



Strip-tillage effect on seedbed soil temperature and other soil physical properties

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Abstract

The no-tillage system is perceived as having lower soil temperatures, wetter soil conditions, and greater surface penetration resistance compared with conventional and other conservation tillage systems. Concerns associated with the effect of the no-tillage system on certain soil physical properties (i.e. soil temperature, moisture, and compaction) prompted this study to evaluate the effect of an alternative tillage system, strip-tillage, on these physical properties, compared with chisel plow and no-tillage systems. The study was conducted on two Iowa State University research and demonstration farms in 2001 and 2002. One site was at the Marsden Farm near Ames, where the soils were Nicollet loam (Aquic Hapludolls) and Webster silty clay loam (Typic Haplaquolls). The second site was at the Northeast Research and Demonstration Farm near Nashua, where the soils were Kenyon loam (Typic Hapludolls) and Floyd loam (Aquic Hapludolls).

Soil temperature increased in the top 5 cm under strip-tillage (1.2–1.4 °C) over no-tillage and it remained close to the chisel plow soil temperature. This increase in soil temperature contributed to an improvement in plant emergence rate index (ERI) under strip-tillage compared with no-tillage. The results show no significant differences in soil moisture status between the three tillage systems, although the strip-tillage soil profile has slightly greater moisture content than chisel plow. Moisture content through the soil profile particularly at the lower depths under all tillage treatments was greater than the plant available water (PAW). However, the changes in soil moisture storage were much greater with strip-tillage and chisel plow than no-tillage from post-emergence to preharvest at 0–30 and 0–120 cm. It was observed also that most change in soil moisture storage occurred between post-emergence and tasseling. Penetration resistance was similar for both strip-tillage and no-tillage, but commonly greater than chisel plow. In general, the findings show that strip-tillage can contribute effectively to improve plant emergence, similar to chisel plowing and conserve soil moisture effectively compared with no-tillage.

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Keywords: Strip-tillage; No-tillage; Chisel plow; Soil temperature; Soil moisture; Soil penetration resistance

1. Introduction

The perceived effect of no-tillage on soil temperature, soil moisture conditions, and soil compaction

has become a major concern among producers considering adopting this tillage system. No-tillage presents a unique challenge in poorly drained soils, in which certain surface soil properties are affected due to the absence of tillage as a corrective measure. Effective tillage systems create an ideal seedbed condition (i.e. soil moisture, temperature, and penetration resistance) for plant emergence, plant development, and unimpeded root growth. Strip-tillage or zone-tillage has the

Abbreviations: ERI, emergence rate index; CP, chisel plow; NT, no-tillage; PAW, plant available water; ST, strip-tillage

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potential of creating such conditions by combining the benefits of conventional tillage and no-tillage by disturbing the row and leaving the interrow with complete residue cover (Vyn and Raimbault, 1993). This unique characteristic of leaving the interrow residue in place, while disturbing a narrow zone 15–20 cm in width by 15–20 cm in depth has attracted the attention of many producers during the last decade who have experienced difficulties with no-tillage. Strip-tillage also offers a potential solution to the challenges associated with both conventional tillage and no-tillage systems by improving the seedbed environment in poorly drained soils due to increases in soil moisture evaporation and soil temperature (Al-Kaisi and Hanna, 2002).

Soil moisture and soil temperature conditions in the seedbed zone (top 5 cm) can promote or delay seed germination and plant emergence (Kaspar et al., 1990; Schneider and Gupta, 1985). Therefore, healthy plant growth and development require soil conditions that have adequate soil moisture and minimal root penetration resistance (Phillips and Kirkham, 1962). Surface residue cover can affect soil temperature by insulating the soil surface and slowing 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 that tillage improves the seedbed conditions and soil structure, resulting in improved drainage and higher soil temperatures in the spring. Therefore, quantifying the effects of tillage systems on soil moisture, soil temperature, and compaction can help explain some of the differences in plant growth and development in different tillage systems.

The impact of a no-tillage system on conserving soil moisture in the top 5 cm following 12 years of various tillage systems was documented in a study by Karlen et al. (1994) in which the gravimetric soil moisture of the no-tillage system had a gravimetric water content of 32.4%, compared to 25.5 and 23.1% for chisel plow and moldboard plow systems, respectively. In another study, Erbach et al. (1992) found that water content was not affected by tillage systems in the top 20 cm of soil. However, the removal of in-row residue while not disturbing the soil was demonstrated to be as effective as the soil disturbance by strip-tillage on reducing soil moisture content at the soil surface. Fortin (1993) found 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, whereas the interrow water content of both no-tillage treatments was higher than that for conventional tillage. Removal of residue from the row can reduce in-row soil moisture content in the seedbed, while conserving interrow soil moisture.

Unlike soil moisture, soil temperature has an inverse relationship with the amount of residue cover (Radke, 1982). The decrease in soil temperature is due to the influence of surface residue by reflecting solar radiation and insulating the soil surface (Shinners et al., 1993; van Wijk et al., 1959). Solar energy at the soil surface is partitioned into soil heat flux, sensible heat reflection, and latent heat for water evaporation. Heat flux in soils depends on the heat capacity and thermal conductivity of soils, which vary with soil composition, bulk density, and water content (Hillel, 1998; Jury et al., 1991). Because soil particles have a lower heat capacity and greater heat conductivity than water, dry soils potentially warm and cool faster than wet soils. Tillage processes alter rates of soil drying and heating because tillage disturbs the soil surface, it also increases air pockets in which evaporation occurs, and ultimately accelerates soil drying and heating. As early as 1956 van Duin had determined the amplitude of soil temperature variation at the surface was greater for tilled versus untilled soil (van Duin, 1956). Hillel (1998) explains this phenomena or change in soil temperature with tillage due to the change in soil thermal conductivity, where tillage caused a lower soil thermal conductivity compared to that of the untilled soil. Soil disturbance due to tillage can shift or change the air to soil particles volume by creating additional air pockets that can be responsible for reducing the heat capacity of the tilled zone.

It was found that even a 1 °C temperature difference could effect corn (*Zea mays* L.) growth (Barlow et al., 1977; Walker, 1969). 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 at a 5 cm soil depth (Kaspar et al., 1990). Therefore, early corn growth and development could significantly be reduced under no-tillage conditions. Kaspar et al. (1990) concluded that 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. It seems that residue cover has

a substantial effect on soil temperature and moisture content. The combination effect of tillage and residue on soil temperature showed that 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 h (Gupta et al., 1983). Soil water and temperature are interrelated because soil warming under wet conditions is hampered due to greater soil heat capacity and more energy being used for water evaporation than warming the soil (Radke, 1982). Several studies have concluded that higher soil water content caused lower soil temperatures and in turn reduced 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; Shinnars et al., 1993).

Soil porosity, structure, and strength are impacted by excessive soil compaction and are often differentiated by penetration resistance (Croissant et al., 1991; Voorhees, 1983). However, 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 (Soane and Pidgeon, 1975). Soane and Pidgeon (1975) 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, a reduction of crop growth and yield is attributed to penetration resistance (Croissant et al., 1991; Phillips and Kirkham, 1962). In a 3-year study, Croissant et al. (1991) determined compacted no-tillage reduced dry bean (*Phaseolus vulgaris* L.) yields by 26% over noncompacted.

It was determined that penetration resistance of no-tillage was slightly higher compared with that of chisel plow in the top 10 cm of the soil (Erbach et al., 1992). Under a wheat (*Triticum aestivum* L.)–sorghum (*Sorghum bicolor* (L.) Moench)–fallow crop rotation, no-tillage had a greater surface penetration resistance than a minimum tillage system (Unger and Jones, 1998). Several studies have found penetration resis-

tance increases with depth, whereas 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 using interrow residue cover to conserve soil moisture for plant growth and development. There is limited research on how strip-tillage affects soil moisture, soil temperature, and penetration resistance. The objectives of this study were to (1) evaluate the effect of strip-tillage on soil temperature, moisture, and compaction and (2) determine the interaction between soil moisture and soil compaction under strip-tillage as compared to chisel plow and no-tillage.

2. Materials and methods

2.1. Site description

The study was conducted on two Iowa State University research and demonstration farms in 2001 and 2002 (Table 1). One site was at the Marsden research farm near Ames, 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 hybrid¹) on 10 May 2001 and 6 May 2002 with seed drop populations of 74,600 and 79,000 plants ha⁻¹, respectively. All treatments were planted with a four-row planter with double disc openers and press wheels at a 5 cm planting depth and 76 cm row spacing. The planter did not have coulters, row cleaners, or starter fertilizer attachments. Seasonal precipitation (October–September) in 2001 was 766 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. 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

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

Table 1
Soil descriptions of the experiment sites near Ames and Nashua, IA

Site	Soil series	Soil classification	BD ^a (g cm ⁻³)	OM ^b (g kg ⁻¹)	pH	PAW ^c (cm ³ cm ⁻³)
Ames	Nicollet	Fine-loamy, mixed, mesic Aquic Hapludolls	1.20	45	6.4	18
	Webster	Fine-loamy, mixed, mesic Typic Haplaquolls	1.35	65	6.9	18
Nashua	Floyd	Fine-loamy, mixed, mesic Aquic Hapludolls	1.35	60	6.7	18
	Kenyon	Fine-loamy, mixed, mesic Typic Hapludolls	1.40	30	6.4	19

^a Bulk density.

^b Organic matter.

^c Plant available water.

of 80,300 plants ha⁻¹ for both years. All treatments were planted with a six-row planter with double disc openers and press wheels at a 5 cm planting depth and 76 cm row spacing. The planter did not have coulters, row cleaners, or starter fertilizer attachments. The seasonal precipitation was 832 and 711 mm in 2001 and 2002, respectively, with a normal precipitation of 864 mm. Before this study, both locations were under a corn–soybean rotation with soybean planted in 2000. In 2001, the plots were split with one half planted to corn and the other half planted to soybeans. This allowed for a corn–soybean rotation for each year of the study. The Ames site had previously been in a no-tillage system, whereas the Nashua site was previously in a chisel plow tillage system.

2.2. Experimental design and management

The study consists of three tillage systems: chisel plow (CP), strip-tillage (ST), and no-tillage (NT). The experimental design used in this study was a randomized complete block design with four replications at each location. Plot dimensions were 36.5 m in length and 27.4 m in width. Each treatment plot was split into two halves; one-half was planted to corn and the other half to soybean to establish a corn–soybean rotation sequence.

On the chisel plow plots, primary tillage consisted of fall chisel plowing followed by field cultivation as the secondary tillage in the spring. Strip-tillage was implemented using a four-row rotor tiller at the Ames site and a four-row fertilizer injector that was modified with mole knives between 51 cm tiller disks at the Nashua site. The rotor tiller blades were 13 cm in length and the blades curved out 5 cm at the end. The mole knife consisted of a shank of 43 cm in length by

1.6 cm in width and a mole of 4.5 cm in width by 9 cm in length. Strip-tillage at both sites resulted in soil disturbed 20 cm in width and 10–15 cm in depth, leaving a mound of 7–10 cm in height. Under no-tillage, the only field operations performed were seed planting and N fertilizer application. For corn crop, N was fall injected at a rate of 170 kg ha⁻¹ in the row zone prior to chisel plowing and strip-tillage, resulting in minimal soil and residue disturbance. At the Ames site, 32% ammonium nitrate (NH₄NO₃) was applied using a spoke point injector (Baker et al., 1989). At the Nashua site, anhydrous ammonia was injected at a 15 cm depth by using mole knives on the chisel plow and strip-tillage plots. For the no-tillage system anhydrous ammonia was applied using a modified toolbar with slot injectors of 1.25 cm wide shanks with a 3.5 cm wide shovel to minimize soil disturbance. For all treatments weeds were controlled using pre- and post-emergence herbicides that are typically used in corn production for central and northeastern Iowa. Also, due to high to very high soil test phosphorus and potassium no additional fertility was applied.

2.3. Soil temperature

Soil and air temperatures were recorded using model 125 WatchDog data loggers (Spectrum Technologies, Plainfield, IL) with external soil temperature thermocouples. The WatchDog data loggers have the ability to record soil and air temperatures with accuracy of ±0.7 °C. Air and soil temperatures were recorded hourly at the Ames site from 5 April 2001 to 13 June 2001 and 1 April 2002–5 May 2002, whereas at the Nashua site air and soil temperatures were recorded only from 11 April 2001 to 24 May 2001. The soil temperature thermocouples were placed

in-row at 5 cm soil depth for all tillage systems. The data loggers were mounted on fiberglass poles 1 m above the ground. Soil temperature for each site and year was evaluated hourly for a 4 day period due to the large amount of data values.

Considerable soil temperature data were collected during this study. However, only a few data sets were selected to be presented here and they represent different weather conditions during data collection. At the Ames site in 2001 a complete data set was used with 4 consecutive days of no precipitation and clear sky. At the same site in 2002, 4 days were selected, where 2 days were cloudy with precipitation and 2 days with no precipitation and with clear sky. At the Nashua site in 2001, 4 days were selected that had a trace of precipitation, where 2 days were with cloudy conditions and other 2 days had clear sky. In 2002, at the Nashua site data were not available due to equipment failure. The rationale for using these data sets of selective days under different weather conditions was to examine the effect of different tillage systems on soil temperatures under different weather conditions, such as air temperature, solar radiation, and moisture conditions.

2.4. Soil moisture measurements

Soil moisture measurements were monitored immediately after corn emergence until the R6 growth stage for a 1.2 m soil depth. Soil moisture was measured for corn plots only 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 soil depth by 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). Surface soil moisture at 0–15 cm soil depth was measured using an Imko TRIME-FM instrument with a TRIME-P3 3-rod probe (MESA Systems Company). Soil moisture access tubes were installed in center of the fifth row in each treatment for two replications for a total of 10 access tubes per site in 2001. In 2002, the number of access tubes installed was increased to include 3 replications or 15 access tubes per site. The access tubes are 44 mm inner diameter, clear plastic, and 1.2 m in length 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 6 mm smaller diameter and 10 cm 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 prevent water entering the tube at the bottom. Between measurements, a plastic cap was placed on the top end of the tube to prevent precipitation, soil, insects, and rodents from occupying the access tubes. The soil volumetric plant available water (PAW) calculation for the soil profiles at the Ames and Nashua sites was based on PAW values that were published in the soil survey reports for these two sites (Andrews and Dideriksen, 1981; Voy, 1995, Table 1).

2.5. 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 were 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 0.1–2 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, biweekly 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 soil 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.

2.6. Crop measurements

An emergence rate index (ERI) was determined using a method outlined by Erbach (1982) in which two

rows, 5.3 m in length, were marked before corn emergence and monitored each day for 10 consecutive days after 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 the number of days after planting, first is the number of days after planting when the first plant emerged, last is the number of days after planting when emergence was completed, $\%n$ is the percentage of plants emerged on day n , and $\%(n - 1)$ is percentage of plants emerged on day $n - 1$. Corn yields were determined by hand harvesting 5.3 m of the center two rows for each plot. All corn ears were shelled to determine the corn yield. Corn grain yields were adjusted to 155 g kg⁻¹ moisture.

2.7. Statistical analysis

Data was analyzed using the SAS statistical Software Package (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 $P \leq 0.05$. The data analysis for each site year was separately performed after the combine analysis across site years of the data was significant.

3. Results and discussion

3.1. Soil temperature

Soil temperatures at the top 5 cm soil depth under ST, CP, and NT show no significant differences early in the spring at the Nashua site in 2001 (Fig. 1). However, soil temperature associated with ST was generally higher than that of NT during the time of the day (12–16 h) when the air and soil temperatures reached a maximum. At both sites, the soil temperature during

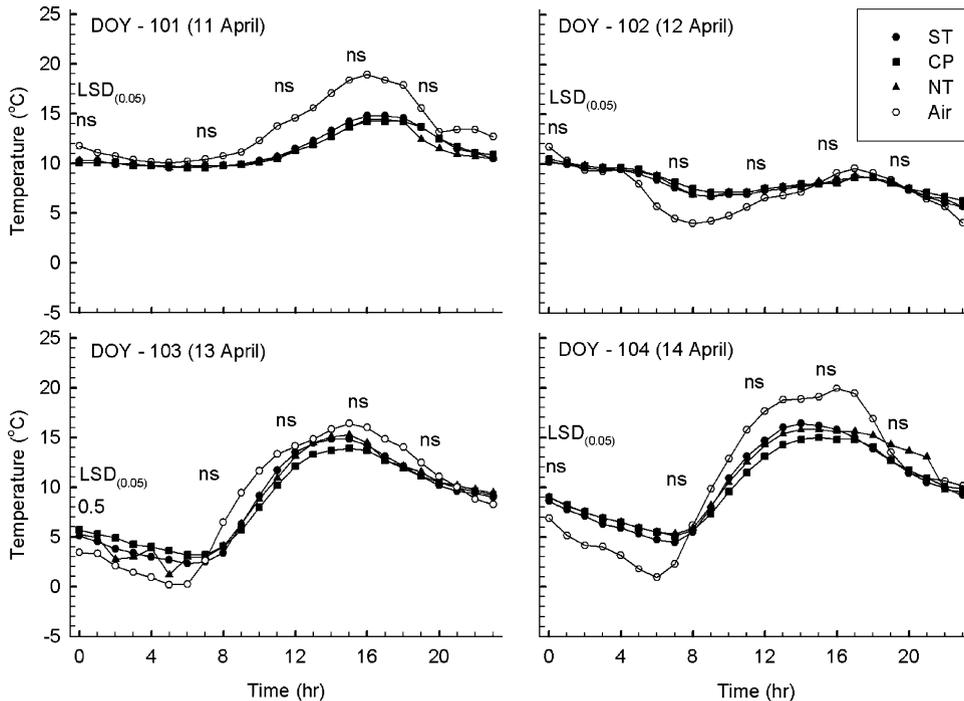


Fig. 1. Hourly soil temperature at the 5 cm soil depth of 4 selected days (DOYs 101 and 102 were overcast and light precipitation, DOYs 103 and 104 were clear and trace precipitation) during 2001 at the Nashua site. The least significant differences for the 0, 8, 12, 16, and 20 h and are according to Fisher’s LSD_(0.05) test.

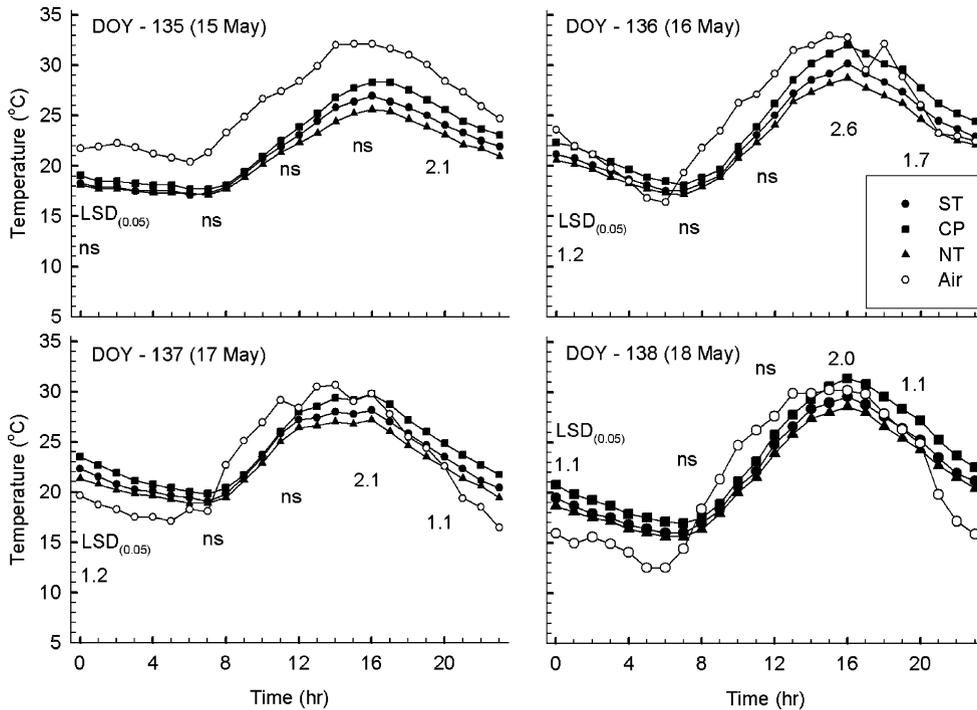


Fig. 2. Hourly soil temperature at the 5 cm soil depth of 4 selected days (DOYs 135–138 had clear sky and dry conditions) during 2001 at the Ames site. The least significant differences for the 0, 8, 12, 16, and 20 h and are according to Fisher's $LSD_{(0.05)}$ test.

the early hours of the day was not significantly different for all tillage systems tillage systems (Figs. 1–3). Results from the Ames site in 2001, show soil temperatures at the 16 and 20 h for ST were not significantly higher than those of CP or NT, but CP had a significantly higher soil temperature than NT (Fig. 2). However, in 2002 at the Ames site, soil temperature associated with ST was significantly greater than that with NT at 12 and 16 h, particularly on day of year (DOY) 95 and 96, when the air temperatures were much greater than those on DOY 97 and 98 (Fig. 3). This suggests the improvement in soil temperature under ST and CP occurred as air temperature increased, whereas ST and CP have little effect on improving soil temperature under cool weather conditions. The results also suggest the effect of ST was more pronounced at the time of the day when air temperature reached its maximum. This is supported by work by van Duin (1956) where he determined that tillage may increase the amplitude of soil temperature resulting in higher maximum soil temperatures. These changes in

soil temperature were due to soil disturbance under ST and CP and are highly related to changes in soil heat flux. Heat flux in the soil depends on the heat capacity and thermal conductivity of soils changed by tillage, which affects soil structure, bulk density, and water content (Hillel, 1998; Jury et al., 1991). Because soil particles have a lower heat capacity and greater heat conductivity than water, therefore, dry soils potentially warm and cool faster than wet soils. In general, the hourly soil temperature trends indicated ST and CP respond more quickly to air temperature than NT. Daily soil temperatures at the 8, 12, and 18 h times for ST, CP, and NT were not significantly different for any tillage system or between tillage systems at the Nashua site in 2001 (Fig. 4). However, at the Ames site, soil temperatures associated with ST were not significantly different from those under either CP or NT, but they were slightly greater than that associated with NT at 12 and 18 h during both years. This finding can be attributed to the effect of both ST and CP in increasing soil evaporation, which resulted in warmer

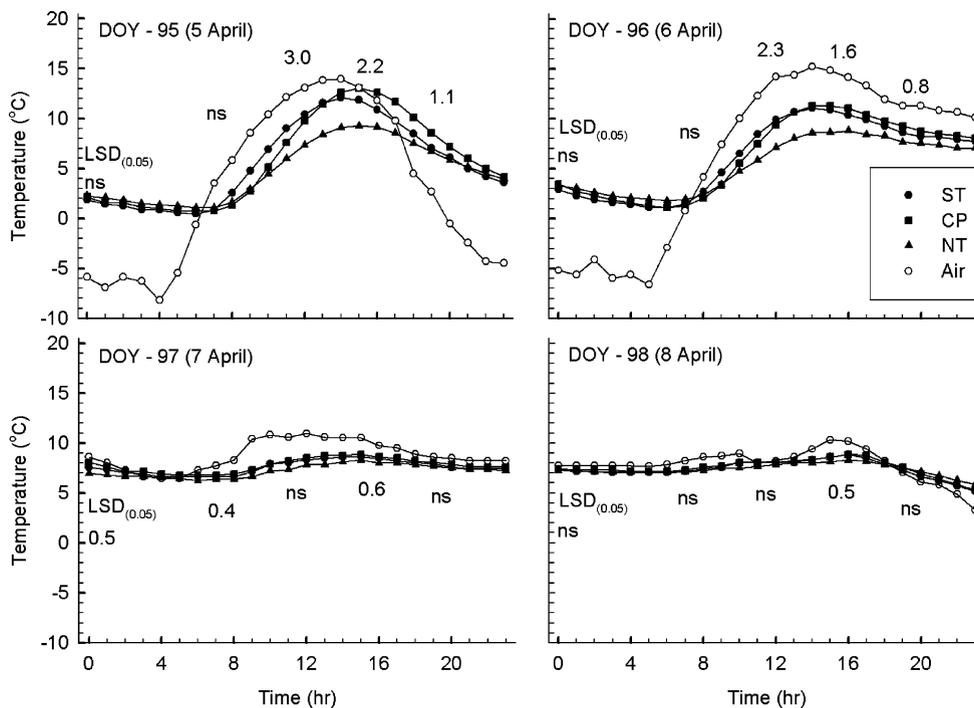


Fig. 3. Hourly soil temperature at the 5 cm soil depth of 4 selected days (DOYs 95 and 96 were dry and clear sky conditions, DOYs 97 and 98 had trace precipitation and overcast conditions) during 2002 at the Ames site. The least significant differences for the 0, 8, 12, 16, and 20 h and are according to Fisher's $LSD_{(0.05)}$ test.

soil temperature. The average increase in soil temperature under ST was 1.4 and 1.2 °C compared with NT and -0.3 and -1.4 °C compared with CP at the 12 and 18 h, respectively, for the Ames site during both years. Also, soil temperatures associated with CP at the Ames site in 2001 were significantly greater than that for NT at 18 h. However, in 2002 at the Ames site, the soil temperatures under ST were significantly greater than that of NT, but similar to that of CP at the 12 and 18 h times of the day. The differences in soil temperatures suggest that the effectiveness of tillage systems in improving soil temperatures at the top 5 cm was more pronounced during the times when air temperature reached its maximum. The increase in soil temperature in the surface layer is due to the influence of tillage on surface residue cover, where residue normally reduces surface temperature by reflecting solar radiation and insulating the soil surface (Shinners et al., 1993; van Wijk et al., 1959). Tillage processes or soil disturbance in general interrupts solar energy partitioning at the soil surface into soil heat

flux, sensible heat reflection, and latent heat for water evaporation by minimizing the soil heat reflection portion due to the distribution of residue cover.

The effect of tillage systems on soil temperature was also indicated by the ERI (Table 2). Generally, the ERI and yield of corn under ST and CP was not significantly different from NT (Table 2). However, ERI of corn under both ST and CP was slightly greater than that of NT. The small differences in ERI value between all tillage treatments can be attributed to the small differences observed in soil temperatures between the three tillage systems. However, regardless of the type of tillage system, differences in ERI between different years were more pronounced than within each year when cool air temperatures were dominant after planting. Thus, it was observed that ERI in 2001 for all tillage systems was 59 and 28% greater than those in 2002, at the Ames and Nashua sites, respectively. In 2001 at the Ames site the average maximum air temperature for the 7 days after planting was 28.7 °C compared with 15.4 °C in 2002 and rainfall

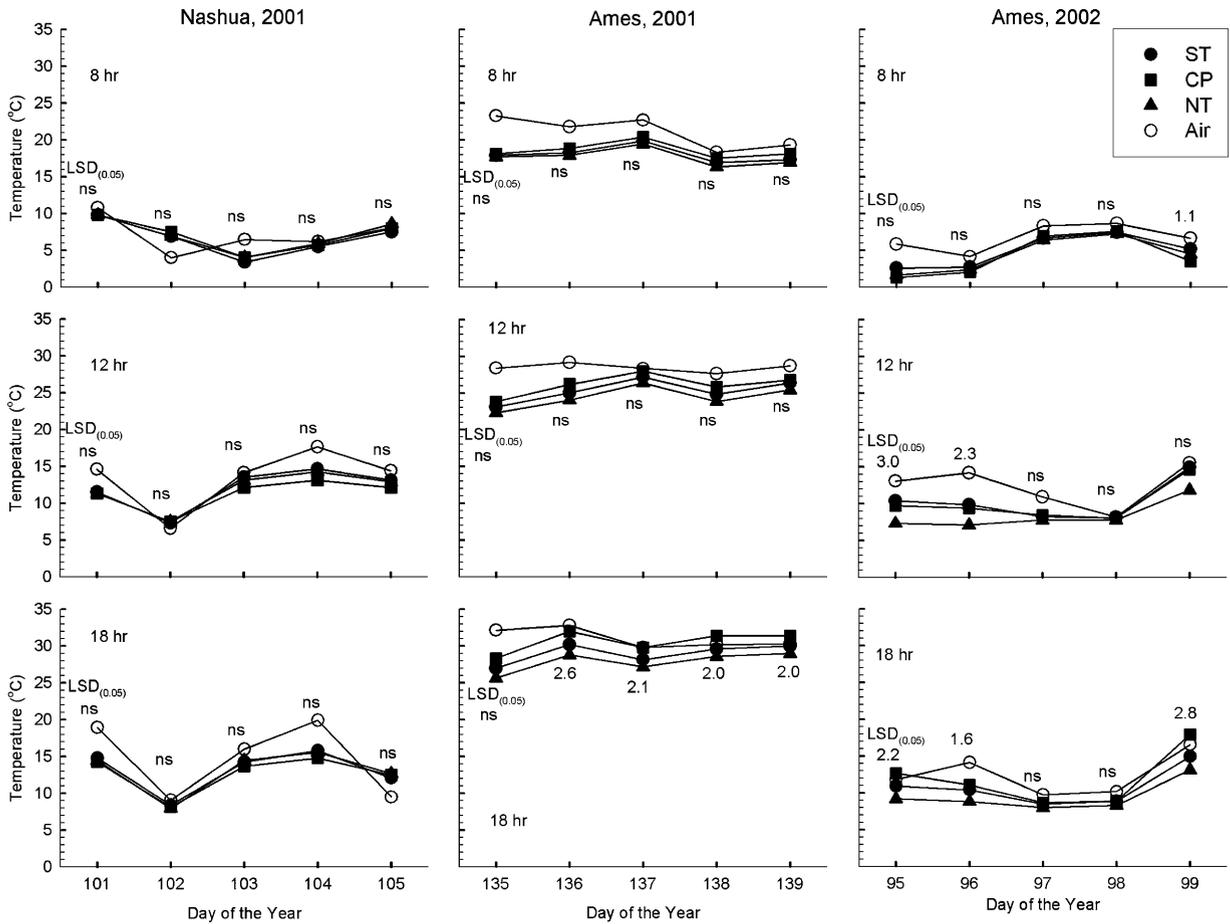


Fig. 4. Daily soil temperature at the top 5 cm at the Nashua and Ames sites at the 8, 12, and 18h during 2001 and 2002. The least significant differences are according to Fisher's $LSD_{(0.05)}$ test.

was 34.5 mm greater. In 2002, the Nashua site also experienced decreased in air temperatures during the 7 days after planting with an average air temperature of 20.7 °C compared with 26.3 °C in 2001

and rainfall was 25.4 mm greater. It was apparent cool soil conditions in 2002 that caused the delay in seed germination and emergence in all tillage treatments.

Table 2
Tillage effects on ERI and corn grain yield in 2001 and 2002

Treatment	ERI				Corn yield (Mg ha ⁻¹)			
	Ames		Nashua		Ames		Nashua	
	2001	2002	2001	2002	2001	2002	2001	2002
ST	16.9a	7.0a	10.0a	7.4b	11.4a	14.2a	13.9a	15.0a
CP	16.8a	6.7a	10.1a	8.2a	12.1a	14.8a	13.3a	14.9a
NT	16.1a	6.3a	9.8a	6.7c	11.5a	14.1a	13.5a	13.1b

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

3.2. Soil moisture

Change in soil moisture is another indicator to evaluate the strip-tillage effect on the soil environment. Soil moisture profiles under ST, CT, and NT for the Ames site, show that the post-emergence soil moisture content was significantly different at the 60 cm soil depth in 2001, where the soil moisture of NT was greater than that of ST and CP in 2001 (Fig. 5). However, at the tasseling and preharvest growth stages for

the Ames site in 2001, the soil moisture content of all tillage systems was not significantly different at any depth. Alternatively, at the Ames site in 2002 the soil moisture of ST was generally greater than that of CP and NT, regardless of depth for the three growth periods (Fig. 5). Despite the differences between all tillage treatments, soil moisture content at various soil depths within the vadose zone, the soil moisture remained above the PAW in both 2001 and 2002 at Ames site (Fig. 5).

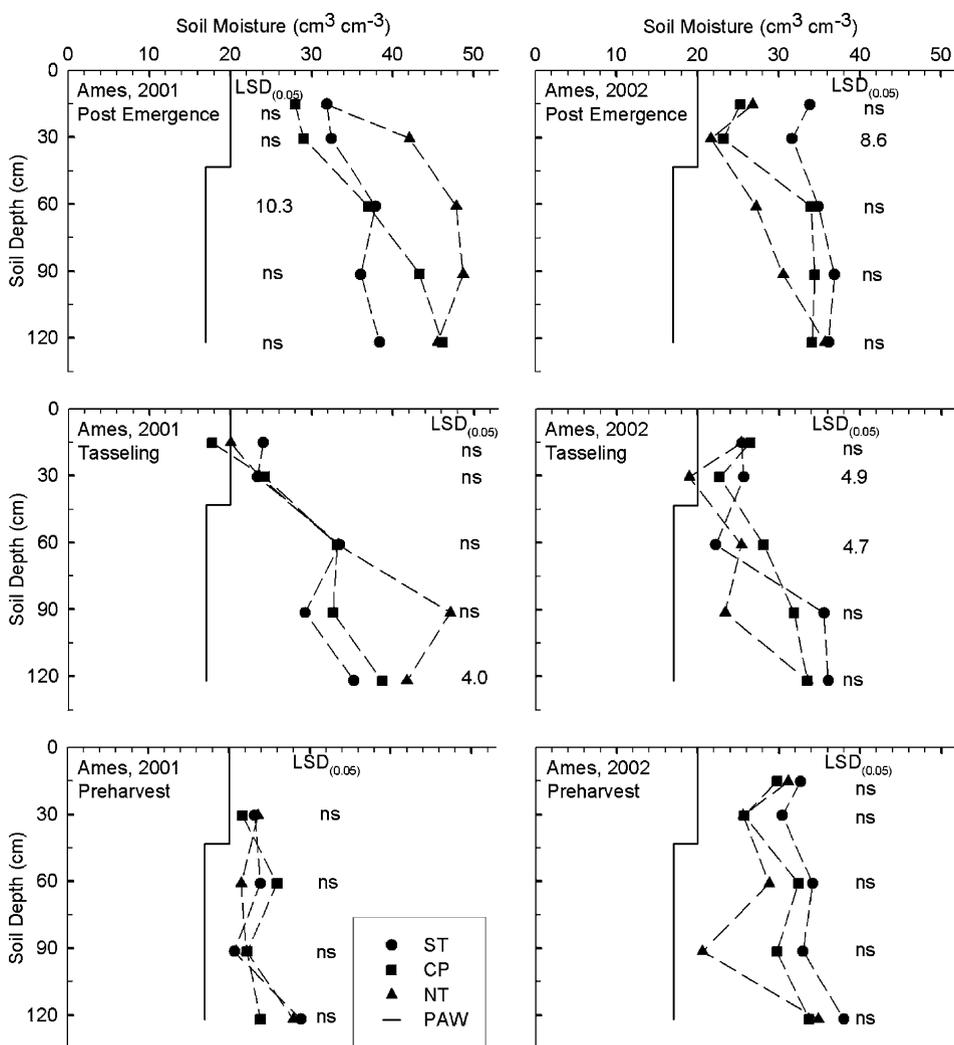


Fig. 5. Soil moisture profile for the Ames site in 2001 and 2002. Post-emergence, tasseling, and preharvest measurements were taken on 8 June, 10 July, and 28 August 2001 and on 28 May, 9 July, and 19 August 2002, respectively. The least significant differences are according to Fisher's $LSD_{(0.05)}$ test.

It was also observed at the Nashua site in 2001, that the soil moisture content at the top 60 cm under NT was lower than that under the ST and CP at the post-emergence, tasseling, and preharvest periods for 1 out of the 4 site years, whereas ST and CP did not result in any significant soil moisture differences (Fig. 6). These lower soil moisture contents under NT are uncharacteristic of NT soil moisture profile where the other 3 site years show the opposite under NT. It is possible to find a minimal effect of NT on conserving soil moisture, especially if the NT is not in a

long established system, such as in our case. It was also found by Erbach et al. (1992) in a study on similar Iowa soils that different tillage systems, including no-till, chisel plow, moldboard plow, and para plow, show no significant difference in soil moisture, while Karlen et al. (1994) concluded no-tillage to have a higher soil moisture content than chisel plowing in the top 5 cm soil depth. Soil moisture at the Nashua site in 2002 was not significantly different for all tillage systems at any depth or recording period, similar to that of Erbach et al. (1992). Tillage systems showed

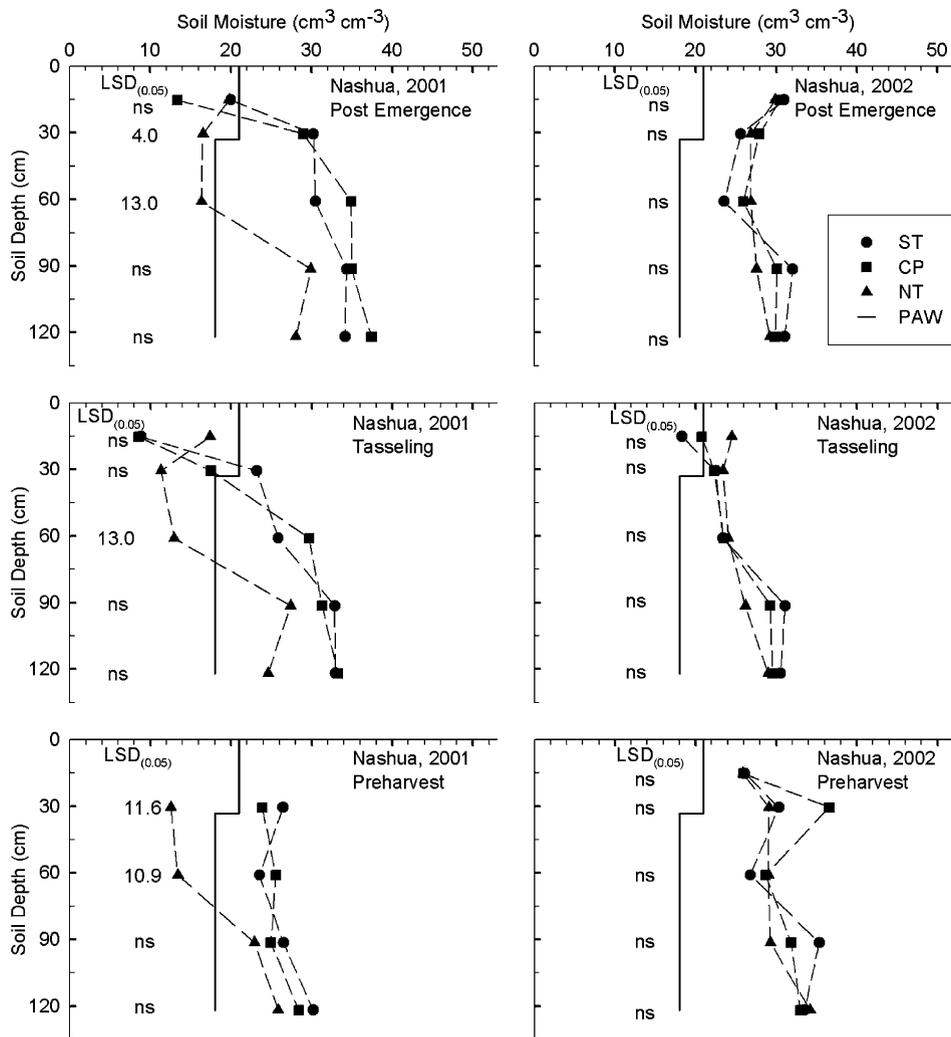


Fig. 6. Soil moisture profile for the Nashua site in 2001 and 2002. Post-emergence, tasseling, and preharvest measurements were taken on 28 June, 12 July, and 22 August 2001 and on 30 May, 16 July, and 20 August 2002, respectively. The least significant differences are according to Fisher's LSD_(0.05) test.

effects on the soil moisture profile at the Nashua and Ames sites in 2001 and at the Ames site in 2002. Soil moisture content differences among all tillage systems were more pronounced in 2001 compared with 2002, where the soil moisture content differences were not significant, especially for the lower depths. Generally, NT had an advantage over ST and CP at the top-soil depths in increasing soil moisture. However, ST and CP had greater influence in increasing soil moisture content at the lower depths of the soil profile. At the Nashua site, in 2001, the soil moisture content in the top 60 cm fell below the PAW mostly for NT at post-emergence, tassel, and preharvest growth stages, whereas ST and CP fell below PAW only in the top 30 cm at post-emergence and tasseling growth stages. In contrast, soil moisture content through the soil profile at the same site in 2002 was greater than the PAW except at the top 15 cm during tassel growth stage (Fig. 6).

Tillage effects on soil moisture storage were not significant in the 0–30 cm soil depth for the Ames site in 2001, but NT showed 13 and 22% more water storage than ST and CP, respectively (Table 3). However, at Ames in 2002, ST stored more soil moisture in the

0–30 cm soil depth than NT at the post-emergence and tasseling period. In 2001, comparing moisture storage in the top 30 cm from post-emergence to tasseling, the moisture storage declined by 29, 25, and 48% for ST, CP, and NT, respectively. Less significant changes in soil moisture storage for the same period were observed in 2002. On the other hand, no considerable changes in soil moisture storage in the top 30 cm were noticed between tasseling and preharvest for all tillage systems. Similar trends were noticed for the 0–120 cm soil profile, where soil moisture storage was not significantly different when comparing tillage systems in both years at the Ames site.

At the Nashua site, the soil moisture storage at the 0–30 cm soil depth did not show significant difference between the three tillage systems during 2001 or 2002 (Table 3). However, changes in soil moisture storage in the 0–30 cm soil depth from post-emergence to tasseling were 36, 38, and 20% greater for ST, CP, and NT, respectively, in 2001, and 29, 26, and 16%, respectively, greater in 2002. On the other hand, no significant changes were observed from tasseling to preharvest in both years. Soil moisture storage in the 0–120 cm soil profile was not significantly different

Table 3

Tillage effects on soil moisture storage at three growth periods for the Ames and Nashua sites during 2001 and 2002

Location	Depth (cm)	Tillage	Post-emergence (mm)		Tasseling (mm)		Preharvest (mm)	
			2001	2002	2001	2002	2001	2002
Ames	0–30	ST	98.1a	99.8a	70.3a	77.9a	70.7a	96.2a
		CP	86.9a	73.8b	65.0a	74.8a	66.0a	84.5a
		NT	112.7a	73.7b	66.3a	67.5b	71.9a	86.5a
	0–120	ST	440.7a	428.7a	314.9a	364.0a	294.6a	416.5a
		CP	472.7a	386.2a	383.5a	359.8a	285.8a	376.6a
		NT	545.8a	358.5a	438.5a	318.1a	290.2a	343.1a
	Rainfall	–	–	44	113	95	209	
Nashua	0–30	ST	76.6a	86.3a	48.8a	62.2a	80.6a	86.0a
		CP	64.5a	89.0a	39.7a	65.6a	72.9a	95.3a
		NT	55.4a	86.6a	43.7a	73.0a	38.3a	83.8a
	0–120	ST	378.5a	350.6a	328.3a	321.5a	325.2a	377.3a
		CP	391.9a	351.0a	327.1a	316.5a	313.3a	380.3a
		NT	281.9a	341.6a	241.7b	314.5a	227.7a	365.7a
	Rainfall	–	–	2	118	124	283	

Post-emergence, tasseling, and preharvest measurements at Ames were taken on 8 June, 10 July, and 28 August 2001 and on 28 May, 9 July, and 19 August 2002, respectively. Post-emergence, tasseling, and preharvest measurements at Nashua were taken on 28 June, 12 July, and 22 August 2001 and on 30 May, 16 July, and 20 August 2002, respectively.

Means within the same column followed by the same letter are not significantly different for each site and depth increment according to a protected Fisher's LSD_(0.05).

for any of the tillage systems. However, in 2002 at the Nashua site soil moisture storage was significantly lower for NT compared to ST and CP during the tasseling period, but not significantly different at the post-emergence or preharvest periods. Changes in soil moisture storage for all tillage systems for the 0–120 cm soil profile were similar to that of 0–30 cm, where most moisture changes occurred between post-emergence and tasseling.

In summary NT, ST, and CP has little effect on soil moisture at both depths. In another study in Iowa, [Erbach et al. \(1992\)](#) found that water con-

tent was not affected by tillage systems in the top 20 cm soil depth, which is consistent with our findings where soil moisture showed no significant differences at the top 30 cm. However, the changes in soil moisture were much greater with ST and CP than NT from post-emergence to preharvest. It was observed also that most change in soil moisture storage occurred between post-emergence and tasseling. This can be attributed to lower amounts of precipitation during the post-emergence to tasseling period than during the tasseling to preharvest period ([Table 3](#)).

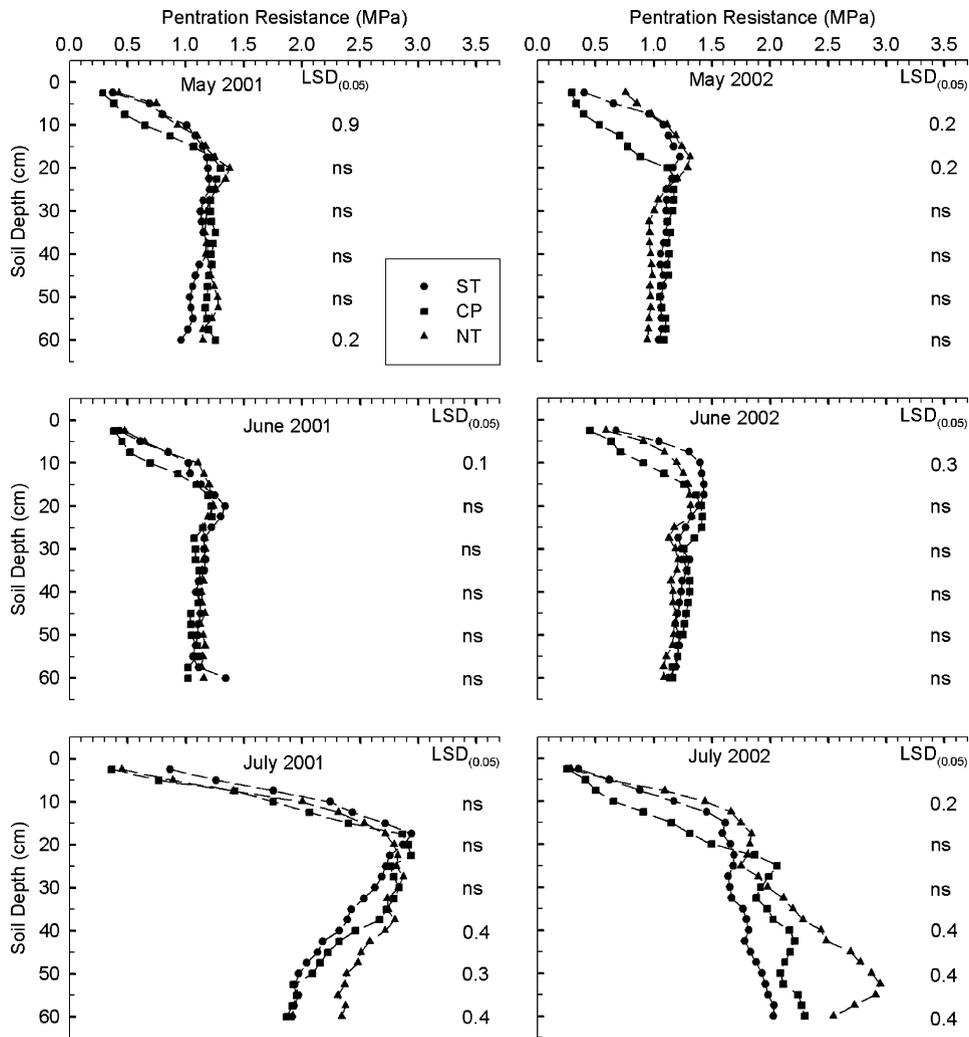


Fig. 7. Penetration resistance for the soil profile at the Ames site in 2001 and 2002. The actual recording periods were 15 May, 12 June, and 10 July 2001 and 14 May, 17 June, and 9 July 2002. The least significant differences are according to Fisher's $LSD_{(0.05)}$ test.

3.3. Penetration resistance

Penetration resistance also can be an indicator that can be used to evaluate tillage effects on soil physical properties. At the Ames site in 2001, tillage treatments show significant differences in soil penetration resistance at the top 10 cm soil depth during May and June (Fig. 7). However, the penetration resistance was not significantly different at the lower soil depths between tillage treatments, except at the 60 cm soil depth where ST was significantly lower than CP and NT in May. However, in July 2001, NT shows significantly greater

penetration resistance than ST and CP at the 40–60 cm soil depths (Fig. 7). In 2002 at the Ames site, during the May and June periods at the 0–10 cm soil depth, ST penetration resistance was similar to that of NT and both had a significantly greater penetration resistance than CP (Fig. 7). However, for the 10–60 cm soil depths, penetration resistance was not significantly different for all tillage treatments. However, during July 2002, the penetration resistance tended to generally increase with soil depth and the penetration resistance of ST was significantly lower than those of CP and NT at soil depths 40–60 cm at the Ames site.

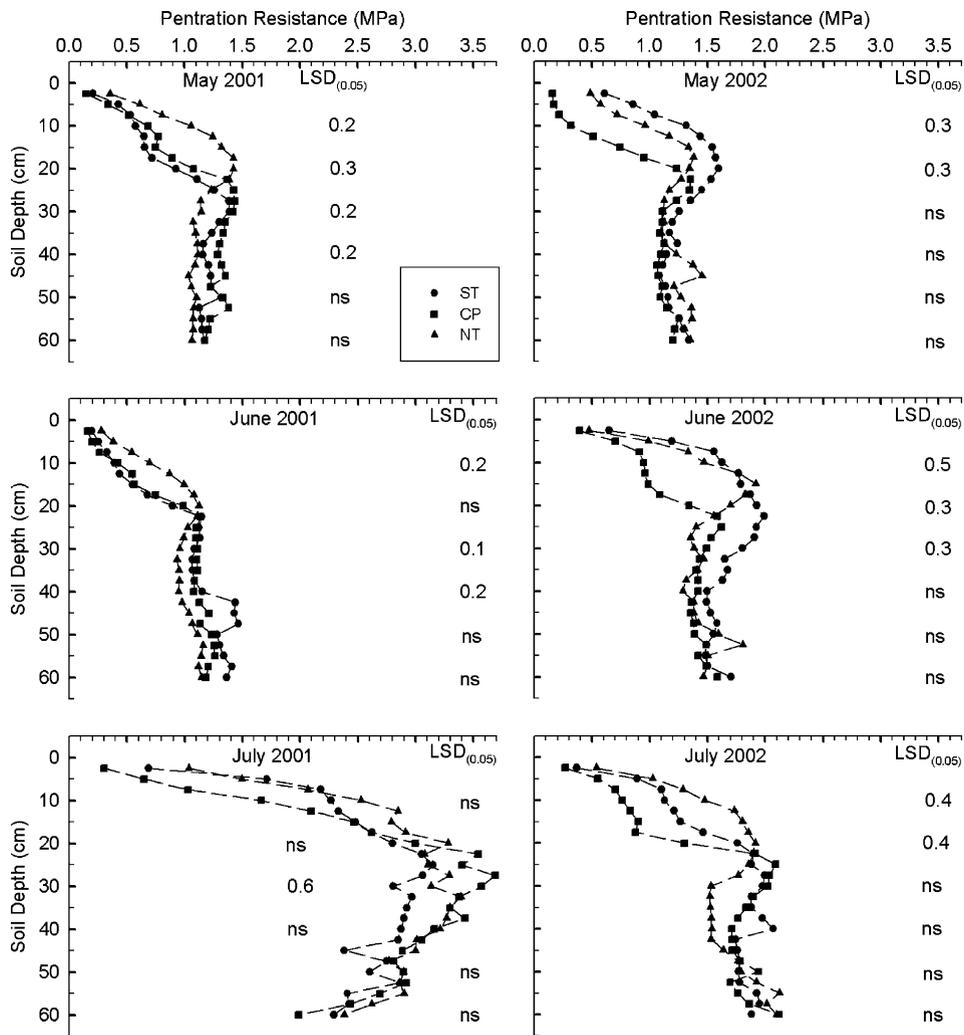


Fig. 8. Penetration resistance for the soil profile at the Nashua site in 2001 and 2002. The actual recording periods were 18 May, 15 June, and 12 July 2001 and 13 May, 18 June, 16 July 2002. The least significant differences are according to Fisher's LSD(0.05) test.

At the Nashua site during May and June 2001, penetration resistance for the top 20 cm soil depth was similar for both ST and CP, but significantly less than that of NT (Fig. 8). However, in July the penetration resistance was not significantly different between CP, ST, and NT at the top 20 cm or at 40–60 cm soil depths. The only significant difference in penetration resistance was observed in July at the 30 cm soil depth between the three tillage treatments. In 2002, at the Nashua site, ST and NT had similar penetration resistance, which was significantly greater than that of CP at the 10–20 cm soil depth in May and 10–30 cm in June. However, in July NT resulted in greater penetration resistance than both ST and CP at 10–20 cm soil

depths. No significant differences in penetration resistance were observed between all tillage treatments during May–July for depths below 20 cm (Fig. 8). In general, the results show high variability in penetration resistance among different tillage systems and it was more pronounced late in the season. It was also observed that penetration resistance under NT was generally greater than that of CP, especially in the top 20 cm soil depth (Figs. 7 and 8).

The relationships between penetration resistance and soil moisture are presented in Fig. 9. The results suggest that penetration resistance for all tillage systems was greatly affected by soil moisture content over time, where greater penetration resistance values

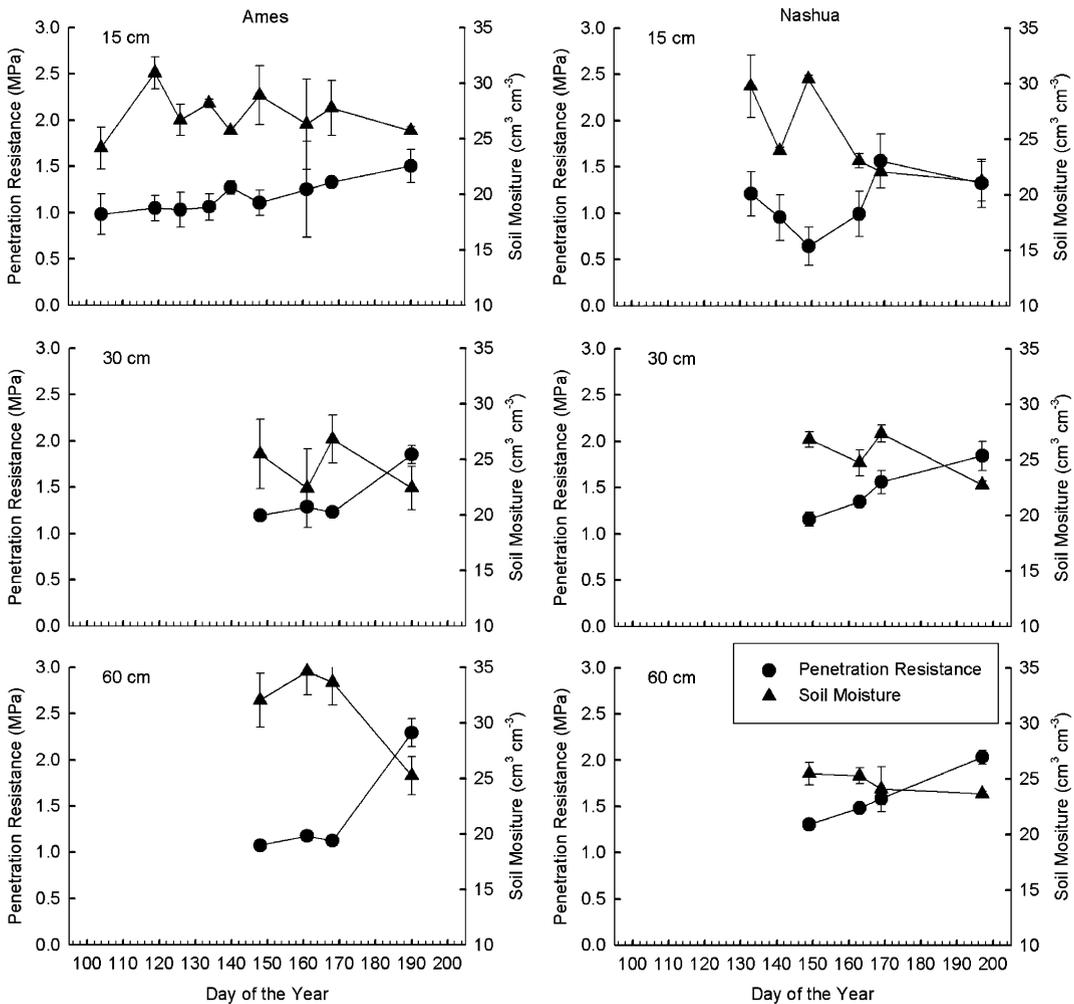


Fig. 9. A comparison of penetration resistance and soil moisture at the 15, 30 and 60 cm soil depth for the Ames and Nashua sites in 2002.

were observed as the growing season progressed and more moisture was depleted from the soil profile at different soil depths. In this study penetration resistance was inversely related to soil moisture particularly at soil depths of 15, 30, and 60 cm soil depths for both sites.

4. Conclusions

The findings of this study show limited advantages strip-tillage can offer over no-tillage in improving soil temperatures in the early spring. Soil temperatures associated with strip-tillage were comparable with chisel plow, and their maximum soil temperatures were greater than those of no-tillage by 1.4–1.9 °C. Daily soil temperatures did not show significant differences between all tillage systems until approximately 18 h, where the maximum air temperature was often reached. This finding suggests that top-soil under strip-tillage and chisel plow had lower heat capacity and greater thermal conductivity than no-tillage due to lower moisture content. The change in soil temperature due to tillage effect was not reflected in improvement of plant emergence rate index or corn grain yield. Changes in soil temperature magnitude due to tillage effects were highly dependent on air temperature throughout the day, when maximum air temperature often resulted in maximum soil temperature. Findings show that strip-tillage can be as effective as no-tillage in conserve soil moisture within the soil profile. The results of this study show no significant differences in soil moisture content for any depth or soil moisture storage in the 0–30 cm and 0–120 cm soil depth increments between all tillage systems, but generally strip-tillage shows greater soil moisture content than chisel plowing and similar values to no-tillage at the lower soil depths. Changes in soil moisture storage were much greater with strip-tillage and chisel plowing than no-tillage from post-emergence to preharvest. It was observed also that most changes in soil moisture storage occurred between post-emergence and tasseling. In this study penetration resistance of strip-tillage was often comparable with no-tillage, but greater than chisel plow at the upper depths (0–20 cm) of the soil profile. At lower depths of the soil profile, strip-tillage generally resulted in decrease in penetration resistance compared

with chisel plow and no-tillage. Penetration resistance and soil moisture were inversely related throughout the soil profile, where the effect of soil moisture on penetration resistance was more pronounced at the 30 and 60 cm soil depths. These benefits of strip-tillage over no-tillage have the potential to promote stronger plant emergence and competitive yield compared with chisel plow. Therefore, strip-tillage may have an advantage over no-tillage in wet poorly drained soils, but justification of implementing the system would be dependent upon site-specific field conditions.

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