REDUCED TILLAGE FIELD CORN (*Zea mays* L.) PRODUCTION IN MANITOBA

A Thesis

Submitted to the Faculty

of

Graduate Studies

The University of Manitoba

by

David Alexander Wall

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

Department of Plant Science

May 1982

REDUCED TILLAGE FIELD CORN (*Zea mays* L.) PRODUCTION IN MANITOBA

BY

DAVID ALEXANDER WALL

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks and gratitude to the following individuals for their assistance given during this study.

Dr. E.H. Stobbe, my advisor, for his guidence and helpful suggestions given during the course of this study and for the opportunity he gave me to learn and grow as a person.

Dr. K.W. Clark and Dr. E.N. Larter, Department of Plant Science, and Mr. G.F. Mills, Department of Soil Science, for their helpful suggestions and advice and their reviewing of this manuscript.

The summer help; Heather Davey, Leslie Michalchuk, Kim Milani, Cathy Bachelo and Robert Doell, without whose help few, if any, soil moisture determinations would have been possible.

David Rourke, Research Associate, Alvin Iverson and Brent Wright, technical staff and Allan Bailey and Carl McGregor, fieldmen, for the assistance given in the practical aspects of farming.

Larry Sernyk for all the help with the computer programs.

My fellow graduate students; Wolfgang Sturny, George Clayton, Brent Wright, Robert Doell and Arumugam Sentinathan, for their cooperation and friendship during the past two years.

To mum and dad for your love, support and encouragement during these past years and for tolerating the clutter of papers and books which I left in every room of the house.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Wall, David Alexander. M.Sc., The University of Manitoba, May, 1982. Reduced Tillage Field Corn (Zea mays L.) Production in Manitoba. Major Professor; Dr. E.H. Stobbe.

Field studies were conducted on field corn (*Zea mays* L.) under various conventional and reduced tillage cropping systems and straw management practices to determine the effect on soil physical properties, crop growth, development and yield. The performance of eight corn hybrids was evaluated under conventional and zero tillage to study the adaptability of hybrids to zero tillage cropping practices.

Corn under zero tillage exhibited delays in emergence, silking and maturity, reduced plant populations, dry matter, plant height and grain yields. The negative effects of zero tillage on crop performance were attributed to poorer seed placement and lower soil temperatures. The lower soil temperatures and higher soil water content which occurred under zero tillage were attributed to the presence of a barley straw mulch on the soil surface.

The performance of the corn grown under conventional tillage, in which the seedbed had been prepared the previous fall, was superior to all other treatments examined. The superior performance of the fall tillage treatment was considered to have resulted from improved seed placement and greater soil moisture.

The removal of the barley straw mulch from the soil surface promoted

earlier silking and maturity, increased plant heights, populations and grain yields in corn. The removal of the straw mulch resulted in increased soil temperatures relative to where the straw mulch had been retained.

The eight hybrids examined exhibited similar responses to zero till -age during the growing season. At harvest, however, the hybrids exhibited a differential yield response to tillage. Four hybrids; Pioneer 3995, Pride R102, Pride R108 and Pickseed 2322 were not affected by zero tillage, while the remaining hybrids; Pickseed 2111, Asgrow RX22, Pioneer 3992 and Funks G4065 exhibited reduced grain yields under the zero tillage treatment.

INTRODUCTION

The move to zero or no tillage for field corn production has been an important development in many areas of the U.S. corn belt. Emphasis has been placed on field corn production under zero tillage due to the importance of corn to the dairy industry. Much of the U.S. dairy production is located in areas where the land is to steep for cultivation without excessive soil erosion (Shear, 1968). Under zero tillage, corn may be grown on steep sloping land with a minimum amount of soil erosion. Corn yields under zero tillage have been reported to equal or exceed those recorded under conventional tillage (Moody et al., 1961; Jones et al., 1968). Current extimates of crop land under zero tillage in the U.S. are 2.9 million hectares or 3.2% of that under conventional tillage crop production (Willey, 1982).

A number of crops have been successfully grown under zero tillage on the Canadian prairies, including; wheat, barley, flax and rapeseed. Attempts to produce field corn under zero tillage, however, have not been successful.

The objective of this study was to compare the growth, development and yield of a corn crop under various tillage and straw management practices and to assess the effect of these practices on soil moisture and soil temperature. A further objective was to determine whether corn hybrids varied in adaptation to zero tillage cropping practices.

LITERATURE REVIEW

Tillage and Mulch Effects on Soil Moisture

Much of the success of corn production under systems of reduced tillage has been attributed to the conservation of soil moisture. A number of studies have shown soil moisture to increase in the surface layers of the soil under zero tillage relative to conventionally tilled soils (Jones et al., 1968; Triplett et al., 1968; Stanholtz and Lillard 1969; Blevins and Cook, 1970; Lal, 1974). Generally, the differences in soil moisture between zero and conventionally tilled soil decreased with increasing soil depth and also as the season progressed (Stanholtz and Lillard, 1969; Blevins and Cook, 1970). Several studies have shown that the ability of corn to survive periods of short term drought was increased with zero tillage cropping practices (Stanholtz and Lillard, 1969; Blevins and Cook, 1970; Gallaher, 1977). Gallaher (1977) reported that removing the mulch associated with the zero tillage treatments decreased the ability of the corn to withstand drought. The importance of the mulch was paramount to moisture conservation under zero tillage. Many of the moisture conserving attributes of zero tillage; reduced evaporative loss of soil moisture, reduced surface runoff and increased infiltration have been attributed to the surface mulches formed by the previous crop residues (Jones et al., 1968; Triplett et al., 1968; Blevins and Cook, 1970; Harrold et al., 1970; Lal, 1974).

Studies examining the use of mulches have shown soil moisture to be increased in the surface layers of the soil (Larson et al., 1960; Moody et al., 1961; Moody et al., 1963). Moody et al. (1963) reported a seven fold decrease in surface runoff when 3 tons/acre of wheat straw was applied to a bare soil surface. Triplett et al. (1968) reported increased infiltration with increasing amounts of chopped corn stover mulch. Decreased runoff and increased infiltration may account for the initial increase in soil moisture during and/or after periods of precipitation, but it does not directly account for the greater soil moisture, relative to bare ground, observed during periods of drying. Increased soil moisture during soil drying occurred primarily due to a reduction in the evaporative loss of moisture from under mulches (Russel, 1939; Moody et al., 1961; Jones et al., 1968; Blevins and Cook, 1970; Stanholtz and Lillard, 1969; Blevins et al. 1971). Russel (1939) determined that mulch -es prolonged soil drying which allowed greater penetration of water, further, mulches decreased evaporation, in part by obstructing solar radiation. Bond and Willis (1969) reported that mulches reduced the initial rate of evaporation, but, given prolonged periods of drying the cumulative evaporative losses were nearly equal for all levels of mulch and bare soil. The reduction of evaporative moisture loss from the soil was greatest when the soil cover was complete, (Willis, 1962). Grebb (1966) reported that evaporative losses of soil moisture decreased in a linear relationship to the amount of straw applied to the soil surface, up to 90% soil coverage (3,360 kg/ha). Russel (1939) found that light applications of straw (2 tons/acre or 4,500 kg/ha) were almost as effective in reducing evaporation as were heavy applications (16 tons/acre or 35,900 kg/ha). Moisture conservation by mulches occurred primarily when the cumulative evaporation between successive rainfalls was less than that of bare soil (Russel, 1939; Bond and Willis, 1969).

As previously stated, the difference in soil moisture between bare and zero tilled (mulched) soils decreased as the season progressed. Stanholtz and Lillard (1969) suggested that the decrease in moisture differences between zero tilled and bare soils occurred due to the 'evapotranspiration phenomenon' whereby early season losses of soil moisture occurred primarily by evaporation from the soil surface. Later in the season the growing plants shaded the soil surface and reduced evaporation, at this point transpirational losses were the main pathway of soil moisture loss. Transpirational losses would be assumed to be similar for both zero tillage and conventionally grown corn.

Tillage Effects on Soil Bulk Density

The effects of zero tillage on soil compaction vary according to the soil type. Cannel and Finney (1973) found that the bulk density of soils under zero tillage was greater than on conventionally tilled soils, except on light textured and high organic matter soils. Several studies have shown increased soil bulk density where corn was produced under zero tillage (Triplett et al., 1968; Harrold et al., 1970; Lal, 1974). Harrold et al. (1970) reported no difference in soil bulk density below the surface 7.5 cm of zero and conventionally tilled soils. Shear and Moschler (1969) and Blevins and Cook (1970) reported no difference in soil bulk density between zero and conventionally tilled soils when the soil type was a loam.

Tillage and Mulch Effects on Soil Temperature

The importance of soil temperature at seeding is due to the minimum temperature at which corn will germinate, generally this is accepted to be about 10^{o}C (Arnon, 1975; Sprague, 1977). At the time of seeding, soil temperatures below 10^{o}C may delay and/or reduce germination. Soil temperatures may be influenced by a number of factors, including; tillage, crop residues and shading of the soil surface by the growing plant.

Allmaras et al. (1972) found that soil temperatures at planting were up to 2^{o}C warmer on conventionally tilled soil where plowing had been done in the fall as opposed to spring plowing. The timing of the tillage operations appeared to influence soil temperatures at seeding. In the absence of tillage, there is evidence to indicate that soil temperatures are lower than on tilled ground (Stanholtz and Lillard, 1969; Blevins and Cook, 1970; Griffith et al., 1973; Lal, 1974; Mock and Erbach, 1977; Gauer, 1981). However, Olson and Schoeberl (1970) found that soil temperatures during the early season were not different between conventional and reduced tillage treatments.

Under zero tillage, maximum soil temperatures were reduced to a greater extent than were the minimum soil temperatures (Stanholtz and Lillard, 1969; Blevins and Cook, 1970; Gauer, 1981). The effect of zero tillage on soil temperature has been found to decrease with increasing soil depth (Stanholtz and Lillard, 1969). The observed reductions in the temperature of zero tilled soil were attributed to the presence of previous crop residues which formed a mulch over the soil surface (Blevins and Cook, 1970; Griffith et al., 1973; Mock and Erbach, 1977). Under reduced tillage, as the amount of residues increased the soil temperature decreased (Griffith et al., 1973; Mock and Erbach, 1977). Larson et al. (1970) reported that the residues from a 100 bu/acre corn crop reduced soil temperatures at the 10 cm depth by about 1.1^{o}C or about 0.4^{o}C for each 900 kg of crop residues. Burrows and Larson (1962) and McCalla and Duley (1946) reported that soil temperatures decreased with increasing rates of crop residues. Gauer (1981) at the University of Manitoba, reported that no depression in soil temperatures occurred under zero tillage when the crop residues had been removed. Further, it was also reported that zero tilled soils with a crop residue mulch were periodically warmer in the early spring than conventionally tilled soil or zero tilled soils from which the mulch had been removed.

A number of studies have reported the effects of straw mulches on soil temperature similar to those of tillage. Mulches tend to affect maximim soil temperatures more than minimum soil temperatures (Van Wijk et al., 1959; Burrows and Larson, 1961; Moody et al., 1963; Onderdonk and Ketcheson, 1973a). The effect of depressing maximum soil temperatures without extensively altering the minimum temperatures resulted in a decrease in the diurnal fluctuation of soil temperatures. The diurnal fluctuation decreased with increasing rates of mulch, as well as with increasing soil depth, (McCalla and Duley, 1946; Burrows and Larson, 1962). The effects of mulches on maximum, minimum and mean daily soil temperature decreased with both increasing soil depth and as the season progressed, however, the effect of the mulch never completely disappeared. As the plants grew and began to shade the soil the difference between mulched and bare soil became less, shading had the same effect as a small amount of mulch, (McCalla and Duley, 1946; Burrows and Larson, 1961). Mulches tended to result in warmer soils when the soils were cooling, as in the fall, and cooler soils when the soils were warming, as in the spring (McCalla and Duley, 1946; Burrows and Larson, 1962).

Several mechanisms are involved in the reduction of soil temperatures by mulches. Shading of the soil surface by the mulch or by the growing plant resulted in the occlusion of solar radiation, (Blevins and Cook, 1970). As the solar radiation is occluded it is unable to warm the soil. Dead grass sod and straw mulches contain non-moving air which acts as an insulator, as a result, straw mulches have low heat conductivities, this may reduce the rate of heat penetration and release leading to delays in soil warming and cooling. Reflectivity or albedo is perhaps the most important property of straw mulches affecting soil temperature. Burrows and Larson (1961) stated that soil temperatures under mulches are reduced because less heat energy reaches the soil surface due to the reflection of heat by the straw. McCalla and Duley (1946) determined that bright clean straw reduced soil temperatures to a greater extent than did decayed straw. Decayed residues, after six months, did not reduce soil temperatures by more than 1 or $2^{o}C$. The reflectivity of the surface residues decreases as the residues undergo decomposition and weathering (Cruse et al., 1980). A combination of increased decomposition and weathering of crop residues as well as increased shading of the soil by the growing plants may account for the decreased effects of mulches on soil temperature, relative to bare ground, later in the season.

The Effects of Tillage and Mulches on the Performance of Field Corn

Germination and Emergence

Few references were found concerning the effects of tillage on the germination and emergence of corn. Mock and Erbach (1977) reported that corn seedlings emerged earlier from conventionally tilled soils than from those under reduced tillage, the reduced tillage treatments had the lowest seed row temperatures. Unlike many of the annual cereals; wheat, barley or wild oats, which are relatively unaffected by soil temperature during germination and emergence (Dubetz et al., 1962), corn exhibits specific temperature requirements. It is generally accepted that little, if any, germination take place at/or below 10^{o}C (Arnon, 1975; Sprague, 1977). Dubetz et al. (1962) and Alessi and Power (1971) determined that no germination occurred at temperatures of 6.0 and 6.7^{o}C, respectively.

The effect of straw mulches on emergence may simulate emergence under reduced tillage cropping. Delayed emergence under straw mulches corresponded to observed reductions in soil temperature beneath mulches (Willis et al., 1957; Burrows and Larson, 1962). Emergence occurred later with increasing rates of mulch, at 8 tons/acre it was physically impossible for the corn seedlings to emerge through the mulch (Burrows and Larson, 1962).

Soil temperature effects on germination and emergence have been studied extensively. McAdam and Hayes (1978) have shown certain genotypes to germinate more readily at lower temperatures than other genotypes. In general, soil warming reduced the time for germination (Rykbost et al., 1975; Cooper and Law, 1978). Iremiren and Milbourn (1979) have shown that soil warming improved the percentage germination. Tillage or mulch treatments resulting in increased soil temperatures decreased the time between sowing and emergence (Willis et al., 1957; Dubetz et al., 1962; Adams, 1967; Ketcheson, 1970; Alessi and Power, 1971; Phillips and Cochrane, 1975; Rykbost et al., 1975; Iremiren and Milbourn, 1979).

Root Growth and Development

The effects of tillage on corn root growth and development have not been extensively studied. Tillage is known to affect a number of soil physical properties, including; bulk density, moisture and temperature, which in turn may influence root growth and development. Lal (1974) reported root growth during the early stages of growth to be depressed by zero tillage. Greater compaction of zero tilled soils has been attributed to restricting the extension of the seminal roots in spring barley (Ellis et al., 1977). Barber (1971) characterized corn roots grown under zero tillage as being of a larger diameter and fewer in number, with the zone of maximum root density located within 10 cm of the soil surface. Similar findings have been reported by Onderdonk and Ketcheson (1973a), having shown that under a mulch of chopped corn stover, corn roots were typical of nodal adventitous roots. Further, it was determined that soil temperatures were reduced by the mulch while soil moisture was increased only after periods of precipitation. Barber (1971) suggested that decreased root growth under zero tillage may be attributed to inhibitory decomposition products released by the straw as it undergoes decomposition.

Straw mulches associated with zero tillage have been found to delay the death of corn plants by maintaining root activity for a longer period of time (Gallaher, 1977). Gallaher (1977) has shown greater root activity deeper in the soil in the presence of a straw mulch, this suggested a more developed root system existed under the mulch, which was better able to utilize soil moisture than the corn root system formed under zero tillage in the absence of the mulch.

The effects of soil temperature on corn root growth are understood to a greater extent than are the effects of tillage. Geotropic response mechanisms which determine the direction of radicle growth may respond to soil temperature. High soil temperatures have been found to result in verticle growth of corn radicles, while decreasing soil temperatures (to 17°C) resulted in horizontal radicle growth (Mosher and Miller, 1972; Onderdonk and Ketcheson, 1973b). Below 17°C Onderdonk and Ketcheson (1973b) reported a return to verticle radicle growth.

Optimum soil temperatures for root growth have been suggested in several studies. Walker (1969) determined that the optimum temperature for corn root growth was 26°C, with significant reductions in root dry matter accumulation occurring at temperatures on either side of this optimum. Grobbelaar (1963) stated that the optimum soil temperature for corn root growth occurs between 20 and 30°C. Root growth was practically inhibited at 5°C. The 26°C optimum should be considered only in general terms as other studies have suggested that the optimum soil temperature for root growth is determined by the genotype of the corn under study (Porter and Moraghan, 1975; McAdam and Hayes, 1978).

Seeding into cold soils (12°C) has been shown to delay root growth (Cal and Obendorf, 1972). Beauchamp and Lathwell (1967) have reported increase root branching and dry weights at low soil temperatures (15°C). Little is known about root configuration under various soil moisture and temperature regimes. The work of Allmaras and Nelson (1971 and 1973) has suggested that root configuration is affected by soil moisture and soil temperature such that straw placement may be an important factor in determining the configuration of the corn root system.

Shoot Dry Matter

Reduced tillage systems tended to result in increased plant dry matter (Moody et al., 1961; Moody et al., 1963; Jones et al., 1968; Shear and Moschler, 1969). These studies have often shown increased dry matter production corresponding to increased soil moisture and/or reductions in the amount of tillage. Other studies have, however, shown plant dry matter, particularly that of corn seedlings, to decrease when grown under reduced tillage (Mock and Erbach, 1977). Along with the reduction in dry matter there occurred a corresponding decrease in soil temperature with decreasing amounts of tillage (Mock and Erbach, 1977).

Walker (1969) has shown the optimum soil temperature for shoot dry matter production in corn seedlings to be 26°C, the same as that reported for root dry matter production. Temperatures on either side of the optimum resulted in a reduction in the dry matter production. Several studies have concluded that the average weight of dry matter per plant increases with increasing root zone temperatures for both seedlings (Burrows and Larson, 1961; Mederski and Jones, 1963; Walker, 1969; Ketcheson, 1970; Phillips and Cochrane, 1975; Mock and Erbach, 1977) and the mature plants (Mederski and Jones, 1963; Ketcheson, 1968;

Phillips and Cochrane, 1975). However, Beauchamp and Lathwell (1967) reported that at predetermined growth stages, seedling dry matter decreased with increasing root temperatures from 15 to 25°C.

Where the soil surface is covered by a straw mulch, reductions in soil temperature could be expected to result in decreased seedling dry weights and possibly reductions in the mature plant dry matter content.

Plant Height

The rate of plant growth under systems of reduced tillage appears to be related to those factors, in the soil enviroment, most limiting to the rate of growth and which may be influenced by the degree of tillage; soil moisture and soil temperature. Plant height is frequently used as an indicator of corn growth. Under zero tillage greater plant heights have been reported relative to conventional tillage (Moody et al., 1961; Jones et al., 1968). Increased plant height under zero tillage may relate to the presence of cereal straw or corn stover mulches. Triplett et al. (1968) reported that plant heights increased with increasing amounts of chopped corn stover. Increased plant height in the presence of mulches has been attributed to increased soil moisture beneath the mulches. Other studies have shown plant heights, particularly during the early stages of growth, to be depressed by reduced tillage (Griffith et al., 1973; Mock and Erbach, 1977). Griffith et al. (1973) have shown reductions in plant height corresponding to decreased amounts of tillage and increasing ground cover (crop residues). Mulches have been found to depress soil temperatures resulting in decreased plant heights. Increasing rates of mulch were found to result in further depressions in soil temperature which corresponded to reductions in plant height (Larson et al., 1960; Burrows and Larson, 1961). Increasing the root zone temperatures have been observed to stimulate corn growth resulting in greater plant heights (Willis et al., 1957; Mederski and Jones, 1963; Jones and Mederski, 1963; Kleinendorst and Bouwer, 1970; Watts, 1972a; Watts, 1972b).

Reductions in corn growth in response to suboptimal root zone temperatures occurs by two mechanisms. By separately regulating the temperature of both the roots and the meristematic region, Kleinendorst and Bouwer (1970) were able to show that while the meristematic region was maintained at a temperature conducive to growth, the rate of leaf extension was relatively unaffected by suboptimal root temperatures. It was further shown that maintaining the roots at a temperature favorable for growth would not compensate for reductions in the rate of growth caused by maintaining the meristematic region at low temperatures. Reductions in the rate of growth induced by soil temperature effects on the meristematic region persist only while the meristematic region remains below ground. Once it is elevated above the soil surface, air temperature regulated the temperature of the meristematic region (Cooper and Law, 1978). Reductions in growth at low meristematic temper -atures are thought to result from a supression of biological processes; cell division, cell elongation and cellular respiration (Beauchamp and Lathwell, 1967; Kleinendorst and Bouwer, 1970; Watts, 1972b).

The second mechanism by which low soil temperatures depress plant growth is by a loss of leaf turgor pressure (Kleinendorst and Bouwer, 1970; Barlow et al., 1977). Decreased leaf water potential resulted from a reduction in the permeability of the root to water at low root temperatures. Barlow et al. (1977) have suggested, however, that the loss of turgor was due to a reduction in the root hydraulic conductivity at the low root temperatures.

Suboptimal root zone temperatures affect both the root and the meristematic region resulting in decreased leaf elongation. Temperature reductions, in the root zone, below $15^{o}C$ have been found to affect the growth reductions induced by the roots to a greater extent than those reductions induced by the meristematic region (Barlow et al., 1977). At $12.5^{o}C$, Barlow et al. (1977) determined that leaf elongation ceased.

Leaf Production

Mock and Erbach (1977) had determined that corn seedlings grown under reduced tillage produced significantly fewer leaves than those grown under conventional tillage practices. Similarly, Cal and Obendorf (1972) reported that seeding into seedbeds with low soil temperatures resulted in juvenile plants having fewer leaves than those sown into warm seedbeds. A greater number of leaf primordia were found to be initiated in the warm soils, resulting in an increase in the final number of leaves produced per corn plant (Cooper and Law, 1977). Similar increases in final leaf numbers were attributed to warmer soils during early plant development (Beauchamp and Lathwell, 1966; Cooper and Law, 1978).

Silking and Maturity

A number of studies have examined the effects of mulches and soil temperature on the development of corn. As previously indicated reductions in soil temperature may result in delayed emergence. In addition to emergence, delays have also been reported in silking and maturity, resulting from decreased soil temperatures. The time to 50% silk decreased in a linear relation to increasing soil temperature (Carr, 1977). The days to 50% silk were advanced by as much as 11 days by artificially increasing the soil temperatures (Jones and Mederski, 1963; Adams, 1970; Phillips and Cochrane, 1975; Rykbost et al., 1975; Iremiren and Milbourn 1979). Straw mulches are reported to depress soil temperatures resulting in delayed silking (Willis et al., 1957; Mock and Erbach, 1977).

The effect of tillage on the rate at which corn reaches maturity has not been well documented. Mock and Erbach (1977) found that the percent grain moisture at harvest was not consistently affected by tillage practices. Griffith et al. (1973) reported that, depending on the location, as the amount of ground cover (crop residues) was increased, maturity was delayed. In addition, those tillage systems which retained the greatest amount of ground cover had the lowest soil temperatures. The effect of mulches may be more important than tillage in determining maturity. Gallaher (1977) reported that corn grown under zero tillage in the presence of a rye mulch matured later than corn grown in the absence of a mulch.

The effects of soil temperature on maturity may be related to the effects of tillage and mulches on the maturity of corn. Using the percent grain moisture as an indicator of maturity, corn was found to mature earlier when grown under a warm soil enviroment (Willis et al., 1957; Iremiren and Milbourn, 1979). Ketcheson (1968) illustrated that the earliest maturity for corn was obtained when both warm soil and warm air temperatures occurred together.

Grain Yield

Grain yields from corn produced under zero tillage may equal or exceed that obtained from conventionally grown corn (Moody et al., 1961; Jones et al., 1968; Triplett et al., 1968; Jones, 1969; Shear and Moschler, 1969; Stanholtz and Lillard, 1969; Blevins et al., 1971). Greater soil moisture is frequently attributed to increasing yields under zero tillage. In drought years the moisture conserving characteristics of zero tillage have been implicated with significant increases in yield (Jones et al., 1968; Lal, 1974). Under drought conditions McCormick and Mackay (1973) found that zero tillage did not exhibit the expected yield advantage over conventionally grown corn. The importance of a straw mulch under zero tillage for increasing yield has been well documented. Gallaher (1977) determined that corn grown under zero tillage with a rye mulch had developed a more extensive root system which was better able to utilize soil moisture than corn grown under zero tillage in the absence of a mulch. The more extensive root system contributed to the mulched corn yielding greater than the unmulched corn. Yield increases under zero tillage are related to moisture conservation, which is determined by the presence and rate of mulches (Triplett et al., 1968; Jones et al., 1968). Triplett et al. (1968) suggested that the amount of straw cover may influence yield to a greater degree than tillage.

Yield reductions under systems of reduced tillage have been reported

(Bolton and Aylesworth, 1957; McCormick and Mackay, 1973; Mock and Erbach, 1977). These yield reductions resulted primarily from reductions in plant populations. With a common plant population no difference in corn yield occurred between conventional and zero tillage (McCormick and Mackay, 1973; Mock and Erbach, 1977). Reduced plant populations under zero tillage were attributed, in part, to variable seed placement, the seed frequently being sown on the soil surface (McCormick and Mackay, 1973). Similar findings were reported by Mock and Erbach (1977), however, the reductions in plant populations under reduced tillage were accounted for by a reduction in soil temperature. Increasing soil temperatures have been found to result in increased plant densities, contributing to increased yields (Phillips and Cochrane, 1975; Iremiren and Milbourn, 1979). In addition to the effects of temperature and variable seed placement on plant populations, heavy concentrations of straw may prevent emergence, Burrows and Larson (1960) reported that at a mulch rate of 8 tons/acre corn seedlings were physically unable to emerge through the mulch.

Aside from the effects on plant populations, soil temperature may also influence yield by directly affecting the plant. Increased soil temperatures have been reported to result in increased corn yields (Larson et al., 1960; Mederski and Jones, 1963; Willis et al., 1957; Ketcheson, 1970; MacMillan and Millette, 1971; Phillips and Cochrane, 1975; Cooper and Law, 1978; Iremiren and Milbourn, 1979). Willis et al., (1957) reported corn yields increased with increasing soil temperature to 74-75^{o}F (at a 4 inch depth), thereafter further increases in soil temperature resulted in decreased yield. Cooper and Law (1978) demonstrated that significant yield increases could be obtained by maintaining warm soil temperatures for as short a period as one week following germination. Soil temperature has been shown to influence the number of grains per ear and also the grain weight (Phillips and Cochrane, 1975; Cooper and Law, 1978). Iremiren and Milbourn (1979) reported a decrease in the number of grains per ear with increasing soil temperature, although they did also report increased grain weight at the warmer soil temperatures.

The affects of air temperature cannot be overlooked in discussing grain yield. Ketcheson (1968) found that air and soil temperatures interacted to influence grain yeild. The greatest corn yields resulted from a combination of low air and high soil temperatures. High air and low soil temperatures resulted in the lowest grain yields.

Cooper and Law (1977) reported a linear relationship between the plant dry matter at 5 weeks post emergence and the final grain yield. It was determined that the dry matter at 5 weeks post emergence was strongly related to both soil and air temperatures as well as soil moisture during the first five weeks of growth. Greater dry matter at five weeks resulted in increased grain yields in corn.

Differential Growth of Hybrids in Response to Soil Temperature

No information was found regarding the differential growth of hybrids in response to tillage practices . There is, however, information regarding the differential growth of hybrids in response to soil temperature, this evidence may apply to reduced tillage situations which result in depressed soil temperatures. McAdam and Hayes (1978) have shown that some hybrids are able to germinate at lower soil temperatures than other hybrids. Several studies have suggested differential growth of hybrids in response to soil temperature (Jones and Mederski, 1963; Cal and Obendorf, 1972; MacLean and Donovan, 1973; Porter and Moraghan, 1975). MacLean and Donovan (1973) observed that corn hybrids with high heat unit ratings were less sensitive to low soil temperatures during early growth. Jones and Mederski (1963) have shown that while soil warming increased the yield of one hybrid, it decreased the yield of several others. The possibility that hybrids vary in the optimum root temperature for growth was illustrated by Porter and Moraghan (1975) having shown two hybrids differed in response to varying root zone temperatures. Porter and Moraghan (1975) concluded that one hybrid exhibited an optimum root temperature of 14-24^{o}C while the optimum for the other hybrid was in excess of 24^{o}C. Cal and Obendorf (1972) suggested that the differential growth of corn hybrids may be related to the relative cold sensitivity of the meristematic tissue.

MATERIALS AND METHODS

Experimental Site

Field experiments were conducted in 1980 and 1981 at the Department of Plant Science field station, Portage la Prairie. The soil type was a Gnadenthal loam (Michalyna and Smith, 1972), the surface layer having a particle size distribution of 14% sand, 51% silt and 35% clay. In 1981 the hybrid/tillage experiment was situated on a Dugas clay (Michalyna and Smith, 1972). The experimental site was established on barley stubble. The barley was grown the previous year under conventional crop management practices.

General Procedures

Tillage Experiments

The effect of tillage and straw cover on crop performance and soil physical properties was examined using a split-block experimental design with four replicates. The experiments compared tillage and crop residue levels. Tillage was examined using various degrees and combinations of primary and secondary tillage. Plots were 25 meters in length and consisted of four rows having a 76 cm row spacing.

Two residue levels were examined by the removal of straw from half of each plot. Straw removal was accomplished by hand raking in 1980 and by the use of a side delivery rake and baler in 1981. No estimate of the amount of straw removed is available for 1980, however, the straw removed from the 1981 tillage experiment was baled and weighed providing an estimated straw removal of 2,000 kg per hectare.

Primary tillage ranged from complete soil disturbance by rotovation to minimal soil disturbance using zero tillage seeding techniques. Spring tillage served as the conventional tillage treatment for the 1980 tillage experiment, while two forms of conventional tillage were examined in 1981, differing in the timing of the tillage operations; spring vs fall primary tillage. A summary of the conventional tillage practices employed during the two years is presented in Table 1.

TABLE 1. Conventional tillage practices.

Treatment	Operation	Number of Operations	Time of Operation
1980			
Conventional Tillage-Spring	Deep Tilled	1	Spring 1980
	Rotovation	2	Spring 1980
	Packed	1	Spring 1980
1981			
Conventional Tillage-Spring	Deep Tilled	1	Spring 1981
	Rotovation	1	Spring 1981
	Harrowed	1	Spring 1981
	Packed	1	Spring 1981
Conventional Tillage-Fall	Deep Tilled	1	Fall 1980
	Double Disced	1	Fall 1980
	Harrowed	1	Spring 1981
	Packed	1	Spring 1981

Two forms of zero tillage were examined, both involved seeding directly into existing barley stubble. The zero tillage treatments differed only in the shape of the cutting coulters which were mounted ahead of double disc openers. Straight and fluted cutting coulters were used.

An intermediate tillage treatment was examined in 1981. This treatment employed an International Harvester strip rotovator, in stubble, to till a 10 cm wide band of soil prior to seeding, leaving the interrow space in an undisturbed condition. A separate operation was required following rotovation to seed the corn into the tilled strips.

Secondary tillage, or interrow cultivation, was conducted when the corn plants were 15-30 cm tall. Interrow cultivation was performed twice each year to a depth of 5 cm.

The tillage experiments were seeded with the grain corn hybrid Pioneer 3995 [corn heat unit (CHU) rating of 2150, (Field Crop Recommendations for Manitoba, 1980)]. Seeding was done with a John Deere Model 71 Flexi-planter, which was modified by the addition of a second tool bar to allow for the attachment of cutting coulters when seeding the zero tillage plots.

Fertilizer and pesticides were applied as required and are summarized in Tables 3, 4 and 5 of the appendix.

Hybrid/Tillage Experiments

The hybrid/tillage experiments were established to compare the performance of corn hybrids under zero and conventional tillage. Eight hybrids were examined in 1980 and 1981 as indicated in Table 2. The hybrids studied ranged in corn heat unit ratings from 2150 to 2550 CHU, (Field Crop Recommendations for Manitoba, 1980).

The performance of the hybrids was examined under both conventional and zero tillage cropping practices, using a split-plot experimental design with four replicates. The plots consisted of four rows having a 76 cm row spacing and were 25 meters in length.

TABLE 2. Hybrids.

	CHU[1] Rating	1980	1981
Pioneer 3995	2150	X	X
Pickseed 2111	2200	X	X
Asgrow RX22	2250	X	X
Pride R102	2350	X	X
Pioneer 3992	2400	X	X
Pride R108	2400		X
Funks G4065	2450	X	X
Pickseed 2322	2550		X

1 Corn heat unit

Fertilizer and pesticides were applied as required and are summarized in Tables 3, 6 and 7 of the appendix. In addition to chemical weed control, interrow cultivation of the conventional tillage plots was employed as needed to control weeds.

Measurement of Soil Physical Properties

Soil Moisture. Soil moisture was determined volumetrically to a depth of 20 cm. Four sampling depths were used; 2.5, 5.0, 10.0 and 20.0 cm, with two samples taken in each plot. Soil samples were taken on a weekly basis for the first six weeks after seeding and thereafter at two to three week intervals up to the beginning of September.

Volumetric soil moisture was determined by inserting a metal ring of a known volume (23.89 cc) into the soil at a prescribed depth. The ring containing the soil was removed and the excess soil trimmed from both ends. The samples were weighed, oven dried, reweighed and the weight of water per unit weight of soil was calculated. The weight of water was then multiplied by the soil bulk density to determine the volumetric soil moisture content of the sample. Volumetric soil moisture was expressed as the percentage of water per unit volume of soil.

The method described above also allowed for the calculation of soil bulk density (gms/cc), which is the weight of oven dried soil divided by the volume of soil.

Soil temperature. Soil temperature was monitored from the time of seeding to mid-September. Temperatures in the seed row were recorded at depths of 2.5, 5.0, 10.0 and 20.0 cm in two replicates and one location per plot. Soil temperature was measured using thermocouples mounted on wooden stakes and inserted in the soil to a predetermined depth. A Campbell Scientific CR5 Digital Recorder was used to record soil temperatures at 3 hour intervals. In 1981, soil temperatures were recorded periodically in the interrow space and seed row of the rotovated strip and zero tillage-straight coulter treatments. Soil temperatures for these periodic readings were measured using thermocouples and a hand held Westcor digital thermometer.

Crop Performance Measurements

Emergence. Plant counts were conducted from the time emergence was first observed until no new plants emerged. Emergence was defined as the point at which the coleoptile became visible above ground. The final plant emergence count served as the basis for calculating the plant populations per hectare for each treatment.

Dry Matter. Plant samples were collected on three occasions in both 1980 and 1981 to determine the average weight of dry matter and the percent dry matter per plant. Seven to ten plants were collected per

TABLE 3. Tillage treatments, 1980

Tillage Treatment	
Primary Tillage	Secondary Tillage
Conventional Tillage-Spring	None
Conventional Tillage-Spring	Interrow Cultivation
Zero Tillage-Fluted Coulter	None
Zero Tillage-Fluted Coulter	Interrow Cultivation
Zero Tillage-Straight Coulter	None
Zero Tillage-Straight Coulter	Interrow Cultivation

TABLE 4. Tillage treatments, 1981

Tillage Treatment	
Ptimary Tillage	Secondary Tillage
Conventional Tillage-Spring	None
Conventional Tillage-Spring	Interrow Cultivation
Conventional Tillage-Fall	None
Conventional Tillage-Fall	Interrow Cultivation
Rotovated Strip Tillage	None
Rotovated Strip Tillage	Interrow Cultivation
Zero Tillage-Fluted Coulter	None
Zero Tillage-Fluted Coulter	Interrow Cultivation
Zero Tillage-Straight Coulter	None
Zero Tillage-Straight Coulter	Interrow Cultivation

TABLE 5. Treatments from which soil temperature data was collected, 1980

Tillage Treatment		Straw Cover
Primary Tillage	Secondary Tillage	
Conventional Tillage-Spring	None	Retained
Zero Tillage-Fluted Coulter	None	Retained
Zero Tillage-Straight Coulter	None	Retained

TABLE 6. Treatments from which soil temperature data was collected, 1981

Tillage Treatment		Straw Cover
Primary Tillage	Secondary Tillage	
Conventional Tillage-Spring	None	Retained
Conventional Tillage-Fall	None	Retained
Rotovated Strip Tillage	None	Retained
Zero Tillage-Fluted Coulter	None	Retained
Zero Tillage-Straight Coulter	None	Retained
Zero Tillage-Straight Coulter	None	Removed

plot and the average fresh and dry weight was determined, allowing for calculation of the weight and percent dry matter per plant.

Silking. The days to 50% silk were calculated based on the number of days from seeding until 50% of the plants samples in each plot had silked. Plants were considered to have silked when the silks became visible exterior to the ear.

Plant Height. Commencing in early June of both years, plant heights were recorded periodically throughout the growing season. Plant height was recorded as the height of the plant to the tip of the upper most leaf extended. The plants to be measured were chosen at random throughout the plot, in 1980, 6 to 15 plants per plot were sampled while 15 plants per plot were measured in 1981.

Leaf Production per Plant. The average number of photosynthetic leaves per plant was determined in 1981. Only those leaves which were still green were counted as being photosynthetic, this excluded the basal leaves which had already senesced at the time of the leaf counts.

Grain Yield. Due to a severe black bird infestation grain yield was based on the average weight of grain per harvested ear. In 1980 the average sample size was 10 ears per plot, while in 1981 the sample size was increased to 13 ears per plot. In 1980, to ensure a harvest sample, a number of ears were bagged at random with 16 lb Kraft bags, the ends having been stapled shut around the base of the ear. These bags offered effective protection to the ear, however, upon becoming wet the bags soon came apart at the seams allowing for further bird damage. In 1981 pollination bags were used which proved to be of a stronger construction than those previously employed.

Grain Test Weight. Two 500 ml samples of grain were removed from the shelled yield sample and weighed. The two samples were averaged and the weight was expressed as grams/0.5 litre.

Percent Grain Moisture. The gravimetric moisture content of the grain was calculated based on a grain sample collected at the time of harvest.

Experimental Design

Tillage Experiments

A split-block experimental design was used for the tillage experiments to facilitate the removal of straw. Main plot treatments were the levels of tillage, while the straw levels, located in strips across the replicate, comprised the subplot treatments.

In both years, two straw treatments were examined; straw retained and straw removed. Tables 3 and 4 summarize the tillage treatments.

The data presented for soil physical properties was obtained from the tillage experiments. Measurements of soil bulk density and volumetric moisture content of the soil were taken in plots which had not received interrow cultivation (secondary tillage). Treatments from which soil temperature data was collected is indicated in Tables 5 and 6.

Measurements of crop performance were collected from all treatments of each replicate except; emergence, seedling dry matter and seedling heights which were determined prior to secondary tillage operations. Prior to secondary tillage duplicate tillage treatments existed in each replicate. Crop performance was assumed to have been the same for duplicated treatments making it unnecessary to conduct plant counts for emergence in the duplicated treatments. Plant counts were made in those treatments which were designed not to have secondary tillage. Similar reasoning applies to the measurements of seedling dry matter and plant height measurements made prior to secondary tillage.

Hybrid/Tillage Experiments

The performance of hybrids under conventional and zero tillage was compared using a split-plot experimental design. The main plot treatments were comprised of hybrids while the subplots were the two levels of tillage under which the hybrids were examined.

Measurements of crop performance were made for all plots and replicates. In 1980, the silage hybrids; Pioneer 3992 and Funks G4065 were handled as silage, consequently grain yield, grain moisture and grain test weight was not obtained for these hybrids. All hybrids regardless of designation; grain or silage, were handled as grain hybrids in 1981.

Experimental Analysis

Data gathered from both tillage and hybrid/tillage experiments was handled in a similar manner. Crop performance data was subjected to an analysis of variance with the appropriate tests being conducted where indicated by the F-tests. Multiple comparisons were made using the Duncans Multiple Range Test, while pairwise comparisons were made using the Least Significant Difference (LSD) method. All statistical tests were conducted at the 5% level of significance. Only those differences significant at the 5% level were considered as meaningful.

Soil moisture and soil bulk density was analyzed by depth and in a similar manner to the crop performance measurements.

Soil temperature was not subjected to statistical analysis due to the volume of data collected. Temperature data will be presented graphically and the trends examined. Seasonal means were calculated for the mean daily and weekly mean maximum and minimum soil temperatures for the four depths examined.

Linear correlations were evaluated for crop performance data to determine what factors, if any, influence the later development and yield of the crop. Correlation of soil physical data with crop performance was not made.

RESULTS AND DISCUSSION

Tillage Experiments

Volumetric Soil Moisture

Differences in volumetric soil moisture occurred between the primary tillage treatments in both 1980 and 1981. Generally, the differences in soil moisture between treatments decreased with increasing soil depth, at the 10 and 20 cm depths the differences, for the individual sampling dates, were not usually significant (Tables 7 to 14). Similar findings have been reported in the literature by Stanholtz and Lillard (1969) and Blevins and Cook (1970). In both years, the greatest differences between tillage treatments occurred early in the growing season.

Significant differences between tillage treatments were noted for the 1980 seasonal mean volumetric soil moisture contents at the 2.5 and 5 cm depths (Table 15). The seasonal mean moisture content was lower under the conventional tillage-spring treatment than under the zero tillage-straight coulter or zero tillage-fluted coulter treatments. The soil moisture content did not differ between the two zero tillage treatments, although greater soil disturbance was noted with the fluted coulter than with the straight coulter. Soil moisture would have been expected to be lower under the zero tillage treatment which resulted in the greatest soil disturbance. The seasonal means for the tillage treatments did not differ at or below the 10 cm depth.

TABLE 7. Volumetric soil moisture at 2.5 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		15.38 b[1]	7.83 b	31.19	12.15 b	19.40 c	9.78	28.99	24.80 b	27.31 b	19.65 b
Zero Tillage-Fluted Coulter		26.16 a	18.95 a	31.41	21.59 a	21.18 b	12.81	31.14	29.19 a	35.61 a	25.34 a
Zero Tillage-Straight Coulter		26.03 a	16.89 a	33.56	17.23 ab	24.58 a	12.26	29.95	28.74 a	33.44 a	24.74 a
	Retained	23.38	17.13	33.35	18.04	23.44*	10.89	30.33	28.25	31.24	24.20*
	Removed	21.67	11.98	30.76	15.93	19.95	12.34	29.73	26.90	33.00	22.28
	L.S.D.	7.05	5.36	4.08	9.27	3.28	1.97	3.34	4.88	4.17	1.41
Conventional Tillage-Spring	Retained	15.58	7.43 d	30.40	11.90	18.93	8.38	29.08	24.90	27.30	19.32 d
	Removed	15.18	8.23 d	31.98	12.40	19.88	11.18	28.90	24.70	27.33	19.98 d
Zero Tillage-Fluted Coulter	Retained	25.10	21.98 a	32.55	22.48	23.03	11.18	32.90	30.28	36.33	26.20 ab
	Removed	27.23	15.93 b	30.28	20.70	19.33	14.45	29.38	28.10	34.90	24.48 bc
Zero Tillage-Straight Coulter	Retained	29.45	22.00 a	37.10	19.75	28.38	13.13	29.00	29.58	35.38	27.06 a
	Removed	22.60	11.78 c	30.03	14.70	20.68	11.40	30.90	27.90	31.50	22.39 cd

* Significant at the 0.05 level.

1 Values within the columns followed by the same letter are not significantly different.

TABLE 8. Volumetric soil moisture at 5.0 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		26.43 b[1]	14.58 b	32.63	30.14 b	23.60 b	13.06	32.35	27.61	28.36 b	25.36 b
Zero Tillage-Fluted Coulter		37.84 a	25.39 a	34.24	35.34 a	24.79 ab	18.14	34.75	30.76	33.41 a	30.52 a
Zero Tillage-Straight Coulter		39.38 a	25.29 a	35.09	36.08 a	28.70 a	17.96	33.24	29.68	32.09 a	30.83 a
	Retained	34.15	15.13*	34.85	32.98	27.21	16.84	33.31	29.23	31.62	28.56
	Removed	34.97	28.38	33.12	34.72	23.83	15.93	33.58	29.48	30.96	29.25
	L.S.D.	8.99	9.12	4.80	2.07	8.05	6.17	4.22	3.27	6.86	2.15
Conventional Tillage-Spring	Retained	25.08	8.63	33.45	31.70	23.75	14.01	32.28	26.25	29.13	24.92
	Removed	27.78	20.53	31.80	28.58	22.38	12.10	32.43	28.98	27.60	25.80
Zero Tillage-Fluted Coulter	Retained	37.60	18.53	33.43	36.38	25.70	17.48	34.00	32.78	33.30	29.91
	Removed	38.08	32.25	35.05	34.30	23.88	18.80	35.50	28.75	33.53	31.13
Zero Tillage-Straight Coulter	Retained	39.70	18.23	37.68	36.08	32.18	19.03	33.65	28.65	32.43	30.85
	Removed	39.05	32.35	32.50	36.08	25.23	16.90	32.83	30.70	31.75	30.82

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

TABLE 9. Volumetric soil moisture at 10.0 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		40.83	28.29	35.85	37.24	31.86	25.56	32.95	33.59	32.78	33.22
Zero Tillage-Fluted Coulter		38.03	34.23	37.51	37.38	29.96	24.24	35.11	32.31	33.81	33.62
Zero Tillage-Straight Coulter		43.35	30.83	36.10	37.61	32.26	23.96	35.75	32.71	31.39	33.78
	Retained	40.41	27.61	37.27	36.47	31.86	23.44	33.70	33.51	31.91	33.12
	Removed	41.06	34.62	35.71	38.35	30.87	25.73	35.51	32.23	33.41	33.96
	L.S.D.	8.48	7.51	9.48	4.76	4.32	4.33	2.91	2.85	5.01	2.15
Conventional Tillage-Spring	Retained	40.43	23.93	35.50	39.38	32.78	24.90	31.90	35.63	32.73	33.02
	Removed	41.23	32.65	36.18	35.10	30.95	26.23	34.00	31.55	32.83	33.41
Zero Tillage-Fluted Coulter	Retained	38.50	29.38	39.63	38.35	29.35	23.63	33.88	32.60	33.08	33.16
	Removed	37.55	39.08	35.40	36.40	30.58	24.85	36.35	32.03	34.55	34.09
Zero Tillage-Straight Coulter	Retained	42.30	29.53	36.65	37.33	33.45	21.80	35.33	32.30	29.93	33.18
	Removed	44.40	32.13	35.55	37.90	31.08	26.13	36.18	33.13	32.38	34.32

TABLE 10. Volumetric soil moisture at 20.0 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		43.63	33.66	38.45	37.46	32.78	28.34	34.48	34.39	34.74	35.33
Zero Tillage-Fluted Coulter		41.28	37.61	39.05	38.44	30.61	26.60	32.90	36.19	35.35	35.34
Zero Tillage-Straight Coulter		43.23	35.46	37.85	41.03	32.23	26.60	33.93	33.41	34.43	35.35
	Retained	42.10	31.56*	39.43	40.74	32.56	27.29	33.48	34.35	35.20	35.19
	Removed	43.33	39.60	37.48	37.21	31.18	27.07	34.05	34.98	34.38	35.49
	L.S.D.	6.26	5.34	9.63	5.44	2.85	9.72	2.98	1.72	6.38	2.50
Conventional Tillage-Spring	Retained	42.98	29.48	39.40	39.95	32.45	27.55	31.83	34.03	34.98	34.74
	Removed	44.28	37.85	37.50	34.98	33.10	29.13	37.13	34.75	34.50	35.91
Zero Tillage-Fluted Coulter	Retained	40.80	34.98	40.75	41.13	31.25	27.00	32.58	37.10	34.75	35.59
	Removed	41.75	40.25	37.35	35.75	29.98	26.20	33.23	35.28	35.95	35.08
Zero Tillage-Straight Coulter	Retained	42.53	30.23	38.13	41.15	33.98	27.33	36.05	31.93	35.88	35.25
	Removed	43.95	40.70	37.58	40.90	30.48	25.88	31.80	34.90	32.98	35.46

* Significant at the 0.05 level.

TABLE 11. Volumetric soil moisture at 2.5 cm under various tillage and straw management practices, 1981.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		23.75 a [1]	17.31	34.28 ab	24.44	30.48	25.60 abc	15.34	12.48	15.31	22.11 ab
Conventional Tillage-Spring		12.25 b	14.75	35.73 a	22.84	29.94	23.84 c	13.82	11.47	16.90	20.17 b
Rotovated Strip Tillage		21.49 a	14.87	33.62 b	25.42	29.64	24.75 bc	15.65	12.23	17.73	21.71 ab
Zero Tillage-Fluted Coulter		20.80 a	16.18	32.75 b	25.49	31.64	27.63 ab	14.85	14.03	19.67	22.56 ab
Zero Tillage-Straight Coulter		20.74 a	20.23	33.64 b	24.10	31.73	28.74 a	16.97	12.76	18.55	23.05 a
	Retained	21.61	18.09*	34.45	24.59	31.20	26.98*	16.06	12.55	18.56	22.68*
	Removed	18.00	15.25	33.55	24.32	30.17	25.24	14.59	12.63	16.70	21.16
	L.S.D.	8.89	1.93	1.04	3.76	1.92	1.23	2.53	2.03	4.70	1.53
Conventional Tillage-Fall	Retained	28.18	15.20	34.05	26.65 a	32.30	24.98	17.48	12.30	15.88	23.00
	Removed	19.33	19.43	34.50	22.23 b	28.65	26.23	13.20	12.65	14.75	21.22
Conventional Tillage-Spring	Retained	13.45	17.35	37.30	23.75 ab	30.15	24.80	13.45	11.15	17.45	20.98
	Removed	11.05	12.15	34.15	21.93 b	29.73	22.88	14.18	11.78	16.35	19.36
Rotovated Strip Tillage	Retained	20.83	18.55	34.70	21.55 b	29.72	24.80	14.30	12.23	19.70	21.82
	Removed	22.15	11.18	32.53	29.28 a	29.55	24.70	17.00	12.23	15.75	21.60
Zero Tillage-Fluted Coulter	Retained	22.15	19.18	32.35	24.70 ab	32.25	30.33	15.48	14.45	20.23	23.46
	Removed	19.45	13.18	33.15	26.28 ab	31.03	24.93	14.22	13.60	19.10	21.66
Zero Tillage-Straight Coulter	Retained	23.45	20.15	33.85	26.30 ab	31.55	30.00	19.58	12.63	19.55	24.12
	Removed	18.02	20.30	33.43	21.90 b	31.90	27.48	14.35	12.90	17.55	21.98

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

TABLE 12. Volumetric soil moisture at 5.0 cm under various tillage and straw management practices, 1981.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		34.08 a	33.98	38.21	30.81	34.10	33.21	28.39	25.21	29.00	31.89 a
Conventional Tillage-Spring		22.04 b	25.51	37.71	28.64	32.40	32.65	25.79	20.26	26.58	27.95 c
Rotovated Strip Tillage		26.44 b	26.89	36.55	28.70	31.96	30.73	25.88	21.45	28.96	28.62 bc
Zero Tillage-Fluted Coulter		28.06 ab	28.14	36.69	29.94	34.26	32.91	26.55	25.63	30.81	30.33 a
Zero Tillage-Straight Coulter		29.14 ab	27.88	35.63	30.51	34.56	34.44	26.51	24.73	28.63	30.23 ab
	Retained	28.20	27.92	36.85	29.83	33.57	32.50	27.17	23.76	29.19	29.89
	Removed	27.71	29.04	37.07	29.61	33.35	33.08	26.08	23.15	28.41	29.72
	L.S.D.	2.82	3.59	3.80	1.98	2.58	3.87	3.87	7.56	5.18	0.54
Conventional Tillage-Fall	Retained	32.25	33.18	27.55	32.13 ab [1]	35.55	33.15	27.50	24.80	28.25	31.60
	Removed	35.90	34.78	38.88	29.50 abc	32.65	33.28	29.28	35.63	29.75	32.18
Conventional Tillage-Spring	Retained	22.05	28.35	38.75	28.63 bc	32.85	34.25	27.40	21.68	27.10	29.01
	Removed	22.03	22.68	36.68	28.65 bc	31.95	31.05	24.18	18.85	26.05	26.90
Rotovated Strip Tillage	Retained	27.13	26.28	35.83	26.85 c	32.75	30.70	26.28	30.28	30.63	28.53
	Removed	25.75	27.50	37.28	30.55 ab	31.18	30.75	25.48	22.63	27.30	28.71
Zero Tillage-Fluted Coulter	Retained	28.23	27.10	36.55	29.15 abc	34.25	32.05	27.78	24.88	31.25	30.14
	Removed	27.90	29.18	36.83	30.73 ab	34.28	33.78	25.33	26.38	30.38	30.53
Zero Tillage-Straight Coulter	Retained	31.33	24.68	35.55	32.40 a	32.45	32.33	26.90	27.18	28.70	30.17
	Removed	26.95	31.08	35.70	28.63 bc	36.68	36.55	26.13	22.28	28.55	30.28

1 Values within columns followed by the same letter are not significantly different.

TABLE 13. Volumetric soil moisture at 10.0 cm under various tillage and straw management practices, 1981.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		35.33	38.66	38.41	37.61 a [1]	35.61	37.51	32.65	30.71	32.94	35.49 a
Conventional Tillage-Spring		31.15	31.71	38.98	35.65 a	36.51	36.11	30.60	28.80	32.75	33.59 b
Rotovated Strip Tillage		31.41	34.89	36.93	32.16 b	34.36	36.00	31.29	27.91	31.76	32.97 b
Zero Tillage-Fluted Coulter		33.85	35.81	37.88	35.79 a	34.30	36.53	31.55	29.53	33.25	34.28 ab
Zero Tillage-Straight Coulter		35.13	35.86	36.16	32.43 b	37.10	36.73	30.66	30.29	34.14	34.28 ab
	Retained	31.64	35.31	37.27	35.91	36.00	36.24	31.32	29.54	33.90	34.13
	Removed	35.11	35.47	38.07	33.55	35.16	36.86	31.39	29.36	32.04	34.11
	L.S.D.	6.42	1.85	4.02	6.22	2.11	2.05	0.99	3.21	3.96	1.30
Conventional Tillage-Fall	Retained	35.18	38.30	37.40	38.88	38.65 a	36.03	30.70	30.45	32.88	35.39
	Removed	35.48	39.03	39.43	36.35	32.58 c	39.00	34.60	30.98	33.00	35.61
Conventional Tillage-Spring	Retained	26.70	34.20	40.82	36.88	37.23 ab	37.73	31.28	30.53	34.23	34.40
	Removed	35.60	29.23	37.13	34.42	35.80 abc	34.50	29.93	27.08	31.28	32.78
Rotovated Strip Tillage	Retained	29.03	33.13	36.88	33.55	33.23 bc	35.48	31.40	27.85	33.50	32.67
	Removed	33.80	36.65	36.98	30.77	35.50 abc	36.53	31.18	27.98	30.03	33.27
Zero Tillage-Fluted Coulter	Retained	33.33	33.07	36.90	37.58	33.90 bc	35.95	30.80	27.85	34.25	33.74
	Removed	34.38	38.55	38.85	34.00	34.70 abc	37.10	32.30	31.20	32.25	34.81
Zero Tillage-Straight Coulter	Retained	33.98	37.83	34.35	32.67	37.00 ab	36.28	32.40	31.03	34.65	34.47
	Removed	36.28	33.90	37.98	32.18	37.20 ab	37.18	28.93	29.55	33.65	34.09

1 Values within columns followed by the same letter are not significantly different.

TABLE 14. Volumetric soil moisture at 20.0 cm under various tillage and straw management practices, 1981.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		36.88	36.74	38.88	36.28	36.96	37.19 a [1]	35.93	33.65	37.34	36.65 a
Conventional Tillage-Spring		35.66	32.19	36.81	37.39	34.85	37.33 a	34.04	31.81	34.76	34.98 b
Rotovated Strip Tillage		33.68	34.70	36.93	33.65	34.81	34.78 b	33.49	30.83	32.54	33.94 c
Zero Tillage-Fluted Coulter		34.93	33.56	37.75	36.08	35.15	37.14 a	35.70	32.56	34.39	35.25 b
Zero Tillage-Straight Coulter		36.83	35.14	36.58	35.55	37.23	36.64 a	33.58	31.63	36.44	35.18 b
	Retained	35.07	34.02	36.54	35.49	36.07	36.81	34.24	32.10	34.50	34.97
	Removed	36.13	34.92	38.24	36 09	35.54	36.42	34.86	32.09	35.69	35.43
	L.S.D.	4.72	4.24	3.56	2.86	1.37	4.65	1.43	1.75	4.33	0.55
Conventional Tillage-Fall	Retained	37.38	35.40	37.43	35.28	37.38	36.80	35.68	33.45	37.55	36.26
	Removed	36.40	38.08	40.33	37.28	36.55	37.58	36.18	33.85	37.13	37.04
Conventional Tillage-Spring	Retained	35.07	35.30	36.28	32.38	35.13	37.35	32.03	29.88	34.20	34.74
	Removed	36.25	29.08	37.35	37.40	34.58	37.30	36.05	33.75	35.33	35.23
Rotovated Strip Tillage	Retained	31.95	33.30	35.90	34.35	35.13	36.38	33.23	29.55	30.73	33.39
	Removed	35.40	36.10	37.95	32.95	34.50	33.18	33.75	32.10	34.35	34.48
Zero Tillage-Fluted Coulter	Retained	34.35	32.33	37.00	35.60	35.63	37.35	36.65	32.45	33.28	34.96
	Removed	35.50	34.80	38.50	36.55	34.68	36.93	34.75	32.68	35.50	35.54
Zero Tillage-Straight Coulter	Retained	36.58	33.75	36.08	34.85	37.08	36.15	33.60	35.18	36.15	35.49
	Removed	37.08	36.53	37.08	36.25	37.38	37.13	33.55	28.08	30.73	34.87

1 Values within columns followed by the same letter are not significantly different.

TABLE 15. The effect of primary tillage and straw cover on the seasonal mean volumetric soil moisture (%), 1980.

Treatment		Depth (cm)			
Primary Tillage	Straw Cover	2.5	5.0	10.0	20.0
Conventional Tillage-Spring		19.65 b[1]	25.36 b	33.22	35.33
Zero Tillage-Fluted Coulter		25.34 a	30.52 a	33.62	35.34
Zero Tillage-Straight Coulter		24.74 a	30.83 a	33.78	35.35
	Retained	24.20*	28.56	33.12	35.19
	Removed	22.28	29.25	33.96	35.49
	L.S.D.	1.41	2.15	2.15	2.50
Conventional Tillage-Spring	Retained	19.32 d	24.92	33.02	34.74
	Removed	19.98 d	25.80	33.41	35.91
Zero Tillage-Fluted Coulter	Retained	26.20 ab	29.91	33.16	35.59
	Removed	24.48 bc	31.13	24.09	35.08
Zero Tillage-Straight Coulter	Retained	27.06 a	30.85	33.18	35.25
	Removed	22.39 cd	30.82	34.32	35.46

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

The drought conditions in 1980 which persisted until late June (see Appendix Table 1 for meteorological data) contributed to the differences observed between tillage treatments, no appreciable precipitation was recorded for 48 days after planting at the Portage la Prairie field station. Excessive soil disturbance in the preparation of the conventional tillage seedbeds coupled with high atmospheric temperatures, prior to and after planting, promoted evaporative soil moisture loss. A mulch of previous crop residues (barley straw) was associated with the zero tillage plots. At the 2.5 cm depth (Table 15) the removal of the straw cover resulted in a significant decrease in the seasonal mean soil moisture content. Further, a significant tillage x straw cover interaction was noted for the volumetric soil moisture at the 2.5 cm depth (Table 15). The interaction between tillage and straw cover indicated that the removal of the straw mulch decreased the soil moisture under the zero tillage-straight coulter treatment but had no effect on the conventional tillage-spring treatment. Soil moisture was less where the straw cover had been removed in the zero tillage-fluted coulter plots, than where it had been retained, but the difference was not significant. Removal of the straw cover had no affect on soil moisture below 2.5 cm. It is evident from the effect of straw removal on soil moisture that the straw mulch associated with the zero tillage treatments was an important factor in increasing soil moisture. Similar findings have been reported by Jones et al. (1968), Triplett et al. (1968), Blevins and Cook (1970), Harrold et al. (1970) and Lal (1974). It is considered that the main effect of the straw cover on conserving soil moisture was that it reduced evaporative moisture loss.

In 1981, differences in soil moisture under the various tillage treatments were observed to the 20 cm depth. In general, those treatments having been rotovated in the spring (conventional tillage-spring and rotovated strip tillage) had the lowest seasonal mean volumetric moisture contents (Table 16). It should be noted here that all sampling for soil moisture was done in the seed row. The differences in soil moisture between the conventional tillage-spring and rotovated strip tillage treatments were not determined for the interrow space. Because, the interrow space of the rotovated strip tillage treatment was undisturbed (identical to that of the zero tillage treatments) it is assumed that the soil moisture would have been greater in the interrow space of the rotovated strip tillage treatment than that of the conventional tillage treatment. The conventional tillage-fall treatment was found to have greater soil moisture than where tillage had been undertaken in the spring (conventional tillage-spring and rotovated strip tillage treatments). The zero tillage treatments exhibited consistently greater soil moisture contents than either the conventional tillage-spring or the rotovated strip tillage treatments, but soil moisture tended to be less than that found under the fall tillage treatment. It appears that spring tillage whether complete (conventional tillage-spring) or in a strip (rotovated strip tillage) reduced soil moisture. It is speculated that spring rotovation increases the soil surface area exposed to the atmosphere, thus increasing the surface area from which evaporation may take place, resulting in greater losses of soil moisture than where the soil is not disturbed, in the spring, prior to planting.

In 1981, as in 1980, the removal of the previous crop residues decreased the seasonal mean soil moisture content at only the 2.5 cm

TABLE 16. The effect of primary tillage and straw cover on the seasonal mean volumetric soil moisture (%), 1981.

Treatment		Depth (cm)			
Primary Tillage	Straw Cover	2.5	5.0	10.0	20.0
Conventional Tillage-Fall		22.11 ab[1]	31.89 a	35.49 a	36.65 a
Conventional Tillage-Spring		20.17 b	27.95 c	33.59 b	34.98 b
Rotovated Strip Tillage		21.71 ab	28.62 bc	32.97 b	33.94 c
Zero Tillage-Fluted Coulter		22.56 ab	30.33 a	34.28 ab	35.25 b
zero Tillage-Straight Coulter		23.05 a	30.23 ab	34.28 ab	35.18 b
	Retained	22.68*	29.89	34.13	34.97
	Removed	21.16	29.72	34.11	35.43
	L.S.D.	1.53	0.54	1.30	0.55
Conventional Tillage-Fall	Retained	23.00	31.60	35.39	36.26
	Removed	21.22	32.18	35.61	37.04
Conventional Tillage-Spring	Retained	20.98	29.01	34.40	34.74
	Removed	19.36	26.90	32.78	35.23
Rotovated Strip Tillage	Retained	21.82	28.53	32.67	33.39
	Removed	21.60	28.71	33.27	34.48
Zero Tillage-Fluted Coulter	Retained	23.46	30.14	33.74	34.96
	Removed	21.66	30.53	34.81	35.54
Zero Tillage-Straight Coulter	Retained	24.12	30.17	34.47	35.49
	Removed	21.98	30.28	34.09	34.87

* Significant at the 0.05 level.
1 Values within columns followed by the same letter are not significantly different.

depth (Table 16). Increased soil moisture under straw mulches has been previously reported (Larson et al., 1960; Moody et al., 1961; Moody et al., 1963). These studies have, however, reported that the differences between straw treatments extended to depths as great as 45 cm. The limited influence of straw removal reported here, may reflect a lesser amount of straw cover or possibly a lower initial soil moisture content throughout the soil profile sampled.

Soil Bulk Density

In 1980, soil bulk density tended to be higher under the zero tillage treatments than under the conventional tillage-spring treatment to a depth of 10 cm. At 20 cm, the conventional tillage-spring treatment and the zero tillage-fluted coulter treatments did not differ (Table 17), while the zero tillage-straight coulter treatment had significantly lower bulk densities than either of the previous treatments.

In 1981, the rotovated strip tillage treatment had the lowest soil bulk densities of all tillage treatments examined (Table 18). The low bulk densities observed under the rotovated strip tillage treatment were attributed to the looseness of the soil in the seed row following rotovation. All soil sampling was conducted in the seed row, had samples been taken in the interrow space of the rotovated strip tillage treatment it is speculated that the bulk densities would have compared to those of the zero tillage treatments.

The bulk densities recorded under the conventional tillage-spring treatment did not typically differ significantly from the conventional tillage-fall treatment. However, at the 10 cm depth, the conventional tillage-fall treatment had a significantly greater soil bulk density

TABLE 17. The effect of primary tillage and straw cover on the seasonal mean soil bulk densities (gms/cc), 1980.

Treatment		Depth (cm)			
Primary Tillage	Straw Cover	2.5	5.0	10.0	20.0
Conventional Tillage-Spring		0.859	0.876 b[1]	0.958	1.029 a
Zero Tillage-Fluted Coulter		0.878	0.926 a	0.993	1.023 a
Zero Tillage-Straight Coulter		0.866	0.926 a	0.989	0.998 b
	Retained	0.852	0.888	0.958*	0.994
	Removed	0.883	0.931	1.014	1.039
	L.S.D.	0.039	0.054	0.047	0.122
Conventional Tillage-Spring	Retained	0.823	0.863	0.959	0.998
	Removed	0.895	0.890	0.992	1.053
Zero Tillage-Fluted Coulter	Retained	0.860	0.891	0.961	1.007
	Removed	0.897	0.960	1.025	1.039
Zero Tillage-Straight Coulter	Retained	0.874	0.911	0.954	0.971
	Removed	0.858	0.942	1.023	1.024

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

TABLE 18. The effect of primary tillage and straw cover on the seasonal mean soil bulk densities (gms/cc), 1981.

Treatment		Depth (cm)			
Primary Tillage	Straw Cover	2.5	5.0	10.0	20.0
Conventional Tillage-Fall		0.891 ab[1]	0.929 a	1.009 a	1.021 a
Conventional Tillage-Spring		0.907 a	0.918 ab	0.981 b	1.010 ab
Rotovated Strip Tillage		0.883 b	0.905 b	0.958 c	0.992 b
Zero Tillage-Fluted Coulter		0.881 b	0.921 ab	0.983 b	1.023 a
Zero Tillage-Straight Coulter		0.886 b	0.923 ab	0.986 b	1.012 ab
	Retained	0.878*	0.913	0.975	1.001*
	Removed	0.901	0.925	0.992	1.023
	L.S.D.	0.016	0.028	0.115	0.019
Conventional Tillage-Fall	Retained	0.882	0.920	0.999	1.005
	Removed	0.901	0.938	1.019	1.040
Conventional Tillage-Spring	Retained	0.907	0.920	0.984	1.016
	Removed	0.907	0.917	0.977	1.004
Rotovated Strip Tillage	Retained	0.867	0.905	0.952	0.985
	Removed	0.899	0.906	0.965	0.999
Zero Tillage-Fluted Coulter	Retained	0.860	0.912	0.962	1.007
	Removed	0.901	0.929	1.000	1.040
Zero Tillage-Straight Coulter	Retained	0.877	0.908	0.982	0.992
	Removed	0.894	0.937	0.990	1.030

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

than that of the conventional tillage-spring treatment (Table 18). Generally, the conventional tillage treatments did not tend to differ from the zero tillage treatments. At the 2.5 cm depth, however, the conventional tillage-spring and the conventional tillage-fall at 10 cm were significantly greater than either zero tillage treatment.

In both 1980 and 1981, straw removal was found to result in increased soil bulk densities than where the straw had been retained, although the difference was not always significant. The lower bulk densities recorded where the straw had been retained may reflect the effect of the straw on intercepting rain droplets. Upon striking the straw, droplets may breakup and/or be reduced in velocity, thus the force with which the droplet strikes the soil surface is reduced. The reduction in force with which the droplet strikes the soil surface may therefore reduce the potential compaction of the soil particles when a droplet strikes.

Soil Temperature

The effects of the various tillage and straw treatments on soil temperatures were compared using the mean weekly maximum and minimum soil temperatures. The seasonal mean maximum, minimum and daily mean soil temperatures are presented in Tables 19, 20 and 21, respectively. Maximum soil temperatures were found to be affected to a greater extent than were the minimum soil temperatures (Tables 19 and 20). This obser-vation is in agreement with findings previously reported by Stanholtz and Lillard (1969), Blevins and Cook (1970) and Gauer (1981). The effect of tillage on soil temperatures decreased with increasing soil depth (Table 19). At the 20 cm depth, although differences were

TABLE 19. The effect of primary tillage on the seasonal mean maximum soil temperatures (^{o}C).

Treatment	Depth (cm) 1980				1981			
	2.5	5.0	10.0	20.0	2.5	5.0	10.0	20.0
Conventional Tillage-Fall					25.94	24.30	22.33	21.39
Conventional Tillage-Spring	29.19	25.44	22.14	19.73	29.08	26.47	21.83	20.83
Rotovated Strip Tillage					27.19	25.69	21.76	20.21
Zero Tillage-Fluted Coulter	27.06	23.42	20.59	18.28	26.25	24.51	22.31	21.13
Zero Tillage-Straight Coulter/Straw Retained	27.46	23.80	20.54	18.69	26.57	25.27	21.42	19.99
Zero Tillage-Straight Coulter/Straw Removed					28.89	27.02	23.57	22.39

TABLE 20. The effect of primary tillage on the seasonal mean minimum soil temperatures (^{o}C).

Treatment	Depth (cm) 1980				1981			
	2.5	5.0	10.0	20.0	2.5	5.0	10.0	20.0
Conventional Tillgge-Fall					12.50	13.52	14.26	14.70
Conventional Tillage-Spring	11.24	13.18	14.40	14.85	11.19	12.78	14.30	15.02
Rotovated Strip Tillage					12.33	13.46	14.41	14.78
Zero Tillage-Fluted Coulter	11.34	12.87	13.97	14.44	12.12	13.11	14.14	14.74
Zero Tillage-Straight Coulter/Straw Retained	11.26	13.06	14.00	14.13	12.59	13.74	14.26	14.82
Zero Tillage-Straight Coulter/Straw Removed					11.36	12.69	14.00	14.57

TABLE 21. The effect of primary tillage on the seasonal mean daily soil temperatures (^{o}C).

Treatment	Depth (cm) 1980 2.5	1980 5.0	1980 10.0	1980 20.0	1981 2.5	1981 5.0	1981 10.0	1981 20.0
Conventional Tillage-Fall					18.43	18.16	17.91	17.57
Conventional Tillage-Spring	19.22	18.85	18.29	17.38	18.74	18.45	17.77	17.19
Rotovated Strip Tillage					18.67	16.60	17.76	17.04
Zero Tillage-Fluted Coulter	18.32	17.80	17.23	16.34	18.40	18.02	17.81	17.50
Zero Tillage-Straight Coulter/Straw Retained	18.73	18.10	17.32	16.52	18.58	18.54	17.50	16.97
Zero Tillage-Straight Coulter/Straw Removed					18.77	18.52	18.16	17.77

evident between tillage treatments, the differences were small and will not be further discussed. The influence of tillage on soil temperature was most pronounced at the 2.5 cm depth. Considerable variation was, however, evident between the replicates which indicated that the soil temperatures immediately below the soil surface may have been influenced more by the surface micro-enviroment than by the tillage treatments. Because of the variability between the replicates, the data for soil temperatures at 2.5 cm is considered to be only marginally reliable for comparing the tillage treatments, little emphasis will be placed on this data.

In general, the soil temperatures were warmer in 1980 than in 1981. The seasonal mean maximum temperatures, 0 to 20 cm inclusive, for 1980 and 1981 were 23.03^{o}C and 23.99^{o}C, respectively.

Differences in the degree of temperature depression, in response to tillage, were apparent between the two years. Comparing the zero tillage-straight coulter treatment with the conventional tillage-spring treatment, the maximum soil temperatures, in the 0 to 20 cm depth, had a mean seasonal depression of 1.5^{o}C in 1980, while in 1981, the depression was 1.24^{o}C. The mean seasonal depression in maximum soil temperatures by soil depth for the zero tillage-straight coulter treatment as compared to the conventional tillage-spring treatment is given in Table 22. The greater depression in soil temperatures observed in 1980 under the zero tillage-straight coulter treatment was attributed to a greater amount of previous crop residues, from the previous barley crop, covering the soil surface than in 1981. Soil temperatures have been found to decrease with increasing rates of crop residues (Burrows and Larson, 1961; McCalla and Duley, 1946).

TABLE 22. Seasonal mean soil temperature depression (^{o}C), 1980 and 1981.

Depth	Year	Conventional Tillage-Spring	Zero Tillage-Straight-Coulter	Temperature Difference
2.5	1980	29.19	27.46	1.73
	1981	29.08	26.57	2.51
5.0	1980	25.44	23.80	1.64
	1981	26.47	25.27	1.20
10.0	1980	22.14	20.54	1.60
	1981	21.83	21.42	0.41
20.0	1980	19.73	18.69	1.04
	1981	20.83	19.99	0.84
Mean	1980	24.12	22.62	1.50
	1981	24.55	23.31	1.24

The mean weekly maximum and minimum soil temperatures for 1980 at the 5 and 10 cm depths are presented in Figures 1 and 2, respectively. At the 5 cm depth, maximum soil temperatures were depressed under the zero tillage-straight coulter treatment by as much as 3.5^{o}C compared to the conventional tillage-spring treatment, although the average temperature depression was 1.6^{o}C (Table 19). The conventional tillage treatment had greater maximum soil temperatures than either zero tillage treatment at both 5 and 10 cm (Figures 1 and 2, respectively). The differences between the conventional and zero tillage treatments persist-ed throughout the season. The two zero tillage treatments tended to exhibit similar trends. During the first four weeks after planting, however, the zero tillage-straight coulter treatment had markedly greater mean weekly maximum soil temperatures at the 5 cm depth than the zero tillage-fluted coulter treatment. At 10 cm, the zero tillage treat-ments paralleled each other throughout the season.

Note: For all soil temperature data (Figures 1 to 10, inclusive) time 0 corresponds to the date of seeding. In both 1980 and 1981, seeding was done on May 12th.

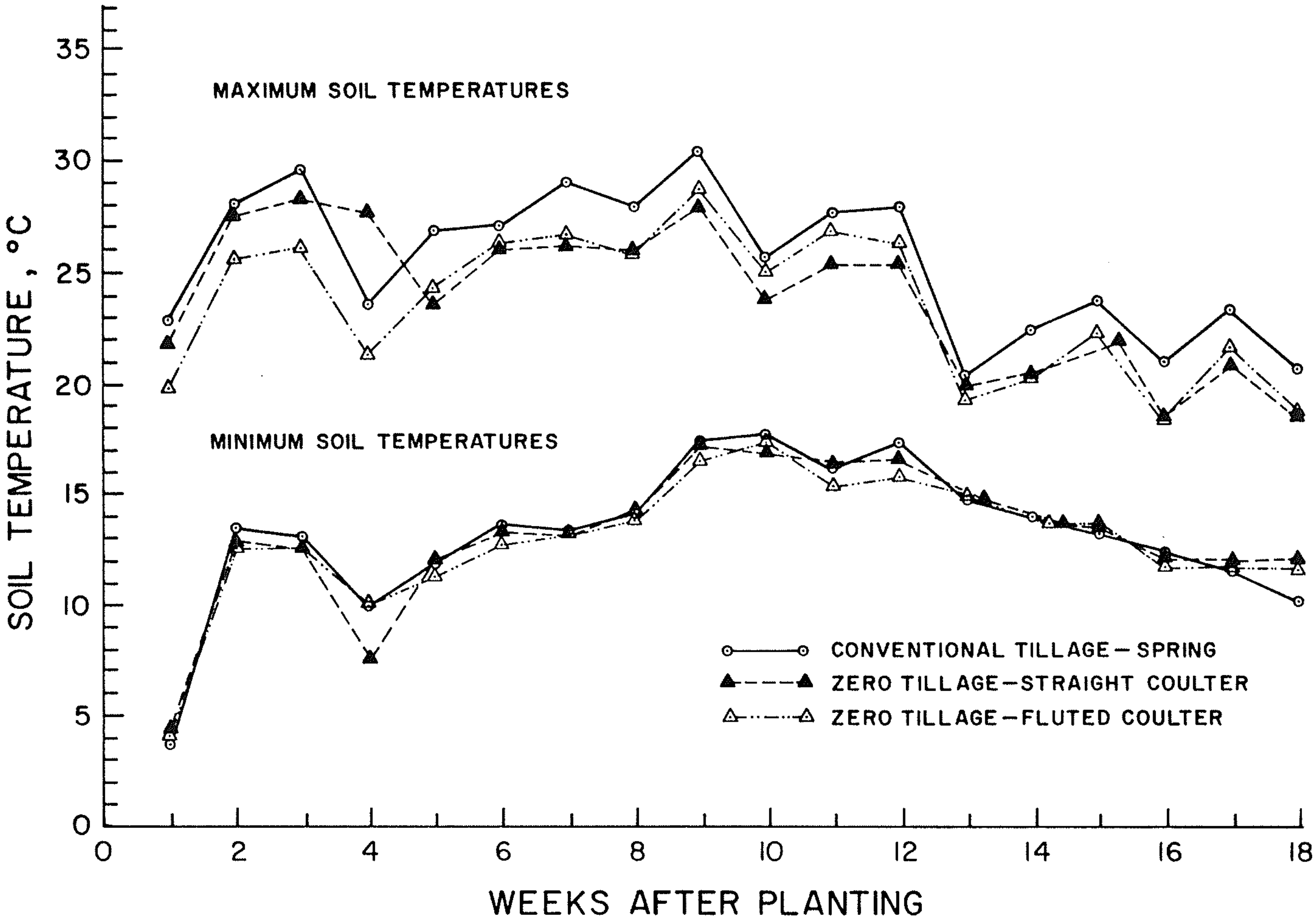

FIGURE 1. Mean weekly maximum and minimum soil temperatures at 5 cm, under conventional tillage-spring, zero tillage-fluted coulter and zero tillage-straight coulter treat -ments, 1980.

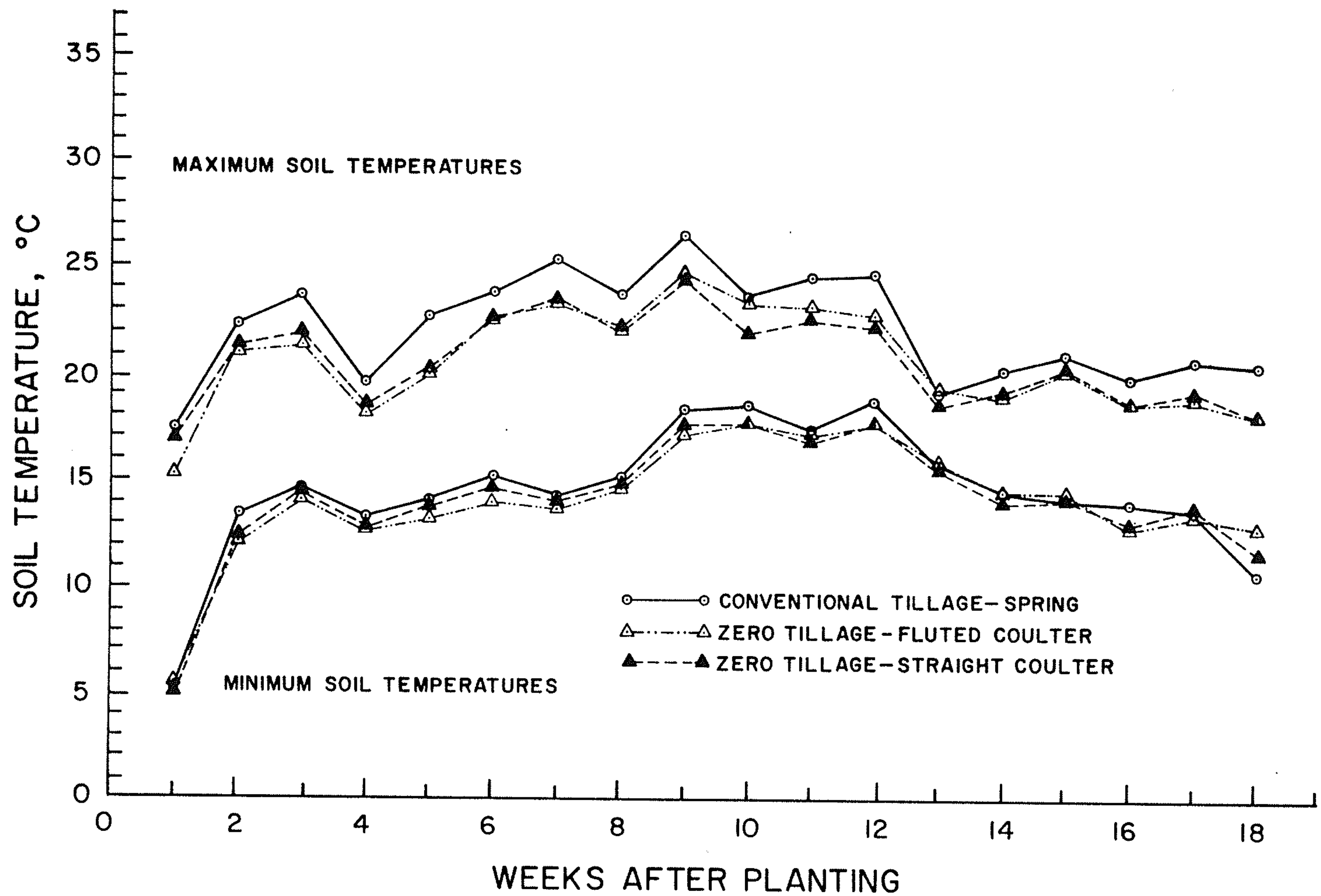

FIGURE 2. Mean weekly maximum and minimum soil temperatures at 10 cm, under conventional tillage-spring, zero tillage-fluted coulter and zero tillage-straight coulter treatments, 1980.

During the early part of the growing season the maximum soil temperatures under the zero tillage-straight coulter treatment, at the 5 cm depth, were periodically greater than those recorded for the conventional tillage-spring treatment. For one five day period, June 2 to June 6, the zero tillage-straight coulter treatment exhibited greater daily maximum soil temperatures than the conventional tillage treatment, at the 5 cm depth. On these occasions, the increase in maximum soil temperature under the zero tillage-straight coulter treatment was as great as $4^{o}C$. Similar findings have been reported by Gauer (1981). The zero tillage-fluted coulter treatment did not exhibit any increase in the maximum soil temperatures over those recorded for the conventional tillage treatment.

Minimum soil temperatures were not influenced by the tillage treatment to as great an extent as were the maximum soil temperatures. At 5 cm no obvious trends in the minimum soil temperatures were apparent between treatments (Figure 1). At the 10 cm depth, however, the conventional tillage-spring treatment tended to have slightly greater minimum soil temperatures than did either of the zero tillage treatments (Figure 2).

The mean weekly maximum and minimum soil temperatures under the various tillage treatments for 1981 are presented in Figures 3 through 10. Comparing the three tillage treatments studied in 1980 (conventional tillage-spring, zero tillage-fluted coulter and zero tillage-straight coulter) similar trends in maximum and minimum soil temperatures were noted in 1981. At the 5 cm depth, the conventional tillage-spring treatment had greater maximum soil temperatures for the first 10 weeks after planting than either of the zero tillage treatments. After 10 weeks, the differences between these treatments became less and variable (Figure 3). The results in 1981, at the 10 cm depth, were not consistent with those observed in 1980. The conventional tillage-spring treatment tended to exhibit greater maximum soil temperatures than either of the zero tillage treatments up to eight weeks after planting. After eight weeks, the zero tillage-fluted coulter treatment exhibited greater maximum soil temperatures than either the zero tillage-straight coulter or the conventional tillage-spring treatments. By the end of the season the differences between the tillage treatments at the 10 cm depth were not appreciable.

The differences in the minimum soil temperatures between the conventional tillage-spring, zero tillage-fluted coulter and the zero tillage-straight coulter treatments were not appreciable at the 5 and 10 cm depths (Figures 3 and 4).

The effect of straw removal on the maximum and minimum soil temper-atures under zero tillage is illustrated in Figures 5 and 6. Removal of the straw cover from the zero tillage-straight coulter treatment resulted in an increase in the mean weekly maximum soil temperatures at both the 5 and 10 cm depth, relative to where the straw cover had been retained. Maximum soil temperatures where the straw had been removed from the zero tillage-straight coulter treatment were similar to those recorded under the conventional tillage-spring treatment. Similar findings have been reported by Gauer (1981). Straw removal resulted in a marked increase in the maximum soil temperatures later in the season, above those recorded for the conventional tillage-spring treatment

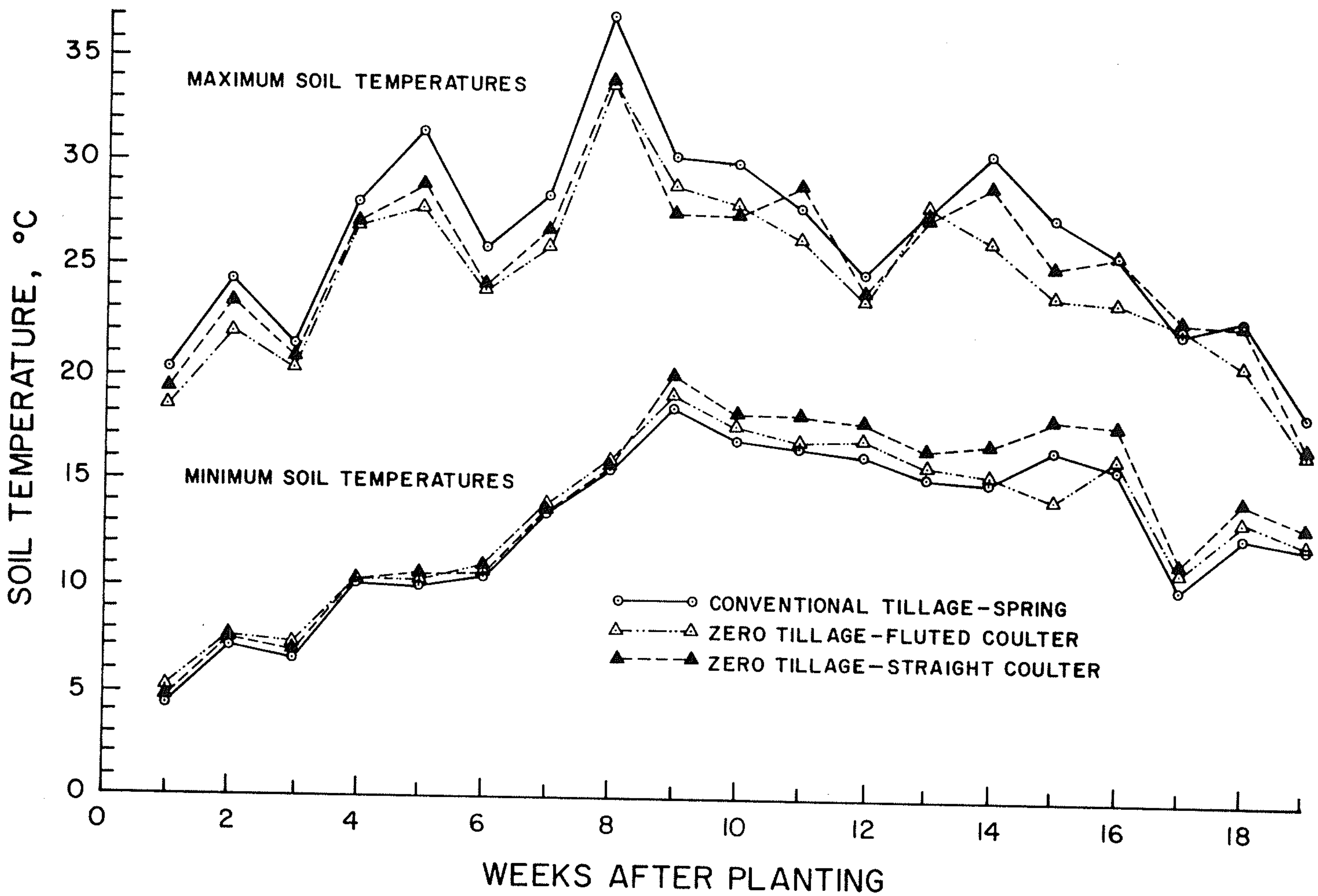

FIGURE 3. Mean weekly maximum and minimum soil temperatures at 5 cm, under conventional tillage-spring, zero tillage-fluted coulter and zero tillage-straight coulter treat -ments for 1981.

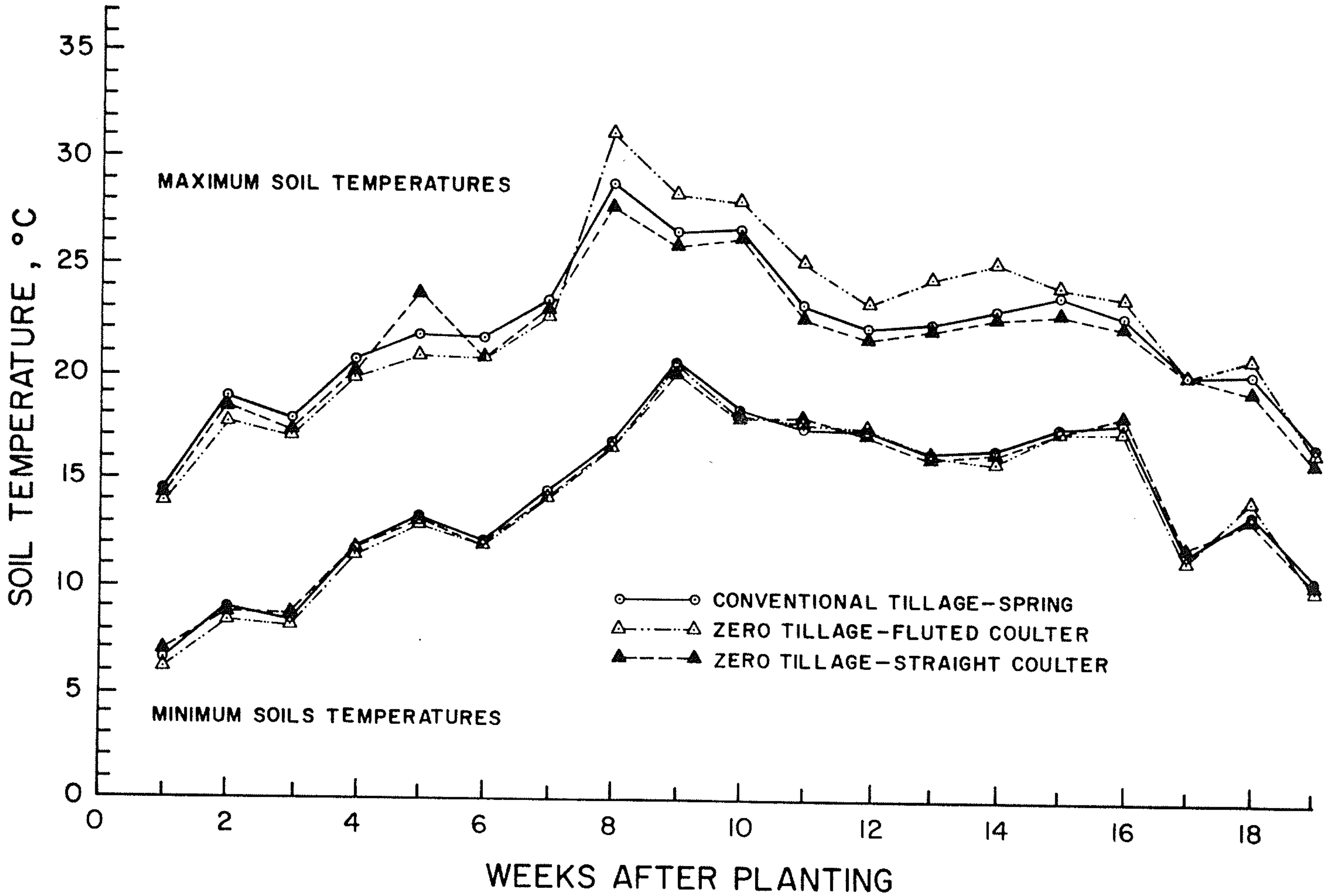

FIGURE 4. Mean weekly maximum and minimum soil temperatures at 10 cm, under conventional tillage-spring, zero tillage-fluted coulter and zero tillage-straight coulter treatments, 1981.

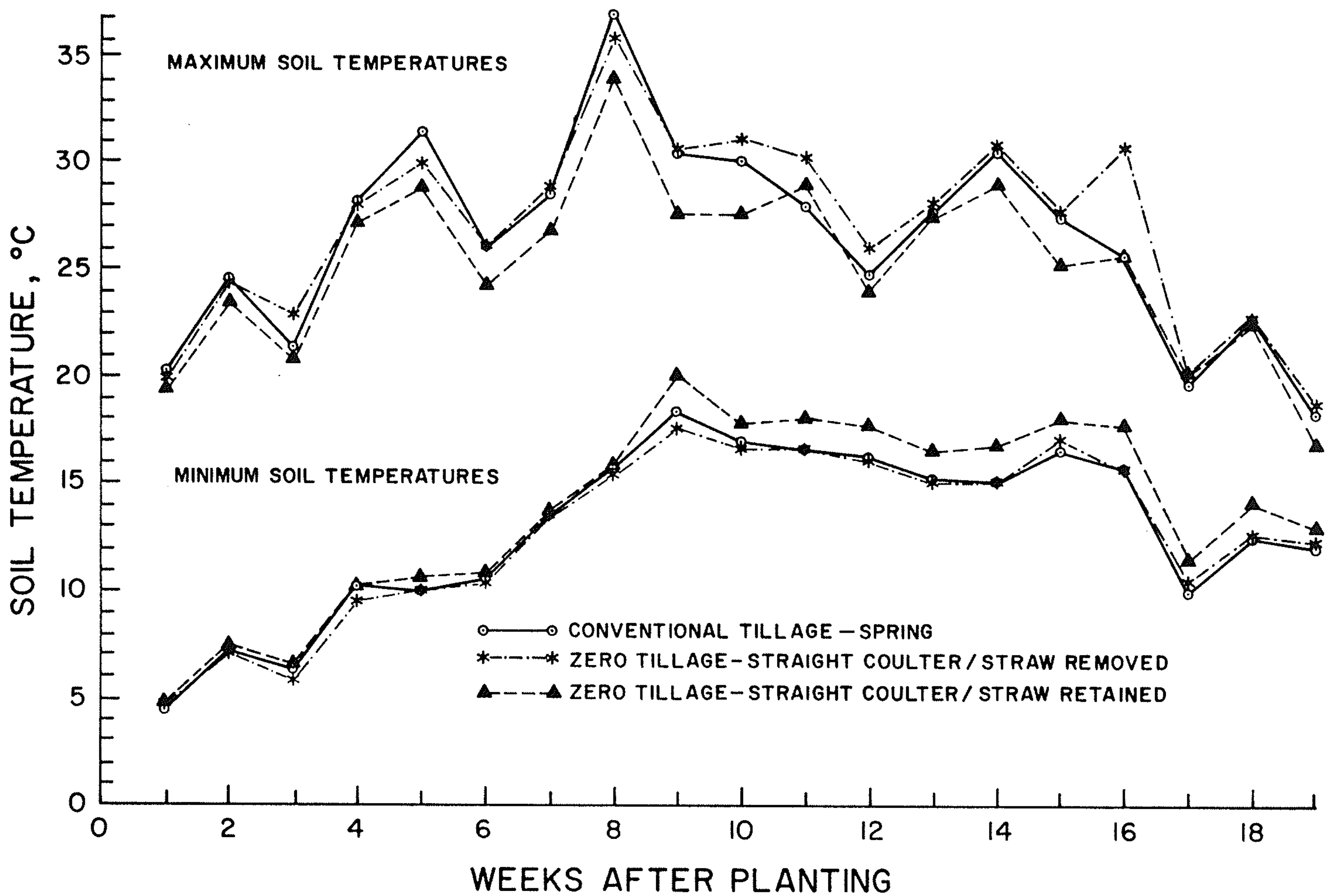

FIGURE 5. Mean weekly maximum and minimum soil temperatures at 5 cm, under conventional tillage-spring, zero tillage-straight coulter/straw retained and zero tillage-straight coulter/straw removed treatments, 1981.

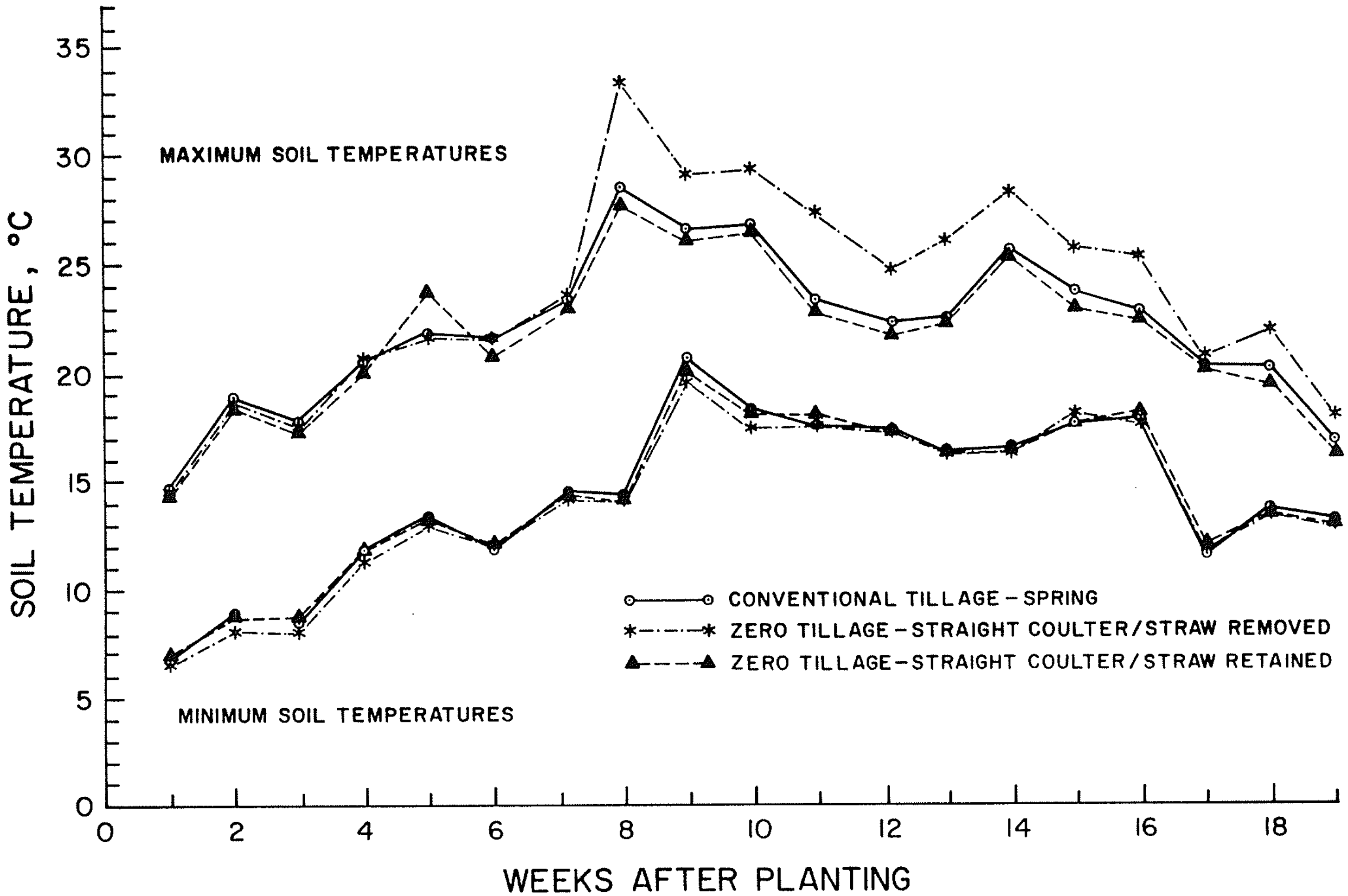

FIGURE 6. Mean weekly maximum and minimum soil temperatures at 10 cm, under conventional tillage-spring, zero tillage-straight coulter/straw retained and zero tillage-straight coulter/straw removed treatments, 1981.

(Figure 6). Straw removal had little influence on the minimum soil temperatures at either depth.

Maximum soil temperatures were increased early in the season by strip rotovation. The rotovated strip tillage treatment increased the maximum soil temperatures, in comparison to the zero tillage-straight coulter treatment, up to the seventh week after planting, at the 5 cm depth (Figure 7). Strip rotovation resulted in greater maximum soil temperatures than the conventional tillage-spring treatment from seeding to the fourth week after planting, thereafter the conventional tillage-spring treatment tended to have the greater maximum soil temperatures at 5 cm. Towards the end of the season no differences between the rotovated strip tillage, zero tillage-straight coulter or the conventional treatments were observed at the 5 cm depth. At the 10 cm depth, maximum soil temperatures did not differ appreciably between the rotovated strip, zero tillage-straight coulter or the conventional tillage-spring treatments. The minimum soil temperatures were not influenced to as great an extent as were the maximum soil temperatures. The conventional tillage-spring treatment tended to have lower minimum soil temperatures at 5 cm than either the zero tillage-straight coulter or the rotovated strip tillage treatments between the 9th and 15th week after planting. At the 10 cm depth there were no apparent differences in the mean weekly minimum soil temperatures between the tillage treatments.

The timing of the conventional tillage operations appeared to be an important factor in determining soil temperature. Spring tillage resulted in a marked increase in the maximum soil temperatures at seeding. The seasonal mean maximum soil temperature at 5 cm, under the conventional tillage-spring treatment was 2.2^{o}C warmer than under the

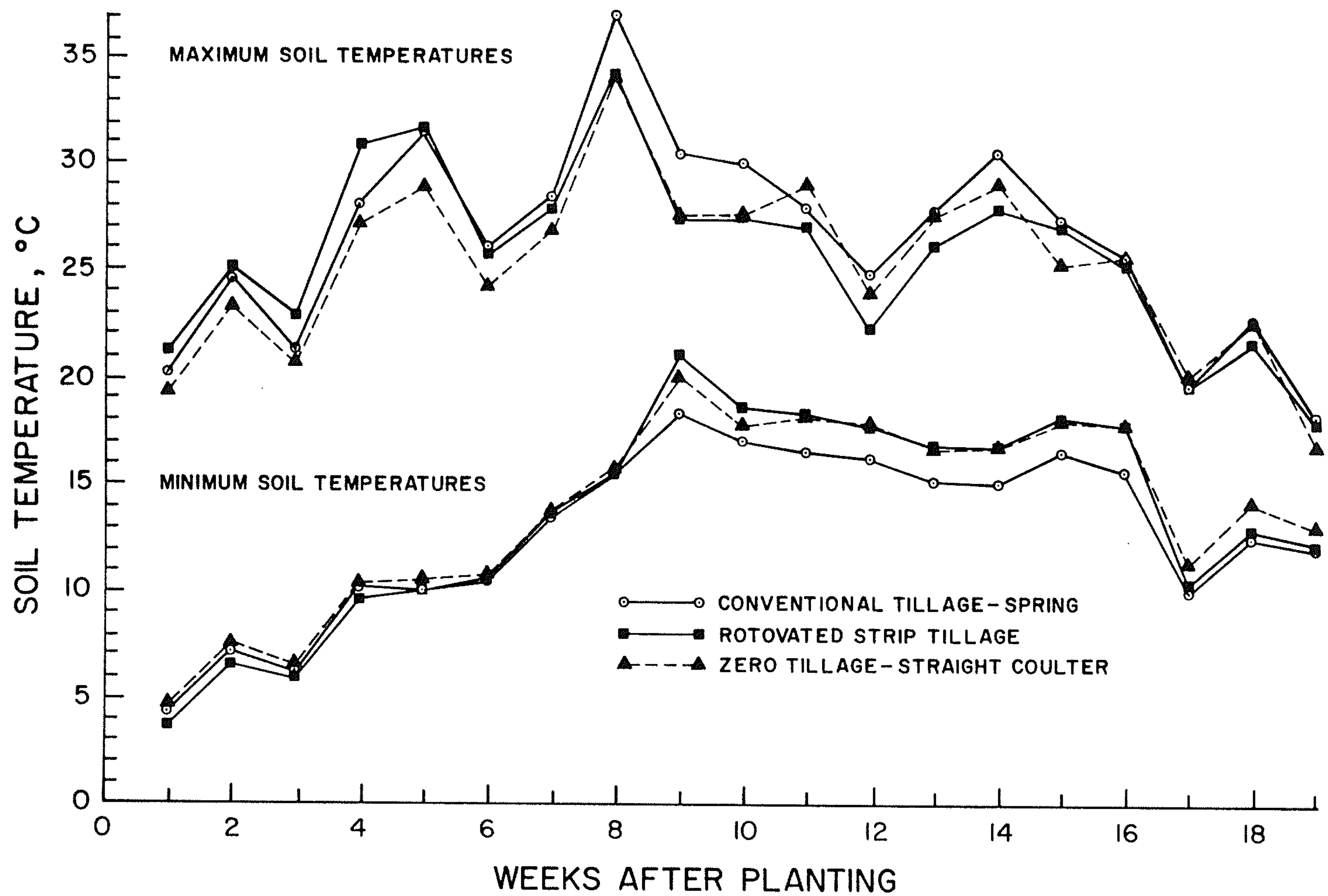

FIGURE 7. Mean weekly maximum and minimum soil temperatures at 5 cm, under conventional tillage-spring, rotovated strip tillage and zero tillage-straight coulter treatments, 1981.

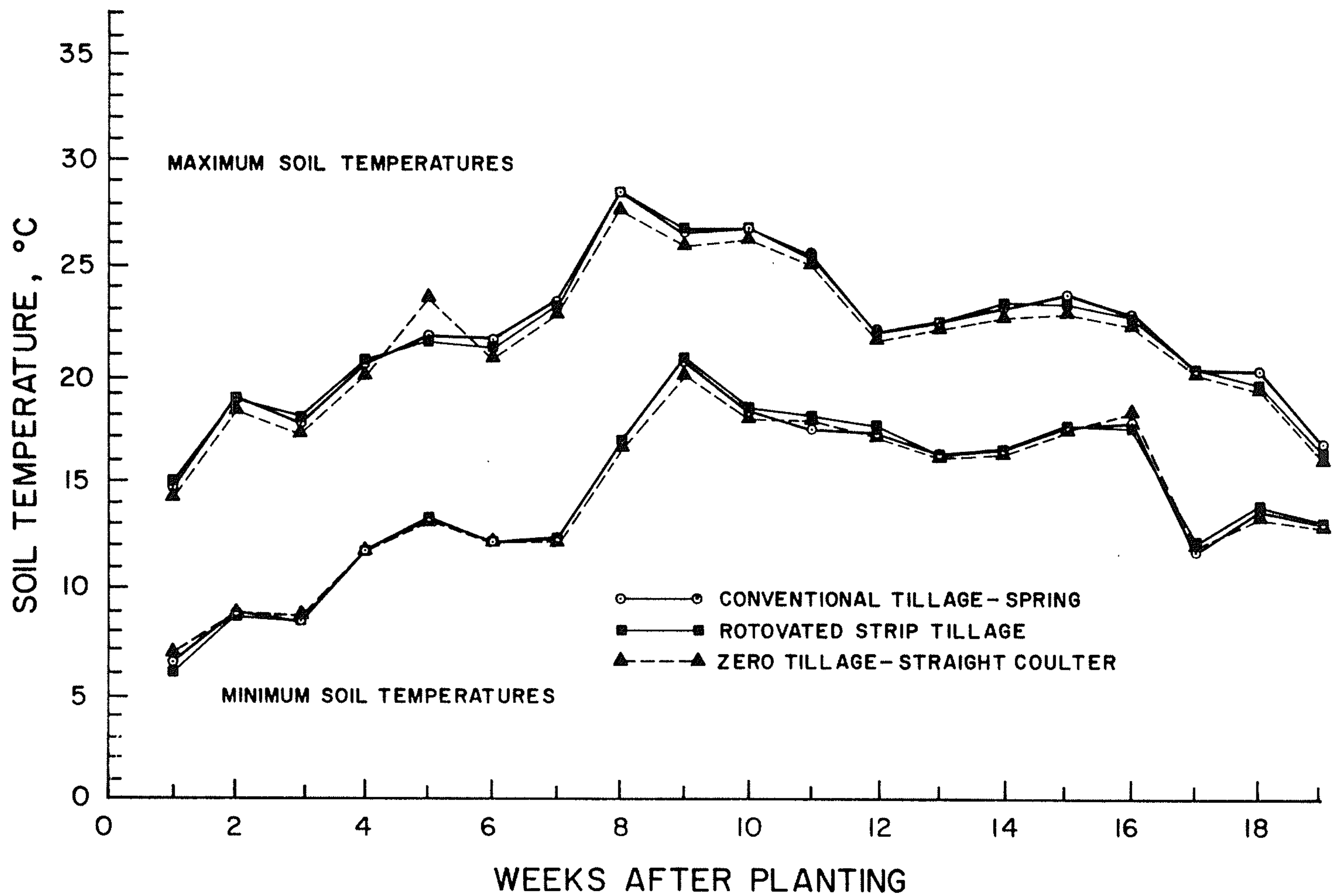

FIGURE 8. Mean weekly maximum and minimum soil temperatures at 10 cm, under conventional tillage-spring, rotovated strip tillage and zero tillage-straight coulter treatments, 1981.

conventional tillage-fall treatment. The effect of spring tillage persisted throughout the season at the 5 cm depth (Figure 9), however, at 10 cm after the seventh week, maximum soil temperatures were greater under the fall tillage treatment to the end of the season. The increase in maximum soil temperatures later in the season under the conventional tillage-fall treatment resulted in the mean maximum soil temperature being 0.5^{o}C warmer than that of the conventional tillage-spring treatment at 10 cm. Minimum soil temperatures tended to be greater at 5 cm (Figure 9) for the conventional tillage-fall treatment than the conventional tillage-spring treatment, while no apparent differences existed between these treatments at the 10 cm depth (Figure 10). The results reported here are contrary to those reported by Allmaras et al. (1972) who found that fall tillage resulted in warmer soil temperatures at planting than spring tillage.

Diurnal Temperature Fluctuation

Tillage influenced the diurnal temperature fluctuation of soil in both 1980 and 1981 (Figures 11 and 12). Soil temperatures under the zero tillage-straight coulter treatment exhibited a smaller diurnal fluctuation compared with that of the conventional tillage-spring treatment. The influence of zero tillage on the diurnal temperature fluctuation was more pronounced in 1980 than in 1981 and this difference was probably due to the greater amount of straw cover on the soil surface in 1980 than in 1981. Burrows and Larson (1961) illustrated that the diurnal temperature fluctuation decreased with increasing amounts of straw cover. The greater diurnal temperature fluctuation under conventional tillage was attributed to higher maximum soil temperatures. As

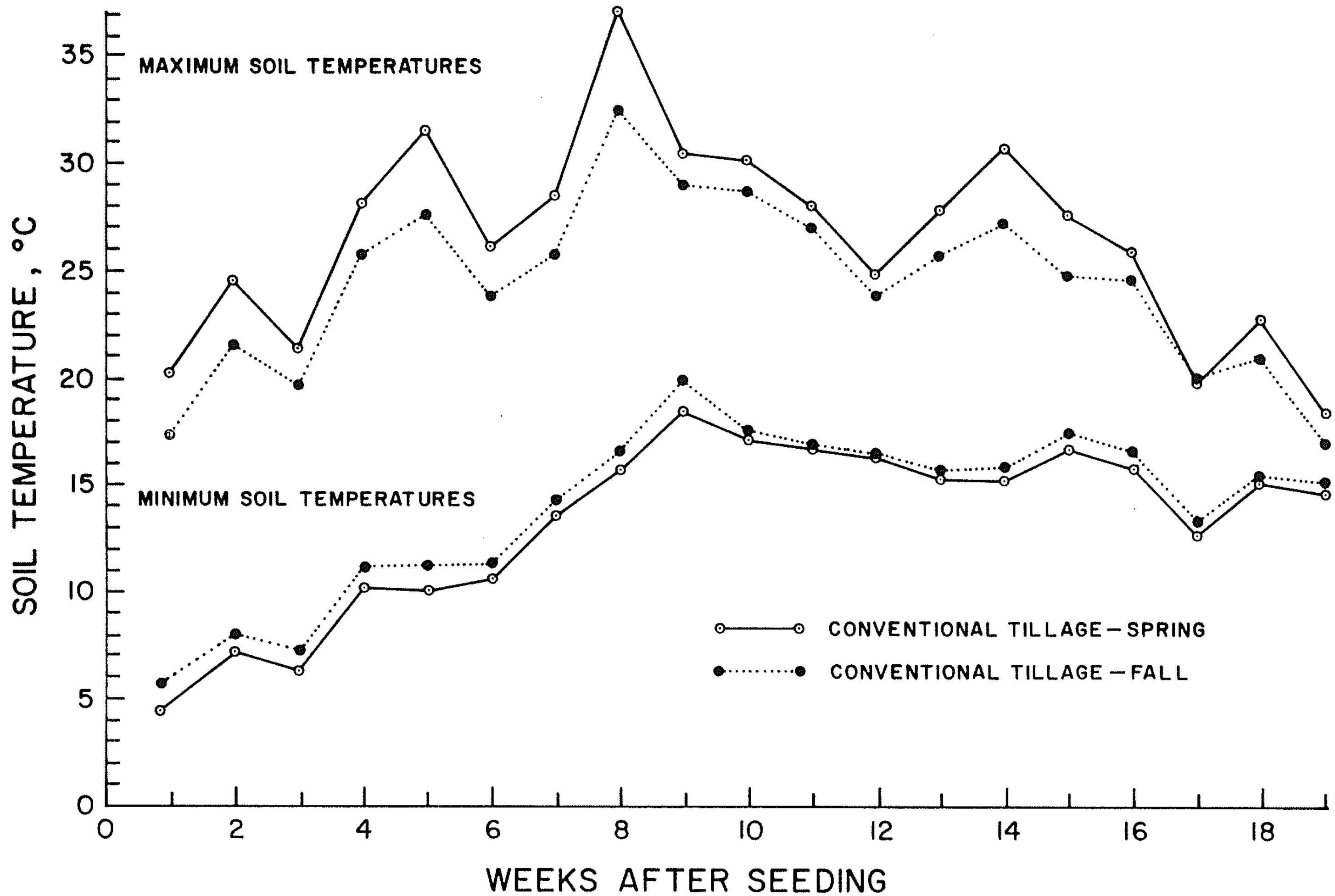

FIGURE 9. Mean weekly maximum and minimum soil temperatures at 5 cm, under conventional tillage-spring and conventional tillage-fall treatments, 1981.

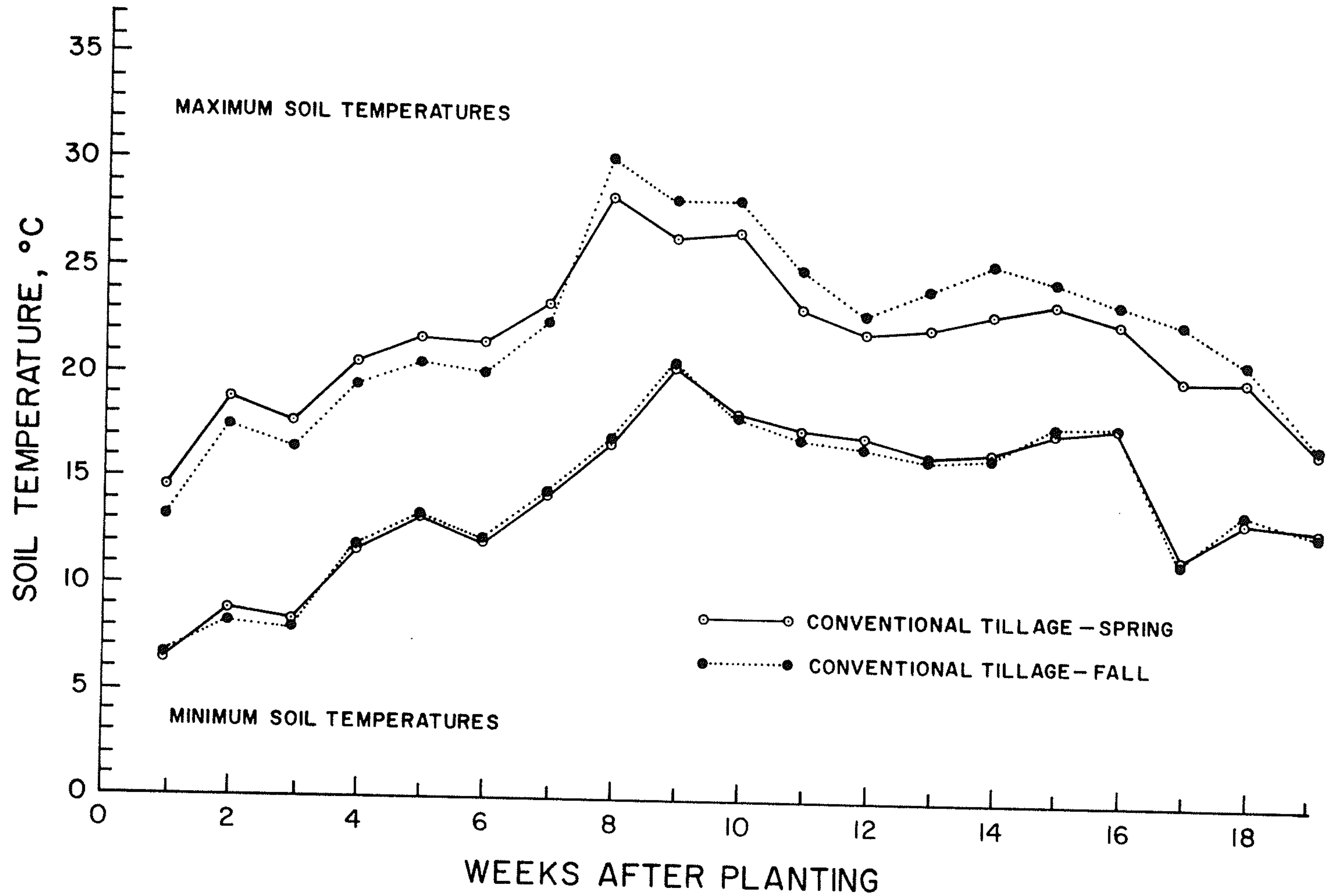

FIGURE 10. Mean weekly maximum and minimum soil temperatures at 10 cm, under conventional tillage-spring and conventional tillage-fall treatments, 1981.

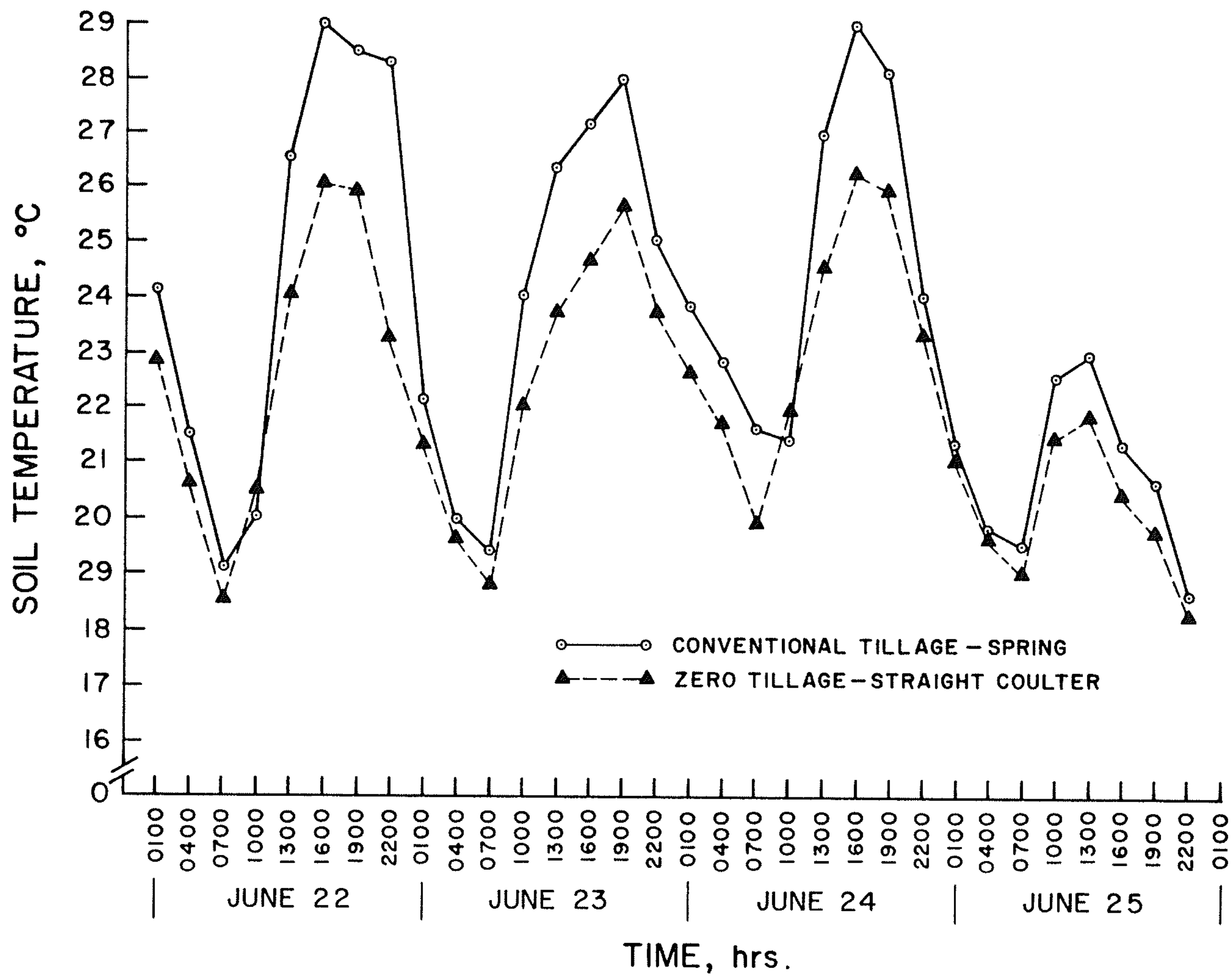

FIGURE 11. Diurnal fluctuation of soil temperatures at 5 cm, under conventional tillage-spring and zero tillage-straight coulter treatments, 1980.

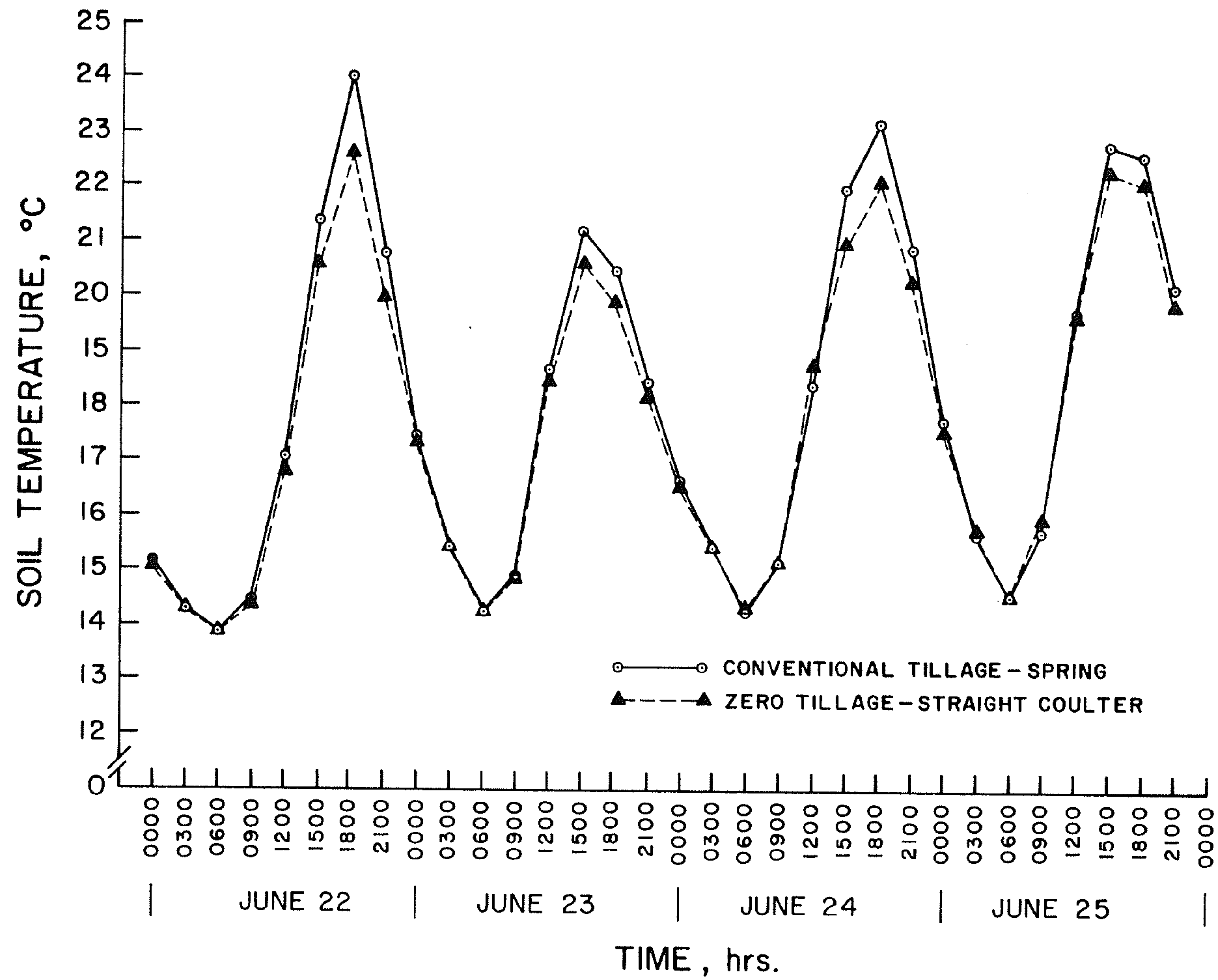

FIGURE 12. Diurnal fluctuation of soil temperatures at 5 cm, under conventional tillage-spring and zero tillage-straight coulter treatments, 1981.

previously indicated the lower maximum soil temperatures under zero tillage were due to the presence of barley straw on the soil surface of the zero tillage plots. The main factor contributing to the smaller diurnal temperature fluctuation under zero tillage was concluded to be the presence of the barley straw on the soil surface which resulted in lower maximum soil temperatures. Decreases in the diurnal temperature fluctuation in the presence of straw mulches have been reported by McCalla and Duley (1946) and Burrows and Larson (1961). Although the mulch was considered to be the primary factor involved in promoting the smaller diurnal temperature fluctuation under zero tillage it should be recognized that soil moisture may have also been a contributing factor. In 1980 the difference between zero and conventional tillage in volumetric soil moisture at the 5 cm depth was greater than in 1981 (Tables 15 and 16). Corresponding to this difference in soil moisture between zero and conventional tillage is the difference in the degree of diurnal temperature fluctuation between 1980 and 1981. In 1980 the greater difference between zero and conventional tillage in soil moisture corresponded to the greater difference in diurnal temperature fluctuations. Soil moisture is known to affect the thermal properties of soil, thermal conductivity, thermal diffusivity and heat capacity (Baver et al., 1972).

Soil Temperatures: Seed Row vs Interrow Spaces

Soil temperatures were measured on eight occasions in the seed row and interrow spaces between May 21 and June 22, 1981, the results are presented in Table 23. Marked differences in soil temperatures occurred between the seed row and interrow spaces, while the differences between the tillage treatments examined (rotovated strip tillage and zero tillage-straight coulter) were not appreciable. The differences between the seed row and the interrow spaces decreased with increasing depth, at the 2.5 cm depth the difference between the seed row and the interrow space was 4.7°C while at the 20 cm depth the difference was only 0.5°C. These results indicated that even with a minimal amount of soil disturbance at seeding (zero tillage-straight coulter) the temperature in the seed row can be increased under zero tillage. The effect of the temperature differences between the seed row and interrow spaces on the growth and development of the root system was not determined. Allmaras and Nelson (1973) suggested that root configuration may be influenced by changes in soil temperature and/or soil moisture resulting from straw placement.

TABLE 23. Comparison of soil temperatures (mean of 8 sampling dates) in the seed row and the interrow spaces under rotovated strip tillage and zero tillage-straight coulter, 1981.

Treatment	Depth (cm)	Soil Temperature °C		Temperature Difference
		Row	Interrow	
Zero Tillage	2.5	22.5	18.1	4.4
Rotovated Strip Tillage	2.5	22.7	17.8	4.9
Zero Tillage	5.0	18.8	16.2	2.6
Rotovated Strip Tillage	5.0	19.5	16.0	3.5
Zero Tillage	10.0	15.6	13.8	1.8
Rotovated Strip Tillage	10.0	15.7	13.7	2.0
Zero Tillage	20.0	12.6	12.1	0.5
Rotovated Strip Tillage	20.0	12.8	12.3	0.5

Soil Moisture Effects on Soil Temperature

Soil moisture is considered to have been a factor contributing to the differences in soil temperature observed between the various primary tillage treatments in 1980 and 1981. In both years the mean seasonal soil moisture was found to be significantly correlated with the seasonal mean weekly soil temperatures (r = -0.88 and -0.69, respectively). No references were found which examined the effects of reduced tillage on soil moisture as it relates to soil temperature. Soil moisture is known to affect several of the thermal properties of soil, including; heat capacity, thermal conductivity and thermal diffusivity (Baver et al., 1972). Heat capacity and thermal diffusivity are probably the most important factors to be considered. The heat capacity of the soil is the amount of energy (calories) necessary to raise one gram of soil one degree centigrade. The heat capacity of the soil increases with increas -ing water content. It would be expected that those soils having high water contents would warm more slowly than those with low water contents as more energy would be required to increase the soil temperature. The thermal diffusivity is the rate at which temperature changes as heat flows into the soil. Thermal diffusivity increases up to an optimum moisture content then decreases. Assuming that the moisture content of the soil under zero tillage is greater than the optimum, then the thermal diffusivity may be less than that of soil under spring tillage. The lower thermal diffusivity may account for the delayed warming of the soil under zero tillage periodically encountered during the early part of the 1980 and 1981 growing seasons. Soil temperature and moisture differences decreased with increasing soil depth. At the 10 cm depth the differences in soil moisture between the tillage treatments were not appreciable in either 1980 or 1981 (Tables 15 and 16). It would be expected that the effects of soil moisture on temperature differences between tillage treatments would be minimal at the lower soil depths.

Crop Growth and Development

Emergence. Differences in the number of days to 50% corn emergence were noted between 1980 and 1981 (Table 24). In general, 50% emergence occurred 3 days earlier in 1980 than in 1981. This difference reflected the warmer soil temperatures which prevailed during the emergence period in 1980. For the first 3 weeks after seeding the mean soil temperature, within the surface 5 cm, averaged 4.6^{o}C warmer in 1980 than in 1981.

Corn emergence was influenced by soil temperature. Corn under both the conventional tillage-spring and the zero tillage-straight coulter treatments reached 50% emergence within similar periods of time, while the time to 50% emergence for the zero tillage-fluted coulter treatment was significantly delayed (Table 24b). Because of the physical similarity between the two zero tillage treatments it was expected that these treatments would have exhibited similar trends in corn emergence. However, examination of the soil temperature data for each treatment showed that marked differences in soil temperature occurred, during the emergence period, between the two zero tillage treatments (Table 25). The mean soil temperature, in the 0 to 5 cm depth, for the zero tillage-fluted coulter treatment during the first 3 weeks after seeding was 1.46^{o}C and 1.54^{o}C lower than the zero tillage-straight coulter and conventional tillage-spring treatments, respectively. It appears that the warmer soil temperatures observed under the zero tillage-straight coulter and conventional tillage-spring treatment, as compared with the zero tillage

TABLE 24. The effect of primary tillage, straw cover and secondary tillage on days to emergence and silking, grain moisture, test weight and yield at harvest.

Treatment	Days to 50% Emergence		Days to 50% Silk		Percent Grain Moisture		Grain Test Weight (gms/0.5 litre)		Grain Yield (gms/ear)	
	1980	1981	1980	1981	1980	1981	1980	1981	1980	1981
a. Primary Tillage x Straw Cover Interactions										
Conventional Tillage-Fall x Retained		13.5	73.0	73.0		31.0		394.1		150.4
x Removed		12.8		73.5		32.3		392.5		150.3
Conventional Tillage-Spring x Retained	11.3	15.0	67.8	74.1	22.2	29.8	377.4	392.2	99.9	146.9
x Removed	11.0	16.8	66.1	74.9	21.8	31.2	381.6	392.4	99.5	152.7
Rotovated Strip Tillage x Retained		16.3		75.1		32.0		389.8		145.8
x Removed		16.5		75.1		32.5		390.5		149.8
Zero Tillage-Fluted Coulter x Retained	15.8	15.8	69.1	74.9	26.2	32.4	363.8	392.5	88.4	144.0
x Removed	11.5	15.8	65.9	74.8	24.4	32.0	368.8	391.9	88.5	147.4
Zero Tillage-Straight Coulter x Retained	11.8	16.3	70.6	75.5	25.7	32.1	362.5	391.9	81.9	146.2
x Removed	11.0	15.8	65.6	75.0	22.3	31.8	372.6	391.2	89.8	147.7
b. Primary Tillage										
Conventional Tillage-Fall		13.1 b		73.3 b		30.5		393.3		150.4
Conventional Tillage-Spring	11.6 b[1]	15.9 a	66.9	74.5 a	22.0	31.6	379.5 a	392.3	98.3 a	149.3
Rotovated Strip Tillage		16.4 a		75.1 a		32.2		390.2		147.8
Zero Tillage-Fluted Coulter	13.6 a	15.8 a	67.5	74.8 a	25.3	32.2	366.3 b	392.2	88.5 b	145.7
Zero Tillage-Straight Coulter	11.4 b	16.0 a	68.1	75.3 a	24.1	32.0	367.6 b	391.6	85.9 b	146.9
c. Straw Cover										
Retained	12.9	15.4	69.2*	74.5	24.7	31.5	367.9*	392.1	89.1*	146.5
Removed	11.2	15.5	65.9	74.7	22.8	31.9	374.3	391.7	92.6	149.6
L.S.D.	2.5	1.7	0.9	1.2	2.6	2.2	2.9	1.4	3.3	7.5
d. Secondary Tillage										
None			67.5	74.2*	23.1	31.3	370.5	391.8	89.8	149.1
Interrow Cultivation			67.5	75.0	24.4	32.1	371.8	392.0	91.9	146.9
L.S.D.			1.0	0.5	2.8	0.9	6.1	1.2	5.6	3.4

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

-fluted coulter treatment, were responsible for the earlier emergence of corn. Numerous other studies have shown that warm soil temperatures promote earlier corn emergence (Willis et al., 1957; Dubetz et al., 1962; Adams, 1967; Ketcheson, 1970; Alessi and Power, 1971; Phillips and Cochrane, 1975; Rykbost et al., 1975; Iremiren and Milbourn, 1979).

TABLE 25. Mean daily soil temperatures in the surface 0 to 5 cm, during the emergence period as influenced by primary tillage treatment, 1980 and 1981.

Year	Tillage Treatment	Mean Daily Soil Temperature °C
1980	Conventional Tillage-Spring	18.66
	Zero Tillage-Fluted Coulter	17.12
	Zero Tillage-Straight Coulter	18.58
1981	Conventional Tillage-Fall	13.11
	Conventional Tillage-Spring	13.88
	Rotovated Strip Tillage	14.01
	Zero Tillage-Fluted Coulter	13.19
	Zero Tillage-Straight Coulter	13.67

Although significant differences in the number of days to 50% emergence of corn occurred between the primary tillage treatments in 1981 (Table 24b), the differences do not appear to be related to soil temper-atures. Corn planted on soils tilled in the fall reached 50% emergence earlier than all other tillage treatments examined, while the mean soil temperature in the seed zone, 0 to 5 cm, during the first 3 weeks after seeding was lower than all other tillage treatments (Table 25). Corn planted in the remaining treatments (conventional tillage-spring, rotovated strip tillage, zero tillage-fluted coulter and zero tillage-straight coulter) did not differ significantly in the number of days to 50% emergence (Table 24b). Two factors may be related to the earlier emergence of corn observed under the fall tillage treatment. During the first 3 weeks following seeding, the conventional tillage-fall treatment tended to have a greater soil moisture content in the surface 5 cm (Table 16). Further, the fall tillage treatment had a visibly superior seedbed than either the spring or the rotovated strip tillage treatments. The seedbeds of the latter treatments were prepared using rotovation, which produced a looser seedbed than that of the fall tillage treatment. The firmer seedbed of the conventional tillage-fall treatment resulted in better seed/soil contact and in combination with the greater soil moisture may have promoted earlier germination and subsequently earlier emergence than under the conventional tillage-spring or rotovated strip tillage treatments. Greater soil moisture may have been a factor which resulted in the conventional tillage-fall treatment emerging ahead of the two zero tillage treatments in 1981 (Table 16).

Retention or removal of the previous crop residues did not significantly influence the rate of emergence of corn, although, in 1980 emergence tended to be delayed by approximately 1½ days when the straw was retained on the soil surface (Table 24c).

The final plant populations per hectare were not affected in 1980 or in 1981 by the primary tillage treatments (Table 26).

Removal of the previous crop residues resulted in a significant increase in the plant population per hectare in 1980, while the plant populations were not affected in 1981 (Table 26).

The lower plant populations observed in 1981 were attributed to an error in the adjustment of the corn planter following its use for seeding sugar beets (Table 26).

TABLE 26. The effect of primary tillage and straw cover on the plant population per hectare.

Treatment	1980	1981
a. Primary Tillage		
Conventional Tillage-Fall		21,416
Conventional Tillage-Spring	51,562	20,882
Rotovated Strip Tillage		20,870
Zero Tillage-Fluted Coulter	43,684	20,779
Zero Tillage-Straight Coulter	50,870	20,232
b. Straw Cover		
Retained	45,082*	20,997
Removed	52,329	20,232
L.S.D.	1,542	1,064

Plant Height. In 1980, plant heights did not differ significantly between tillage treatments on any sampling date (Table 27b, Figure 13). A similar trend was noted in 1981, the conventional tillage-spring, rotovated strip tillage, zero tillage-straight coulter and zero tillage-fluted coulter treatments did not differ significantly from one another on any sampling date (Table 28b). However, the conventional tillage-fall treatment resulted in significantly taller plants than all other tillage treatments examined, on all but the final sampling date. Figure 14 illustrates the magnitude of the differences between the conventional tillage-fall and all the other tillage treatments, represented by the conventional tillage-spring treatment.

Secondary tillage (interrow cultivation) did not affect plant height in 1980 (Table 27d), while in 1981 plant height was greater later in the season where no secondary tillage had been employed (Table 28d), although the final plant height was not affected by interrow cultivation in either year. In 1981, the depressing effect of secondary tillage on

TABLE 27. The effect of primary tillage, straw cover and secondary tillage on plant heights (cm), 1980

Treatment		Sampling Date			
	June 11	June 26	July 10	July 16	July 24
a. Primary Tillage x Straw Cover Interactions					
Conventional Tillage-Spring x Retained	27.4	59.3	109.8	147.7	172.9
x Removed	30.6	66.6	121.8	162.1	182.7
Zero Tillage-Fluted Coulter x Retained	26.6	59.7	103.1	139.8	171.3
x Removed	30.4	66.3	123.0	163.9	179.8
Zero Tillage-Straight Coulter x Retained	25.5	58.6	102.2	139.7	174.4
x Removed	34.1	68.2	121.8	158.9	177.8
b. Primary Tillage					
Conventional Tillage-Spring	29.0	63.0	115.8	154.9	177.8
Zero Tillage-Fluted Coulter	28.5	63.0	113.1	151.9	175.6
Zero Tillage-Straight Coulter	29.8	63.4	112.0	149.3	176.1
c. Straw Cover					
Retained	26.5*	59.2*	105.0*	142.4*	172.9
Removed	31.7	67.0	122.2	161.6	180.2
L.S.D.	1.5	4.5	13.4	18.0	9.8
d. Secondary Tillage					
None			114.1	151.6	176.1
Interrow Cultivation			113.1	152.4	177.0
L.S.D.			6.4	4.4	3.9

* Significant at the 0.05 level.

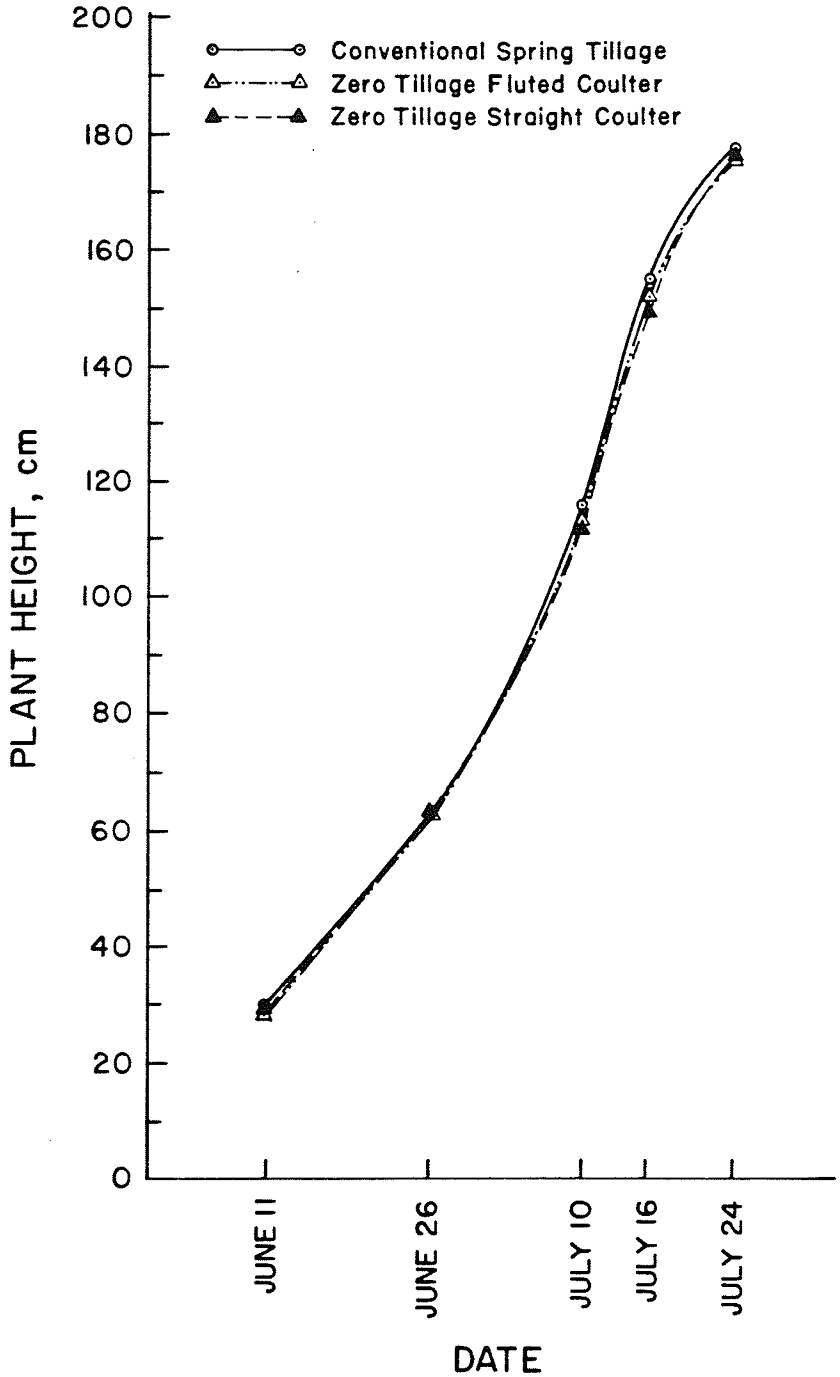

FIGURE 13. Plant heights (cm) under conventional tillage-spring, zero tillage-fluted coulter and zero tillage-straight coulter treatments for 1980.

TABLE 28. The effect of primary tillage, straw cover and secondary tillage on plant heights (cm), 1981.

Treatment		Sampling Date						
		June 8	June 16	June 23	July 1	July 7	July 21	August 25
a. Primary Tillage x Straw Cover Interactions								
Conventional Tillage-Fall	x Retained	20.1	28.7	37.9	62.3	96.4 a [1]	186.9	202.7
	x Removed	19.7	25.6	33.2	60.3	93.4 ab	187.3	204.2
Conventional Tillage-Spring	x Retained	17.1	25.2	29.9	56.1	89.3 bc	182.6	202.7
	x Removed	16.3	24.0	29.4	54.5	85.7 c	187.3	201.3
Rotovated Strip Tillage	x Retained	15.6	23.7	30.6	51.2	82.3 de	174.4	201.1
	x Removed	16.1	23.6	29.3	51.7	82.7 de	176.5	205.6
Zero Tillage-Fluted Coulter	x Retained	16.6	24.0	30.8	53.6	85.4 cd	177.9	197.4
	x Removed	17.4	24.3	30.5	52.7	86.1 c	175.4	199.0
Zero Tillage-Straight Coulter	x Retained	14.9	23.2	29.7	49.6	79.4 e	170.4	198.3
	x Removed	16.3	24.3	29.2	54.5	86.5 c	176.4	201.9
b. Primary Tillage								
Conventional Tillage-Fall		19.9 a	28.1 a	35.6 a	61.3 a	94.9 a	187.1 a	202.8
Conventional Tillage-Spring		16.7 b	24.6 b	29.6 b	55.3 b	87.5 b	178.9 ab	203.2
Rotovated Strip Tillage		15.8 b	23.7 b	30.0 b	51.4 b	82.5 b	175.5 b	203.4
Zero Tillage-Fluted Coulter		17.0 b	24.1 b	30.7 b	53.1 b	85.6 b	176.7 b	198.4
Zero Tillage-Straight Coulter		15.6 b	23.7 b	29.5 b	52.1 b	82.9 b	173.4 b	200.2
c. Straw Cover								
Retained		16.8	25.0	31.8	54.6	86.5	178.5	200.2
Removed		17.1	24.8	30.2	54.7	86.9	178.2	202.9
L.S.D.		1.4	1.6	11.5	2.6	4.7	8.6	5.3
d. Secondary Tillage								
None				31.5	55.8	89.0*	182.4*	202.8
Interrow Cultivation				30.6	53.5	84.4	174.2	200.3
L.S.D.				2.7	2.4	3.7	5.3	3.1

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

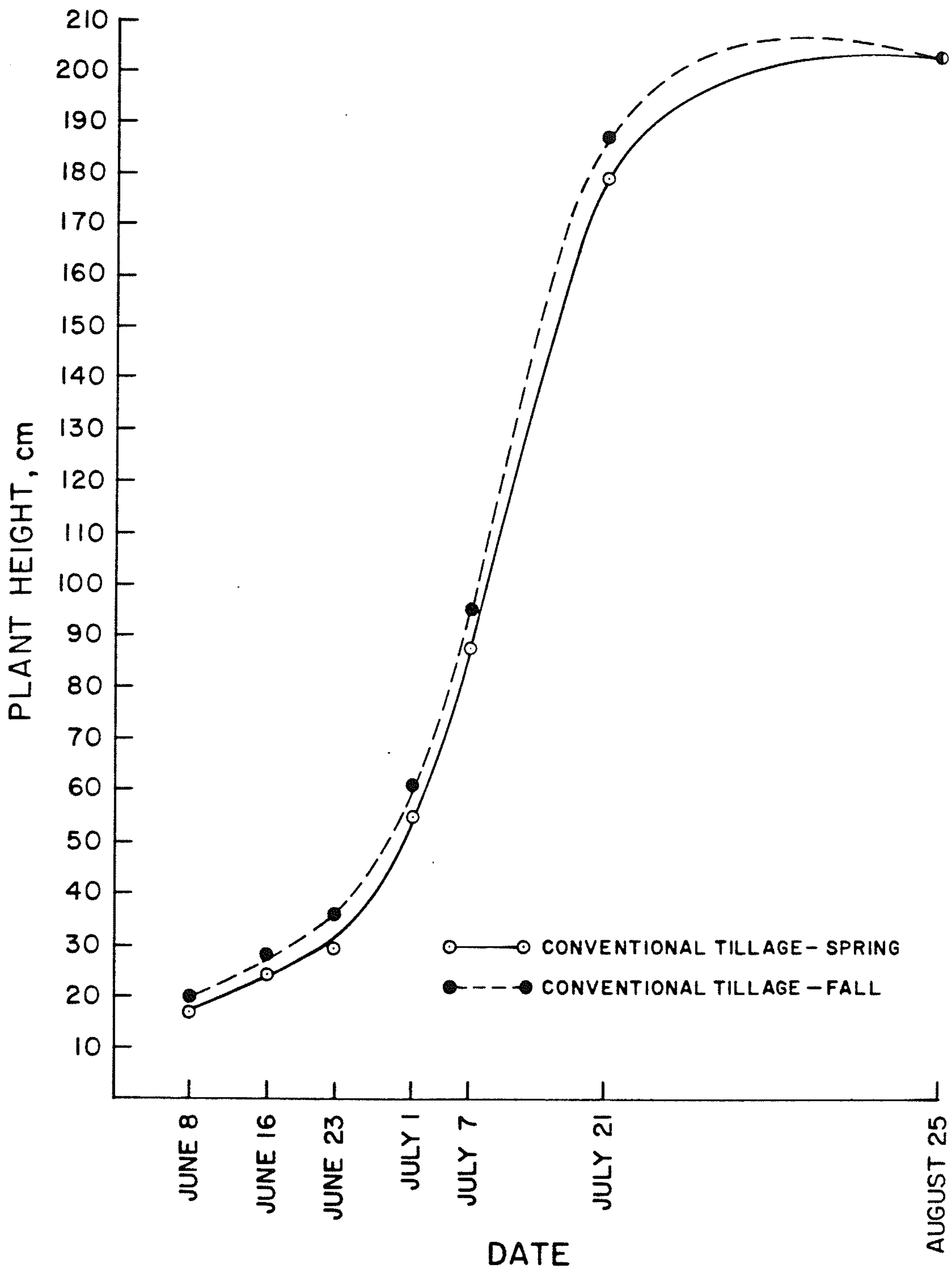

FIGURE 14. Plant heights (cm) under conventional tillage-spring and conventional tillage-fall treatments, 1981.

plant height was attributed to 'root prunning' which reduced the vigor of the plants. Interrow cultivation resulted in considerable soil disturbance immediately adjacent to the plants which probably disrupted the soil/root contact. Vigor of the corn plants was visibly reduced following interrow cultivation.

In 1980, the removal of the previous crop residues resulted in greater plant heights than where the residues had been retained on the soil surface (Table 27c, Figure 15). The difference in height between retention and removal of the straw cover was significant for the first four sampling dates. Final plant height was not affected by the removal of the straw cover.

The lower plant heights observed where the straw cover had been retained was attributed to a reduction in soil temperatures beneath the mulch. As has already been shown, soil temperatures were found to be increased under zero tillage when the straw mulch was removed (Figures 5 and 6). Increased plant height in response to increasing soil temperatures has been reported in the literature (Willis et al., 1957; Mederski and Jones, 1963; Jones and Mederski, 1963; Kleinendorst and Bouwer, 1970; Watts, 1972a; Watts, 1972b). Similar reductions in plant height as those reported where the straw cover had been retained in 1980 have been reported by Larson et al. (1960) and Burrows and Larson (1961). Further, these studies have shown that the reductions in plant height under the mulches where due to reduced soil temperatures.

As has been previously indicated, soil temperatures under the conventional tillage-fall treatment were lower than those recorded under the conventional tillage-spring treatment (Figures 9 and 10). However,

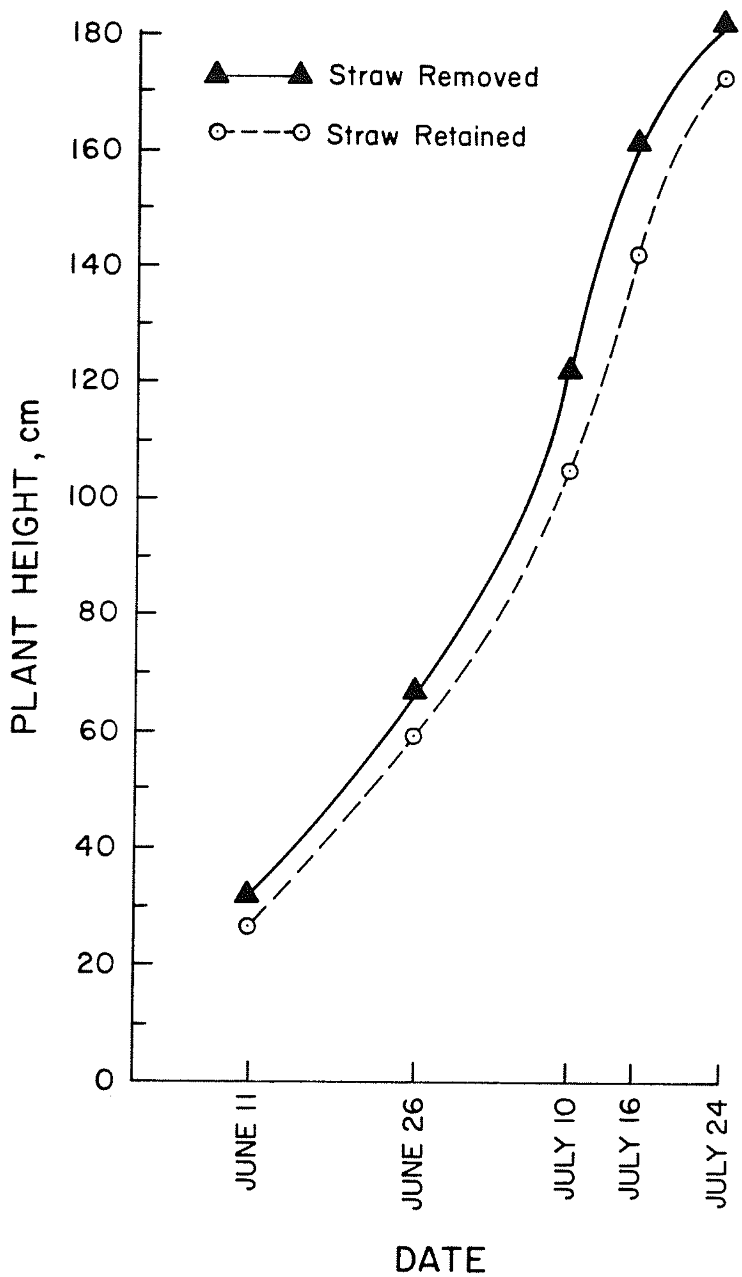

FIGURE 15. Plant heights (cm), straw retained vs straw removed treatments for 1980.

plant heights under the conventional tillage-fall treatment were signif-icantly greater than those plants grown under the other tillage treatments. The lower soil temperatures and correspondingly greater plant heights observed under the conventional tillage-fall treatment are contrary to the findings reported in the literature (Willis et al., 1957; Larson et al., 1960; Burrows and Larson, 1961; Mederski and Jones, 1963; Jones and Mederski, 1963; Kleinendorst and Bouwer, 1970; Watts, 1972a; Watts, 1972b). Clearly there were other factors involved in determining plant heights under the conventional tillage treatments. The fall tillage treatment was found to have had a greater seasonal mean volumetric soil moisture content than the rotovated strip tillage of the conventional tillage-spring treatments and a slightly greater amount than the zero tillage treatments (Table 16). The increased soil moisture under the fall tillage treatment may have stimulated plant growth, resulting in greater plant heights. Greater soil moisture under mulches has been reported to increase plant height (Moody et al., 1963; Jones et al., 1963; Triplett et al., 1968).

Silking. Tillage did not significantly affect the date on which the corn reached the 50% silk stage in 1980, although, the corn in the zero tillage plots tended to silk ½ to 1 day later than in the conventional tillage plots (Table 24b). Interrow cultivation did not affect the rate at which the corn reached the 50% silk stage in 1980.

In 1981, silking was influenced by both primary and secondary tillage. Corn grown under the fall tillage treatment silked significantly earlier than all other primary tillage treatments examined (Table 24b). In 1981, soil temperature was not considered to be a factor in the silking response of the corn to tillage. The earlier silking observed under the fall tillage treatment was due to earlier germination and emergence. The number of days to 50% emergence and the days to the 50% silk stage were significantly correlated (r = 0.59). Corn that received interrow cultivation (secondary tillage) reached the 50% silk stage later than corn which did not receive interrow cultivation (Table 24d). Following interrow cultivation there was a visible reduction in the vigor of the corn, which was attributed to root pruning. The reduction in vigor retarded plant development resulting in a delay in silking.

In 1980, the interaction between straw cover and tillage was not significant (Table 24a), however, the effect of straw removal on the number of days required for the corn to reach the 50% silk stage was more pronounced under zero tillage than under conventional tillage. Removal of the straw cover in the conventional tillage plots resulted in the corn reaching the 50% silk stage 1.7 days earlier than where the straw cover had been retained, while in the zero tillage plots removal of the straw cover resulted in the corn reaching the 50% silk stage 4.1 days earlier (Table 24a). The difference in the silking response of the corn, grown under conventional and zero tillage, to the removal of the straw cover reflects the relative amount of straw left on the soil surface following removal. Following seedbed preparation the amount of previous crop residues left on the soil surface, where the straw cover had been retained, was less in the conventional tillage plots than in the zero tillage plots, but greater than in the conventional tillage plots where the straw cover had been removed prior to seedbed preparation. The difference in the amount of residues on the soil surface between where the straw cover had been retained and removed was less in the conventional tillage plots than in the zero tillage plots and is reflected in the smaller differences in the number of days to the 50% silk stage. It is considered that as the amount of straw cover on the soil surface was reduced, soil temperatures were increased, which subsequently resulted in earlier silking. When the effect of straw cover is examined, regardless of the tillage treatment, it was found that the removal of the straw cover resulted in a significant decrease in the number of days required for the corn to reach the 50% silk stage (Table 24c). Removal of the straw cover from the soil surface of the zero tillage-straight coulter treatment was found to have increased the soil temperatures compared to where the straw cover had been retained (Figures 5 and 6). The warmer soil temperatures observed where the straw cover had been removed is considered to have promoted earlier silking. Delays in silking have been reported in the literature when the corn was grown in the presence of a straw mulch which resulted in lower soil temperatures (Willis et al., 1957; Mock and Erbach, 1977).

In 1981, the removal of the straw cover did not affect the number of days required for the corn to reach the 50% silk stage.

Maturity. The relative maturity of the corn at harvest was determined by the percent grain moisture and the grain test weight. The percent grain moisture was not significantly affected by primary tillage, secondary tillage or by the removal of straw cover in either 1980 or 1981 (Table 24). In 1980, however, the corn grown under conventional tillage tended to have a lower percent grain moisture content than corn grown under the zero tillage treatments (Table 24b). The tillage x straw cover interaction was not significant, but it was noted that the conven -tional tillage plots responded less to the removal of the straw cover than did the zero tillage plots (Table 24a). Removal of the straw cover from the conventional tillage plots decreased the percent grain moisture by 0.3 percentage points, while the mean decrease in grain moisture was 2.6 percentage points when the straw cover was removed from the zero tillage plots (Table 24a). The greater grain moisture at harvest observed under zero tillage and also where the straw cover had been retained inferred that maturity had been delayed under these treatments. These differences in the percent grain moisture were not statistically significant, but the differences were nevertheless considered to be meaningful. Under normal drying conditions 1.7 days are required for the percent grain moisture to drop by one percentage point (Helgason, 1982). If this relationship held true in 1980, then the higher percent grain moisture of corn grown under the zero tillage-straight coulter treatment relative to the conventional tillage-spring treatment may represent a delay in maturity of 3.5 days, while maturity may have been delayed by 5.6 days under the zero tillage-fluted coulter treatment, relative to the conventional tillage-spring treatment. The removal of straw would also have promoted earliness, allowing the grain to mature 3.2 days earlier relative to where the straw cover had been retained. The differences in the percent grain moisture between the tillage and straw treatments were inappreciable in 1981.

In 1980, the conventional tillage-spring treatment had a greater grain test weight than either of the zero tillage treatments (Table 24b). The greater grain test weights indicated that the conventionally grown corn was relatively more advanced at harvest than was the corn produced under the zero tillage treatments. The differences in grain test weight between the tillage treatments were not appreciable in 1981.

Straw removal was found to result in greater grain test weights in 1980, while in 1981 grain test weights did not differ significantly between straw cover treatments.

Grain test weight did not differ between secondary tillage treatments in either 1980 or 1981.

The greater percent grain moisture content and the lower test weights observed in 1980 under the zero tillage treatments suggests that the relative maturity of the corn was delayed compared to the conventional tillage treatment. As has been previously discussed, the mean maximum soil temperatures were reduced under the zero tillage treatments compared to the conventional tillage-spring treatment (Table 19). Lower soil temperatures are considered to have resulted in the delayed maturity of the corn grown under the zero tillage treatments and also where the straw cover had been retained on the soil surface. The earliness to maturity in corn has been reported in the literature to be influenced by soil temperature (Willis et al., 1957; Iremiren and Milbourn, 1979).

Plant Dry Matter. In 1980, significant differences in plant dry matter were not observed between the various tillage treatments (Table 29b). At harvest, however, corn grown under the two zero tillage treatments tended to have greater dry weights than corn grown under the conventional tillage treatment. The increase in dry matter at harvest was attributed to greater soil moisture in the zero tillage plots. Increased plant dry matter under reduced tillage has been reported in the literature and has been attributed to increased soil moisture (Moody et al., 1961; Moody et

TABLE 29. The effect of primary tillage, straw cover and secondary tillage on the average weight (gms) dry matter per plant.

Treatment		Sampling Date 1		Sampling Date 2		Sampling Date 3[3]	
		1980 (2½)[1]	1981 (3)	1980 (5½)	1981 (8)	1980 (21)	1981 (21)
a. Primary Tillage x Straw Cover Interactions							
Conventional Tillage-Fall	x Retained		0.105		15.32		98.38
	x Removed		0.115		14.55		91.42
Conventional Tillage-Spring	x Retained	0.085	0.095	2.67 cd	10.83	42.15	91.95
	x Removed	0.105	0.078	3.28 b	9.52	46.55	92.80
Rotovated Strip Tillage	x Retained		0.092		9.40		83.01
	x Removed		0.072		10.49		98.04
Zero Tillage-Fluted Coulter	x Retained	0.070	0.070	2.77 cd	8.73	49.05	86.80
	x Removed	0.091	0.070	3.18 bc	10.19	48.87	80.31
Zero Tillage-Straight Coulter	x Retained	0.063	0.074	1.92 e	9.44	41.03	86.60
	x Removed	0.099	0.073	3.71 a	9.19	52.06	81.89
b. Primary Tillage							
Conventional Tillage-Fall			0.110 a[2]		14.93 a		90.52
Conventional Tillage-Spring		0.095	0.086 b	2.97	10.17 b	44.35	92.38
Rotovated Strip Tillage			0.082 bc		9.94 b		90.52
Zero Tillage-Fluted Coulter		0.080	0.070 c	2.97	9.46 b	48.96	83.55
Zero Tillage-Straight Coulter		0.081	0.073 bc	2.81	9.31 b	46.54	84.24
c. Straw Cover							
Retained		0.073	0.087	2.45*	10.74	44.08	89.35
Removed		0.098	0.081	3.39	10.78	49.16	88.89
L.S.D.		0.035	0.022	0.64	2.39	12.17	2.00
d. Secondary Tillage							
None					11.60*	45.83	88.99
Interrow Cultivation					9.92	47.40	89.25
L.S.D.					1.05	5.09	5.86

* Significant at the 0.05 level.

1 The number enclosed by brackets is the number of weeks after planting when plant samples were collected.

2 Values within columns followed by the same letter are not significantly different.

3 The third sampling date corresponds to harvest, the weight represents the weight of the stover less the ears.

al., 1963; Jones et al., 1968).

In 1980 at 5½ weeks after planting, plant dry matter was greater where the straw cover had been removed than where it had been retained (Table 29a and 29b). This increase in plant dry matter is considered to have resulted from vigorous plant growth in response to warmer soil temperatures where the straw cover had been removed (Table 19). At harvest, removal of the straw cover tended to increase the stover dry weights. A number of studies have shown seedling dry weights to increase with increasing soil temperatures (Burrows and Larson, 1962; Mederski and Jones, 1963; Walker, 1969; Ketcheson, 1970; Phillips and Cochrane, 1975; Mock and Erbach, 1977).

In 1981, plant dry matter was found to be affected by both primary and secondary tillage, but was not affected by the removal of the straw cover (Table 29). At three and eight weeks after planting corn grown under the fall tillage treatment had greater dry weights compared to all other tillage treatments examined (Table 29b). Corn grown under the conventional tillage-spring and the rotovated strip tillage treatments had lower dry weights than those plants grown under the fall tillage treatment, but tended to have greater dry weights than the corn grown under either of the zero tillage treatments. There was a significant correlation between the number of days from 50% emergence to the time the dry matter samples were collected and the dry matter at three and eight weeks ($r = 0.70$ and 0.60, respectively). This correlation between emergence and dry matter suggests that those treatments which promoted earlier emergence allowed for a greater period of dry matter accumulation. Although not significant, the average stover dry weight at harvest was lower under the zero tillage treatments compared to all the other primary tillage treatments examined (Table 29b).

Plant dry matter was reduced by secondary tillage (interrow cult-ivation) at eight weeks after planting, but by harvest no difference in stover dry matter between treatments was detected. The reduction in plant dry matter by interrow cultivation was considered to have been due to root damage during the tillage operation and increased soil moisture loss from the interrow spaces.

Grain Yield. In 1980, the grain yield per ear was found to be significantly affected by both primary tillage and straw cover. The conventional tillage-spring treatment resulted in greater grain yields than either of the zero tillage treatments (Table 24b). Straw removal increased the grain yields compared to where the straw cover had been retained (Table 24c). In 1980, no appreciable precipitation was recorded for 48 days after planting. It was expected that moisture conservation under zero tillage may have resulted in a grain yield advantage over conventional tillage. In spite of the greater soil moisture observed under zero tillage (Table 16) the grain yields were significantly less than those obtained under conventional tillage, this suggests that moisture was not the most important factor in determining the grain yields in 1980. Moisture conservation under zero tillage has been reported to result in greater yields than conventional tillage under drought conditions (Jones et al., 1968; Lal, 1974).

In 1980, the grain yield per ear was found to be significantly correlated with the grain test weight (r = 0.75). The increased grain test weight may have resulted from a longer grain filling period under the conventional tillage treatment. Grain test weight and the number of days from the 50% silk stage to harvest were significantly correlated (r = 0.60). As has been previously discussed, the number of days to the 50% silk stage was influenced by the soil temperatures. It appears that grain yield may thus be indirectly affected by the temperature of the soil.

In 1981, the grain yield per ear was not affected by primary tillage or secondary tillage or by the removal of the straw cover (Tables 24b, 24c and 24d). Grain yields were markedly greater in 1981 than in 1980. The greater grain yields observed in 1981 may be accounted for by both timely precipitation and decreased plant populations. In 1981, the plant population per hectare was approximately 43% less than in 1980 (Table 25). Grain yields per plant have been reported to decrease with increasing plant populations (Willey, 1982). The lower plant populations of 1981 would have been expected to increase the grain yield per plant due to a decrease in the interplant competition for moisture and nutrients. The decreased competition between plants may have also contributed to the limited number of significant differences observed between tillage treatments in 1981.

Root Growth and Development. In 1980 and 1981, the mean soil temperatures in the 0 to 20 cm depth under the conventional tillage-spring treatment were 18.44°C and 18.04°C, respectively, while under the zero tillage-straight coulter treatment the mean soil temperatures were 17.67°C and 17.90°C, respectively. It is important to consider these soil temperatures as it indicates that the mean soil temperatures under both the conventional and zero tillage treatments were well below the optimum soil temperatures for root growth reported by Grobbelaar (1963), 20 to 30^{o}C, and Walker (1969), 26^{o}C. In the two years in which this study was undertaken no attempt was made to assess the effect of the various tillage and straw management practices on corn root growth and development. In all the tillage treatments examined, the mean seasonal soil temperatures were below the 26^{o}C optimum reported by Walker (1969). Those treatments which resulted in the lowest mean soil temperatures (zero tillage-fluted coulter, zero tillage-straight coulter, rotovated strip tillage and where the straw cover had been retained) may have depressed root dry matter accumulation to a greater extent than under the conventional tillage treatments or where the straw cover had been removed. Walker (1969) observed that as the soil temperatures were decreased below the 26^{o}C optimum there was a corresponding decrease in root dry matter. In the 1980 tillage experiment, the corn grown under zero tillage exhibited reduced grain yields compared with corn grown under conventional tillage. Aside from the effects of reduced soil temperature on yield it is also a possibility that the lower yields may reflect decreased available soil moisture. Barber (1971) determined that the zone of maximum rooting under zero tillage was in the surface 10 cm. Greater rooting depths of corn grown under conventional tillage may have increased the available soil moisture and thus increased grain yields.

Allmaras and Nelson (1973) have shown root configuration to be affected by tillage and straw placement. Their studies using rotovated strips have shown that root growth was confined to the verticle projections of the rotovated strip with little lateral proliferation. Assuming that root growth was limited by strip rotovation in the 1981 tillage experiment, it may be a possible explanation for the lack of success with this treatment. Allmaras and Nelson (1973) have implied a relation -ship between soil moisture and soil temperature on the effect of mulches in the interrow space on root growth. Mulches placed between rows when soil moisture was low and soil temperatures were high reduced lateral root growth, while lateral growth was increased by mulches when soil moisture was high and soil temperatures were low. High soil moisture and low soil temperatures (below the $26^{o}C$ optimum) prevailed in all treatments in 1981. Differences in root distribution would not have been expected in 1981 between the tillage treatments.

Hybrid/Tillage Experiments

Straw Cover

No measurements were made to determine the amount of previous crop residues covering the soil surface of the zero tillage plots. Several general comments concerning the straw cover can, however, be made with reference to the 1980 and 1981 straw cover. In both years, the appearance of the straw at seeding was clean and bright. The 1981 zero tillage plots appeared to have a greater amount of previous crop residues than in 1980. The distribution of straw was more uniform in 1980 than in 1981. Localized concentrations of straw, corresponding to the position of the swath, were evident in 1981.

Seeding

In 1980, no problems were encountered when seeding the conventional and zero tillage plots.

In 1981, soil penetration was more difficult under conventional tillage, necessitating the application of maximum pressure to the seed runs, in order to obtain adequate seed placement in the soil. A considerable amount of 'hairpinning' was noted when seeding the zero tillage plots. The straw covering the soil surface of the zero tillage plots was not always cut and in some instances it was forced into the seed runs. Where straw concentrations were high, seed was occasionally found to be deposited on the soil surface of the zero tillage plots. Variable seed placement in seeding zero tillage plots has been reported by McCormick and Mackay (1973).

Hybrid Performance Under Zero and Conventional Tillage

Emergence. The interaction between hybrids and tillage for the number of days required for the corn to reach 50% emergence was not significant in 1980 or 1981, nor were any differences noted between the hybrids examined (Table 30). In 1981, however, the number of days to 50% emergence was delayed by almost six days under the zero tillage treatment as compared to the conventional tillage treatment. Similar findings were reported in the tillage experiments. Where heavy concentrations of straw occurred, in the zero tillage plots, emergence was visibly reduced. Whether the reduction in emergence resulted from physical limitations imposed by the presence of excessive amounts of mulch, as those reported by Burrows and Larson (1961), or poor seed placement, was not determined. However, it is speculated that excessive amounts of straw were forced into the seed rows during seeding, as a result good seed/soil contact was not established. Under these conditions the seed may have initiated germination, then dessicated as the seed row dried.

The interaction between hybrids and tillage for plant population

TABLE 30. The effect of hybrids and primary tillage on the days to emergence and silking, grain moisture, test weight and yield at harvest.

Treatment		Days to 50% Emergence		Days to 50% Silk		Percent Grain Moisture		Grain Test Weight (gms/0.5 litre)		Grain Yield (gms/ear)	
Hybrid	Tillage	1980	1981	1980	1981	1980	1981	1980	1981	1980	1981
Pioneer 3995		12.5	19.4	71.1 d[1]	79.8 d	36.1	35.4 d	370.4	389.3 a	92.52 b	133.15 f
Pickseed 2111		12.3	18.5		81.5 c		37.5 bcd		389.9 ab		151.39 de
Asgrow RX22		13.1	21.4	78.3 c	84.8 ab	36.4	36.8 cd	355.7	384.4 a	114.91 a	162.87 bcd
Pride R102		12.5	18.9	78.9 bc	84.5 ab	35.6	37.6 bcd	355.2	387.0 a	84.86 b	158.73 cd
Pioneer 3992		12.4	19.1	80.4 ab	84.3 ab		39.4 abc		376.5 bc		144.71 ef
Pride R108			17.8		83.3 b		36.1 cd		374.9 bc		173.37 ab
Funks G4065		12.6	19.3	81.0 a	86.0 a		42.5 a		369.7 c		185.44 a
Pickseed 2322			17.5		84.9 ab		41.0 ab		392.8 a		167.39 bc
	Conventional Tillage	12.7	16.1*	76.7*	81.9*	34.4	36.9	364.0	387.3*	101.34	167.72*
	Zero Tillage	12.4	21.8	79.2	85.3	37.7	39.7	357.0	378.8	93.51	151.54
	L.S.D.	N.S.	1.8	1.8	1.1	N.S.	N.S.	N.S.	5.5	N.S.	8.06
Pioneer 3995	Conventional Tillage	12.5	12.0	69.8	78.3	33.8	33.4	380.6	394.2	100.55	136.74 e
	Zero Tillage	12.5	17.0	72.5	81.3	33.5	37.3	360.2	384.4	84.48	129.57 e
Pickseed 2111	Conventional Tillage	12.5	11.8		80.3		36.6		395.2		168.38 bc
	Zero Tillage	12.0	18.8		82.8		38.4		384.7		134.40 e
Asgrow RX22	Conventional Tillage	12.5	13.3	76.0	82.5	34.9	36.4	359.9	388.5	123.77	171.58 b
	Zero Tillage	13.8	16.5	80.5	87.0	38.0	37.1	351.6	380.2	106.05	154.15 c
Pride R102	Conventional Tillage	13.3	13.5	79.0	82.5	34.6	36.3	351.5	392.2	79.71	165.80 bcd
	Zero Tillage	11.8	16.8	78.8	86.5	36.0	38.8	359.0	381.7	90.01	151.65 d
Pioneer 3992	Conventional Tillage	13.5	12.0	79.0	82.0		39.5		379.9		155.20 cd
	Zero Tillage	11.3	16.3	81.8	86.5		39.2		373.1		134.21 e
Pride R108	Conventional Tillage		13.3		81.8		33.7		379.2		180.78 b
	Zero Tillage		14.5		84.8		38.6		370.7		166.00 bcd
Funks G4065	Conventional Tillage	12.0	13.3	79.5	84.8		40.3		372.9		197.85 a
	Zero Tillage	13.3	17.3	82.5	87.3		44.6		366.4		173.02 b
Pickseed 2322	Conventional Tillage		12.8		83.3		38.8		396.4		165.40 bcd
	Zero Tillage		16.3		86.5		43.2		389.3		169.39 bc

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

per hectare was not significant, while significant differences between hybrids were noted (Table 31). Pride R102, Pioneer 3992 and Pioneer 3995 exhibited the greatest plant populations per hectare while Pickseed 2111 had the lowest plant population of all hybrids examined (Table 31). Although not significant, the plant populations per hectare appeared to be greater under zero tillage than under conventional tillage in 1980[1]. Plant populations per hectare were lower under zero tillage than under conventional tillage in 1981, due to variable seed placement (Table 31).

Frost Damage. A light frost occurred on/or around June 2, 1980. Following the frost, plant counts were conducted in each treatment to determine the number of plants exhibiting visible frost injury; water soaked spots on the leaves, and/or necrosis. The results were extremly variable and no significant differences in frost damage were found between the hybrids, although some hybrids appeared to have sustained greater damage; Asgrow RX22 and Funks G4065 (Table 32). There was no significant interaction between the hybrids and tillage treatments for frost injury. Plants grown under zero tillage were found to have sustained a greater amount of frost damage (Table 32). Moody et al. (1963) reported similar findings, where plants grown under a mulch exhibited a greater incidence of frost injury. Mulches contain non-moving air which acts as an insulator, resulting in low heat conductivities,

1. In 1980, two replicates were discarded due to severe weed competition, poor emergence and vandalism (a vehicle having driven through the plots late in the season). In addition, due to the poor overall performance of Pickseed 2111, this hybrid was discarded part way through the growing season. As a result of these deletions, the error degrees of freedome was reduced, resulting in increased tabular F-values.

TABLE 31. The effect of hybrids and tillage on plant population, dry matter yield and grain yield per hectare.

Treatment		Plant Population per Hectare		Total Dry Matter Production (kgs/ha)		Grain Yield (kgs/ha)	
Hybrid	Tillage	1980	1981	1980	1981	1980	1981
Pioneer 3995		35,269	27,431 abc[1]	5,067	5,956 cd	3,126	3,684 cd
Pickseed 2111			19,320 d		4,817 d		3,037 d
Asgrow RX22		31,168	25,699 c	6,487	7,078 bc	3,498	4,237 bc
Pride R102		41,011	26,702 bc	6,834	7,491 ab	3,518	4,290 bc
Pioneer 3992		30,621	30,074 ab	5,096	8,314 ab		4,404 bc
Pride R108			30,712 a		8,886 a		5,382 a
Funks G4065		30,348	25,881 c	6,136	8,417 ab		4,869 ab
Pickseed 2322			26,520 bc		8,554 ab		4,425 bc
	Conventional Tillage	20,788	32,033*	3,985	9,222*	2,340	5,351*
	Zero Tillage	46,588	21,051	7,863	5,656	4,421	3,231
	L.S.D.	N.S.	3,439	N.S.	965	N.S.	622
Pioneer 3995	Conventional Tillage	26,247	35,724	4,059	8,026	3,034	4,885
	Zero Tillage	44,292	19,138	6,075	3,885	3,219	2,482
Pickseed 2111	Conventional Tillage		25,335		6,829		4,261
	Zero Tillage		13,305		2,804		1,813
Asgrow RX22	Conventional Tillage	18,045	30,803	4,085	8,763	4,119	5,283
	Zero Tillage	44,292	20,596	8,890	5,395	2,877	3,190
Pride R102	Conventional Tillage	29,528	32,626	4,974	9,615	3,407	5,419
	Zero Tillage	52,494	20,778	8,693	5,367	3,628	3,160
Pioneer 3992	Conventional Tillage	2,186	33,902	298	9,441		5,263
	Zero Tillage	52,493	26,246	9,895	7,187		3,546
Pride R108	Conventional Tillage		36,999		10,892		6,665
	Zero Tillage		24,424		6,881		4,099
Funks G4065	Conventional Tillage	27,887	28,980	6,509	9,826		5,742
	Zero Tillage	32,809	22,783	5,763	7,007		3,997
Pickseed 2322	Conventional Tillage		31,896		10,383		5,290
	Zero Tillage		21,143		6,726		3,561

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

which may limit the rate of release of stored soil heat (Blevins and Cook, 1970). In the case of the frost damage reported here, stored soil heat may not have been released at a sufficiently rapid rate to prevent frost injury, due to the presence of the previous crop residues that formed a mulch on the soil surface of the zero tillage plots.

TABLE 32. Effect of frost on corn seedlings in 1980.

Hybrids	Tillage	Percent Frost Damaged Plants[1]
Pioneer 3995		14.25
Asgrow RX22		37.13
Pride R102		11.63
Pioneer 3992		14.25
Funks G4065		33.88
	Conventional Tillage	6.83*
	Zero Tillage	35.13
	L.S.D.	28.58

* Significant at the 0.05 level.

1 Expressed as the percentage of sampled plants exhibiting visible symptoms of frost injury.

Plant Height. In 1980, the interaction between hybrids and tillage for plant height was significant for only one sampling date, July 16 (Table 33). On this date, Asgrow RX22 was the only hybrid to be significantly affected by zero tillage, under zero tillage the plant heights of Asgrow RX22 were found to be significantly shorter than the Asgrow RX22 grown under conventional tillage. The interaction between hybrids and tillage for plant height was not significant on any sampling date in 1981 (Table 34). In neither year was the final plant height affected by the tillage treatments, although the differences between hybrids were significant. In 1981, with the exception of the final

TABLE 33. The effect of hybrids and tillage on plant heights (cm), 1980.

Treatment		Sampling Date					
Hybrids	Tillage	June 11	June 26	July 16	July 23	July 30	August 8
Pioneer 3995		25.68 ab[1]	69.95	145.94 a	163.13	171.85	167.90 b
Asgrow RX22		23.77 b	61.96	120.35 b	163.76	193.58	191.68 a
Pride R102		26.45 a	67.18	119.93 b	165.89	188.70	192.23 a
Pioneer 3992		21.03 c	76.65	111.93 b	155.99	181.23	184.75 a
Funks G4065		23.84 b	85.23	123.05 b	156.28	189.43	190.68 a
	Conventional Tillage	23.91	84.70	128.81*	165.07	183.38	183.81
	Zero Tillage	24.20	59.69	119.59	156.95	186.53	187.08
	L.S.D.	N.S.	N.S.	8.47	N.S.	N.S.	N.S.
Pioneer 3995	Conventional Tillage	25.58	69.06	147.58 a	165.80	171.45	167.25
	Zero Tillage	25.79	70.83	144.30 a	160.45	172.25	168.55
Asgrow RX22	Conventional Tillage	23.66	74.77	132.18 b	168.88	193.10	192.85
	Zero Tillage	23.88	49.15	108.53 de	158.65	194.05	190.50
Pride R102	Conventional Tillage	26.43	80.43	119.03 cd	170.48	188.80	194.25
	Zero Tillage	24.68	53.93	120.43 c	161.30	188.60	190.20
Pioneer 3992	Conventional Tillage	21.35	97.38	117.00 cde	157.80	176.00	175.30
	Zero Tillage	20.70	55.91	106.85 e	154.18	186.45	194.20
Funks G4065	Conventional Tillage	24.05	101.86	128.25 bc	162.38	187.55	189.40
	Zero Tillage	23.64	68.61	117.85 cde	150.18	191.30	191.95

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

TABLE 34. The effect of hybrids and tillage on plant heights (cm), 1981.

Treatment		Sampling Date								
Hybrid	Tillage	June 8	June 16	June 22	July 2	July 10	July 20	July 27	August 11	August 25
Pioneer 3995		13.01	19.89	25.59	52.69	87.56	148.12	178.27	193.64 d[1]	193.50 d
Pickseed 2111		14.99	20.08	26.68	51.63	87.75	147.07	177.97	194.90 d	198.96 c
Asgrow RX22		13.16	18.89	24.36	47.29	80.70	144.41	185.51	228.70 ab	231.29 a
Pride R102		13.02	18.81	25.57	49.32	83.37	138.66	177.13	213.45 c	214.65 b
Pioneer 3992		12.64	18.28	24.43	49.22	82.79	141.64	176.36	219.03 bc	218.00 b
Pride R108		11.89	18.10	23.28	48.50	86.70	145.72	186.83	213.93 c	214.96 b
Funks G4065		12.59	20.05	28.13	52.05	87.85	148.58	179.98	225.21 ab	217.65 b
Pickseed 2322		14.23	20.31	26.84	47.36	88.17	146.72	184.55	235.46 a	232.44 a
	Conventional Tillage	15.97*	21.68*	29.09*	60.11*	97.56*	165.42*	198.62*	220.68*	221.45
	Zero Tillage	10.42	16.92	22.12	39.41	73.76	124.67	163.03	210.40	208.92
	L.S.D.	0.84	2.05	1.68	5.88	3.24	12.88	13.83	6.70	N.S.
Pioneer 3995	Conventional Tillage	16.14	23.53	30.51	66.52	102.72	170.20	190.77	199.08	201.13
	Zero Tillage	9.89	16.25	20.68	38.86	73.19	126.03	165.77	188.20	185.88
Pickeeed 2111	Conventional Tillage	16.69	22.28	30.24	60.51	94.17	161.54	188.18	198.23	205.30
	Zero Tillage	13.30	17.88	23.12	42.76	81.33	132.60	167.75	191.58	192.63
Asgrow RX22	Conventional Tillage	16.89	21.63	27.47	58.10	92.86	169.07	204.35	232.18	237.45
	Zero Tillage	9.43	16.15	21.24	36.48	68.53	119.75	166.68	225.23	225.13
Pride R102	Conventional Tillage	16.53	21.05	29.41	61.88	93.03	155.97	197.50	217.18	216.95
	Zero Tillage	9.51	16.58	21.73	36.77	73.71	121.35	156.77	209.73	212.35
Pioneer 3992	Conventional Tillage	15.35	20.85	27.05	61.05	98.08	165.89	201.44	226.20	227.23
	Zero Tillage	9.94	15.70	21.81	37.39	67.05	117.38	151.29	211.85	208.78
Pride R108	Conventional Tillage	13.00	18.68	25.82	55.62	99.44	169.72	205.02	224.00	231.00
	Zero Tillage	10.78	17.53	20.74	41.39	73.95	121.72	168.64	203.85	206.55
Funks G4065	Conventional Tillage	15.30	22.45	31.61	60.43	99.08	161.65	198.01	233.25	226.28
	Zero Tillage	9.88	17.65	24.65	43.68	76.63	135.50	161.95	217.18	209.03
Pickseed 2322	Conventional Tillage	17.84	23.00	30.66	56.79	101.11	169.37	203.67	235.30	233.88
	Zero Tillage	10.61	17.63	23.01	37.92	75.23	123.02	165.43	235.63	231.00

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

sampling date, the plant heights of corn grown under conventional tillage were significantly taller on all sampling dates than corn grown under zero tillage. Similar findings were observed in the 1981 tillage experiment. It should be noted here that the seedbed of the 1981 hybrid/ tillage experiment was prepared in the fall of 1980, thus the conventional tillage treatment is the equivalent of the conventional tillage-fall treatment of the 1981 tillage experiment.

Leaf Production. In 1981, leaf counts were conducted to establish the number of photosynthetic leaves per plant. Although the hybrid x tillage interaction was not significant for the number of leaves per plant, significant differences between hybrids and tillage treatments were noted. In general, those hybrids having the highest heat unit ratings produced the greatest number of leaves per plant (Table 35). Corn grown under conventional tillage produced significantly more leaves per plant than corn grown under zero tillage (Table 35).

Leaf counts were conducted late in the season, after the lower leaves had already begun to senesce and may have resulted in some inaccuracy as to the true number of leaves produced per plant. The data, nevertheless, suggests that tillage influenced the production of leaves, through modification of soil temperatures. A greater number of leaf primordia have been found to be initiated when corn was grown in warm soils (Cooper and Law, 1977).

TABLE 35. The effects of hybrids and tillage on the number of leaves per plant.

Treatment			Number of Photosynthetic Leaves per Plant
Hybrid	Corn Heat Unit Rating[1]	Tillage	
Pioneer 3995	2150		9.91 d
Pickseed 2111	2200		10.09 d
Asgrow RX22	2250		11.00 c
Pride R102	2350		10.29 d
Pioneer 3992	2400		12.16 a
Pride R108	2400		12.50 a
Funks G4065	2450		12.36 a
Pickseed 2322	2550		11.53 b
		Conventional Tillage	11.57*
		Zero Tillage	10.89
		L.S.D.	0.49

* Significant at the 0.05 level.
1 From: Field Crop Recommendations for Manitoba, 1980.

Silking. The interaction between hybrids and tillage for the number of days required for the corn to reach the 50% silk stage was not found to be significant in either 1980 or 1981, although differences between hybrids and tillage treatments were observed. In general, those hybrids with the higher heat unit ratings silked progressively later in both 1980 and 1981 (Table 30). In both years, the corn grown under zero tillage reached the 50% silk stage significantly later than the corn grown under the conventional tillage treatment. In 1980, silking was delayed by 2.5 days under zero tillage and 3.4 days in 1981, relative to the time required for the conventionally grown corn to reach the 50% silk stage.

Maturity. In 1980 and 1981, the interaction between hybrids and tillage for the precent grain moisture and the grain test weight was not significant (Table 30). Significant differences in the percent grain moisture at harvest were found between the hybrids in 1981, with the later maturing hybrids (higher heat unit ratings) generally having the greater percent grain moisture at harvest (Table 30). Although the percent grain moisture was not significantly different between corn grown under zero or conventional tillage, the corn produced under zero tillage tended to have a greater percent grain moisture. Similar findings were observed in the 1980 tillage experiment which indicated that the corn grown under zero tillage matured later than corn grown under conventional tillage.

Significant differences in grain test weights occurred between the hybrids and tillage treatments in 1981. Those hybrids having the lower heat unit ratings were generally found to have greater grain test weights (Table 30). The grain test weight was lower under the zero tillage treatment than under the conventional tillage treatment, which indicated that corn grown under zero tillage was relatively less mature at harvest than was corn grown under conventional tillage.

Plant Dry Matter. The interaction between hybrids and tillage for plant dry matter was not found to be significant in 1980 or in 1981. At harvest, in both 1980 and 1981, the differences in dry matter between hybrids was found to be significant (Table 36). In general, the later season hybrids, those having high heat unit ratings, produced the greatest amount of dry matter per plant.

Plant dry matter at 5 weeks after planting, in 1981, was greater under conventional tillage than under zero tillage (Table 36). The

TABLE 36. The effect of hybrids and tillage on plant dry matter at 5 weeks after planting and at harvest.

Treatment: Hybrid	Treatment: Tillage	Dry Matter per Plant at 5 Weeks[1], 1981	Stover Dry Matter at Harvest (Stover - Ears) (gms) 1980	Stover Dry Matter at Harvest (Stover - Ears) (gms) 1981	Total Plant Dry Matter at Harvest (Stover + Ears) (gms) 1980	Total Plant Dry Matter at Harvest (Stover + Ears) (gms) 1981
Pioneer 3995		0.34	41.49	80.60 d	149.18	213.75 c
Pickseed 2111		0.26		87.64 cd		239.03 c
Asgrow RX22		0.26	74.59	110.54 bc	213.96	275.71 b
Pride R102		0.26	62.24	116.94 b	167.33	273.40 b
Pioneer 3992		0.28		130.72 ab	141.44	275.42 b
Pride R108		0.22		115.52 b		288.88 b
Funks G4065		0.30		135.20 ab	166.67	320.66 a
Pickseed 2322		0.27		155.50 a		322.90 a
	Conventional Tillage	0.36*	64.08	121.12*	166.74	288.83*
	Zero Tillage	0.19	54.80	112.05	168.69	263.60
	L.S.D.	0.06	N.S.	3.16	N.S.	6.78
Pioneer 3995	Conventional Tillage	0.49	44.46	86.97	161.64	223.70
	Zero Tillage	0.19	38.52	74.23	136.73	203.80
Pickseed 2111	Conventional Tillage	0.31		101.34		269.72
	Zero Tillage	0.21		73.93		208.33
Asgrow RX22	Conventional Tillage	0.36	80.20	113.33	229.60	284.91
	Zero Tillage	0.17	68.98	107.75	198.32	261.90
Pride R102	Conventional Tillage	0.35	67.58	128.27	169.07	294.08
	Zero Tillage	0.18	56.90	105.62	165.59	257.34
Pioneer 3992	Conventional Tillage	0.34		123.48	115.33	278.68
	Zero Tillage	0.21		137.96	167.55	272.68
Pride R108	Conventional Tillage	0.27		115.52		296.30
	Zero Tillage	0.17		115.51		281.47
Funks G4065	Conventional Tillage	0.40		140.49	158.08	338.35
	Zero Tillage	0.21		129.95	175.08	302.97
Pickseed 2322	Conventional Tillage	0.37		159.55		324.95
	Zero Tillage	0.18		151.46		320.85

1 Weeks after planting.
* Significant at the 0.05 level.

increase in dry matter indicated that plants grown under conventional tillage were more vigorous during the early stages of growth. The dry matter at 5 weeks after planting was found to be significantly correlated with the number of days from 50% emergence to the time the plant samples were collected (r = 0.55), this suggested that earlier emergence allowed for a greater period of dry matter accumulation.

The stover dry matter (stover - ears) was greater under conventional tillage than under zero tillage in 1981, a similar trend occurred in 1980 although the difference was not significant (Table 36).

The total dry matter per plant (stover + ears) was significantly greater under conventional tillage than under zero tillage in 1981, but the difference was not significant in 1980 (Table 36).

Dry matter production on a per hectare basis was markedly different between 1980 and 1981 (Table 31). In 1980, the zero tillage plots yielded approximately 3,900 kg/ha more than the conventional tillage plots. The trend was reversed in 1981, the conventional tillage plots yielding 3,500 kg/ha more dry matter than the zero tillage plots. The difference in dry matter production per hectare between 1980 and 1981 reflects the differences in plant populations per hectare (Table 31). Low soil moisture in the spring of 1980, due to a combination of drought and excessive soil disturbance, resulted in reduced plant stands under the conventional tillage treatments. In 1981, the greatest plant population per hectare was obtained under conventional tillage.

Grain Yield. In 1980, while the interaction between hybrids and tillage for grain yield was not significant, the hybrids appeared to exhibit a differential yield response to tillage (Table 30). Pride R102 exhibited increased grain yields under zero tillage, while Pioneer 3995 and Asgrow RX22 showed decreased yields under zero tillage compared with conventional tillage. In 1981, the interaction between hybrids and tillage for grain yield was found to be significant (Table 30). Four of the eight hybrids examined showed significantly decreased yields under zero tillage; Pickseed 2111, Asgrow RX22, Pioneer 3992 and Funks G4065, the four remaining hybrids did not differ significantly in yield under zero or conventional tillage; Pioneer 3995, Pride R102, Pride R108 and Pickseed 2322. There was no apparent relationship between the yield response of the hybrids under the two tillage systems and the corn heat unit rating of each hybrid. In all cases, with the exception of Pickseed 2322, grain yields tended to be less under zero tillage than under conventiona tillage. No references to the differential yield response of hybrids to tillage were found in the literature. The reductions in soil temperature which occurred under zero tillage may have resulted in the differential yield response of the hybrids observed in 1980 and 1981. An interaction between hybrids and soil temperature has been reported to influence the yield of corn (Jones and Mederski, 1963).

CONCLUSIONS

From the results presented in this study, it is evident that the degree of tillage is an important factor in the production of field corn in Manitoba. Zero tillage has been shown to detrimentally affect the growth and development of corn. The detrimental effects of zero tillage on field corn production are manifested in; delayed emergence, silking and maturity, reduced plant populations and rates of plant growth and lower grain yields. The main factor in determining the effects of zero tillage on corn growth and development appears to be soil temperature. Lower soil temperatures under zero tillage are considered to have resulted in the observed delays in emergence, silking and maturity and the reductions in growth and yield. Moisture was found to be greater under zero tillage than under conventional spring tillage in both 1980 and 1981, but it did not compensate for the effects of reduced soil temperatures on plant growth, development and yield. The lower plant populations observed under zero tillage in the 1981 hybrid/tillage experiment resulted from inadequate seed placement and 'hairpinning'. The row crop planter used in 1980 and 1981 did not have sufficient weight to achieve proper seed placement and the frequent lack of straw cutting ability, of the cutting coulters, resulted in an unacceptible amount of 'hairpinning'.

The intermediate tillage treatment (rotovated strip tillage) did not exhibit any advantages in relation to zero or conventional tillage. The loose seedbed produced by rotovation is considered to have been, in part, responsible for the lack of success with this treatment. Under the rotovated strip tillage and also the zero tillage-straight coulter treatment, soil temperatures were found to be lower in the interrow spaces than in the seed rows, which indicated that minimal amounts of tillage are capable of promoting soil warming in the seed row.

Fall conventional tillage was found to exhibit a marked advantage over the zero tillage and spring tillage treatments. Fall tillage promoted earlier emergence and silking and the plants exhibited more vigorous growth. The beneficial attributes of fall tillage appear to be related to providing a suitable seedbed for planting and conservation of accumulated soil moisture. Soil temperature was not considered to be a factor in the success of the fall tillage treatment.

Secondary tillage (interrow cultivation) did not appear to have any affect on corn growth, development and yield.

The retention of the previous crop residues was an important factor in the production of corn under zero tillage. Removal of the straw cover from the soil surface of the zero tillage plots resulted in an increase in soil temperatures. Soil temperatures where the straw had been removed were equal to and in some cases greater than those recorded under the conventional tillage-spring treatment. Straw retention was found to also affect soil moisture, but only in the surface 2.5 cm. Earlier silking, maturity, increased plant heights, plant populations and grain yields were observed where the straw cover had been removed. The effects of removing the straw cover from the soil surface on crop performance was attributed to warmer soil temperatures recorded where the straw cover had been removed than where it had been retained prior to seedbed preparation and planting.

The eight hybrids examined responded similarly to zero tillage cropping during the growing season, although a differential yield response was observed among the hybrids. Four of the eight hybrids examined were not affected by zero tillage; Pioneer 3995, Pride R102, Pride R108 and Pickseed 2322, while the remaining four hybrids yielded significantly less under zero tillage; Pickseed 2111, Asgrow RX22, Pioneer 3992 and Funks G4065. In general, the later season hybrids (those having high heat unit ratings) under zero tillage exhibited greater yields than the early season hybrids (those having low heat unit ratings) under conventional tillage. It may be possible, therefor, to use a late season hybrid in areas where drought conditions or soil erosion is prevelent, under zero tillage rather than an early season hybrid under conventional tillage, as long as the average heat unit accumulation for the region will allow the use of a late season hybrid.

RECOMMENDATIONS FOR FURTHER STUDIES

- If further studies on row crops under zero tillage are to be undertaken, it is recommended that a commercial zero tillage row crop planter be obtained, as several problem areas were encountered with the modified conventional planter used in 1980 and 1981.
- Further studies using rotovated strips as an alternative to zero tillage are recommended. Areas which require further investigation include the effect of increasing the width of the tilled strip, on soil moisture and soil temperature and the timing of the rotovation operation.
- Insufficient attention was given to the interrow spaces of any tillage treatment examined. The interrow space under rotovated strip tillage accounted for over 85% of the total plot area. Further studies should be undertaken to ascertain the effect of the differences in soil temperature, and possibly soil moisture differences between the interrow space and the seed row on root growth and development in relation to the growth and yield of the corn crop.
- In further studies, the need for secondary tillage (interrow cultivation) should be examined not in context to seedbed preparation but with respect to weed control only.

LIST OF REFERENCES

Adams J.E. 1967. Effect of mulches and bed configuration. I. Early season soil temperatures and emergence of grain sorghum and corn. Agronomy Journal 59:595-599.

Adams J.E. 1970. Effect of mulches and bed configuration. II. Soil temperature and growth and yield responses of grain sorghum and corn. Agronomy Journal 62:785-790.

Alessi J. and Power J.F. 1971. Corn emergence in relation to soil temperature and depth of seeding. Agronomy Journal 63:717-719.

Allmaras R.R. and Nelson W.W. 1971. Corn root configurations as influenced by some row-interrow variats of tillage and straw mulch management. Soil Sci. Soc. Amer. Proc. 35:974-980.

Allmaras R.R. and Nelson W.W. 1973. Corn root configuration responses to soil temperature and matric suction. Agronomy Journal 65:725-730.

Allmaras R.R., Nelson W.W. and Hallauer E.A. 1972. Fall vs spring plowing and related soil heat balance in the western corn belt. University of Minnesota, Agricultural Experimental Station Technical Bulletin 283.

Arnon I. 1975. Mineral Nutrition of Maize. International Potash Inst., Bern, Switzerland.

Barber S.A. 1971. Effect of tillage practices on corn (Zea mays L.) root distribution and morphology. Agronomy Journal 63:724-726.

Barlow E.W.R., Boersma L. and Young J.L. 1977. Photosynthesis, transpiration and leaf elongation in corn seedlings at suboptimal soil temperatures. Agronomy Journal 69:95-100.

Baver L.D., Gardner W.H. and Gardner W.R. 1972. Soil Physics. 4th Ed. John Wiley and Sons, Inc., New York.

Beauchamp E.G. and Lathwell D.J. 1966. Effect of root-zone temperatures on corn leaf morphology. Canadian J. Plant Sci. 46:593-601.

Beauchamp E.G. and Lathwell D.J. 1967. Root zone temperature effects on the early development of maize. Plant and Soil 26:224-234.

Blevins R.L. and Cook D. 1970. No-tillage: its influence on soil moisture and soil temperature. Kentucky Agricultural Experimental Station Progress Report 187.

Blevins R.L., Cook D. and Phillips S.H. 1971. Influence of no till on soil moisture. Agronomy Journal 63:593-596.

Bolton E.F. and Aylesworth J.W. 1957. A comparison of some tillage methods for corn on a brookston clay soil. Canadian J. Plant Sci. 37:113-119.

Bond J.J. and Willis W.O. 1969. Soil water evaporation: Surface residue rate and placement effects. Soil Sci. Soc. Amer. Proc. 33:445-448.

Burrows W.C. and Larson W.E. 1962. Effect of amount of mulch on soil temperature and early growth of corn. Agronomy Journal 54:19-23.

Cal J.P. and Obendorf R.L. 1972. Differential growth of corn hybrids seeded at cold root zone temperatures. Crop Sci. 12:572-573.

Cannel R.Q. and Finney J.R. 1973. Effects of direct drilling and reduced cultivation on soil conditions for root growth. Outlook on Agriculture 7:184-189.

Carr M.K.V. 1977. The influence of temperature on the development and yield of maize in Britian. Annals of Applied Biology 87:261-266.

Cooper P.J.M. and Law R. 1977. Soil temperature and its association with maize yield variations in the highlands of Kenya. J. Agric. Sci. 89:355-363.

Cooper P.J.M. and Law R. 1978. Enhanced soil temperature during early growth and its association with maize development and yields in the highlands of Kenya. J. Agric. Sci. 89:569-577.

Cruse R.M., Linden D.R., Radke J.K., Larson W.E. and Larutz K. 1980. A model to predict tillage effects on soil temperature. Soil Sci. Soc. Amer. Proc. 44:

Dubetz S., Russel G.C. and Anderson D.T. 1962. Effect of soil temperature on seedling emergence. Canadian J. Plant Sci. 42:481-487.

Ellis F.B., Elliott J.G., Barns B.T. and Howse K.R. 1977. Comparison of direct drilling, reduced cultivation and ploughing on the growth of cereals. 2. Spring Barley on a sandy loam soil: soil physical conditions and root growth. J. Agric. Sci. 89:631-642.

Gallaher R.N. 1977. Soil moisture conservation and yield of crops no till planted in rye. Soil Sci. Soc. Amer. J. 41:145-147.

Gauer E.L. 1981. Soil temperature and moisture of conventional and zero tilled soils in Manitoba. M.Sc. Thesis, University of Manitoba, Winnipeg, Manitoba.

Grebb B.W. 1966. Effect of surface applied wheat straw on soil water losses by solar distillation. Soil Sci. Soc. Amer. Proc. 30:786-788.

Griffith P.R., Mannering J.V., Galloway H.M., Parsons S.D. and Richey C. B. 1973. Effect of 8 tillage planting systems on soil temperature, percent stand, plant growth and yield of corn on five indiana soils. Agronomy Journal 65:321-326.

Grobbelaar W.P. 1963. Responses of young maize plants to root temperatures. Meded Landbouwhogesch Wageningen 63:1-71.

Harrold L.L., Triplett G.B. and Edwards W.M. 1970. No-till corn-characteristics of the system. Agric. Eng. 51:128-131.

Helgason S.B. 1982. Personal Communication.

Iremiren G.O. and Milbourn G.M. 1979. The influence of soil temperatures as controlled by mulching on growth and development of maize. Annals of Applied Biology 91:397-401.

Jones J.B. and Mederski H.J. 1963. Effect of soil temperature on corn plant development and yield: II. Studies with six inbred lines. Soil Sci. Soc. Amer. Proc. 27:189-192.

Jones J.N., Moody J.E., Shear G.M., Moschler W.W. and Lillard J.H. 1968. The no tillage system for corn (Zea mays L.). Agronomy Journal 60:17-20.

Jones J.N. 1969. Effects of tillage, no tillage and mulch on soil water and plant growth. Agronomy Journal 61:719-721.

Ketcheson J.W. 1968. Effect of controlled air and soil temperature and starter fertilizer on growth and nutrient composition of corn. Soil Sci. Soc. Amer. Proc. 32:531-534.

Ketcheson J.W. 1970. Effects of heating and insulating soil on corn growth. Canadian J. Soil Sci. 50:379-384.

Kleinendorst A. and Brouwer R. 1970. The effect of temperature of the root medium and of the growing point of the shoot on the growth, water content and sugar content of maize leaves. Neth. J. Agric. Sci. 18:140-148.

Lal R. 1974. No-till effects on soil properties. Plant and Soil 40: 321-331.

Larson W.E., Burrows W.C. and Willis W.O. 1960. Soil temperature, soil moisture and corn growth as influenced by mulches of crop residues. 7th International Congress of Soil Science. Madison, Wisconsin. Pages 629-637.

Larson W.E., Triplett G.B., Van Doren D.M. and Music G.J. 1970. Problems with no till crops: Will it work everywhere? Crops and Soils Magazine.

MacLean A.J. and Donovan L.S. 1973. Effects of soil temperature on early growth of six single-cross corn hybrids. Canadian J. Soil Sci. 53:128-129.

MacMillan K.A. and Millet J.F.G. 1971. Influences of mulch on soil temperature and corn yields. Canadian J. Soil Sci. 51:305-307.

McAdam J.H. and Hayes P. 1978. The effect of temperature on the germination of seven cultivars of Zea mays L. Record of Agricultural Research pp 55-61.

McCalla T.M. and Duley F.L. 1946. Effect of crop residues on soil temperature. J. Amer. Soc. Agronomy 38:75-89.

McCormick S.J. and Mackay A. 1973. An evaluation of the requirements of direct seeded maize in Waikato. Proceedings of the Agronomy Society of New Zealand 3:39-45.

Mederski J.H. and Jones J.B. 1963. Effect of soil temperature on corn plant development and yield. I. Studies with a corn hybrid. Soil Sci. Soc. Amer. Proc. 27:186-189.

Michalyna W. and Smith R.E. 1972. Soils of the Portage la Prairie Area. Report No. 17. Manitoba Soil Survey.

Mock J.J. and Erbach D.C. 1977. Influences of conservation tillage enviroments on growth and conservation productivity of corn. Agronomy Journal 69:337-340.

Moody J.E., Shear G.M. and Jones J.N. 1961. Growing corn without tillage. Proc Soil Sci. Soc. Amer. 25:516-517.

Moody J.E., Jones J.N. and Lillard J.H. 1963. Influence of straw mulch on soil moisture, soil temperature and the growth of corn. Soil Sci. Soc. Amer. Proc. 27:700-703.

Mosher P.N. and Miller M.H. 1972. Influence of soil temperature on geotrophic response of corn roots. Agronomy Journal 64:459-462.

Olson T.C. and Schoeberl L.S. 1970. Corn yields, soil temperature and water use with four tillage methods in the western corn belt. Agronomy Journal 62:229-232.

Onderdonk J.J. and Ketcheson J.W. 1973a. Effect of stover mulch on soil temperature, corn root weight and phosphorus fertilizer uptake. Soil Sci. Soc. Amer. Proc. 37:904-906.

Onderdonk J.J. and Ketcheson J.W. 1973b. Effect of soil temperature on direction of corn root growth. Plant and Soil 39:177-186.

Phillips R.H. and Cochrane J. 1975. The production of forage maize and the effect of bitumen mulch on soil temperature. Agricultural Meteorology 14:399-404.

Porter G.A. and Moraghan J.T. 1975. Differential responses of two corn inbreds to varying root temperature. Agronomy Journal 67:515-518.

Russel J.C. 1939. The effect of surface coverage on soil moisture losses by evaporation. Soil Sci. Soc. Amer. Proc. pp 65-70.

Rykbost K.A., Boersma L., Mack H.J. and Schmisseur W.E. 1975. Yield responses to soil warming: Agronomic crops. Agronomy Journal 67:733-738.

Shear G.M. 1968. The development of the no-till concept in the U.S. Outlook on Agriculture 5:247-251.

Shear G.M. and Moschler W.W. 1969. Continuous corn by the no-till and conventional tillage method: A 6-year comparison. Agronomy Journal 61:524-526.

Sprague G.F. (ed) 1977. Corn and Corn Improvement. American Society of Agronomy Inc., Publisher, Madison, Wisconsin.

Stanholtz V.O. and Lillard J.H. 1969. Tillage system effects on water use efficiency. Journal of Soil and Water Conservation 24:186-189.

Triplett G.B., Van Doren D.M. and Schmidt B.L. 1968. Effect of corn stover mulch on no-tillage corn yield and water infiltration. Agronomy Journal 60:236-239.

Van Wijk W.R., Larson W.E. and Burrows W.C. 1959. Soil temperature and early growth of corn from mulched and unmulched soil. Soil Sci. Soc. Amer. Proc. 23:428-434.

Walker J.M. 1969. One degree increments in soil temperature affect maize seedling behaviour. Soil Sci. Soc. Amer. Proc. 33:729-736.

Watts W.R. 1972a. Leaf extension in Zea mays. I. Leaf extension and water potential in relation to root-zone and air temperatures. J. Expt. Bot. 23:704-712.

Watts W.R. 1972b. Leaf extension in Zea mays. II. Leaf extension in response to the temperature of the apical meristem, of the air around the leaves, of the root zone. J. Expt. Bot. 23:713-721.

Willey R.W. 1982. Plant population and crop yield, From: The Handbook of Agricultural Productivity. Vol. I. Miloslav R. (ed). CRC Press Inc., Baco Raton, Florida.

Willis W.O. 1962. Effect of partial surface covers on evaporation from soil. Soil Sci. Soc. Amer. Proc. 26:598-601.

Willis W.O., Larson W.E. and Kirkham D. 1957. Corn growth as affected by soil temperature and mulch. Agronomy Journal 49:323-328.

APPENDIX TABLE 1. Atmospheric temperatures and precipitation recorded at the Portage la Prairie field station, 1980.

	May			June			July			August			September			October		
	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm
Date	Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.	
1	28.5	5.4		14.7	5.6		22.2	9.2		25.6	14.7		20.0	8.3		17.8	5.6	1.4
2	30.0	7.6		18.3	1.1		29.4	13.9		23.3	10.8		21.4	13.3		6.1	2.2	1.9
3	31.1	9.8		24.4	5.6		27.5	15.0		24.2	9.2		22.8	11.7		11.1	3.9	
4	22.6	7.6		26.7	15.6		18.6	14.7	4.8	18.9	13.3	37.6	28.9	7.8	8.4	11.7	-0.6	
5	20.1	3.6		26.1	13.9	0.8	25.6	88.9		20.6	13.6		23.3	10.3		18.9	3.6	
6	7.8	-1.2		17.2	12.2		30.0	15.6		18.1	10.8		28.8	7.8		21.7	3.6	
7	10.2	-1.0		17.2	5.6		30.6	9.4	2.3	21.9	11.9	10.7	35.8	8.9		25.6	7.8	
8	13.6	-4.5		24.2	8.9		28.3	11.9		19.7	11.9	4.6	26.7	11.9	13.2			
9	18.2	3.4		25.6	10.0		32.8	14.2		19.7	8.9		19.2	6.7				
10	9.1	0.0		27.2	7.5		30.6	15.6		14.7	11.7		26.7	12.2				
11	10.6	2.1		33.1	15.0		29.7	16.7	1.9	21.1	10.0	0.7	21.1	8.3				
12	9.2	3.1		24.4	18.6	0.5	30.0	17.3		23.3	13.9	1.5	12.2	9.4	1.0			
13	11.5	-0.8		22.8	10.8	0.5	34.6	16.3		20.3	12.5	3.1	18.1	7.2	14.2			
14	15.2	2.4		16.4	10.3	0.5	15.0	14.2	6.7	22.2	11.4		19.2	4.2				
15	21.8	-1.0		20.0	4.2		23.6	13.6		25.0	8.1		17.2	5.6				
16	21.9	3.1		27.2	6.7		24.2	14.4	4.3	17.5	11.4		10.0	3.6				
17	27.0	10.5		20.6	11.7		26.4	13.6		17.5	11.4		4.2	1.9	1.4			
18	24.8	10.5		19.4	8.3		25.5	14.7		25.3	9.4	26.9	9.7	-1.1	1.1			
19	20.5	13.0		23.1	5.8		21.9	13.3		28.6	14.4		6.4	2.5	6.4			
20	31.7	9.4		27.5	12.2		16.9	13.6		20.0	15.8		9.7	3.6				
21	32.5	17.2		28.3	11.7		31.7	13.3	0.8	20.8	13.9	88.9	12.5	7.8				
22	37.2	22.8		33.9	15.8		27.5	10.3		20.8	10.3		10.6	1.7	10.2			
23	34.4	20.6		33.9	16.1	0.1	30.2	17.5		22.5	12.2		8.3	1.1				
24	33.3	13.9		30.6	20.0		25.8	14.7		28.6	10.3		8.1	4.4				
25	32.5	16.1		22.7	11.4		22.2	7.5		18.1	10.8		8.3	0.8	1.4			
26	31.7	16.9		18.6	9.7		26.9	10.6		18.6	7.2	0.4	15.0	1.7				
27	32.2	15.6		16.7	11.1		26.4	12.8		21.1	4.2		14.2	-0.8				
28	29.8	18.1		15.5	11.7		27.2	12.2		20.3	10.3		24.4	5.3				
29	25.8	13.9		22.8	10.8		32.8	14.2		19.2	11.7	0.6	17.2	8.3	0.1			
30	20.0	8.1		26.4	12.5	37.3	28.9	13.6		20.6	10.3		25.8	7.7				
31	21.3	4.5					29.4	15.8		21.1	9.2							
	23.1	8.1		23.5	10.7	39.7	26.9	13.2	20.8	21.2	11.1	175.0	17.3	5.9	57.5	16.1	3.7	3.3

APPENDIX TABLE 2. Atmospheric temperatures and precipitation recorded at the Portage la Prairie field station, 1981

Date	May			June			July			August			September			October		
	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm	Temp. °C		Rain mm
	Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.	
1	15.7	-2.4		21.0	11.0		28.5	17.8		23.2	11.6		19.0	6.1		9.7	2.2	
2	19.2	8.9		23.4	5.7		25.3	17.2		24.4	14.0		23.9	10.8		12.0	4.1	
3	11.8	3.6		27.2	6.8	12.4	28.0	15.0		23.0	14.2	6.6	15.3	7.7		8.5	4.8	25.9
4	1.2	0.1		19.8	14.0		31.0	15.9		33.5	14.6	0.1	20.0	3.2		9.0	6.9	
5	13.7	-3.8		24.0	12.3		29.8	17.0		21.0	17.7	55.9	23.2	13.2		10.0	2.9	0.5
6	18.4	-2.2		23.2	11.9		38.0	15.0		24.5	17.6		18.8	14.7		12.9	0.5	
7	20.6	3.0		22.4	13.9		33.6	23.0		28.1	16.0		21.9	10.1		12.1	3.5	
8	15.1	-1.2		18.9	10.0	4.6	25.0	17.7		21.4	16.6		27.0	17.0				
9	8.7	-4.2		19.0	9.0	3.8	28.9	13.7		22.9	11.3	1.3	26.0	14.1				
10	12.1	-0.5		18.7	8.0		27.7	13.0		28.1	13.9		31.4	10.4				
11	17.2	4.1		20.7	9.5		25.2	14.6		31.4	17.0		24.8	12.5				
12	20.3	0.3		19.7	8.0		28.3	16.3	3.6	24.9	14.3		23.8	14.0				
13	21.8	-0.8		20.0	13.6		30.6	15.0		32.1	14.8		21.1	8.2				
14	22.9	1.8		16.0	12.8	19.7	22.9	17.0	0.1	22.8	12.0		18.3	7.4				
15	15.0	6.0		12.8	9.3	8.1	23.2	17.1	19.3	21.0	10.0		14.2	5.4				
16	18.0	3.0		24.1	7.0		21.2	14.8		23.0	6.8		20.1	7.1				
17	22.0	4.0		20.0	11.4	8.4	23.8	14.0		29.6	13.0		18.8	4.1				
18	25.0	3.0		16.7	9.4		26.0	14.8		28.8	13.6		23.1	10.9	1.3			
19	27.0	2.5		20.2	8.7	0.6	27.2	16.0		28.7	14.9		19.1	6.0				
20	29.5	9.0		21.8	9.5		20.5	15.8		26.3	14.1		18.9	2.8				
21	30.4	10.6		19.3	8.8		22.8	8.8		25.6	16.9		16.1	9.1				
22	19.2	14.2		19.5	12.0		22.4	10.1		26.0	14.4		14.0	7.1				
23	7.3	5.3		20.0	9.5	4.4	27.8	14.0		24.3	18.4	14.2	12.0	5.5				
24	8.9	6.8	28.7	23.0	11.0		19.2	13.4		26.9	17.9		22.2	1.7				
25	14.2	8.2		23.5	12.5	1.7	20.0	8.7		25.8	16.7		17.6	3.4				
26	21.0	12.0		26.4	10.0		23.3	6.0		26.5	17.0		14.9	3.1				
27	20.0	9.0		27.4	15.6		26.8	10.1		26.1	12.4		8.3	0.6	29.0			
28	24.0	11.9	8.1	22.1	13.5	9.4	26.0	13.7		25.9	12.0		1.3	-0.7	4.8			
29	15.2	7.0		25.0	11.8		25.1	15.3	0.9	28.4	12.9		10.4	0.2	0.5			
30	18.8	2.5		25.0	14.7	15.7	27.2	16.7	25.6	29.7	13.3	4.6	6.8	3.5	7.9			
31	22.0	11.0					22.4	15.0		19.0	6.1							
	17.9	4.3	36.8	21.4	10.4	88.8	26.1	14.6	49.5	25.9	14.1	82.7	18.4	7.3	43.5	10.6	3.6	25.9

APPENDIX TABLE 3. Supplimentary nutrients.

Year	Nitrogen (kgs/ha)	Phosphorous (kgs/ha)	Potassium (kgs/ha)
1980	40	50	40
1981	96	34	0

APPENDIX TABLE 4. Weed and Insect control practices for the 1980 tillage experiment.

Date	Treatment	Application Method	Rate	Comments
May 9	Eradicane	Preplant Incorporate	5.0 kg/ha	Conventional Plots Only
May 15	Banvel + 2,4-D	Post Emergence	350 ml/ha + 425 g/ha	
June 5	Roundup	Directed Post Emergence	1.12 kg/ha	
June 9	Atrex-plus	Post Emergence	2.8 kg/ha	
June 10	Dowco 290	Post Emergence	0.4 kg/ha	

APPENDIX TABLE 5. Weed and insect control practices for the 1981 tillage experiment.

Date	Treatment	Application Method	Rate	Comments
Sept. 11	2,4-D + Dowco 290	Fall Preplant	0.45 kg/ha + 0.3 kg/ha	
Sept. 29	Roundup + 2,4-D	Fall Preplant	1.12 kg/ha + 0.4 kg/ha	
May 5	Eradicane	Preplant Incorporate	5.0 kg/ha	Conventional Plots Only
May 27	Decise	Post Emergence	20.0 g/ha	
June 9	Atrex-plus	Post Emergence	2.8 kg/ha	

APPENDIX TABLE 6. Weed and insect control practices for the 1980 hybrid/tillage experiment.

Date	Treatment	Application Method	Rate	Comments
May 9	Eradicane	Preplant Incorporate	5.0 kg/ha	Conventional Plots
May 15	Banvel + 2,4-D	Pre Emergence	350 ml/ha + 425 g/ha	
June 5	Roundup	Directed Post Emergence	1.12 kg/ha	
June 9	Atrex-plus	Post Emergence	2.8 kg/ha	
June 10	Dowco 290	Post Emergence	0.4 kg/ha	
June 11	Interrow Cultivation			Conventional Plots

APPENDIX TABLE 7. Weed and insect control practices for the 1981 hybrid/tillage experiment.

Date	Treatment	Application Method	Rate	Comments
May 5	Eradicane	Preplant Incorporate	5.0 kg/ha	Conventional Plots
May 13	Roundup	Pre Emergence	3.4 kg/ha	
May 27	Atrex-plus	Post Emergence	2.8 kg/ha	
May 27	Decise	Post Emergence	20.0 g/ha	
June 10	Interrow Cultivation			Conventional Plots
July 14	Paraquate	Directed Post Emergence	2.25 l/ha	Zero Tillage Plots

APPENDIX TABLE 8. Soil bulk densities (gms/cc) at 2.5 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		0.860	0.868	0.837	0.881	0.883	0.858	0.827	0.874	0.843	0.859
Zero Tillage-Fluted Coulter		0.736	0.893	0.889	0.948	0.937	0.862	0.769	0.898	0.863	0.878
Zero Tillage-Straight Coulter		0.749	0.981	0.863	0.950	0.910	0.920	0.790	0.901	0.888	0.866
	Retained	0.753	0.823*	0.861	0.937	0.907	0.854	0.795	0.874	0.865	0.852
	Removed	0.810	0.972	0.866	0.915	0.913	0.906	0.796	0.908	0.864	0.883
	L.S.D.	0.305	0.108	0.092	0.058	0.033	0.122	0.150	0.090	0.043	0.039
Conventional Tillage-Spring	Retained	0.798	0.758	0.812	0.844	0.869	0.816	0.824	0.864	0.823	0.823
	Removed	0.922	0.978	0.863	0.919	0.897	0.900	0.829	0.883	0.864	0.895
Zero Tillage-Fluted Coulter	Retained	0.613	0.872	0.870	0.998	0.861	0.892	0.840	0.898	0.892	0.860
	Removed	0.884	0.990	0.856	0.902	0.958	0.949	0.741	0.905	0.884	0.897
Zero Tillage-Straight Coulter	Retained	0.848	0.834	0.901	0.971	0.991	0.855	0.721	0.860	0.882	0.874
	Removed	0.624	0.948	0.878	0.925	0.884	0.869	0.817	0.936	0.844	0.858

* Significant at the 0.05 level.

APPENDIX TABLE 9. Soil bulk densities (gms/cc) at 5.0 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		0.918	0.866	0.865	0.927 b	0.872	0.857	0.874	0.845	0.865	0.876 b[1]
Zero Tillage-Fluted Coulter		1.003	0.866	0.910	1.056 a	0.902	0.868	0.924	0.895	0.908	0.926 a
Zero Tillage-Straight Coulter		1.037	0.854	0.921	1.069 a	0.928	0.872	0.884	0.861	0.910	0.926 a
	Retained	0.960	0.752*	0.893	1.030	0.901	0.858	0.879	0.838	0.883	0.888
	Removed	1.012	0.970	0.904	1.004	0.899	0.873	0.910	0.896	0.906	0.931
	L.S.D.	0.245	0.070	0.104	0.093	0.147	0.035	0.096	0.078	0.121	0.054
Conventional Tillage-Spring	Retained	0.884	0.785	0.871	0.995	0.880	0.848	0.872	0.805	0.864	0.863
	Removed	0.951	0.945	0.859	0.898	0.863	0.866	0.877	0.885	0.865	0.890
Zero Tillage-Fluted Coulter	Retained	0.977	0.719	0.861	1.092	0.858	0.851	0.886	0.898	0.881	0.891
	Removed	1.030	1.013	0.957	1.020	0.946	0.886	0.963	0.893	0.936	0.960
Zero Tillage-Straight Coulter	Retained	1.018	0.754	0.947	1.044	0.968	0.876	0.877	0.813	0.903	0.911
	Removed	1.056	0.954	0.896	1.095	0.889	0.868	0.891	0.909	0.917	0.942

* Significant at the 0.05 level.
1 Values within columns followed by the same letter are not significantly different.

APPENDIX TABLE 10. Soil bulk densities (gms/cc) at 10.0 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		1.102	0.883	0.904	1.114	1.020	0.952	0.907	0.952	0.943	0.958
Zero Tillage-Fluted Coulter		1.045	0.990	0.966	1.136	0.996	0.958	0.972	0.926	0.948	0.993
Zero Tillage-Straight Coulter		1.128	0.949	0.956	1.112	0.998	0.947	0.965	0.941	0.902	0.989
	Retained	1.069	0.839*	0.935	1.119	0.981	0.934	0.915	0.936	0.892*	0.958*
	Removed	1.115	1.042	0.949	1.123	1.028	0.971	0.982	0.942	0.970	1.014
	L.S.D.	0.226	0.153	0.115	0.093	0.070	0.072	0.094	0.051	0.051	0.047
Conventional Tillage-Spring	Retained	1.071	0.767	0.873	1.135	1.025	0.958	0.872	1.007	0.920	0.959
	Removed	1.133	0.999	0.935	1.093	1.015	0.947	0.942	0.896	0.966	0.992
Zero Tillage-Fluted Coulter	Retained	1.061	0.861	0.976	1.154	0.935	0.928	0.929	0.887	0.917	0.961
	Removed	1.029	1.119	0.957	1.119	1.058	0.988	1.015	0.964	0.980	1.025
Zero Tillage-Straight Coulter	Retained	1.074	0.888	0.957	1.068	0.986	0.914	0.943	0.915	0.840	0.954
	Removed	1.183	1.009	0.955	1.156	1.010	0.979	0.988	0.967	0.964	1.023

* Significant at the 0.05 level.

APPENDIX TABLE 11. Soil bulk densities (gms/cc) at 20.0 cm under various tillage and straw management practices, 1980.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	June 23	July 2	July 9	July 15	August 1	August 15	August 29	September 4	
Conventional Tillage-Spring		1.176	0.993	1.024	1.110	0.982	0.988	1.018	0.963	0.975	1.029 a [1]
Zero Tillage-Fluted Coulter		1.176	1.037	1.009	1.122	0.982	0.957	0.944	0.993	0.984	1.023 a
Zero Tillage-Straight Coulter		1.130	0.966	0.996	1.103	0.966	0.957	0.987	0.921	0.953	0.998 b
	Retained	1.126	0.884*	1.026	1.108	0.946	0.960	0.971	0.941*	0.963	0.994
	Removed	1.195	1.113	0.993	1.116	1.007	0.975	0.995	0.977	0.978	1.039
	L.S.D.	0.169	0.031	0.116	0.104	0.073	0.140	0.047	0.023	0.122	0.122
Conventional Tillage-Spring	Retained	1.150	0.881	1.026	1.108	0.952	0.965	0.979	0.950	0.967	0.998
	Removed	1.202	1.105	1.021	1.112	1.012	1.012	1.057	0.976	0.983	1.053
Zero Tillage-Fluted Coulter	Retained	1.136	0.949	1.053	1.144	0.955	0.957	0.916	0.997	0.953	1.007
	Removed	1.216	1.124	0.965	1.101	1.009	0.956	0.973	0.989	1.015	1.039
Zero Tillage-Straight Coulter	Retained	1.093	0.822	1.000	1.071	0.931	0.958	1.020	0.876	0.970	0.971
	Removed	1.167	1.110	0.993	1.134	1.000	0.957	0.955	0.967	0.936	1.024

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

APPENDIX TABLE 12. Soil bulk densities (gms/cc) at 2.5 cm under various tillage and straw management practices, 1981.

Primary Tillage		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		0.879	0.912	0.870 b[1]	0.861	0.837	0.865	0.888	0.981 a	0.931 b	0.891 ab
Conventional Tillage-Spring		0.896	0.916	0.904 a	0.896	0.859	0.879	0.896	0.933 b	0.980 a	0.907 a
Rotovated Strip Tillage		0.874	0.893	0.838 b	0.856	0.819	0.889	0.914	0.936 b	0.926 b	0.883 b
Zero Tillage-Fluted Coulter		0.880	0.921	0.840 b	0.849	0.817	0.893	0.870	0.902 b	0.954 ab	0.881 b
Zero Tillage-Straight Coulter		0.861	0.887	0.849 b	0.864	0.844	0.898	0.901	0.915 b	0.952 ab	0.886 b
	Retained	0.844*	0.892	0.858	0.846	0.832	0.875	0.885	0.928	0.946	0.878*
	Removed	0.912	0.920	0.863	0.883	0.838	0.894	0.903	0.938	0.952	0.901
	L.S.D.	0.061	0.121	0.096	0.060	0.108	0.033	0.064	0.028	0.090	0.016
Conventional Tillage-Fall	Retained	0.863	0.905	0.851	0.839	0.869	0.855	0.870	0.968	0.914	0.882
	Removed	0.895	0.918	0.890	0.882	0.804	0.875	0.906	0.993	0.948	0.901
Conventional Tillage-Spring	Retained	0.854	0.911	0.922	0.911	0.853	0.880	0.879	0.952	0.997	0.907
	Removed	0.938	0.923	0.886	0.882	0.865	0.879	0.913	0.915	0.964	0.907
Rotovated Strip Tillage	Retained	0.850	0.873	0.854	0.806	0.817	0.871	0.883	0.921	0.925	0.867
	Removed	0.899	0.913	0.822	0.905	0.821	0.906	0.946	0.950	0.927	0.899
Zero Tillage-Fluted Coulter	Retained	0.834	0.900	0.834	0.801	0.790	0.876	0.861	0.897	0.948	0.860
	Removed	0.927	0.941	0.846	0.897	0.844	0.910	0.880	0.907	0.961	0.901
Zero Tillage-Straight Coulter	Retained	0.818	0 870	0.828	0.872	0.831	0.894	0.932	0.907	0.944	0.877
	Removed	0.903	0.904	0.870	0.856	0.857	0.902	0.870	0.924	0.960	0.894

* Significant at the 0.05 level.

1 Values within columns followed by the same letter are not significantly different.

APPENDIX TABLE 13. Soil bulk densities (gms/cc) at 5.0 cm under various tillage and straw management practices, 1981.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		0.931	0.945	0.894	0.865	0.853	0.926	0.941	1.007	0.998	0.929 a [1]
Conventional Tillage-spring		0.905	0.935	0.939	0.894	0.869	0.927	0.902	0.933	0.961	0.918 ab
Rotovated Strip Tillage		0.883	0.896	0.907	0.862	0.840	0.920	0.870	0.963	1.006	0.905 b
Zero Tillage-Fluted Coulter		0.917	0.930	0.900	0.846	0.857	0.921	0.893	0.999	1.023	0.921 ab
Zero Tillage-Straight Coulter		0.898	0.918	0.899	0.908	0.865	0.950	0.906	0.967	0.991	0.923 ab
	Retained	0.890	0.917	0.888	0.879	0.850	0.929	0.894	0.981	0.989	0.913
	Removed	0.924	0.932	0.927	0.870	0.864	0.929	0.912	0.967	1.003	0.925
	L.S.D.	0.093	0.141	0.058	0.044	0.030	0.056	0.071	0.098	0.055	0.028
Conventional Tillage-Fall	Retained	0.894	0.947	0.866	0.850 b	0.882	0.922	0.916	1.028	0.979	0.920
	Removed	0.968	0.943	0.922	0.881 ab	0.824	0.930	0.967	0.986	1.018	0.938
Conventional Tillage-Spring	Retained	0.867	0.938	0.946	0.908 ab	0.875	0.944	0.904	0.935	0.961	0.920
	Removed	0.944	0.931	0.931	0.880 ab	0.863	0.909	0.901	0.930	0.961	0.917
Rotovated Strip Tillage	Retained	0.891	0.916	0.871	0.861 ab	0.846	0.920	0.860	0.983	0.998	0.905
	Removed	0.875	0.876	0.943	0.863 ab	0.835	0.920	0.881	0.943	1.014	0.906
Zero Tillage-Fluted Coulter	Retained	0.915	0.917	0.886	0.826 b	0.834	0.931	0.879	0.999	1.021	0.912
	Removed	0.918	0.942	0.914	0.866 ab	0.881	0.910	0.908	1.001	1.024	0.929
Zero Tillage-Straight Coulter	Retained	0.881	0.870	0.873	0.953 a	0.813	0.926	0.912	0.960	0.986	0.908
	Removed	0.915	0.967	0.925	0.863 ab	0.918	0.975	0.901	0.975	0.995	0.937

1 Values within columns followed by the same letter are not significantly different.

APPENDIX TABLE 14. Soil bulk densities (gms/cc) at 10.0 cm under various tillage and straw management practices, 1981.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		0.973	1.049	0.948	1.013 a [1]	0.931	1.022	0.993	1.077	1.076	1.009 a
Conventional Tillage-Spring		0.955	0.991	0.963	0.966 b	0.964	1.012	0.915	1.028	1.030	0.981 b
Rotovated Strip Tillage		0.935	0.985	0.960	0.909 b	0.890	0.991	0.946	0.995	1.016	0.958 c
Zero Tillage-Fluted Coulter		0.994	1.038	0.923	0.937 b	0.904	0.987	0.948	1.046	1.051	0.983 b
Zero Tillage-Straight Coulter		0.970	1.023	0.913	0.955 ab	0.922	1.020	0.949	1.053	1.069	0.986 b
	Retained	0.926	1.014	0.915	0.971	0.912	0.996	0.943	1.042	1.058	0.975
	Removed	1.004	1.021	0.968	0.942	0.932	1.017	0.957	1.037	1.039	0.992
	L.S.D.	0.160	0.043	0.110	0.143	0.074	0.039	0.029	0.036	0.058	0.115
Conventional Tillage-Fall	Retained	0.960	1.052	0.915	1.040	0.965	0.999	0.934	1.066 ab	1.066	0.999
	Removed	0.986	1.046	0.980	0.987	0.898	1.046	1.052	1.088 a	1.085	1.019
Conventional Tillage-Spring	Retained	0.879	1.017	0.987	0.972	0.974	1.033	0.902	1.056 ab	1.040	0.984
	Removed	1.032	0.966	0.939	0.960	0.954	0.991	0.929	0.999 b	1.021	0.977
Rotovated Strip Tillage	Retained	0.898	0.973	0.934	0.918	0.859	0.996	0.977	0.994 b	1.024	0.952
	Removed	0.971	0.977	0.986	0.901	0.921	1.016	0.914	0.995 b	1.008	0.965
Zero Tillage-Fluted Coulter	Retained	0.971	0.986	0.890	0.955	0.884	0.964	0.917	1.014 ab	1.077	0.962
	Removed	1.018	1.089	0.955	0.919	0.924	1.009	0.980	1.079 ab	1.025	1.000
Zero Tillage-Straight Coulter	Retained	0.925	1.042	0.848	0.969	0.881	1.019	0.987	1.079 ab	1.084	0.982
	Removed	1.016	1.004	0.978	0.941	0.963	1.021	0.910	1.025 ab	1.055	0.990

1 Values within columns followed by the same letter are not significantly different.

APPENDIX TABLE 15. Soil bulk densities (gms/cc) at 20.0 cm under various tillage and straw management practices, 1981.

Treatment		Sampling Date									Seasonal Mean
Primary Tillage	Straw Cover	May 13	May 19	May 26	June 2	June 9	June 23	July 7	July 28	August 10	
Conventional Tillage-Fall		0.922	1.003	0.999	0.996	0.950	1.050 ab[1]	1.020	1.070	1.110	1.021 a
Conventional Tillage-Spring		1.049	0.978	0.977	1.038	0.927	1.015 bc	0.990	1.037	1.082	1.010 ab
Rotovated Strip Tillage		0.975	1.017	0.964	0.951	0.932	1.001 c	0.959	1.062	1.067	0.992 b
Zero Tillage-Fluted Coulter		1.010	1.024	0.989	1.004	0.939	1.060 a	1.035	1.075	1.073	1.023 a
Zero Tillage-Straight Coulter		0.991	1.017	0.964	0.983	0.969	1.033 abc	0.977	1.085	1.084	1.012 ab
	Retained	0.983	1.002	0.954	0.986	0.939	1.029	0.975	1.056	1.079	1.001*
	Removed	1.024	1.013	1.003	1.002	0.948	1.035	1.017	1.075	1.087	1.023
	L.S.D.	0.112	0.051	0.068	0.064	0.042	0.082	0.054	0.081	0.037	0.019
Conventional Tillage-Fall	Retained	1.000	0.982	0.974	0.967	0.949	1.028	0.964	1.072	1.113	1.005
	Removed	0.983	1.024	1.056	1.024	0.951	1.073	1.076	1.068	1.107	1.040
Conventional Tillage-Spring	Retained	1.034	1.029	0.985	1.056	0.942	1.025	0.968	1.025	1.083	1.016
	Removed	1.063	0.928	0.970	1.020	0.911	1.004	1.012	1.050	1.081	1.004
Rotovated Strip Tillage	Retained	0.952	1.016	0.934	0.959	0.945	1.034	0.941	1.032	1.048	0.985
	Removed	0.999	1.019	0.994	0.944	0.919	0.969	0.978	1.091	1.086	0.999
Zero Tillage-Fluted Coulter	Retained	0.968	1.011	0.974	0.999	0.945	1.013	1.042	1.060	1.054	1.007
	Removed	1.053	1.037	1.004	1.009	0.993	1.053	1.029	1.091	1.092	1.040
Zero Tillage-Straight Coulter	Retained	0.961	0.974	0.935	0.951	0.913	1.046	0.962	1.094	1.096	0.992
	Removed	1.022	1.059	0.993	1.015	0.962	1.074	0.992	1.077	1.072	1.030

* Significant at the 0.05 level.

1 Values within columns followed by same letter are not significantly different.