measure the profile (15-120 cm) volumetric water content (MESA Systems Company, Medfield, MA, USA). Surface soil moisture at 0-15 cm was measured using an Imko TRIME-FM instrument with a TRIME-P3 3-rod probe (MESA Systems Company, Medfield, MA, USA). Soil moisture access tubes were installed in two replications for each treatment, totaling of ten access tubes per site in 2001. In 2002, the number of access tubes installed was increased to include three replications for each treatment or fifteen access tubes per site. The clear plastic access tubes are 44 mm in diameter by 1.2 m long with a 1 mm wall thickness. The access tubes were installed by modifying the instructions developed by Imko to conform to a Giddings model GSRPS hydraulic soil probe (Giddings Machine Company, Fort Collins, CO). A 41 mm slotted soil tube adapted with a quick relief bit was used to remove a 1.1 m long soil core. To ensure the access tube had good contact with the soil a slightly smaller diameter and shorter soil core was removed. After the soil core was removed the access tube was installed using a steel guide and ramming head to avoid damaging the access tube. With the tube installed a rubber stopper assembly was placed in the bottom of the tube to guarantee the absence of a water table or ponding within the tube. Between measurements a plastic cap was placed on the tube to prevent precipitation, soil, insects, and rodents from occupying the access tubes.

Water Use Efficiency

The water use efficiency (WUE) was determined as follows:

$$WUE = GY / ET$$

where, WUE is water use efficiency, GY is grain yield, and ET is seasonal crop water use.

Seasonal ET (ET) was determined by using potential ET (ET_p) collected from weather stations near each site. The ET_p was multiplied by a crop coefficient based on dryland corn water use for Iowa (Roygard et al., 2002; Schwab et al., 1993) at different growth stages to determine the seasonal crop water use (ET). The ET was estimated for corn from emergence to physiological maturity. For the Ames corn site, the ET was estimated to be 568 and 614 mm for 2001 and 2002, respectively, while the ET for the Nashua corn site was estimated at 522 mm in 2001and 527 mm in 2002.

Statistical Analysis

Data was analyzed using the SAS statistical software package (SAS, 2001). The GLM Procedure was used to perform the analysis of variance, which was appropriate for a randomized complete block design for ERI, yield, dry matter, soil moisture, WUE, and N uptake. Means were separated using the least significant difference (LSD) when treatment effects were significant. Statistical significance was evaluated at $P \leq 0.05$.

RESULTS AND DISCUSSION

Emergence Rate Index

Fall strip-tillage with fall N fertilizer application (FST-FF) showed no significant improvement in ERI over the FST-SF, SST-SF, FCT-FF, or NT-FF treatments at the Ames site in 2001 (Table 2.2). Alternatively, the ERI of SST-SF treatment was significantly greater than that of FCT-FF and NT-FF in 2002 at the Ames site and NT-FF only at the Nashua site in both years. This can be attributed to the timing effect of both strip-tillage and fertilizer application early in the spring, where soil disturbance attributed to soil evaporation and seedbed warming compared to fall conventional tillage and no-tillage systems. In general, all strip-tillage treatments had a greater ERI than the FCT-FF and NT-FF treatments. Also, fall strip-tillage with spring N fertilizer application (FST-SF) ERI showed significant advantages over FST-FF and NT-FF treatments at the Nashua site in 2001 (Table 2.2). This can be attributed to soil disturbance early in the spring during fertilizer injection, which enhanced soil evaporation. Similar to the Ames site, strip-tillage treatments showed an advantage over the other tillage systems in promoting faster corn emergence at the Nashua site in 2001. In 2002, generally the ERI was not significantly different for any strip-tillage treatments. In general, strip-tillage treatments tend to have an ERI greater than conventional or no-tillage at both years and sites, except in a few cases.

In 2002, the ERI for all treatments was on average 59% and 28% lower than those in 2001 at both the Ames and Nashua sites, respectively (Table 2.2). Weather conditions at the Ames site in 2002 were much cooler in the 7 days following planting, where the average maximum air temperatures were 15.4°C compared to 28.7°C in 2001 and rainfall increased by 34.5 mm. The Nashua site experienced a similar trend in the 7 days following planting in 2002 except to a lesser degree than 2001, where the average maximum air temperatures were 20.7°C compared to 26.3°C, respectively, and rainfall was 25.4 mm higher in 2002. These cool, wet conditions can cause delayed seed germination and emergence minimizing the effect of strip-tillage in improving ERI.

Dry Matter Production and Plant N Uptake

All strip-tillage and N fertilizer treatments show no significant differences in dry matter production compared to FCT-FF and NT-FF at the V6, V12, VT, and R6 growth stages in both years and sites (Table 2.3). Neither strip-tillage timing nor N fertilizer timing resulted in significant differences in dry matter production between the treatments. However, at the R6 growth stage FST-FF produced slightly more dry matter than FCT-FF or NT-FF. The plant N uptake at different growth stages showed there were no significant differences between all treatments (Table 2.4). However, generally plant N uptake was greater for FCT-FF treatment than NT-FF and FST-FF at V6, V12, VT, and R6 in both years and sites. The general trend indicated FST-FF increased N uptake for all growth stages compared to the NT-FF treatment across sites and years. This can be attributed to the effect of N placement within the tilled zone, where it becomes more available to the plant compared to the other treatments.

Corn Grain Yield, Grain N Uptake, and Y:N Ratio

In 2001 and 2002, yield responses among all strip-tillage treatments and timing of N fertilizer applications were not significantly different at the Ames site (Table 2.5), even when FST-FF was compared to FCT-FF or NT-FF. However, it appeared yield associated with FCT-FF was much greater than those associated with all other treatments. Also, at the Nashua site, the yield for the timing of strip-tillage and fertilizer application treatments showed no significant differences. Similarly, yield for most strip-tillage treatments showed no significant difference compared to FCT-FF and NT-FF in 2001. In contrast, in 2002 corn yields associated with FST-FF were significantly greater than those of FST-SF and NT-FF at the Nashua site. In general, FST-FF showed a slight yield advantage over SST-SF and the other treatments.

Similarly, grain N uptake under all strip-tillage treatments showed no significant differences regardless of the time of N application at both sites and years, except where NT-FF grain N uptake was significantly lower than all other treatments at the Nashua site in 2002 (Table 2.5). The yield to N ratio (Y:N) was significantly greater with FST-FF compared to FCT-FF and NT-FF in 2001 at the Ames site (Table 2.5). Alternatively, the Y:N ratio for the 2002 growing season showed no significant differences between all treatments. The Y:N ratio of FST-FF was significantly different from FST-SF treatment only in 2001 and 2002 at the Nashua site. In summary, strip-tillage treatments showed no significant improvements in grain production per unit of N over the other tillage systems in both years at both sites, except in 2001 at the Ames site.

Corn Water Use Efficiency

Strip-tillage and N fertilizer timing treatments showed no significant improvement in the corn WUE for both years and sites (Table 2.6). However, FST-FF showed a slight advantage in corn WUE over the other strip-tillage treatments, but it has similar corn WUE compared to FCT-FF and NT-FF treatments. This suggests strip-tillage has no significant advantages over conventional tillage or no-tillage in improving corn WUE. Strip-tillage also has little effect in changing soil moisture status, where only a limited zone was disturbed within the field.

Soil Moisture Content

At the Ames site, post-emergence soil moisture showed significant differences between treatments at the 60 cm soil depth in 2001, where NT-FF > FST-FF = FST-SF = SST-SF = FCT-FF (Fig. 2.1). However, there were no significant differences in moisture content between all treatments at pre-harvest period for all depths in 2001 and at the post-emergence and pre-harvest periods in 2002 at the Ames site. At the Nashua site, in 2001, soil moisture content under NT-FF was consistently lower than that under the other four treatments (Fig. 2.2). When contrasting tillage effects (FCT-FF, FST-FF, NT-FF) on soil moisture, FCT-FF treatment soil moisture was significantly higher than that of NT-FF treatment at 60 and 90 cm and 30 and 60 cm for the post-emergence or pre-harvest periods, respectively. At the Nashua site during 2002, soil moisture content for all depths of all treatments was not significantly different at the post-emergence or pre-harvest periods.

The general trend at the Ames site showed there was an overall soil moisture decrease of the pre-harvest soil moisture profile compared to the post-emergence soil moisture profile at all soil depths during 2001 (Fig. 2.1). Conversely, during both years at the Nashua site trends showed there was no considerable change in soil moisture content at all depth increments under all treatments, when the post-emergence soil moisture profile was compared to that of pre-harvest (Fig. 2.2). This suggests the moisture used by the corn was provided almost solely by rainfall throughout the growing season.

CONCLUSIONS

Strip-tillage has the potential to maintain and possibly improve corn yields over other tillage systems. Results of this study show strip-tillage was competitive with conventional tillage and generally had an advantage over no-tillage in improving ERI. Spring strip-tillage and fertilizer application have improved ERI over fall strip-tillage. It was also observed that ERI was mostly affected by cold air temperatures and wet conditions, where a drop in air temperature and wet conditions in 2002 at the Ames site caused a much lower ERI than in 2001 when the weather conditions were stable. The advantage strip-tillage had over no-tillage in having greater ERI did not result in a yield advantage. In general, strip-tillage had no significant impact on increasing corn yields compared to other tillage systems in this study. However, strip-tillage was very comparable with conventional tillage as both generally yielded greater than no-tillage.

Corn dry matter production and N uptake were commonly improved using strip-tillage over no-tillage, but the effectiveness of strip-tillage still lags behind conventional tillage. The improvement in N uptake can be attributed to the effectiveness of N application in the row. Early N uptake was highly affected by tillage system, where conventional tillage out performed strip-tillage and strip-tillage out performed no-tillage. While, N uptake was less consistent, the trend indicated no-tillage was at a disadvantage compared to strip-tillage and conventional tillage. Tillage or N fertilizer timing had no significant effects on Y:N ratio or corn WUE. The corn WUE of both strip-tillage and conventional tillage were generally similar, yet greater than that of no-tillage.

The findings of this study strongly suggested strip-tillage has no significant advantages in improving corn yield, N uptake, and water use efficiency over no-tillage or conventional tillage systems, except in very few cases in central and northeast Iowa. The results also revealed strip-tillage may have a slight advantage over no-tillage at the onset of the growing season by improving seed germination. This advantage did not translate into a significant yield increase regardless of the different timings of strip-tillage and N fertilizer applications. Therefore, the promotion of strip-tillage should be site and weather condition specific to justify the adoption of the practice. It was also apparent that soils under cold and poorly drained conditions could benefit early in the season by implementing a strip-tillage system due to the improvement in soil seedbed conditions.

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Table 2.1. Soil descriptions of the experiment sites near Ames and Nashua, Iowa.

Site	Soil Series	Soil Classification	Soil Texture	BD†	OM†	pH
				g cm^{-3}	g kg^{-1}	
Ames	Nicollet	Aquic Hapludolls	loam	1.20	45	6.4
	Webster	Typic Haplaquolls	silty clay loam	1.35	65	6.9
Nashua	Floyd	Aquic Hapludolls	loam	1.35	60	6.7
	Kenyon	Typic Hapludolls	loam	1.40	30	6.4

†BD, bulk density; OM, organic matter

Table 2.2. Tillage and N fertilizer timing effects on corn ERI in 2001 and 2002.

	Ames		Nashua	
Treatment†	2001	2002	2001	2002
FST-FF	16.9a‡	7.0ab	10.0bc	7.4b
FST-SF	17.3a	6.9b	11.2a	7.7ab
SST-SF	17.9a	7.7a	11.0ab	7.7ab
FCT-FF	16.8a	6.7b	10.1abc	8.2a
NT-FF	16.1a	6.3b	9.8c	6.7c
Contrasts§				
Tillage	ns	ns	ns	*
Strip	ns	*	ns	ns
Fertilizer	ns	ns	*	ns

† FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

‡ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

§ Tillage, FST-FF vs. FCT-FF vs. NT-FF; Strip, FST-SF vs. SST-SF; Fertilizer, FST-FF vs. FST-SF.

*, ns; Significant at 0.05 and 0.10 probability levels and not significant at 0.10 probability level, respectively.

Table 2.3. Tillage and N fertilizer timing effects on corn dry matter production in 2001 and 2002.

Site	Treatment†	V6		V12		VT		R6	
		2001	2002	2001	2002	2001	2002	2001	2002‡
		Mg ha^{-1}							
Ames	FST-FF	0.38a§	0.18a	1.96b	3.78a	5.83a	5.92a	21.47a	
	FST-SF	0.35a	0.20a	2.12b	3.74a	6.63a	6.35a	19.17a	
	SST-SF	0.36a	0.17a	2.31ab	3.91a	5.88a	6.41a	18.78a	
	FCT-FF	0.47a	0.28a	2.97a	4.57a	7.96a	6.12a	20.84a	
	NT-FF	0.28a	0.16a	2.24b	3.35a	6.28a	5.09a	20.83a	
	Contrasts¶								
	Tillage	*	ns	*	*	*	ns	ns	
	Strip	ns	ns	ns	ns	ns	ns	ns	
	Fertilizer	ns	ns	ns	ns	ns	ns	ns	
Nashua	FST-FF	0.27a	0.08a	2.94a	2.77a	5.84a	5.69a	23.61a	13.66a
	FST-SF	0.24a	0.10a	3.03a	2.87a	6.80a	5.42a	21.54a	11.23a
	SST-SF	0.27a	0.07a	3.64a	2.44a	6.83a	5.12a	22.63a	10.44a
	FCT-FF	0.29a	0.10a	3.57a	3.05a	7.07a	5.90a	20.99a	11.07a
	NT-FF	0.26a	0.08a	2.99a	2.56a	6.53a	5.45a	22.48a	9.52a
	Contrasts								
	Tillage	ns	ns	ns	ns	ns	ns	ns	**
	Strip	*	*	ns	ns	ns	ns	ns	ns
	Fertilizer	ns	ns	ns	ns	ns	ns	ns	ns

† FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

‡ Data is not available for the Ames site.

§ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

¶ Tillage, FST-FF vs. FCT-FF vs. NT-FF; Strip, FST-SF vs. SST-SF; Fertilizer, FST-FF vs. FST-SF.

*, **, ns; Significant at 0.05 and 0.10 probability levels and not significant at 0.10 probability level, respectively.

Table 2.4. Tillage and N fertilizer timing effects on plant N uptake for corn at different growth stages in 2001 and 2002.

		V6		V12		VT		R6	
Site	Treatment†	2001	2002	2001	2002	2001	2002	2001	2002‡
		kg ha^{-1}							
Ames	FST-FF	16.8a§	8.9a	59.8a	120.2a	113.2a	137.1a	140.3a	
	FST-SF	15.7a	10.2a	64.1a	95.4a	133.2a	144.6a	136.4a	
	SST-SF	15.8a	8.8a	67.2a	104.4a	122.4a	155.5a	127.2a	
	FCT-FF	20.9a	14.3a	89.8a	115.9a	156.6a	136.7a	149.9a	
	NT-FF	12.2a	7.9a	67.1a	84.8a	141.1a	110.6a	148.1a	
	Contrasts¶								
	Tillage	*	*	*	**	**	ns	ns	
	Strip	ns	ns	ns	ns	ns	ns	ns	
	Fertilizer	ns	ns	ns	**	ns	ns	ns	
Nashua	FST-FF	12.5a	4.1a	82.8a	91.9a	119.4a	146.4a	172.3a	106.3a
	FST-SF	10.8a	5.4a	81.3a	107.9a	144.2a	156.2a	148.4a	104.3a
	SST-SF	13.3a	3.8a	102.2a	93.0a	145.7a	145.8a	186.3a	89.0a
	FCT-FF	14.1a	5.3a	99.7a	102.7a	150.8a	141.5a	178.9a	83.6a
	NT-FF	11.9a	3.7a	79.2a	78.9a	135.3a	124.7a	152.2a	67.2a
	Contrasts								
	Tillage	ns	ns	ns	ns	ns	ns	ns	**
	Strip	ns	*	**	ns	ns	ns	*	ns
	Fertilizer.	ns	**	ns	ns	ns	ns	ns	ns

† FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

‡ Data is not available for the Ames site.

§ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

¶ Tillage, FST-FF vs. FCT-FF vs. NT-FF; Strip, FST-SF vs. SST-SF; Fertilizer, FST-FF vs. FST-SF.

*, **, ns; Significant at 0.05 and 0.10 probability levels and not significant at 0.10 probability level, respectively.

Table 2.5. Tillage and N fertilizer timing effects on corn grain yield, grain N uptake, and the Y:N ratio in 2001 and 2002.

	Corn Yield				Grain N Uptake				Y:N Ratio			
	Ames		Nashua		Ames		Nashua		Ames		Nashua	
Treatment†	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
	------- $Mg\ ha^{-1}$ -------				--------- $kg\ ha^{-1}$ ---------				------- $Mg\ Mg^{-1}$ -------			
FST-FF	11.4a‡	14.2a	13.9a	15.0a	130.1a	164.6a	161.6a	174.0a	87.4a	86.8a	85.9bc	85.9a
FST-SF	11.2a	13.8a	13.4a	13.4b	135.7a	160.8a	144.0a	178.6a	82.7ab	85.8a	93.5a	75.0b
SST-SF	11.3a	14.7a	13.3a	13.3b	141.0a	172.5a	147.8a	185.2a	80.1b	85.3a	90.3ab	71.9b
FCT-FF	12.1a	18.8a	13.3a	14.9a	156.4a	159.0a	160.0a	173.5a	77.2b	86.9a	83.3c	86.0a
NT-FF	11.5a	14.1a	13.5a	13.1b	142.3a	158.2a	147.3a	147.0b	81.2b	89.0a	91.5ab	89.1a
Contrasts§												
Tillage	ns	ns	ns	*	ns	*	ns	*	*	ns	*	ns
Strip	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Fertilizer	ns	ns	ns	*	**	ns	ns	*	**	ns	*	*

† FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

‡ Means within the same column with same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

§ Tillage, FST-FF vs. FCT-FF vs. NT-FF; Strip, FST-SF vs. SST-SF; Fertilizer, FST-FF vs. FST-SF.

*, **, ns; Significant at 0.05 and 0.10 probability levels and not significant at 0.10 probability level, respectively.

Table 2.6. Tillage and N fertilizer timing effects on corn grain WUE in 2001 and 2002.

	Ames		Nashua	
Treatment†	2001	2002	2001	2002
	------ kg ha^{-1} mm^{-1} ------			
FST-FF	20.0a‡	23.2a	26.6a	28.3a
FST-SF	19.7a	22.4a	25.7a	25.4b
SST-SF	19.8a	24.0a	25.5a	25.2b
FCT-FF	21.3a	22.5a	25.5a	28.2a
NT-FF	20.3a	22.9a	25.8a	24.8b
Contrasts§				
Tillage	ns	ns	ns	*
Strip	ns	*	ns	ns
Fertilizer	ns	ns	ns	*

† FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

‡ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

§ Tillage, FST-FF vs. FCT-FF vs. NT-FF; Strip, FST-SF vs. SST-SF; Fertilizer, FST-FF vs. FST-SF.

*, **, ns; Significant at 0.05 and 0.10 probability levels and not significant at 0.10 probability level, respectively.

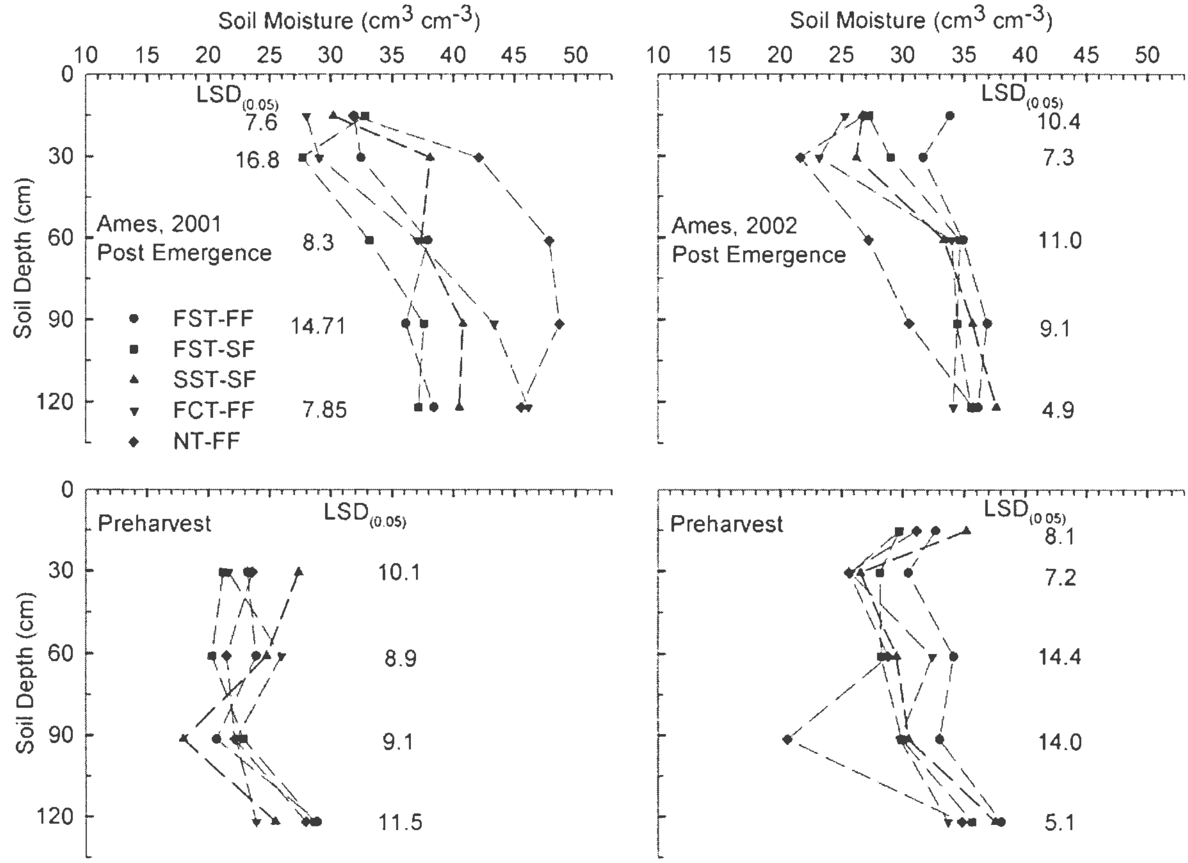

Figure 2.1. Soil moisture profile for the Ames, Iowa site during 2001 and 2002. The post-emergence soil moisture measurements were on 8 June 2001 and 28 May 2002 and the pre-harvest soil moisture measurements were on 28 August 2001 and 19 August 2002. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

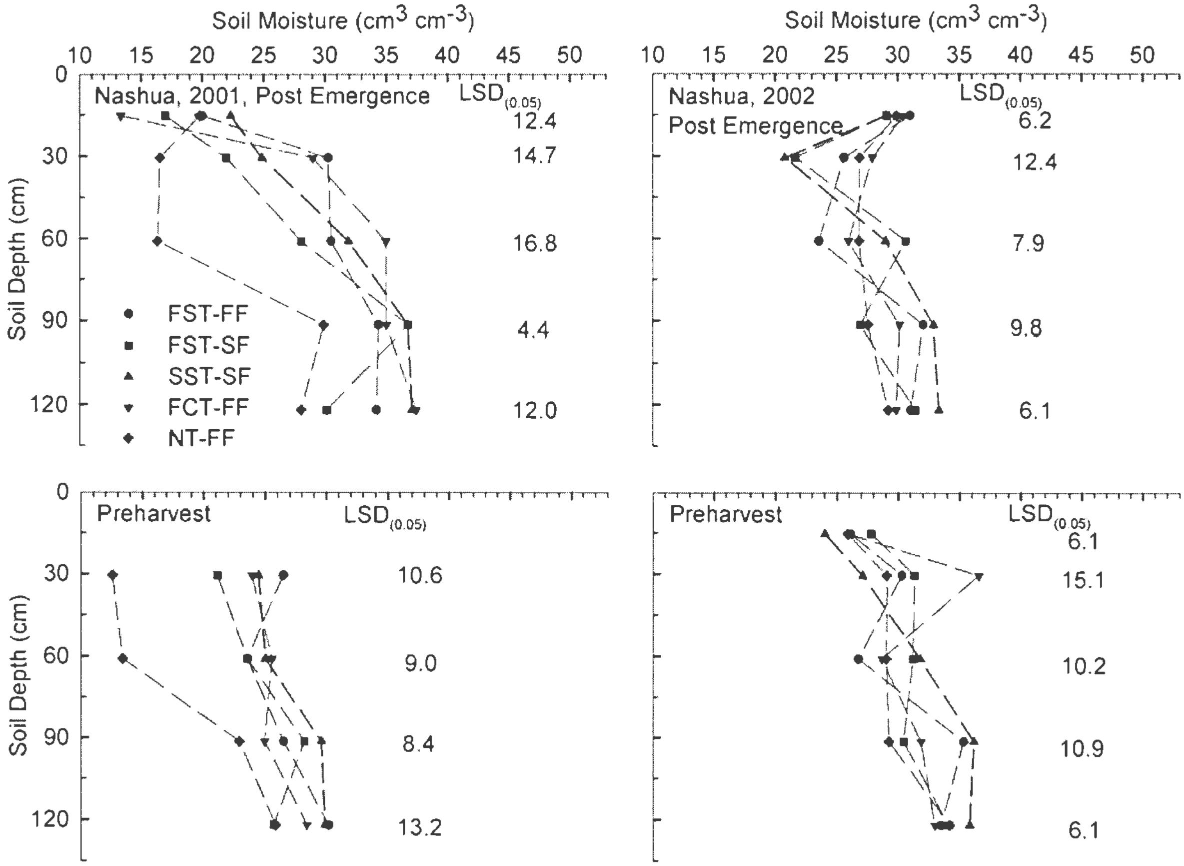

Figure 2.2. Soil moisture profile for the Nashua, Iowa site during 2001 and 2002. The post-emergence soil moisture measurements were on 28 June 2001 and 30 May 2002 and the pre-harvest soil moisture measurements were on 22 August 2001 and 20 August 2002. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

CHAPTER 3

EVALUATION OF N APPLICATION TIMING AND STRIP-TILLAGE EFFECTS ON N USE BY CORN AND NITRATE MOVEMENT

INTRODUCTION

Iowa has repeatedly led the United States in corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) production with 15% of the 62.2 million hectares nation wide in corn and soybean production according to the National Agricultural Statistics Service (N.A.S.S., 2002). On average, 98% of corn hectares in production receive N fertilization, and in Iowa alone approximately 0.7 million metric tons of N fertilizer is being applied on 5 million hectares of corn each year (N.A.S.S., 2002). Nitrogen fertilizer application is often the cause of increased 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 like methemoglobinemia (Fletcher, 1991; Keeney and Follett, 1991). Many soil and water quality problems are associated with conventional tillage along with other problems that effect water resources (Baker and Laflen, 1983; Mickelson et al., 2001; Zalidis et al., 2002).

It is well known that soil NO_3-N is very mobile in the soil, therefore it is susceptible to deep leaching and surface water runoff. Weed and Kanwar (1996) showed results from a three year corn-soybean rotation in which moldboard plowing reduced tile flow by an average of 2 cm of water compared to no-tillage. In the same study, the average NO_3-N concentration in the tile flow of no-tillage was lower (21.9 mg L^{-1}) than that of moldboard plowing (36.9 mg L^{-1}), while the average NO_3-N loss from the no-tillage system was 74 kg ha^{-1} less than the moldboard plow system. Randall and Iragavarapu (1995) found similar trends under continuous corn from an eleven year study. In this study NO_3-N losses were not as extreme for moldboard plowing (43 kg ha^{-1}) as compared to no-tillage (41 kg ha^{-1}). The narrow difference in NO_3-N loss between the two systems was attributed to the greater length of the study which provided greater variability in the soil and environmental conditions.

With concerns about the impacts of N management and the timing of N application on water quality, tillage systems need to be evaluated on how they effect soil and water resources. The susceptibility of N to leaching, denitrification, volatilization, and immobilization is increased with fall application compared to spring application (Dinnes et al., 2002). During conditions were N becomes deficient crop productivity can decline rapidly (Kucey and Schaalje, 1986; Randall et al., 1997; Reeves et al., 1993; Torbert et al., 2001; Welch et al., 1971). In addition, fall N application can lead to significant N losses, rendering it less effective for plant uptake, thus delaying N application until the spring can reduce NO_3-N losses due to leaching and surface water runoff (Carefoot and Janzen, 1997; Malhi and Nyborg, 1983). In southern Minnesota, NO_3-N losses into tile drains were reduced by 36% with spring N application compared to fall N application (Randall, 1997).

Tillage systems have a significant effect on organic matter dynamics by affecting different C and N pools in the soil. Soil disturbance incorporates surface residue, which increases the rate of residue decomposition and increases soil aeration (McCarthy et al., 1995). This process will impact soil organic N mineralization whereby readily available N for plant use is increased (Dinnes et al., 2002). Tillage systems and N fertilization timing can influence the amount of N lost and residual soil N in the soil profile. The deeper NO_3-N accumulates in the soil profile, the greater the potential for NO_3-N leaching into shallow water tables (Keeney and Follett, 1991). Halvorson et al. (2001) found conventional and conservation tillage systems accumulated more soil NO_3-N down to 150 cm compared to no-tillage in a spring wheat (*Triticum aestivum* L.) -fallow annual cropping study in North Dakota. The study concluded conventional and conservation tillage systems were able to mineralize more N at the soil surface due to soil disturbance. In Georgia, Sainju and Singh (2001) found similar evidence where more intensive tillage systems accumulated more NO_3-N than no-tillage under corn with a cover crop. In Canada, fall versus spring N application was evaluated for N application timing effects on residual soil N (Carefoot and Janzen, 1997). It was found that spring N application had greater soil N reserves at the 0-120 cm soil depth and plant N uptake compared to fall N application, indicating that fall N application is prone to more environmental N losses than spring N application.

Conservation tillage practices are a viable means of increasing N uptake by corn plants. Grain N content is often greater for no-tillage systems due to no-tillage crops being more efficient at removing soil N than crops grown using conventional tillage (Angle et al., 1993). Several studies found no-tillage increases grain N uptake slightly over conventional tillage and is generally equal to that of conservation tillage (Angle et al., 1993; Halvorson et al., 2001; Sainju and Singh, 2001). Alternatively, other studies found N deficiencies are more common in no-tillage systems than conventional tillage systems (Mehdi et al., 1999; Olson and Kurtz, 1982), translating into less grain N uptake. This was also evident from the findings of a study in southwestern Quebec in which grain N uptake under no-tillage systems were slightly less than grain N uptake for conservation and conventional tillage systems (Mehdi et al., 1999).

In the early 1990's the concept of an alternative tillage system, strip-tillage, began to increase in popularity and use. This system offers a unique opportunity to apply nutrients and prepare a seedbed in one tillage operation. This characteristic provides a solution to the potential problems associated with conventional tillage systems, namely increased NO_3-N leaching and surface water runoff. Generally, strip-tillage disturbs a narrow zone of 15-20 cm wide and 15-20 cm deep in the previous crop row, whereas the interrow area is left undisturbed. Therefore, the concepts of strip-tillage can be identified as a tillage system as well as a nutrient application system (Al-Kaisi and Hanna, 2002). The timing of strip-tillage and N application may be crucial to both water quality and N availability. However, there is a lack of research on tillage and N timing for strip-tillage. Therefore, the objectives of this study were to (i) evaluate the effect of strip-tillage on available soil N use and (ii) determine the impact of fall versus spring N application on NO_3-N movement under strip-tillage, conventional tillage and no-tillage systems.

MATERIALS AND METHODS

Site Description

The study was conducted on two Iowa State University research and demonstration farms in 2001 and 2002 (Table 3.1). One site was at the Marsden research farm near Ames, Iowa, where the soils were Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludolls) and Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls). This site was planted to corn (Fontenelle 4741 hybrid) on 10 May 2001 and 6 May 2002 with seed drop populations of 74,600 and 79,000 plants ha^{-1}, respectively. Seasonal precipitation (October through September) in 2001 was 766 mm and 713 mm for 2002 with a normal precipitation of 813 mm. The second site was at the Northeast Research and Demonstration Farm near Nashua, Iowa. Soils at this site were Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls) and Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls). 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. The seasonal precipitation was 832 and 711 mm in 2001 and 2002, respectively, with a normal precipitation of 864 mm. Prior to this study both locations were under a corn-soybean rotation with soybeans planted in 2000. The Ames site had previously been under a no-tillage corn soybean rotation, while the Nashua site was previously under a conservation tillage corn soybean rotation.

Experimental Design and Management

The study consists of three tillage systems; conventional tillage, strip-tillage, and no-tillage. The strip-tillage treatments consist of fall and spring strip-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 conventional tillage with fall N fertilizer application (FCT-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 long and 27.4 m wide. Each treatment plot was split into two halves; one half was planted to corn and the other to soybeans to establish a corn-soybean rotation sequence.

On the conventional tillage 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 modified with mole knives followed by 51 cm hiller disks at the Nashua site. The mole knife consisted of a shank of 43 cm long by 1.6 cm wide and a mole of 4.5 cm wide by 9 cm long. Strip-tillage at both sites resulted in soil disturbed 20 cm wide and 10 to 15 cm deep leaving a berm of 7 to 10 cm high. Under no-tillage, the only field operation completed was seed planting and N fertilizer application. For all treatments N was injected at a rate of 170 kg N ha^{-1} in the row zone, resulting in minimal soil and residue disturbance. At the Ames site 32% ammonium nitrate (NH_4NO_3) was applied using a spoked point injector. At the Nashua site anhydrous ammonia was injected at a 15 cm depth using mole knives on the conventional tillage and strip-tillage plots and a nurse applicator with 1.25 cm wide shanks with a 3.5 cm wide shovel on the no-tillage plots. The nurse applicator was utilized on the no-tillage plots to minimize soil and residue disturbance. Weeds were controlled using pre- and post- emergence herbicides. At the Ames site in 2001, 2.2 L ha^{-1} of glyphosate (Roundup) was applied pre-emergence and no post-emergence herbicide was applied. In 2002, 2.2 L ha^{-1} of glyphosate (Roundup) was applied both pre- and post-emergence. At the Nashua site in 2001, 2.5 L ha^{-1} of dimethenamid (Frontier) was applied pre-emergence and 2.5 L ha^{-1} of bentazon + atrazine (Laddock) applied post-emergence. In 2002, 1.5 L ha^{-1} of dimethenamid (Outlook) was applied pre-emergence and 3.5 L ha^{-1} of dicamba + atrazine (Marksman) was applied post-emergence.

Soil N Measurements

Prior to establishing the study soil samples were taken in the fall of 2000 for each site before tillage or N application was implemented to the treatments. For each subsequent year (2001 and 2002), soil samples were taken immediately following harvest. The soil samples were taken to a depth of 1.2 m in the following increments; 0-15, 15-30, 30-60, 60-90, 90-120 cm. Soils samples were kept in plastic lined paper bags and placed in a cooler. After sample collection the samples were immediately air dried and analyzed for total N (for the 0-15 cm depth) by dry combustion using a LECO CHN-2000[2] C-N analyzer (LECO Corporation, St. Joseph, MI) and for NO_3-N (for the 0-120 cm depths) using a Lachat QuickChem 4 in 2000 and 2001 and a Lachat QuickChem 8000 (Lachat Instruments, Milwaukee, WI) in 2002.

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

Nitrate Leaching

Soil water samples were collected to measure NO_3-N leached after rain events for each tillage and N timing treatment at a 1.2 m depth using a suction lysimeter with a porous ceramic cup. The lysimeters were constructed of 1.2 m long PVC tubes with a 3 cm inner diameter and were placed in the corn row. 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 around the lysimeter to prevent a preferential flow path. Afterwards, the slurry was allowed to reach equilibrium with the soil water before a vacuum was applied. Collection of soil-water samples from the suction lysimeters occurred 24 hours after a rainfall event equal to or exceeding 10 mm, potentially causing NO_3-N leaching conditions. To collect a soil water sample a vacuum of 0.59 MPa was applied to the lysimeters using a battery operated pump supplied by SoilMoisture Equipment Corporation (Goleta, CA). Prior to applying a vacuum the tubes were emptied of any free water. The vacuum was applied 24 hours before a water sample was collected. The water samples were collected in plastic nalgene bottles and placed in a cooler. The water samples were frozen if NO_3-N analysis was not done immediately. The water samples were thawed to room temperature prior to analyzing them for NO_3-N 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 long, 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 35°C for seven days. The dried grain samples were analyzed for total N by dry combustion using a LECO CHN-2000 C-N analyzer (LECO Corporation, St. Joseph, MI). Grain N uptake was calculated based on the total dry mass multiplied by the respective total N concentration. A ratio of corn grain yield to grain N uptake (hereafter referred to as Y:N ratio) was determined by dividing each treatment's yield by its respective grain N uptake.

Statistical Analysis

Data was analyzed using the SAS statistical software package (SAS, 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, profile soil NO_3-N, soil water NO_3-N, grain N uptake, grain yield, and Y:N ratio. Means were separated using a least significant difference (LSD) when treatment effects were significant. Statistical significance was evaluated at $P \leq 0.05$.

RESULTS AND DISCUSSION

Residual Soil NO_3-N

The residual soil NO_3-N for the Ames site over the duration of the study did not show significant differences between all treatments except for at the 15 cm soil depth (Fig. 3.1). At the 15 cm soil depth FST-FF had a significantly higher residual soil NO_3-N than NT-FF. Also, FST-FF did not result in a significantly different residual soil NO_3-N compared to FST-SF and SST-SF, indicating no affect due to the timing of N application and strip-tillage. In general, at the Ames site only a slight increase in residual soil NO_3-N was observed for all treatments throughout the soil profile for the duration of the study. At the Nashua site the overall residual soil NO_3-N was significantly lower for NT-FF at the 30 and 60 cm soil depths compared to FST-FF and FCT-FF (Fig. 3.1) and at the 15, 90, and 120 cm soil depths residual soil NO_3-N was not significantly impacted by the three tillage systems. The trends of residual soil NO_3-N at the Nashua site indicated that NO_3-N accumulated more at 120 cm under NT-FF than under both FST-FF and FCT-FF treatments.

The residual soil NO_3-N for the 120 cm soil profile after the first and second year was not significantly different between all treatments at the Ames site (Table 3.2). In the first year residual soil NO_3-N had a net loss for all treatments ranging from 1.7 to 19.9 kg ha^{-1} except for the SST-SF treatment, which had a slight gain of 2.0 kg ha^{-1}. This suggests less NO_3-N was lost from the soil profile under the spring strip-tillage. The second year showed an increase of residual soil NO_3-N for all treatments, except NT-FF in which there was a net loss of 3.1 kg ha^{-1}. The residual soil NO_3-N was slightly higher for the fall N fertilizer application compared to that of spring N fertilization. Over the two year, FST-FF and NT-FF resulted in significantly lower residual soil NO_3-N build up (9.8 and -5.2 kg ha^{-1}, respectively) compared to FCT-FF (30.3 kg ha^{-1}). The timing of N fertilizer application and strip-tillage did not reduce overall residual soil NO_3-N loss compared to the other treatments.

At the Nashua site the residual soil NO_3-N for the first year indicated fertilization timing and tillage systems impacted residual soil NO_3-N (Table 3.2). The residual soil NO_3-N for SST-SF was significantly higher than FST-SF (109.8 and 19.6 kg ha^{-1}, respectively). The residual soil NO_3-N after the second year showed no significant difference in NO_3-N loss between all tillage systems. However, the overall (2000 to 2002) residual soil NO_3-N indicated that FST-FF and FCT-FF had significantly greater residual soil NO_3-N than NT-FF, but all showed a net increase in residual soil NO_3-N.

Soil NO_3-N Distribution Through the Soil Profile

The soil NO_3-N distribution profile at the Ames site in 2000 and 2001 did not indicate any significant differences between all treatments (Fig. 3.2). However, in 2002 the soil NO_3-N content was significantly greater for FST-FF compared to FST-SF, FCT-FF, and NT-FF in the top 15 cm, while FCT-FF had significantly higher soil NO_3-N content than NT-FF at the 90 and 120 cm soil depth. Generally, in 2002 NT-FF had lower soil NO_3-N content than the other treatments and FCT-FF was consistently higher. The overall trend for the Ames site indicated that there was a slight increase in soil NO_3-N content from year to year with consistent increases in NO_3-N accumulations at all soil depths.

At the Nashua site, soil NO_3-N content was not significantly different between all treatments for the background soil sampling in 2000 (Fig. 3.2). In 2001, the soil NO_3-N content showed significant differences between all treatments at all soil depths except the 15 and 30 cm soil depths. In the upper depths soil NO_3-N content was generally higher for NT-FF, while at the lower depths of FCT-FF NO_3-N content was generally higher. The soil NO_3-N content showed no significant difference between treatments for all depths in 2002. However, soil NO_3-N content under FCT-FF was slightly greater than under FST-FF and the soil NO_3-N content under NT-FF was generally the lowest. At the Nashua site, the overall trend indicated a large net accumulation of soil NO_3-N at the 60 to 120 cm soil depths and only a slight increase at 0-30 cm.

The NO_3-N content of the soil profile for the Ames site was not significantly different for treatments for the initial sampling in 2000 and for the 2001 growing season (Table 3.3).

However, in the fall of 2002 FST-SF and NT-FF caused significantly lower soil NO_3-N build up in the soil profile than FCT-FF. At the Nashua site the initial soil NO_3-N content was not significantly different for all treatments. In 2001, the soil NO_3-N content was significantly higher for SST-SF compared to FST-SF, indicating the effect of N fertilizer timing (spring application) in reducing N losses. The soil NO_3-N content in 2002 showed the tillage effect on N loses where NT-FF had the lowest NO_3-N build up compared to FCT-FF and FST-FF. This suggests that NO_3-N loss is much greater with NT-FF compared to the other tillage systems.

Soil NO_3-N Leaching

In 2001 and 2002 at the Ames site the soil-water NO_3-N concentration was not significantly different between all treatments indicating no effect due to tillage systems or timing of N fertilizer application and strip-tillage on NO_3-N concentrations (Fig. 3.3). In 2001, soil water NO_3-N losses showed little change throughout the growing season, while in 2002 the NO_3-N concentration dropped significantly after day of year (DOY) 150. At the Nashua site in 2001, there was no significant difference between all treatments in soil NO_3-N losses, but an overall decrease in NO_3-N concentration from the beginning to the end of the season was observed. At the Nashua site unlike 2001, 2002 was more variable in the amount of NO_3-N movement during the growing season. The soil NO_3-N concentration for FST-FF decreased as the season progressed, while NT-FF increased after DOY 190 as the rainfall amount increased. However, soil NO_3-N concentration differences were only significant between treatments at DOY 150 and 171, where at both dates FST-FF resulted in significantly greater soil NO3-N concentrations than that of NT-FF. The average soil NO_3-N concentration per leaching rainfall event did not show significant differences between all treatments for either location during 2001 or 2002 (Fig. 3.4). Generally, at the Ames and Nashua site the average soil NO_3-N leached was slightly reduced for NT-FF compared to FST-FF and FCT-FF, except at the Ames site in 2001, where FST-FF was lower than FCT-FF and NT-FF.

Yield Response and Grain N Uptake

In 2001 and 2002, yield responses among all strip-tillage treatments and timing of N fertilizer applications were not significantly different at the Ames site (Table 3.4), even when

FST-FF was compared to FCT-FF or NT-FF. However, it appeared yield associated with FCT-FF was much greater than those associated with all other treatments. Also, at the Nashua site in 2001, strip-tillage and timing of N fertilizer application showed no significant yield differences. Similarly, yield for most strip-tillage treatments showed no significant difference compared to FCT-FF and NT-FF in 2001. In contrast, in 2002 corn yields associated with FST-FF were significantly greater than those of FST-SF and NT-FF at the Nashua site. In general, FST-FF showed a slight yield advantage over SST-SF and the other treatments.

Similarly, grain N uptake under all strip-tillage treatments showed no significant differences regardless of the time of N application at both sites and years, except where NT-FF grain N uptake was significantly lower than all other treatments at the Nashua site in 2002 (Table 3.4). The yield to N ratio (Y:N) was significantly greater with all strip-tillage and fertilizer timing treatments compared to FCT-FF and NT-FF in 2001 at the Ames site (Table 3.4). Alternatively, the Y:N ratio for the 2002 growing season showed no significant differences between all treatments. The Y:N ratio of FST-FF was significantly different from FST-SF only in 2001 and 2002 at the Nashua site. In summary, strip-tillage treatments showed no significant improvements in grain production per unit of N over other tillage systems in both years at both sites, except in 2001 at the Ames site.

CONCLUSION

The findings of this study suggest residual soil NO_3-N in the soil profile varies from year to year depending on climatic conditions. However, at both the Ames and Nashua sites no-tillage and strip-tillage generally resulted in lower residual soil NO_3-N build up than conventional tillage, and the timing of N fertilizer application had a relatively insignificant effect on soil nitrate. At the Ames site, the NO_3-N distribution in the soil profile was uniform through the soil profile. Alternatively, at the Nashua site there was greater NO_3-N accumulation in the lower depths of the soil profile, indicating the potential of NO_3-N leaching. Soil-water NO_3-N concentrations for strip-tillage was not significantly different from the other treatments regardless of the timing of tillage systems and N fertilizer application. The trends for soil NO_3-N leaching generally decreased as the growing season progressed due to a decrease in the amount of rainfall and soil-water movement. Strip-tillage, in general, had no significant impact on increasing corn yields compared to other tillage systems in this study. However, strip-tillage was very comparable with conventional tillage, as both generally yielded greater than no-tillage. Alternatively, grain N uptake was commonly improved using strip-tillage over no-tillage, but the effectiveness of strip-tillage still lags behind conventional tillage. It was also apparent from this study that tillage or N fertilizer timing had no significant effects on the Y:N ratio.

Under the conditions of this study the results revealed strip-tillage would not significantly impact N leaching or the build up of N in the soil profile compared to conventional tillage and no-tillage. However, grain yields and N uptake may be improved for strip-tillage compared to no-tillage although the Y:N ratio difference remains insignificant. Therefore, the promotion of strip-tillage should be considered for its potential to improve grain yields, N uptake, and seedbed conditions rather than for its ability to reduce N movement in the soil profile.

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Table 3.1. Soil descriptions of the experiment site near Ames and Nashua, Iowa.

Site	Soil Series	Soil Classification	Soil Texture	BD†	OM†	pH
				g cm^{-3}	g kg^{-1}	
Ames	Nicollet	Aquic Hapludolls	loam	1.20	45	6.4
	Webster	Typic Haplaquolls	silty clay loam	1.35	65	6.9
Nashua	Floyd	Aquic Hapludolls	loam	1.35	60	6.7
	Kenyon	Typic Hapludolls	loam	1.40	30	6.4

† BD, bulk density; OM, organic matter.

Table 3.2. Residual soil NO_3-N of the 0-120 cm soil depth for each growing season and overall from 2000 to 2002.

	Ames†			Nashua†		
Treatment‡	2001	2002	Overall	2001	2002§	Overall§
	kg ha^{-1}					
FST-FF	-19.9a¶	29.8a	9.8b	88.0ab	-8.1a	79.9a
FST-SF	-2.5a	15.4a	13.0ab	19.6b		
SST-SF	2.0a	11.7a	13.8ab	109.8a		
FCT-FF	-1.7a	32.9a	30.3a	133.8a	-29.3a	104.6a
NT-FF	-2.2a	-3.1a	-5.2b	78.8ab	-66.9a	11.9b

† Residual soil NO_3-N for 2001 and 2002 are calculated as current year minus previous year and the overall is 2002 minus 2000.

‡ FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

§ Data is not available for treatments FST-SF and SST-SF of the Nashua site in 2002.

¶ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

Table 3.3. Total soil NO_3-N of the 0-120 cm soil depth for the falls of 2000, 2001, and 2002.

	Ames			Nashua		
Treatment†	2000	2001	2002	2000	2001	2002‡
	- - - - - - - - - - - - - - - kg ha^{-1} - - - - - - - - - - - - - - -					
FST-FF	33.8a§	13.8a	43.6ab	21.0a	109.0ab	100.9ab
FST-SF	25.2a	22.7a	37.1b	23.8a	43.3b	
SST-SF	30.2a	32.2a	44.0ab	28.4a	138.1a	
FCT-FF	30.2a	28.5a	60.4a	22.5a	156.3a	127.0a
NT-FF	32.5a	30.3a	27.3b	42.3a	121.1ab	54.2b

† FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

‡ Data is not available for treatments FST-SF and SST-SF of the Nashua site in 2002.

§ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

Table 3.4. Tillage and N fertilizer timing effects on corn grain yield, grain N uptake, and Y:N ratio in 2001 and 2002.

	Corn Yield				Grain N Uptake				Y:N Ratio			
	Ames		Nashua		Ames		Nashua		Ames		Nashua	
Treatment†	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
	- - - - - - - Mg ha^{-1} - - - - - - -				- - - - - - - - - kg ha^{-1} - - - - - - - - -				- - - - - - - - Mg Mg^{-1} - - - - - - - -			
FST-FF	11.4a‡	14.2a	13.9a	15.0a	130.1a	164.6a	161.6a	174.0a	87.4a	86.8a	85.9bc	85.9a
FST-SF	11.2a	13.8aa	13.4a	13.4b	135.7a	160.8a	144.0a	178.6a	82.7ab	85.8a	93.5a	75.0b
SST-SF	11.3a	14.7a	13.3a	13.3b	141.0a	172.5a	147.8a	185.2a	80.1b	85.3a	90.3ab	71.9b
FCT-FF	12.1a	18.8a	13.3a	14.9a	156.4a	159.0a	160.0a	173.5a	77.2b	86.9a	83.3c	86.0a
NT-FF	11.5a	14.1a	13.5a	13.1b	142.3a	158.2a	147.3a	147.0b	81.2b	89.0a	91.5ab	89.1a

† FST-FF, fall strip-tillage with fall N fertilizer; FST-SF, fall strip-tillage with spring N fertilizer; SST-SF, spring strip-tillage with spring N fertilizer; FCT-FF, conventional tillage with fall N fertilizer; NT-FF, no-tillage with fall N fertilizer.

‡ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.

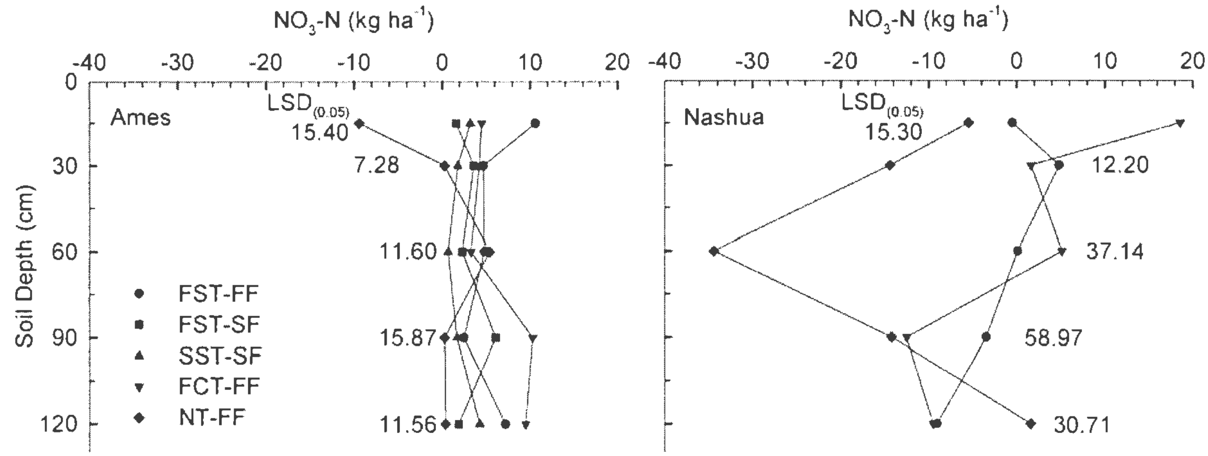

Figure 3.1. Residual soil NO_3-N for the duration of the study (2000 to 2002) for the Ames and Nashua sites. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

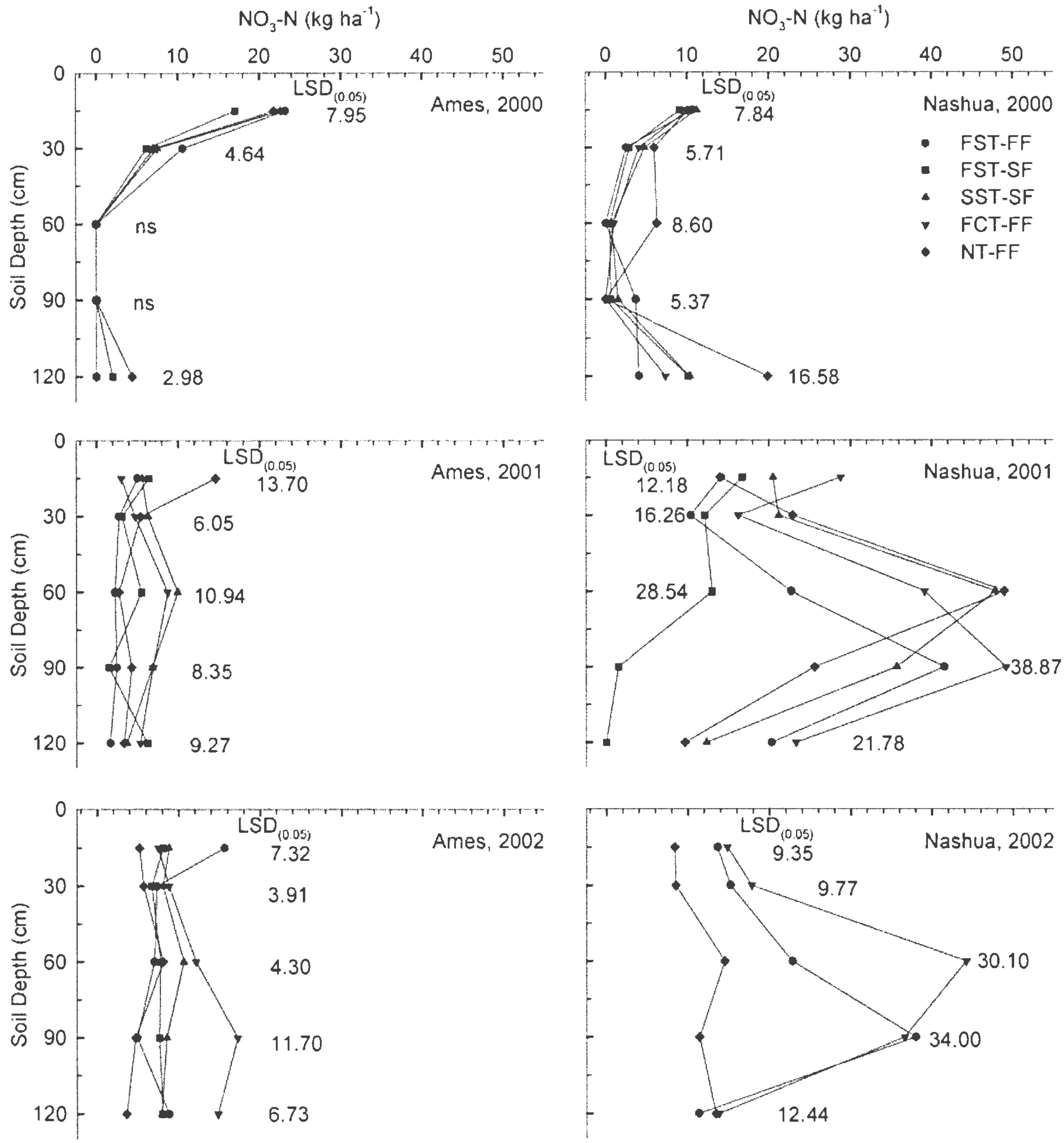

Figure 3.2. Soil NO_3-N distribution profile for Ames and Nashua from 2000 to 2002. Soil samples were between harvest and fall tillage. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

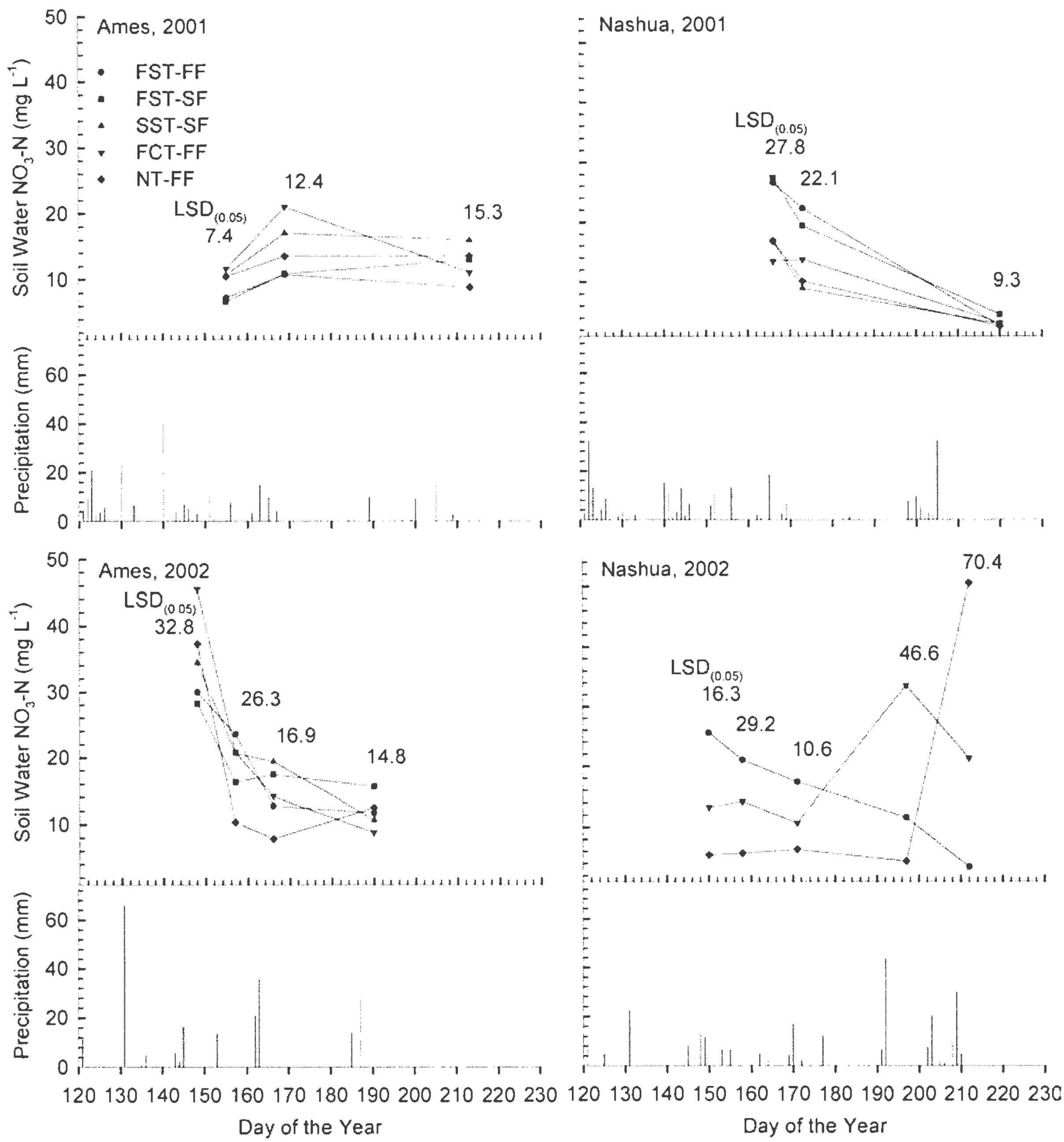

Figure 3.3. Precipitation and NO_3-N concentration leached after rainfall events for the Ames and Nashua sites in 2001 and 2002. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

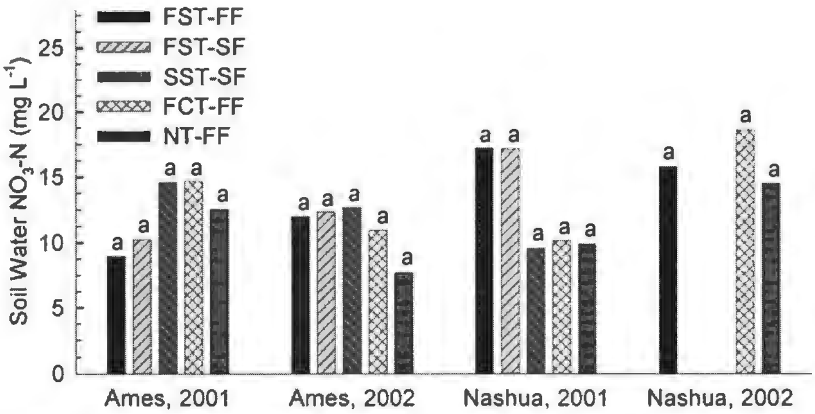

Figure 3.4. Average soil NO_3-N concentration collected per leaching rainfall event at a 120 cm soil depth by lysimeters for the Ames and Nashua sites in 2001 and 2002. The mean separations are based on least significant differences are according to a protected Fisher $LSD_{(0.05)}$.

CHAPTER 4

EVALUATION OF STRIP-TILLAGE EFFECTS ON SOIL TEMPERATURE, MOISTURE, AND COMPACTION

INTRODUCTION

The perceived effect of conservation tillage systems, namely no-tillage, on soil temperature, soil moisture, and soil compaction has increased during the last two decades. No-tillage presents a unique challenge, in which the surface soil properties are affected due to the absence of tillage as a corrective measure. Effective tillage and planting systems create an ideal seedbed condition (soil moisture, temperature, and penetration resistance) for plant emergence, plant growth, and unimpeded root growth. Soil moisture and temperature have the ability to promote or delay seed germination and plant emergence (Kaspar et al., 1990; Schneider and Gupta, 1985). Plant growth and development requires a soil condition that has adequate soil moisture and minimal root penetration resistance (Phillips and Kirkham, 1962). Therefore, quantifying the affects of tillage systems on soil moisture, temperature, and compaction can help account for differences in plant growth and development.

Soil temperature can be affected by surface residue cover causing cooler surface soil temperatures and slower soil drying in the spring (Fortin, 1993; Kaspar et al., 1990) in spite of reducing soil erosion and surface runoff (Cruse et al., 2001). Mahboubi and Lal (1998) indicate tillage enhances the seedbed and soil structure resulting in improved drainage and higher soil temperatures in the spring. Strip-tillage has the potential to combine the benefits of conventional tillage and no-tillage by disturbing the row and leaving the interrow with complete residue cover (Vyn and Raimbault, 1993). Typically, strip-tillage leaves the interrow residue in place, while disturbing a narrow zone 15-20 cm wide by 15-20 cm deep. This characteristic of strip-tillage is a potential solution to the challenges of conventional tillage and no-tillage by enhancing the seedbed to promote soil-water evaporation and increased soil temperature (Al-Kaisi and Hanna, 2002).

The ability of no-tillage to conserve soil moisture is illustrated in a twelve year study by Karlen et al. (1994) in which no-tillage had a gravimetric water content of 32.4% that was significantly greater than chisel plow and moldboard plow, 25.5 and 23.1% respectively. However, Erbach et al. (1992) concluded that water content was not affected by tillage systems. Some advantages of strip-tillage can be illustrated by research that removed in-row residue while not disturbing the soil. Fortin (1993) determined that bare row no-tillage and conventional tillage had a lower water content from planting to emergence than no-tillage with in-row residue cover, while the interrow water content of both no-tillage systems was higher than that for conventional tillage. This suggests that removing the residue from the row can reduce in-row soil moisture conditions in the seedbed, while conserving interrow soil moisture.

Unlike soil moisture, soil temperature has a inverse relationship to the amount of residue cover (Radke, 1982). This is due to the ability of surface residue to reflect solar radiation and insulate the soil (Shinners et al., 1993; van Wijk et al., 1959). The utilization of surface energy is affected by heat flux, heat reflected, and latent heat of evaporation. The heat flux of a soil depends on the heat capacity and conductivity of soils at various conditions (Hillel, 1998; Jury et al., 1991). Because soil particles have a lower heat capacity and greater heat conductivity than water, dry soils potentially warm up faster than wet soils. Tillage has the ability to alter rates of soil drying and heating. As tillage disturbs the soil surface it also increases air pockets in which evaporation occurs (Hillel, 1998), ultimately accelerating soil drying and heating.

It was found that even a 1°C temperature difference could effect corn (*Zea mays* L.) growth (Barlow et al., 1977; Walker, 1969) and the average maximum daily spring soil temperature under corn and soybean (*Glycine max* L. Merr.) residue was reduced by an average of 5.25°C over a two year period at a 5 cm depth (Kaspar et al., 1990). Therefore, early corn growth and development could significantly be reduced under no-tillage conditions. Kaspar et al. (1990) concluded the creation of a residue free band without soil disturbance has the potential to decrease the number of days required for emergence by 2.5 days and increase corn grain yields by 0.31 Mg ha^{-1}.

Residue cover has a greater effect on soil temperature than soil disturbance, while soil water content is influenced more by tillage systems. In Minnesota, moldboard plowing and no-tillage with no residue cover had a higher soil temperature than no-tillage with residue cover. However, the difference between moldboard plowing and no-tillage with residue cover was approximately one-third the difference between no-tillage with and without residue at 14 hr (Gupta et al., 1983). Soil water and temperature are interrelated because soil warming under wet conditions is hampered due to more energy being used for evaporation than warming the soil (Radke, 1982). Several studies have concluded higher water contents cause lower soil temperatures and in turn reduce seed germination and emergence (Griffith et al., 1973; Morrison and Gerik, 1983). Corn emergence is influenced more by soil temperature and to a lesser extent by soil moisture (Schneider and Gupta, 1985; Shinners et al., 1993).

Soil porosity, structure, and strength are often impacted by excessive soil compaction and are often differentiated by penetration resistance (Croissant et al., 1991; Voorhees, 1983). Alternatively, Soane and Pidgeon (1975) indicate it is difficult to associate penetration resistance with root penetration due to the ability of roots to produce exudates and follow the path of least resistance. However, they indicate when compression is the mode of soil structural failure penetration resistance is better correlated with root penetration than when cracking is the mode of failure. Penetration resistance is a common measure of soil strength, where increased penetration resistance restricts root growth (Singh et al., 1992; Taylor and Ratliff, 1969; Voorhees et al., 1975). Therefore, penetration resistance is attributed to a reduction of crop growth and yield (Croissant et al., 1991; Phillips and Kirkham, 1962). In a three year study, Croissant et al. (1991) determined compacted no-tillage treatments reduced dry bean (*Phaseolus vulgaris* L.) yields by 26% over non-compacted treatments.

Soil compaction is a result of larger, heavier machinery being adopted. However, in many cases soil consolidation is resistant to natural amelioration and requires tillage to some degree (Voorhees, 1983). Erbach et al. (1992) concluded a reduction in soil consolidation by fall tillage was negated through natural processes, spring seedbed preparation, and planting under a corn-soybean rotation. It was also determined that penetration resistance of no-tillage was slightly higher compared to a chisel plow system in the top 10 cm of the soil. Under a wheat (*Triticum aestivum* L.) -sorghum [*Sorghum bicolor* (L.) Moench] -fallow crop rotation in Texas, no-tillage had a greater surface penetration resistance than a minimum tillage system (Unger and Jones, 1998). Several studies have determined penetration resistance increases with depth, while the tillage system is less influential as depth increases (Erbach et al., 1992; Unger and Jones, 1998; Vyn and Raimbault, 1993).

Strip-tillage has the potential to increase soil temperatures in-row while utilizing interrow residue cover to conserve water for plant growth and development. There is a lack of research on how strip-tillage affects soil moisture, temperature, and penetration resistance. Therefore, the objectives of this study were to (i) evaluate the effect of strip-tillage on soil temperature, moisture, and compaction (ii) determine the interaction between soil moisture and soil compaction under strip-tillage as compared to conventional tillage, and no-tillage.

MATERIALS AND METHODS

Site Description

The study was conducted on two Iowa State University research and demonstration farms in 2001 and 2002 (Table 4.1). One site was at the Marsden research farm near Ames, Iowa, where the soils were Nicollet loam (fine-loamy, mixed, mesic Aquic Hapludolls) and Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls). This site was planted to corn (Fontenelle 4741 hybrid) on 10 May 2001 and 6 May 2002 with seed drop populations of 74,600 and 79,000 plants ha^{-1}, respectively. Seasonal precipitation (October through September) in 2001 was 766 mm and 713 mm for 2002 with a normal precipitation of 813 mm. The second site was at the Northeast Research and Demonstration Farm near Nashua, Iowa. Soils at this site were Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls) and Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls). 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. The seasonal precipitation was 832 and 711 mm in 2001 and 2002, respectively, with a normal precipitation of 864 mm. Prior to this study both locations were under a corn-soybean rotation with soybeans planted in 2000. The Ames site had previously been under a no-tillage corn soybean rotation, while the Nashua site was previously under a conservation tillage corn soybean rotation.

Experimental Design and Management

The study consists of three tillage systems; fall conventional tillage with fall N fertilizer (FCT-FF), fall strip-tillage with fall N fertilizer (FST-FF), and no-tillage with fall N fertilizer (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 long and 27.4 m wide. Each treatment plot was split into two halves; one half was planted to corn and the other half to soybeans to establish a corn-soybean rotation sequence.

On the conventional tillage 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 four row fertilizer injector that was modified with mole knives between 51 cm hiller disks at the Nashua site. The mole knife consisted of a shank of 43 cm long by 1.6 cm wide and a mole of 4.5 cm wide by 9 cm long. Strip-tillage at both sites resulted in soil disturbed 20 cm wide and 10-15 cm deep leaving a berm of 7-10 cm high. Under no-tillage, the only field operation completed were seed planting and N fertilizer application. For all treatments N was injected at a rate of 170 kg ha^{-1} in the row zone, resulting in minimal soil and residue disturbance. At the Ames site 32% ammonium nitrate (NH_4NO_3) was applied using a spoked point injector. At the Nashua site anhydrous ammonia was injected at a 15 cm depth using mole knives on the conventional tillage and strip-tillage plots and a nurse applicator with 1.25 cm wide shanks with a 3.5 cm wide shovel on the no-tillage plots. The nurse applicator was utilized on the no-tillage plots to minimize soil and residue disturbance. Weeds were controlled using pre- and post- emergence herbicides. At the Ames site in 2001, 2.2 L ha^{-1} of glyphosate (Roundup) was applied pre-emergence and no post-emergence herbicide was applied. In 2002, 2.2 L ha^{-1} of glyphosate (Roundup) was applied both pre- and post-emergence. At the Nashua site in 2001, 2.5 L ha^{-1} of dimethenamid (Frontier) was applied pre-emergence and 2.5 L ha^{-1} of bentazon + atrazine (Laddock) applied post-emergence. In 2002, 1.5 L ha^{-1} of dimethenamid (Outlook) was applied pre-emergence and 3.5 L ha^{-1} of dicamba + atrazine (Marksman) was applied post-emergence.

Soil Temperature

Soil and air temperature were recorded using Model 125 WatchDog[3] data loggers (Spectrum Technologies, Plainfield, IL) with external soil temperature thermocouples. The WatchDog data loggers have the ability to record soil and air temperature with an accuracy of ±0.7°C. The data loggers have the capability of recording 3,500 points in time intervals ranging from 1-120 min. The data recordings were downloaded using a software program with the ability to graph soil and air temperature as function of day and time. Air and soil temperature was recorded on an hourly basis from early to mid April and was terminated two weeks after planting in 2001 and at the time of planting in 2002. The soil temperature thermocouples were placed in-row at a 5 cm soil depth for all tillage systems. The loggers were mounted on fiberglass poles 1 m off the ground. Soil temperature for each site and year was evaluated using on a hourly basis for a four day period due to the large amount of data values. The data set was selected from periods that had consistent data with no missing values for any replications or treatments.

Soil Moisture Measurements

Profile soil moisture measurements were monitored after corn emergence until the R6 growth stage, while surface soil moisture was monitored from the beginning of May until the R6 growth stage. Soil moisture was measured for only the corn plots at both sites. Soil moisture measurements were taken at five increments through the soil profile: 0-15, 15-30, 30-60, 60-90, and 90-120 cm using time domain reflectometry (TDR). An Imko TRIME-FM instrument with a TRIME-T3 tube access probe was used to measure the profile (15-120 cm) volumetric water content (MESA Systems Company, Medfield, MA, USA). Surface soil moisture at 0-15 cm was measured using an Imko TRIME-FM instrument with a TRIME-P3 3-rod probe (MESA Systems Company, Medfield, MA, USA). Soil moisture access tubes were installed in each treatment for two replications for a total of ten access tubes per site in 2001. In 2002, the number of access tubes installed was increased to include three replications or fifteen access tubes per site. The clear plastic access tubes are 44 mm in diameter by 1.2 m long with a 1 mm wall thickness. The access tubes were installed by

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

modifying the instructions developed by Imko to conform to a Giddings model GSRPS hydraulic soil probe (Giddings Machine Company, Fort Collins, CO). A 41 mm slotted soil tube adapted with a quick relief bit was used to remove a 1.1 m long soil core. To ensure the access tube had good contact with the soil a slightly smaller diameter and shorter soil core was removed. After the soil core was removed the access tube was installed using a steel guide and ramming head to avoid damaging the access tube. With the tube installed a rubber stopper assembly was placed in the bottom of the tube to guarantee the absence of a water table or ponding within the tube. Between measurements a plastic cap was placed on the tube to prevent precipitation, soil, insects, and rodents from occupying the access tubes.

Soil Penetration Resistance

Soil resistance was determined using a Rimik CP-20 penetrometer (Soil Measurement Systems, Tucson, AZ). The Rimik CP-20 has an internal data logger with enough memory to store 750 insertion points. The data is downloaded using software with the capability of plotting the data by depth as an average or for each insertion point. The penetrometer used a 30° cone with a base 1.27 cm in diameter. The targeted insertion speed was 1.3 m min^{-1}, with a range of 1-2 m min^{-1}. In 2001, penetration resistance measurements were recorded in the middle of May, June, and July and in 2002 readings were taken weekly in May, bi-weekly in June, and once in the middle of July for each tillage system. For each measurement period, three insertion points per plot were recorded at 2.5 cm depth increments down to 60 cm. Each insertion point for each measurement period was located randomly within each corn plot with the stipulation that measurements were taken in-row.

Crop Measurements

An emergence rate index (ERI) was determined using a method outlined by Erbach (1982) in which two rows 5.3 m long were staked prior to corn emergence and monitored each day for ten consecutive days following the first emergence. ERI was calculated using the following equation (Erbach, 1982);

$$ERI = \sum_{n=first}^{last} \frac{[\%n - \%(n-1)]}{n}$$

where, %n is percentage of plants emerged on day n, %(n-1) is percentage of plants emerged on day n-1, n is number of days after planting, first is number of days after planting when the first plant emerged, and last is number of days after planting when emergence was completed. Corn yields were determined by hand harvesting the center two rows 5.3 m long of each plot. All corn ears were shelled to determine the corn yield. Corn grain yields were adjusted to 155 g kg^{-1} moisture.

Statistical Analysis

Data was analyzed using the SAS statistical software package (SAS, 2001). The GLM Procedure was used to perform the analysis of variance, which was appropriate for a randomized complete block design, for soil temperature, moisture, penetration resistance, emergence rate index, and corn yield. Means were separated using a least significant difference (LSD) when treatment effects were significant. Statistical significance was evaluated at $P \leq 0.05$.

RESULTS AND DISCUSSION

Soil Temperature

Fall strip-tillage, FCT-FF, and NT-FF showed small differences in soil temperatures for the selected days of monitoring early in the spring at the Nashua site in 2001, where no significant differences between tillage systems at any time of the day were observed (Fig. 4.1). The results showed soil temperature associated with FST-FF was greater than that associated with NT-FF during the time of the day (12-16 hours) when the air and soil temperatures reached a maximum. The differences in soil temperature observed between FST-FF and NT-FF averaged 0.19°C. Alternatively, at both sites the soil temperatures during the early hours of the day were not significantly different for all tillage systems tillage systems (Figs. 4.1, 4.2, and 4.3). Results from the Ames site in 2001 show soil temperatures at the 16 and 20 hours for FST-FF were not significantly higher than those of FCT-FF or NT-FF, but FCT-FF had a significantly higher soil temperature than NT-FF (Fig. 4.2). However, in 2002 at the Ames site, soil temperature associated with FST-FF was significantly greater than that associated with NT-FF at the 12 and 16 hours, particularly on day of year (DOY) 95 and 96, when the air temperatures were much greater than those on DOY 97 and 98 (Fig. 4.3). This suggests the improvement in soil temperature under FST-FF and FCT-FF was increased significantly as the air temperature increased, while FST-FF and FCT-FF have little effect on improving soil temperature under cool weather conditions. The results also suggest the effect of FST-FF were more pronounced at the time of the day when air temperature reached its maximum. In general, the hourly soil temperature trends indicated FST-FF and FCT-FF respond more quickly to air temperature than NT-FF. This was evident during the time of the day when maximum air temperature was reached compared to cool air temperatures.

Daily soil temperature results at the 8, 12, and 16 hours of the day for FST-FF, FCT-FF, and NT-FF were not significantly different for any tillage systems at the Nashua site in 2001 (Fig. 4.4). However, at the Ames site FST-FF soil temperatures were not significantly different from either FCT-FF or NT-FF, but were slightly greater than that associated with NT-FF and slightly less than that associated with FCT-FF at the 12 and 16 hours during both years. This can be attributed to the effect of both FST-FF and FCT-FF in increasing soil evaporation, which resulted in warmer soil temperature. The differences in soil temperature between FST-FF and NT-FF averaged 1.4 and 1.2°C compared to -0.3 and -1.4°C between FST-FF and FCT-FF at the 12 and 16 hours, respectively, for the Ames site during both years. Soil temperatures associated with FCT-FF at the Ames site in 2001 were significantly greater than that for NT-FF at 16 hours. Conversely, at the 12 and 16 hours the soil temperatures for FST-FF were significantly greater than those of NT-FF, but similar to those of FCT-FF during 2002 at the Ames site. Overall, the results suggest the 12 to 16 hour period is the time of the day, for all days and locations, where the greatest differences in soil temperatures were observed between all tillage systems. Also, this suggests the effectiveness of tillage systems in improving soil temperatures at the top 5 cm was more pronounced during the time periods when air temperature reached its maximum.

The effect of tillage systems on soil temperature was reflected by differences on emergence rate index for corn (Table 4.2). Generally, the ERI and yield of corn under FST-FF and FCT-FF was not significantly greater than that of NT-FF corn (Table 4.2). However, ERI of both FST-FF and FCT-FF was greater than that of NT-FF corn. The small differences in ERI value between all tillage treatments can be attributed to the small differences observed between soil temperatures of the three tillage systems. However, differences in ERI between years for all tillage systems were more pronounced between years within each location, where cool air and soil temperatures in the 7 days following planting were attributed with an average of 59% and 28% decrease in the emergence rate index for corn from 2001 to 2002 at the Ames and Nashua sites, respectively. In 2002 at the Ames site the average maximum air temperature for the 7 days following planting was 15.4°C compared to 28.7°C in 2001 and rainfall was increased by 34.5 mm. In 2002 the Nashua site also experienced decreased temperatures during the 7 days following planting with an average air temperature of 20.7°C compared to 26.3°C in 2001 and rainfall was increased by 25.4 mm. It was apparent cool soil conditions in 2002 caused the delay in seed germination and emergence.

Soil Moisture

Change in soil moisture is another indicator to evaluate the strip-tillage effect on the soil environment. Soil moisture profiles under FST-FF, FCT-FF, and NT-FF for the Ames site, show the post-emergence soil moisture content was significantly different at the 60 cm soil depth in 2001, where the soil moisture of NT-FF was greater than that of FST-FF and FCT-FF in 2001 (Fig. 4.5). At the tasseling and pre-harvest growth stages for the Ames site in 2001 the soil moisture content of tillage systems was not significantly different at any depth. Alternatively, at the Ames site in 2002 the soil moisture of FST-FF was generally greater than those of FCT-FF and NT-FF regardless of depth for the three growth periods (Fig. 4.5). It was observed that at the Nashua site in 2001 soil moisture under NT-FF was consistently lower than that under the FST-FF and FCT-FF at the post-emergence, tasseling, and pre-harvest periods, while FST-FF and FCT-FF did not result in any significant soil moisture differences (Fig. 4.6). Conversely, soil moisture at the Nashua site in 2002 was not significantly different for all tillage systems at any depth or recording period. Tillage systems showed effects on the soil moisture profile at the Nashua and Ames sites in 2001 and at the Ames site in 2002. Soil moisture content was more pronounced in 2001 compared to 2002 where the soil moisture content differences were not significant, especially for the lower depths (Figs. 4.5 and 4.6).

Penetration Resistance

Penetration resistance is another indicator that can be used to evaluate tillage effects. At the Ames site in 2001 penetration resistance showed no significant differences except at the surface between all tillage treatments through the soil profile and at different times during the growing season. However, the penetration resistance was significantly greater at the 20 cm depth compared to all other depths for all tillage treatments (Fig. 4.7). However, for the May and June periods at the 0-10 cm soil depth FST-FF penetration resistance was similar to that of NT-FF, and both had a significantly higher penetration resistance than FCT-FF. Alternatively, for the 10-60 cm soil depth FST-FF was generally similar to that of FCT-FF and NT-FF. During the July period the penetration resistance tended to generally increase with depth and the penetration resistance of FST-FF was lower than that of FCT-FF and NT-FF at the Ames site for both years. At the Nashua site during both years, penetration resistance was not significantly different for the 20-60 cm soil depth of all tillage systems (Fig. 4.8). During May and June of 2001 at the Nashua site penetration resistance for the 0-20 cm soil depth was similar for FST-FF and FCT-FF, but significantly less than that of NT-FF. However, in July the penetration resistance was significantly less for FCT-FF than that of FST-FF or NT-FF. In 2002 at the Nashua site, FST-FF and NT-FF had similar penetration resistance, which was significantly higher than that of FCT-FF in May and June, but in July FST-FF resulted in similar penetration resistance to that of FCT-FF. The overall results of this study show the disparity in penetration resistance values among different tillage systems was more pronounced late in the season, and some cases showed greater penetration resistance values in NT-FF compared to the other two tillage treatments, especially in the top 20 cm soil depth (Figs. 4.7 and 4.8).

The relationship between penetration resistance and soil moisture are presented in Figure 4.9. The results suggest penetration resistance for all tillage systems was greatly affected by soil moisture content over time, where greater penetration resistance values were observed as the growing season progressed and more moisture was depleted from the soil profile at different depths. This indicated penetration resistance increased from the beginning of the season to the end with a decline of soil moisture content for all depths. Therefore, soil moisture and penetration resistance were inversely related and significantly affected at depths of 15, 30, and 60 cm depths for both sites.

CONCLUSION

The findings of this study indicate the potential advantage strip-tillage has over no-tillage in improving soil temperatures in the spring. Soil temperatures associated with strip-tillage were comparable with conventional tillage, and their maximum soil temperatures were greater than those of no-tillage by 1.4-1.9°C. The results show strip-tillage slightly improved soil temperature more than no-tillage. Daily soil temperatures did not show significant differences between tillage systems in improving soil temperature until approximately 16 hours, where the maximum air temperature was often reached. This suggests strip-tillage and conventional tillage had lower heating capacity and greater heat conductivity than no-tillage due to lower moisture content allowing the soil to heat more rapidly. The change in soil temperature due to tillage effect was reflected in the improvement of the emergence rate index of both strip-tillage and conventional tillage, but did not significantly impact corn yield. Changes in soil temperature magnitude due to tillage effects were highly dependent on the improvement in air temperature throughout the day, when maximum air temperature often resulted in maximum soil temperature. Strip-tillage has the potential to conserve soil moisture comparable to no-tillage. The results of this study indicate no significant difference in soil moisture content between all tillage systems for any depth, but generally strip-tillage conserved more water than conventional tillage and similar to no-tillage at the lower soil depths. In this study penetration resistance of strip-tillage was often comparable with no-tillage, but greater than conventional tillage at the upper depths (0-20 cm) of the soil profile. At lower depths of the soil profile strip-tillage generally resulted in decreased penetration resistance compared to conventional tillage and no-tillage. Penetration resistance and soil moisture were inversely related throughout the soil profile, where the affect of soil moisture on penetration resistance was more pronounced at the 30 and 60 cm soil depths. These benefits of strip-tillage have the potential to promote stronger emergence and competitive yields compared with conventional tillage. Therefore, strip-tillage may have a slight advantage over no-tillage, but justification of implementing the system would be dependant upon particular field conditions, management systems, environmental conditions and economics.

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Table 4.1. Soil descriptions of the experiment sites near Ames and Nashua, Iowa.

Site	Soil Series	Soil Classification	Soil Texture	BD†	OM†	pH
				g cm^{-3}	g kg^{-1}	
Ames	Nicollet	Aquic Hapludolls	loam	1.20	45	6.4
	Webster	Typic Haplaquolls	silty clay loam	1.35	65	6.9
Nashua	Floyd	Aquic Hapludolls	loam	1.35	60	6.7
	Kenyon	Typic Hapludolls	loam	1.40	30	6.4

†BD, bulk density; OM, organic matter

Table 4.2. Tillage effects on ERI and corn grain yield in 2001 and 2002.

	ERI				Corn Yield			
	Ames		Nashua		Ames		Nashua	
Treatment†	2001	2002	2001	2002	2001	2002	2001	2002
					- - - - - - - - - Mg ha^{-1} - - - - - - - - -			
FST-FF	16.9a‡	7.0a	10.0a	7.4b	11.4a	14.2a	13.9a	15.0a
FCT-FF	16.8a	6.7a	10.1a	8.2a	12.1a	18.8a	13.3a	14.9a
NT-FF	16.1a	6.3a	9.8a	6.7c	11.5a	14.1a	13.5a	13.1b

† FST-FF, fall strip-tillage; FCT-FF, conventional tillage; NT-FF, no-tillage.
‡ Means within the same column followed by the same letter are not significantly different according to a protected Fisher $LSD_{(0.05)}$.
*, **, ns; Significant at 0.05 and 0.10 probability levels and not significant at 0.10 probability level, respectively.

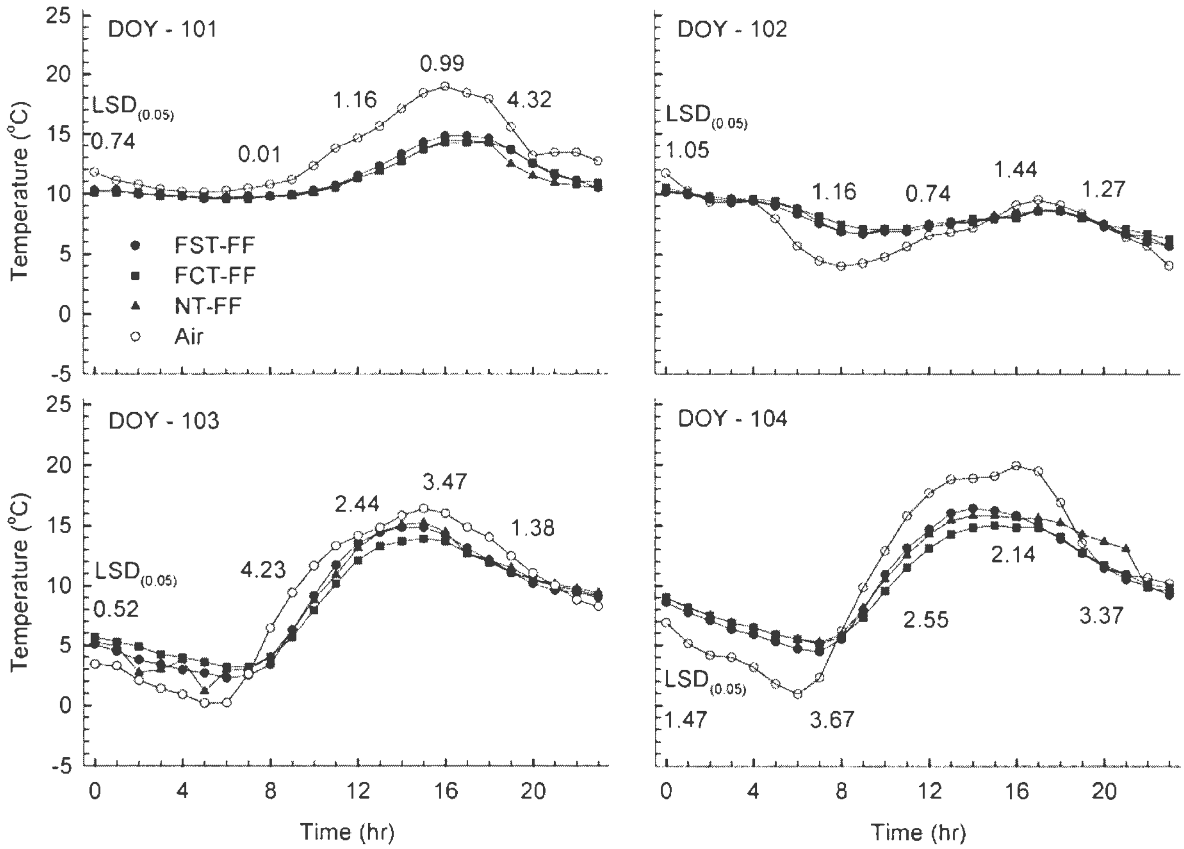

Figure 4.1. Hourly soil temperature at the 2 cm soil depth of 4 selected days during 2001 at the Nashua site. The least significant differences are for the 0, 8, 12, 16, and 20 hours and are according to an unprotected Fisher $LSD_{(0.05)}$.

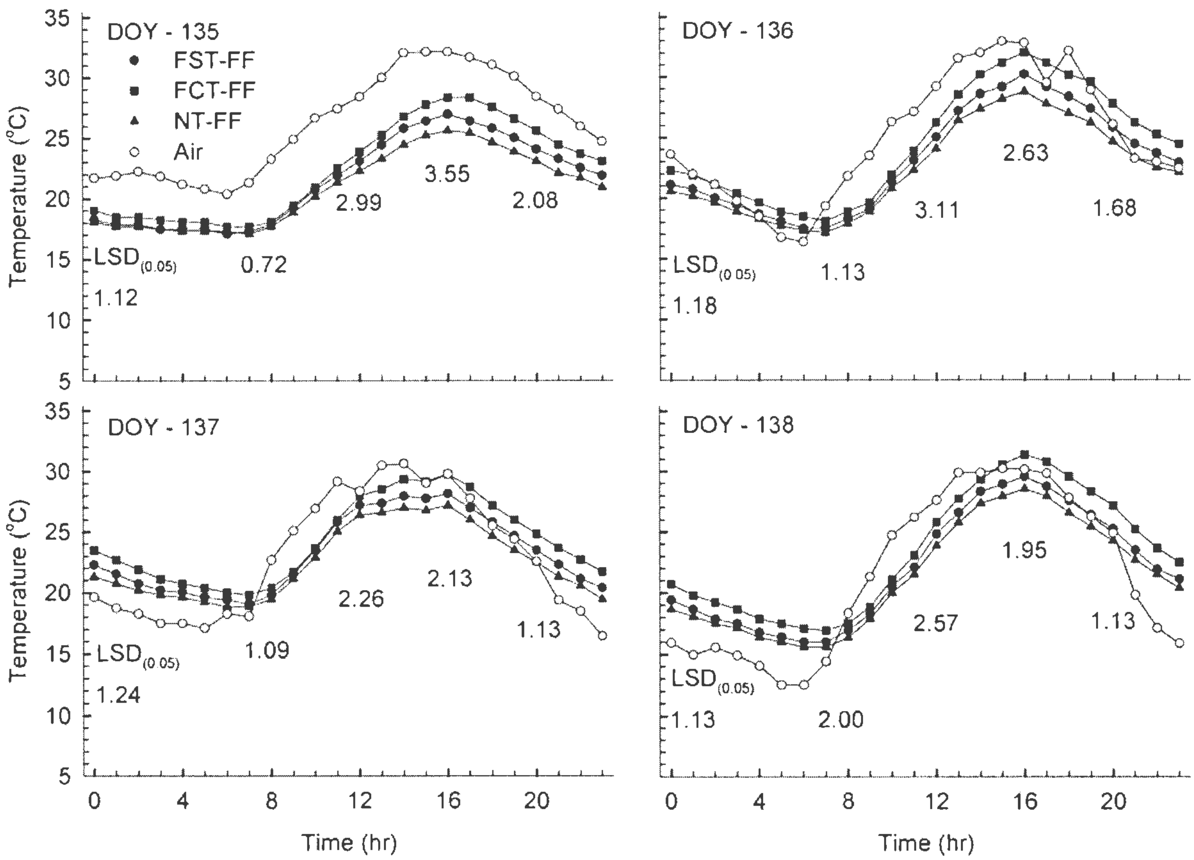

Figure 4.2. Hourly soil temperature at the 2 cm soil depth of 4 selected days during 2001 at the Ames site. The least significant differences are for the 0, 8, 12, 16, and 20 hours and are according to an unprotected Fisher $LSD_{(0.05)}$.

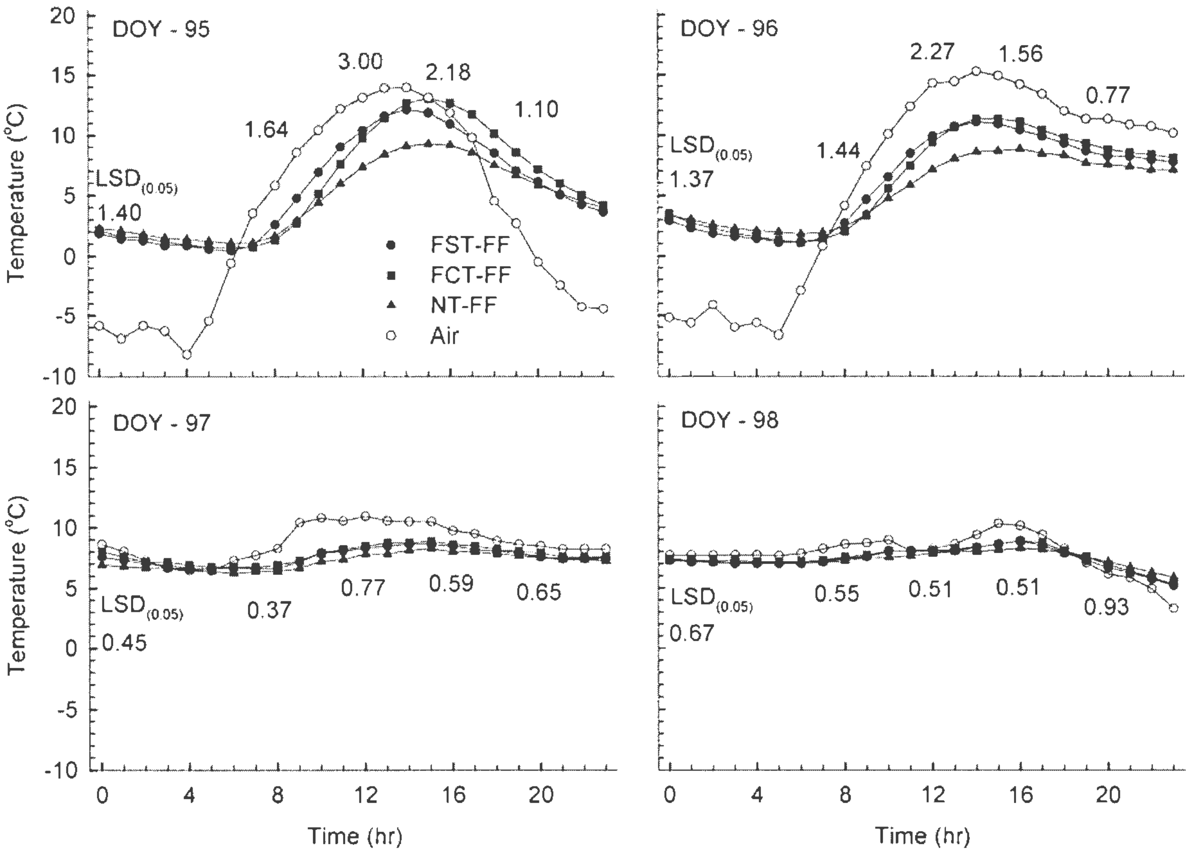

Figure 4.3. Hourly soil temperature at the 2 cm soil depth of 4 selected days during 2002 at the Ames site. The least significant differences are for the 0, 8, 12, 16, and 20 hours and are according to an unprotected Fisher $LSD_{(0.05)}$.

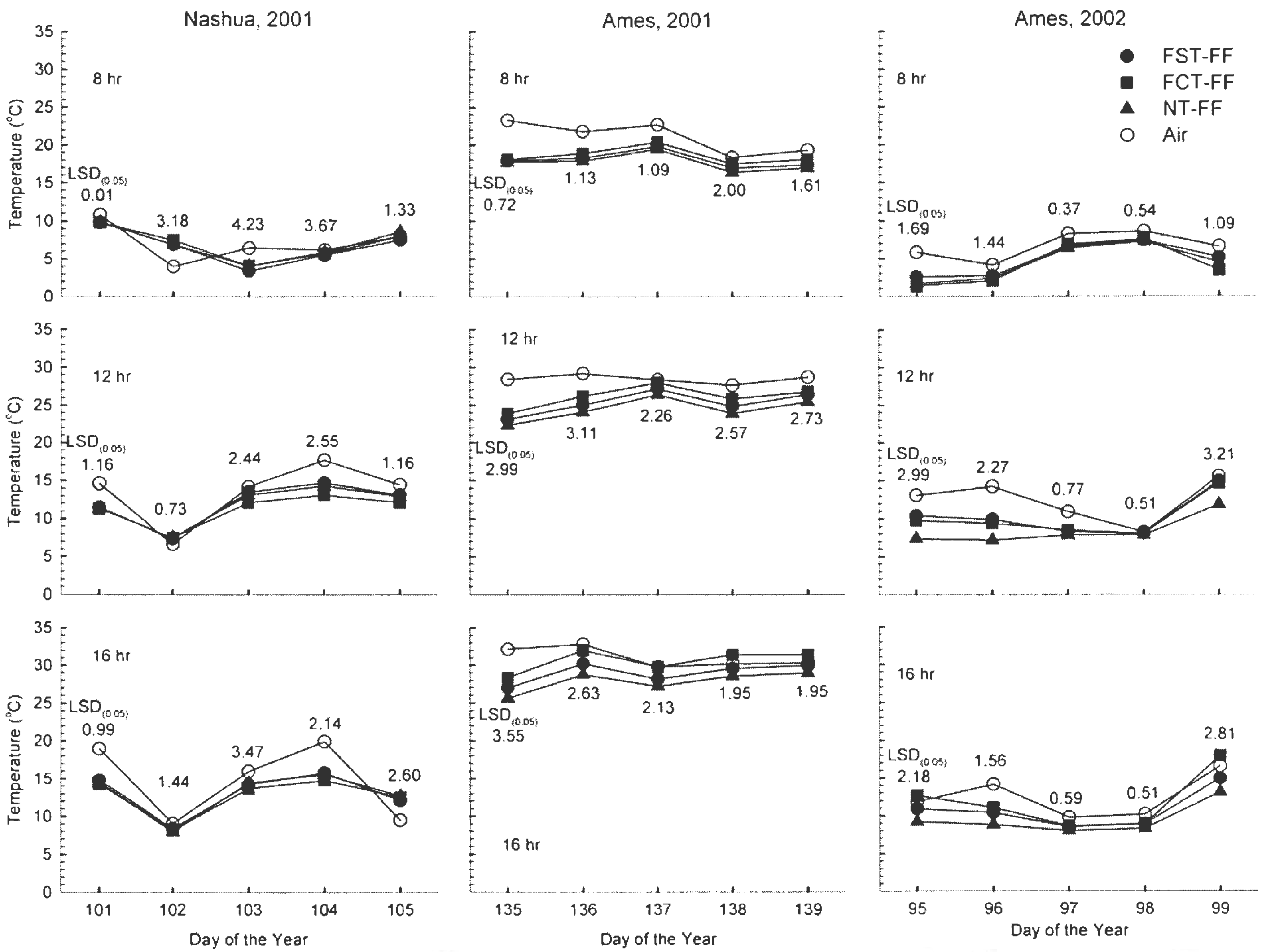

Figure 4.4. Daily soil temperature at the Nashua and Ames sites at the 8, 12, and 16 hours during 2001 and 2002. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

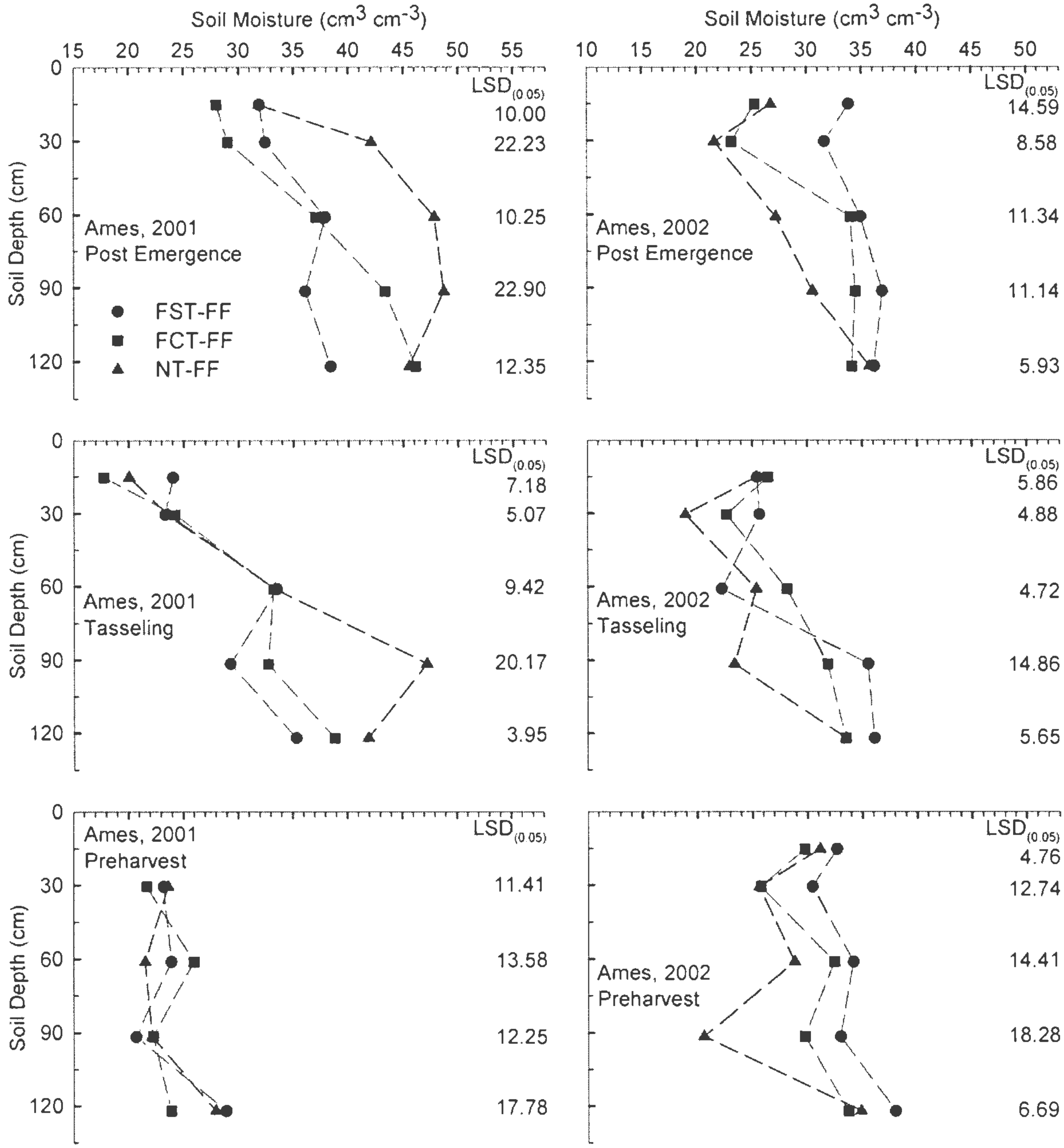

Figure 4.5. The soil moisture profile for the Ames site in 2001 and 2002. The post emergence, tasseling, and preharvest measurements were taken on 8 June, 10 July, and 28 August of 2001 and 28 May, 9 July, and 19 August of 2002, respectively. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

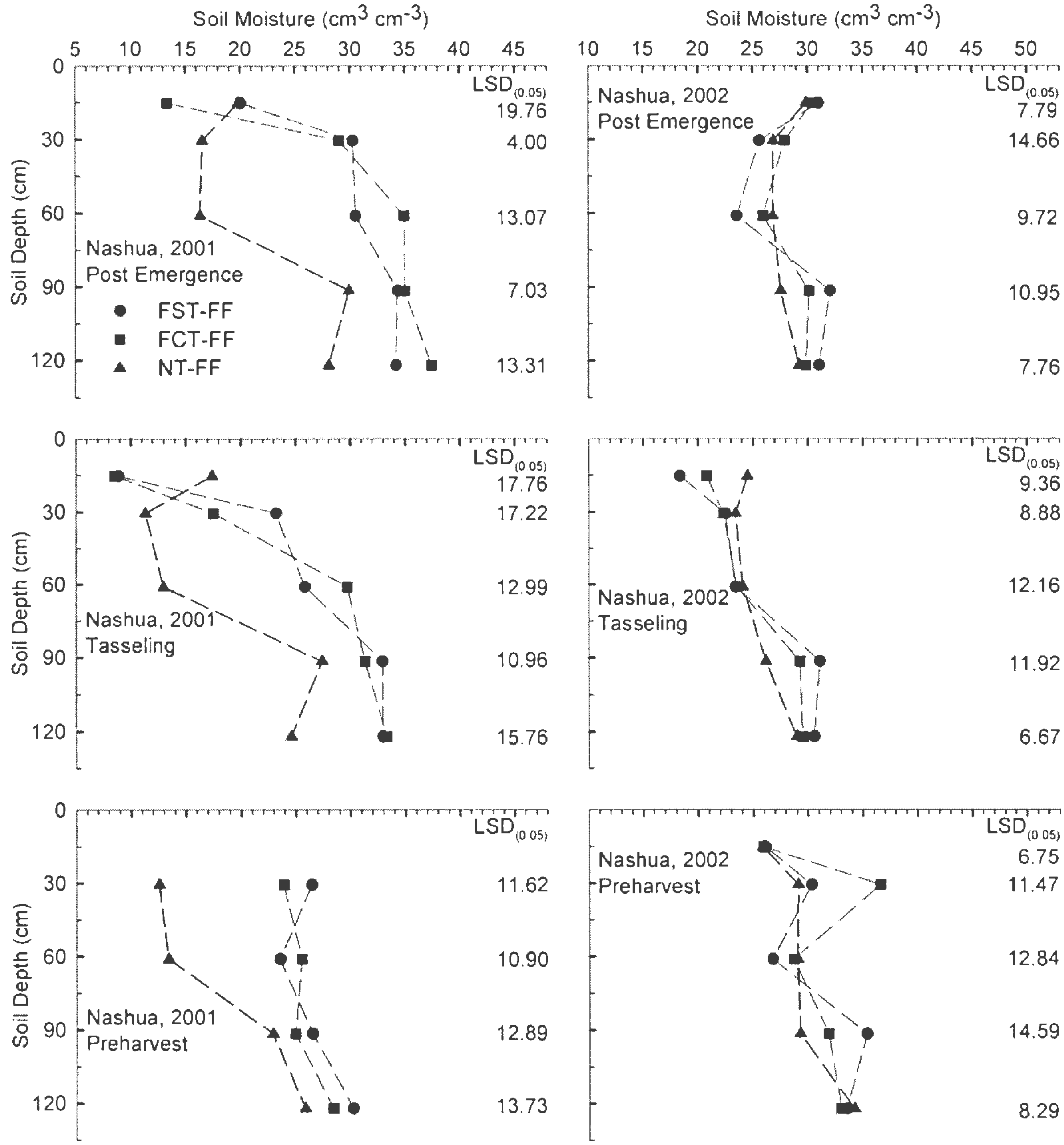

Figure 4.6. The soil moisture profile for the Nashua site in 2001 and 2002. The post emergence, tasseling, and preharvest measurements were taken on 28 June, 12 July, and 22 August of 2001 and 30 May, 16 July, and 20 August of 2002, respectively. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

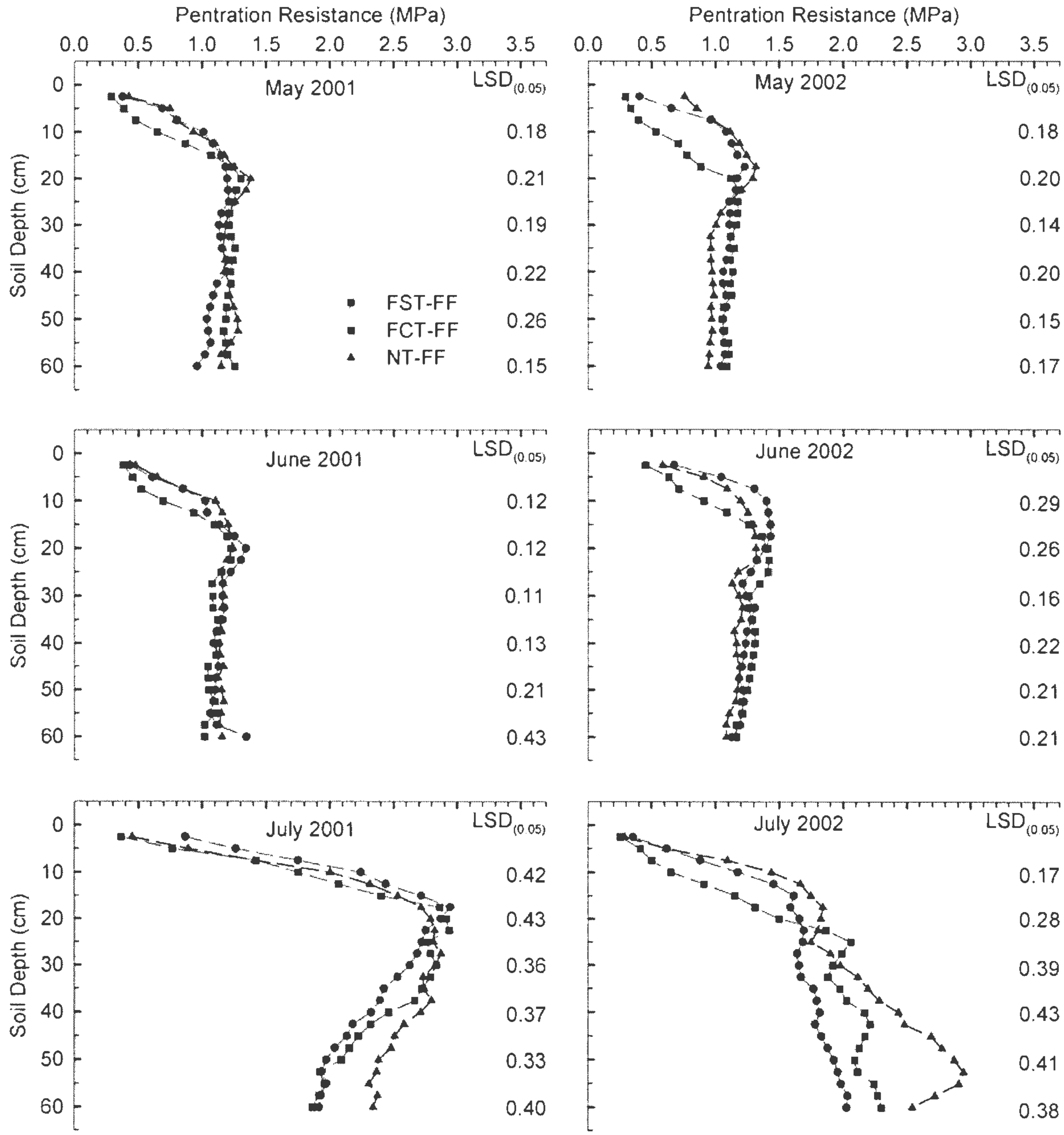

Figure 4.7. Penetration resistance for the soil profile at the Ames site in 2001 and 2002. The actual recording periods were 15 May, 12 June, and 10 July of 2001 and 14 May, 17 June, and 9 July of 2002, respectively. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

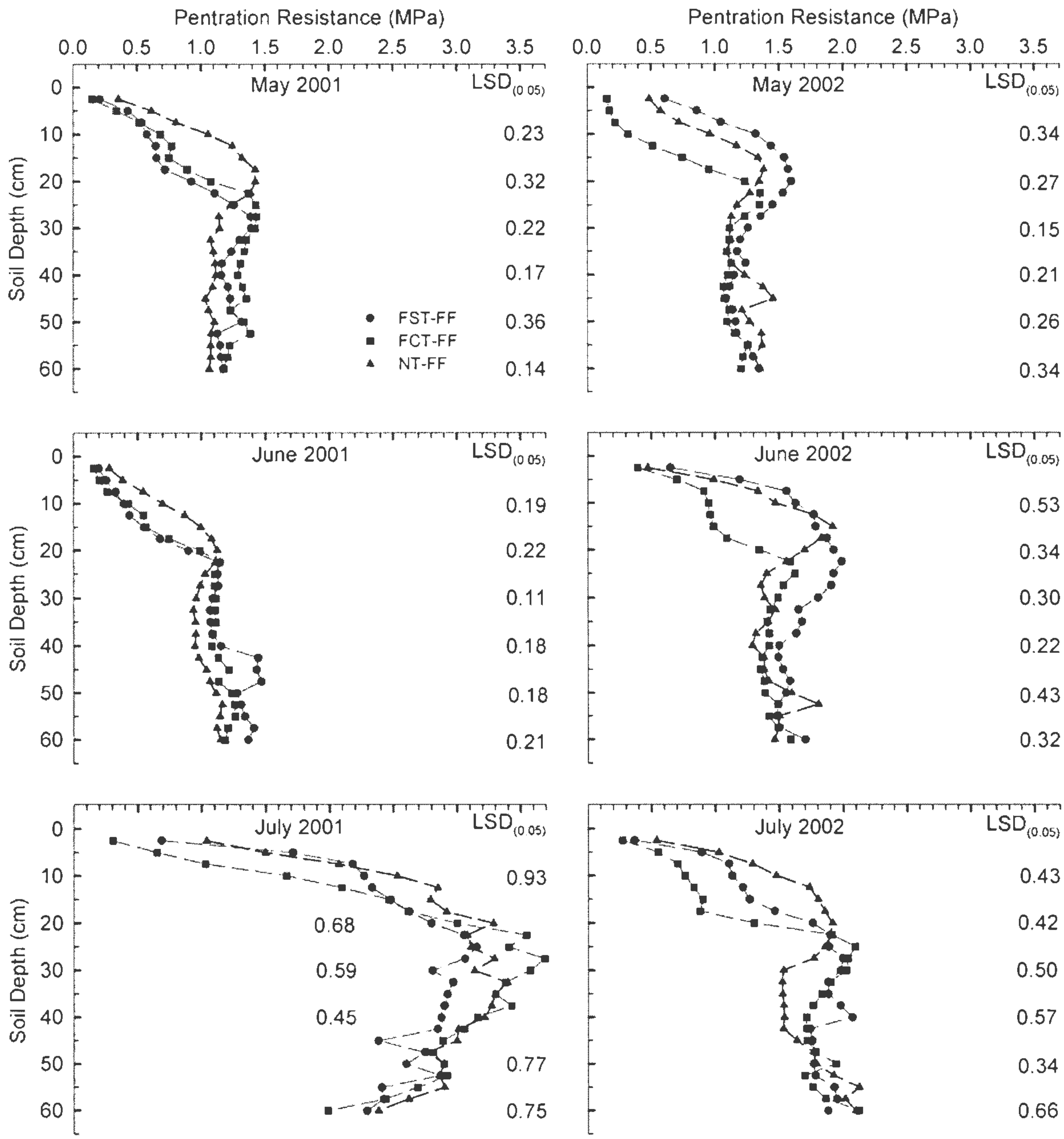

Figure 4.8. Penetration resistance for the soil profile at the Nashua site in 2001 and 2002. The actual recording periods were 18 May, 15 June, and 12 July of 2001 and 13 May, 18 June, 16 July of 2002, respectively. The least significant differences are according to an unprotected Fisher $LSD_{(0.05)}$.

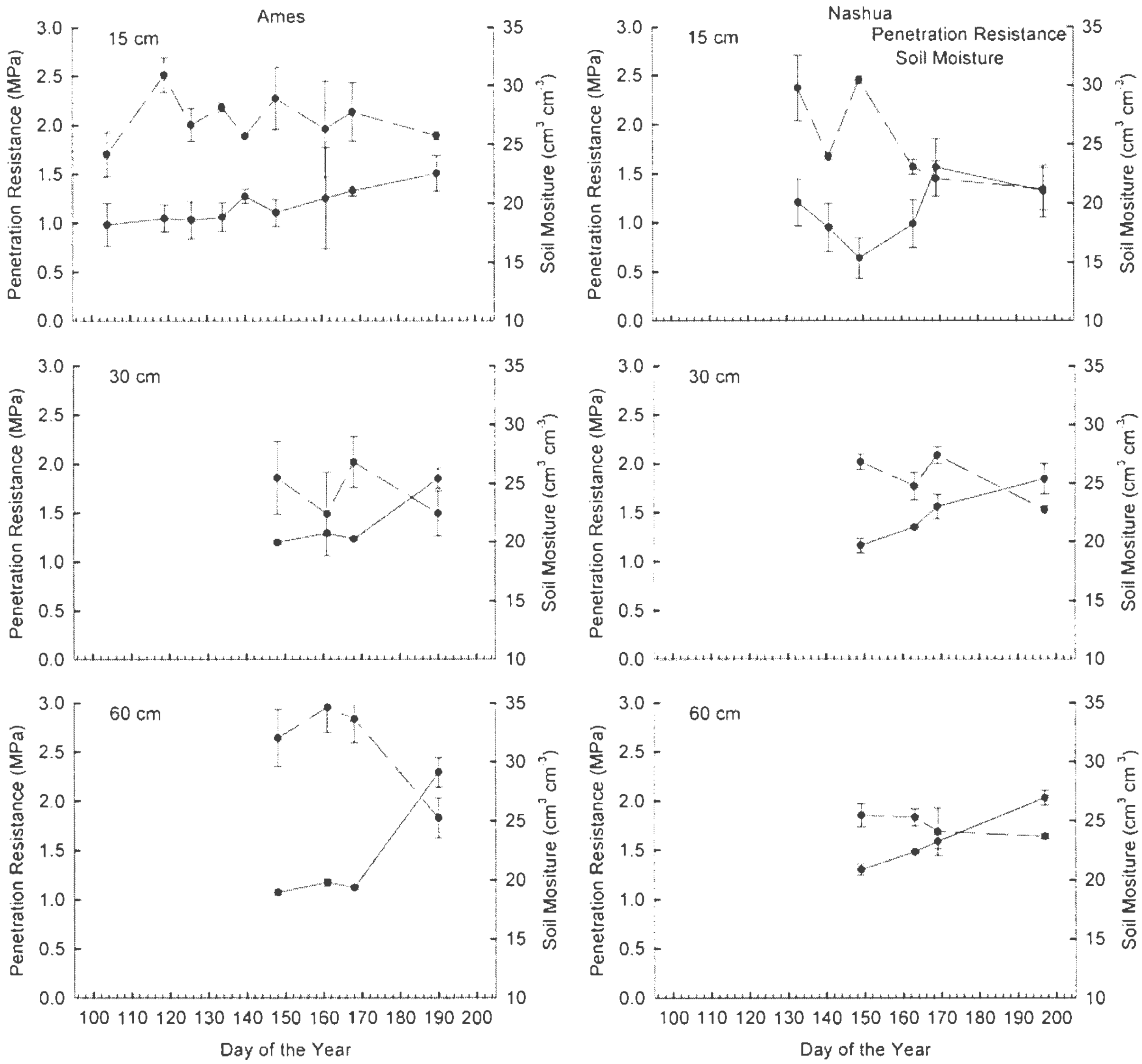

Figure 4.9. A comparison of penetration resistance and soil moisture at the 15, 30, and 60 cm soil depth for the Ames and Nashua sites in 2002.

CHAPTER 5

GENERAL CONCLUSIONS

The findings of this study strongly suggest strip-tillage has no significant advantages in improving corn yield, N uptake, and water use efficiency over no-tillage or conventional tillage systems, except in very few cases. However, the results revealed strip-tillage slightly accelerates seed germination over no-tillage at the onset of the growing season. This advantage did not significantly increase yield regardless of the timing of strip-tillage and N fertilizer applications. Grain yields and N uptake were improved for strip-tillage compared to no-tillage, yet the yield to N ratio differences remain insignificant. At the Ames and Nashua sites, no-tillage and strip-tillage generally resulted in lower residual soil NO_3-N build up than conventional tillage, and the timing of N fertilizer application had a relatively insignificant effect on soil nitrate build up. Soil NO_3-N leaching under strip-tillage was not significantly different from the other treatments regardless of the timing of tillage systems and N fertilizer application. The trends for soil NO_3-N leaching generally decreased as the growing season progressed due to a decrease in the amount of rainfall and soil water movement.

The findings of this study illustrate the potential advantage strip-tillage has over no-tillage in improving soil temperatures in the spring. Soil temperatures associated with strip-tillage were comparable with conventional tillage, and their maximum soil temperatures were greater than those of no-tillage by 1.4-1.9°C. Changes in soil temperature magnitude due to tillage effects were highly dependent on the improvement in air temperature throughout the day, where maximum air temperatures often resulted in maximum soil temperatures. There was no significant difference in soil moisture content between all tillage systems at any depth, but generally the soil moisture content under strip-tillage was greater than that of conventional tillage and similar to no-tillage at the lower soil depths. Soil penetration resistance for strip-tillage was often comparable with that of no-tillage, but greater than conventional tillage at the top 0-20 cm soil depth. The results show soil penetration resistance and soil moisture were inversely related throughout the soil profile, where the effect of soil moisture on soil penetration resistance were more pronounced at the 30 and 60 cm soil depths.

Strip-tillage has an advantage over no-tillage in improving soil conditions under cold and poorly drained soils. It also possesses the potential to reduce surface runoff compared to conventional tillage and a slight improvement of corn yields, N uptake, and seedbed conditions compared to no-tillage. Therefore, the adoption of strip-tillage should be site specific and limited to cold and poorly drained soils.