THE EFFECT OF PLANTING DATES AND TILLAGE SYSTEMS UPON SOIL TEMPERATURES

BY

ISMETH FIRDAUS

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University of Sriwijaya
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Thesis Approved:

Eugene G. Krenzer, Jr.
Thesis Adviser

Robert L. Westerman

Kevin J. Donnelly

Norman N. Durham
Dean of Graduate College

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CHAPTER I

INTRODUCTION

American farmers, blessed with great natural resources, high technology, and ambition, are the envy of the world in terms of agricultural efficiency and productivity. Yet today the time-honored tillage practices employed on American farms are being questioned, evaluated, and changed. The overwhelming trend is toward less and less tillage. The ultimate step in this direction is the elimination of tillage completely, or no-tillage farming (Rice, 1983).

The interest in and adoption of no-tillge systems of crop production is growing rapidly in the U.S (Conservation Tillage Information Center, 1983). The use of no-tillage systems has demonstrated some advantages over conventional methods. Soil erosion can be minimized due to residue cover left on the soil surface under a no-tillage system. Residue cover also enhances water conservation by reducing evaporation and by increasing water infiltration at the soil surface. Energy spent on tillage operations can also be reduced, which saves the farmer time and tillage operation costs.

The use of no-tillage system, however, can create some obstacles to more rapid adoption. The residue cover left on the soil surface may act as a host of insect, rodents, and disease. The technology of selection, and application of herbicides to compensate for the use of a plowing for weed control in the past, are now highly demanded as well. In addition, residue cover may also decrease soil temperature by reducing solar radiation reaching the soil surface. Lower soil temperature may affect planting times in many areas. In northern latitudes, planting is delayed until the soil temperature at a given depth in soil profile has reached a predetermined level for several consecutive days. In southern latitudes, little or no delay normally occurs. Nonetheless, some concern has been expressed regarding lower soil temperature when a no-tillage system is used.

In Oklahoma, farmers have two diverse philosophies about when to plant wheat (Triticum aestivum L). One trend is to consider forage as a ultimate goal, so earlier planting time is preferable to the one recommended for grain production. Another direction is to optimize grain production.

Historically, according to Krenzer et al. (1986), no-tillage for wheat production in Oklahoma had been associated with reduced yields. One reason given is that the soil temperature under no-tillage is usually cooler than soil temperature under conventional tillage systems.

The degree to which various tillage systems alter soil physical properties, such as bulk density, mechanical impedance, water content, and soil temperature etc., is poorly understood, and at resent, cannot be adequately predicted. This is due to the fact that, in general, each tillage operation produces non-uniform changes in soil physical properties (Cassel, 1982). Moreover, present day theory can only provide a semiquantitative interpretation of the above phenomena (Hillel, 1980). Despite these difficulties, a quantitative assessment of the impact of tillage on the thermal properties of soil is both feasible and practical by observing soil temperature.

Although preliminary data on soil temperatures under no-tillage and conventional tillage systems for wheat production in Oklahoma have been collected, more detailed studies are needed. Futhermore, the influence of planting times on soil temperatures under such tillage systems has not been investigated. For these reasons the effects of conventional tillage (plow, disk, and v-blade) and no-tillage systems, along with the amount of residue cover left on the soil surface, were quantified by measuring soil temperatures using copper-constantan thermocouples. Another meaningful way to summarize soil temperature data is the use of growing degree day (GDD) models. The magnitude of soil temperatures and GDD under different tillage systems was examined by combining tillage systems with planting dates.

These studies were designed to: (1) determine the magnitude of soil temperature differences under no-tillage and conventional tillage systems, (2) determine the influence of planting dates upon soil temperatures under no-tillage and conventional tillage systems.

CHAPTER II

LITERATURE REVIEW

Any manipulation that changes soil condition may be considered tillage. This includes tillage for such purposes as weed control and incorporation of soil amendments (Schafer et al, 1982). The art of tillage began when man first domesticated and cultivated plants. Tillage tools have evolved from rudimentary ones operated by humans to more sophisticated ones powered by animals and eventually by machines.

Modern technology has given farmers many tillage systems to choose from. These range from what is termed conventional tillage (plowing, disking, harrowing, etc.) to reduced tillage (in which one or more tillage operations are eliminated) to no-tillage (in which all tillage operations are left out).

Conventional tillage refers to a full or maximum tillage program, consisting of both primary tillage (moldboard plowing) and secondary tillage (disking, horrowing or cultivating). A typical conventional tillage program might consist of the following operations: molboard plowing, disking once or twice, horrowing or field cultivating once or twice, planting and fertilizing, cultivating or using a rotary hoe once or twice, spraying with herbicides.

Conservation tillage has been one of the most rapidly adopted agricultural practices of the past 15 years (CTIC, 1983). The primary impetus for conservation tillage has been decreased soil erosion; fuel, labor, and machinery costs; and increased soil water storage and yields (USDA, 1975). Conservation tillage may be broadly defined as tillage practices that reduce soil and water losses as compared with conventional tillage methods (Mannering and Fenster, 1983). The Soil Conservation Service strictly defines conservation tillage as any system with 30 percent or greater of ground cover remaining on the soil surface after planting. Conservation tillage systems include no-till, ridge till, strip till, mulch tillage, reduced tillage, and minimum tillage. No-tillage is the most extreme example of conservation tillage, with the only soil disturbance created by coulters positioned ahead of planter units, therefore leaving a very high percent of the previous crop residue on the soil surface.

Historically, no-tillage on wheat (Triticum aestivum L) production in Oklahoma had been associated with reduced yield (Krenzer et al., 1986). One reason given is the soil temperature under no-tillage is usually cooler than under conventional tillage systems (Jacks et al., 1955; Krenzer et al., 1986).

Soil temperature is a function of the net amount of heat that enters or leaves the soil and of the thermal properties of the soil (Hillel, 1980; Rosenberg et al, 1983). The amount of heat that enters or leaves the soil surface depends on radiation, and the partitioning of the solar radiation in the soil heat flux, among convective heat, conductive heat, and latent heat.

The modes of energy transfer at the soil surface may occur by any or all of these mechanisms such as radiation, convection, and latent heat. However, the primary process of heat transport within the soil is by molecular conduction. Radiation, convection, and latent heat are generally of secondary importance (Hillel, 1980; Rosenberg et al., 1983).

Hillel (1980) defines radiation as the emission of the energy in the form of electromagnetic waves from all bodies above -273 C. Since the temperature of the soil surface is generally of the order of 27 C (though it can range, of course, from below 0 C, the freezing point, to, even higher than 57 C), the radiation emmitted by the soil surface has its peak intensity at a wavelength of about 10 um and its wavelength distribution over the of 3-50 um. These are the wavelengths of the real infrared, or heat, radiation.

The second mode of energy transfer, called convection, involves the movement of heat-carrying mass. Convection is defined in the Glossary of Meteorology (Huschke, 1959) as "mass motion of fluid" (air, in this case) resulting in transport and mixing of the properties of the air. So convection involves the flow of heat between surface and air as "sensible" heat flux. Hillel (1980) defines soil heat flux as heat flow into or out of the soil.

According to Rosenberg et al. (1983), objects that absorb radiation or to which energy is supplied become warmer than their surroundings and in turn dispose of some of that energy by convection. Normally, during the daytime heat will be transferred from the warm soil or crop surface to the cooler air above. At night, when the air is warm and the surface is cool, the converse situation prevails and heat will be transferred to the surface. This phenomenon can be explained as follows. From sunrise on, a considerable amount of radiant energy is required for warming up the soil and crop, which at the time are cooler than the air above. Until these surfaces become warm relative to the air above, no net "sensible" heat flux to air occurs. "Sensible" heat flux is defined as heat flux that is transmitted from the surface to the air above (Hillel, 1980). More and more energy goes into warming the air as the surface become hotter. During the night, the temperature of the soil surface falls rapidly because of radiational cooling, so that the surface becomes cool.

Conduction, the third mode of energy transfer, is the propagation of heat within the body by internal molecular motion. Since temperature is an expression of kinetic energy of a body's molecules, the existence of a temperature difference within a body will normally cause the transfer of kinetic energy. This transfer occurs by the numerous collisions of rapidly moving molecules from the warmer region of the body with their neighbors in the colder region. Thus the process of heat conduction tends to equalize the kinetic energy of the body's molecules.

In addition to three modes of energy transfer described above, the fourth example which is the composite phenomenon, is latent heat transfer. A prime example is the process of distillation, which includes the heat-absorbing stage of evaporation, followed by the convective or diffusive movement of the vapor, and ending with the heat releasing stage of condensation (Hillel, 1980).

Surface temperature depends on the rate at which energy enters and leaves the soil surface. Van Duin (1956) studied the influence of tillage, plowing, rototilling etc., on the energy balance, as affected by changes in the surface reflectivity and in the upper layer's volumetric heat capacity and thermal conductivity. On the basis of theoretical calculations and field measurements, he concluded that the loosening of the top soil reduced the heat intake and heat loss of a soil, and caused more of the heat exchange to take place in the surface soil compared to the soil layer below. As a result during periods of increasing soil temperatures, soils are warmer near the surface when tilled, and cooler near the surface when left undisturbed. During periods of decreasing soil temperatures the reverse is the case. The order of magnitude of the changes, on an annual basis, is about 0.5 to 1.0 C.

The generalization of Van Duin (1956) was confirmed by Hay et al. (1978) who discovered that, in England, plowed soil received significantly more heat in the spring during the first 20 days after planting than direct drilled soil. Plowed soil accumulated more than twice the number of degree hours over 10 C at the 5 cm depth than did direct drilled soil.

The degree to which various tillage systems alter the physical properties of soil, such as bulk density, mechanical impedance, soil water content, and soil temperature etc., is poorly understood, and at present, cannot be adequately predicted. This is due to the fact, that, in general, each tillage operation produces non-uniform changes in soil physical properties (Cassel, 1982). Moreover, present day theory can only provide a semiquantitative interpretation of observed influences of soil surface condition, including the presence of mulching materials and various tillage treatments, on the thermal regime (Hillel, 1980). Despite these difficulties, a quantitative assessment of the impact of tillage on the thermal properties of soil is both feasible and practical with properly executed soil temperature monitoring.

Within a given geographical location soil temperatures vary, because the partitioning of the energy arriving at the surface depends on the thermal properties of the soil. The color, roughness, exposure, thermal conductivity, and water content of the soil layer in contact with the air above it all have an effect on the heat dynamics of the soil.

Tillage or loosening of the upper soil layer by mechanical means changes the thermal conductivity of this layer (Wierenga et al., 1982). Since the energy of the soil surface is partitioned and transformed into alternative fluxes, and since the soil surface is the most accessible part of the system and the most amenable to manipulation, the majority of the methods aimed at affecting soil heat are surface treatments. These include covering, or mulching, the surface, for example with straw, so as to warm or cool the soil and/or to reduce evaporation. Other methods are based on the mechanical manipulation of the soil's top layer, for example by tillage machinery (Hillel, 1980).

The amount and distribution of straw residue left on the surface will determine how much soil temperature is affected (Black, 1970; Van Doren and Allmaras, 1978; Gauer et al., 1982). Some tillage systems leave the mulch material in the bands between the rows, causing more local effect on soil temperature. For example Griffith et al. (1973) compared eight tillage-planting systems and found that systems that leave the most surface residue have the coolest afternoon soil temperature. The range from lowest to highest, at eight weeks after planting corn in summer, was about 3.5 C in northern Indiana, 2.6 C in southern Indiana, and 2.0 C in eastern Indiana.

Krenzer et al. (1986) reported temperature differences between moldboard plow and no-tillage plots at a 5 cm depth during two segments of time during the 1984 wheat growing season. The mean temperature between Aug.29 - Sep. 2 was 34 C in the moldboard plow area while under no-tillage plots it averaged 26 C.

Rosenberg et al. (1983) define mulch as "any soil cover that constitutes a barrier to the transfer of heat or vapor". For example, straw mulch which is created by combines blowing out small-grain straw over fields at harvest time used in this study. Other examples are manufactured mulch such as plastic, aluminum, and paper etc.

Soil temperature can be affected by the presence of mulch in several ways. The basic role of mulching is to constitute a barrier to the transfer of heat or vapor (Rosenberg et al., 1983). The presence of mulch reduces the quantity of direct solar radiation reaching the soil surface by reflecting more radiation back to the atmosphere than bare soil (a straw mulch usually has a higher albedo, the reflectance coefficient, than bare soil). Since mulched soil loses less water via evaporation than bare soil, the thermal conductivity is greater, thus conducting the heat away from the soil surface more rapidly, causing less warming of the surface. However, the heat capacity of wet soil is greater than for dry soil, requiring more heat to change the temperature of a unit volume of soil 1 C (Phillips and Phillips, 1984). Considerable research has been conducted regarding the effects of residues or mulches on soil temperatures. The magnitude of temperature changes resulting from tillage operations or mulching can vary substantially. For example, in Iowa the soil temperature at 10 cm below surface covered with 6250 kg per ha of grain straw mulch was reduced, on the average, by 0.1-1.5 C during May and June as compared with that of bare soil (Willis et al., 1957). Mulch (7500 kg per ha of grain straw) depressed the mean of the daily average 10 cm soil temperature under the residue covered surface as much as 2.2 C compared to bare soil in 23 location-years in the eastern United States (Almaras et al., 1964). With chopped corn stalks applied at 0 to 9 metric tons/ha, soil temperature in Iowa at a 10 cm depth during May and June was lowered an average of about 0.4 C/metric ton of mulch (Burrows and Larson, 1962).

Unger (1978) investigated the effects of various amount of wheat straw mulch on soil temperature. He applied the wheat straw to the soil surface at rates ranging between 0 to 12 metric tons/ha, and found that increased mulch rates decreased the average soil temperatures, maximums, minimums, and standard deviations during all fallow seasons. With 8 metric tons mulch/ha, Unger measured, a 5-day average soil temperature difference of 2.9 C, 1.4 C, 0.8 C, and 2.3 C at the 10 cm depth in summer, in fall, in winter, and in spring respectively, in southern Great Plains soil. As expected, maximum temperatures were affected more than mean temperatures.

Soil temperature data could be more meaningful if presented in terms of growing degree days (GDD) because GDD is a means of relating temperature to plant growth and development. The equation for GDD is as follows:

$$GDD = \sum_{i} (T_i max + T_i min) /2 - T\ base$$

Where $T_i max$ is the maximum daily temperature, $T_i min$ is the daily minimum temperature and T base is a minimum base temperature below which growth does not occur. The base soil temperature which should be used for wheat has been debated (Klepper et al., 1982). A fair amount of support has been developed for the use of 0 C on the basis that it is the temperature at which growth is halted for wheat (Friend, 1966; Gallagher, 1979; Kemp and Blacklow, 1982; Johnson and Kanemasu, 1983; Bauer et al., 1984). Baker et al. (1986) observed that base temperature estimates fluctuated between -1.5 to +0.8 C, yet these estimates were not significantly different from 0 C at the 5 % level of confidence. Temperature measurements in these studies are based on soil temperature. Hay and Wilson (1982) suggest that the best linear relation between leaf development and temperature is obtained by using soil temperature near the depth of the growing point.

In general, reduced tillage with residue causes colder soil temperature early in the spring. Because temperatures are lower in the spring with conservation tillage as compared with conventional tillage, planting may be delayed 6 to 7 days in northern latitudes of the USA when conservation tillage is used (Unger and Stewart, 1976). In southern latitudes, little or no delay normally occurs. Nonetheless, some concern has been expressed concerning lower soil temperatures when conservation tillage is used. Although lower temperatures may delay planting in spring, lower temperatures under surface residues in summer may beneficially influence late planted crops or crops growing during hot periods (Allen et al, 1975; Rockwood and Lal, 1974).

In Oklahoma, farmers have two diverse philosophies concerning the time of planting wheat. One trend is to consider forage as ultimate goal, so earlier planting time, late August or early September, is preferable to the one recommended for grain production to assure fall and winter forage prodution potential. Another direction is to optimize grain production, so later planting date, mid

September or early October, is favorable (Bates, 1975-1983; Phillips, 1975; Elder, 1960).

Comprehensive experiments providing sufficient data on soil temperatures under different tillage systems in relation to planting times for wheat production have not been conducted. For these reasons, the necessity of more detailed studies are needed to see the soil temperature differences under different tillage systems, and to determine whether planting dates can influence soil temperatures under different tillage systems.

CHAPTER III

MATERIALS AND METHODS

These experiments consisted of two studies. The first study evaluated the effect of tillage systems on soil temperatures and growing degree days (GDD) accumulation. The second considered the influence of planting dates upon soil temperatures and GDD under different tillage systems. The experiments were conducted on a Pulaski course-loamy, mixed, thermic Typic Ustifluvent (fine sandy loam 0-2 percent slope) soil at the Oklahoma State University North Agronomy Research Farm, Stillwater, Oklahoma. All plots were in wheat prior to the beginning of these studies which were initiated in 1982-83. Measurements were taken in the 1984-85 and 1985-86 year of a tillage system study where the particular tillage system remained on the particular plot each year of the study.

Soil temperatures were measured using copper-constantan thermocouples. The copper leads were connected to the high input of differential channels and constantan leads were connected to the low side of a Campbell Scientific CR-7 Data Logger. To make a thermocouple temperature measurement, the CR-7 must know the temperature of the reference junction. The CR-7 takes the reference temperature, converts it to the equivalent thermocouple (TC) voltage, adds the measured TC voltage and converts the sum to temperature through a polynomial fit to the TC output curve.

Soil temperatures were measured, using thermocouples, at 5 cm below the soil surface which is approximately the depth at which the crown of wheat plant develops. Soil temperatures were measured every five minutes, stored in memory, and hourly means digitally calculated with a built-in microprocessor. Hourly means were then stored on a cassette recorder and finally transfered to a microcomputer. The following values were determined: the average of maximum, minimum, and mean soil temperatures, and growing degree days (GDD) during 5-day and 4-day periods for the first and second studies, respectively. The average of maximum, and minimum soil temperatures were obtained by the summation the maximum, and minimum soil temperatures during 5 or 4 - day periods divided by 5 or 4 respectively. The average of mean soil temperatures were calculated from the summation of the average of maximum and minimum soil temperatures during 5 or 4 of day period observations, divided by two.

Growing degree days (GDD) were calculated from the summation of maximum and minimum daily soil temperatures, and divided by two minus the base temperature (which is zero) for each day, and accumulated for the periods of 5 or 4 days.

Soil temperature measurements were concluded at the growth stage 6 (Feekes scale). At this stage the plant canopy should be complete enough to dominate any residue effects. Also the growing points are moving up into the plant canopy rather than remaining in the soil.

First Study

A randomized complete block design with four replications was used in the 1984-1985 study. Each replication had four treatments consisting of minimal, low, intermediate, and maximum surface residue. The plot size was 15 by 38 meters. Tillage operations were conducted as soon after harvest as soil condition would allow. Tillage in minimal residue plots consisted of moldboard plowing to a depth of 20 cm following harvest. These plots were subsequently disked as needed for weed control. The low surface residue plots were disked following harvest, and weed control was accomplished as needed by disking. Intermediate surface residue plots were swept at a depth of 12 cm with a 2.5 meter v-blade following harvest, and weed control after the v-blade operation was accomplished with herbicides only, so approximately 75 percent of the residue would be retained on the soil surface. The maximum residue plots had no tillage and weed control was accomplished through the use of various herbicides. Uniform herbicide applications were sprayed across all treatments (Table I).

Planting was performed using a Crustbuster double disk opener no-till drill with 25 cm row spacing. Planting dates and seeding rates varied for each year of the study (Table II). The hard red winter wheat cultivar TAM W-101 was used.

Percent ground cover (the percent of the soil surface covered by crop residue) was measured immediately after planting and was determined by the point count system as described by Owensby (1973).

In each plot, four copper-constantan thermocouples were randomly installed. Totally, there were 64 thermocouples connected to a Campbell Scientific, model CR 7 data logger during the first year study.

Data of 5-day periods were selected. If soil temperature data were collected for each of the 24 hours per day for 5 consecutive days, that set of data was eligible to be grouped. There were 8 groups of 5-day periods of data. Those data were analyzed to obtained soil temperature maximums, minimums, means, and GDD. Soil temperatures during December to January, mid winter, could not be collected because the equipment malfunctioned at near zero temperature. A randomized block analyses of variance was run, for the 8 groups of 5-day periods, in order to test for differences in tillage effects on soil temperature. When the F test was significant, Duncan's Multiple Range Tests were used to determine significant differences in soil temperature means among tillage systems.

Second Study

A randomized complete block experimantal design with a split plot arrangement with four replications was used for the 1985-1986 wheat growing season. The main plots were tillage system treatments, consisting either of conventional methods (CT) or no-till (NT) as described in the first study. Weed control in the NT plots during the fallow period was achieved through the use of various herbicides (Table I). The subplot treatment consisted of four planting dates (Table II). The hard red winter wheat cultivar TAM W-101 was used. A crustbuster double disk opener no-till drill was utilized in 1985. A row spacing of 25 cm and a seeding rate of 70 kg per ha was used in this study, with the exception of the December planting date where seeding rate was increased to 100 kg per ha (Table II). Planting depth was approximately 5 cm depending on soil moisture conditions at the time of planting. The plot size was 7.6 by 23 meters. Percent ground cover was determined as described in the first study.

For each plot three copper-constantan thermocouples were randomly installed. There were 96 thermocouples connected to a Campbell Scientific, model CR 7 data logger.

Data were analyzed to obtain temperature maximums, minimums, means, and GDD. There were 6 groups of 4-day periods. The six groups were selected, based on the method described in the first study. The split plot analyses of variance procedure was used to determine the F values for soil temparatures and GDD data. Interactions between tillage systems and planting dates were tested to see if they were significant. If the calculated F values were significant and no interaction existed , F tests were used to determine if significant differences between tillage methods existed within a planting date. Duncan's Multiple Range Tests were used to determine significant differences in means among planting dates across tillage systems. If significant interaction existed the procedure as outlined by Steel and Torrie (1980) was used for comparing the effects of subplot treatments (planting dates) for a given main plot treatment (tillage system).

CHAPTER IV

RESULTS AND DISCUSSIONS

Soil Temperatures and GDD under Different Tillage Systems

In this section soil temperature differences under different tillage systems will be addressed using the results of the first year study. Discussions will focus upon soil temperature differences during several five day periods throughout the vegetative growth stage of wheat.

Tillage systems had an effect on the amount of residue cover left on the soil surface (Table III). The highest and the lowest amount of residue covers were found under no-tillage and moldboard plow treatments, respectively. Different tillage systems, associated with the percentage of residue covers, affected soil temperatures and growing degree days (GDD) accumulation. The effect on these parameters was highly dependent on the seasons (Table IV).

The four tillage systems used in this study, generally, can be divided into two categories, based upon their effects on soil temperatures and GDD. The moldboard plow and disk systems were similar and frequently they were not significantly different in their affect upon soil temperature and GDD, and v-blade and no-tillage were likewise similar, but different from the plow and disk system.

The discussion on soil temperatures is based on 5-day periods of observation. Eight blocks of 5-day periods of soil temperature data were selected throughout growing season. The first block was observed from 20 - 25 September in early fall; the second and the third were monitored from 16 - 21 Nov. and 21 - 26 Nov. in fall season; the fourth block was observed from 27 Nov. - 2 Dec. in early winter; the fifth one was monitored from 21 - 25 Feb. in early spring; the six, seventh and eight blocks observed from 11 - 16 March, 16 - 21 March, and 21 - 26 March, respectively in spring. Each of these blocks would be discussed individually.

Observation revealed that maximum soil temperatures were usually cooler under no-tillage than under moldboard plow system throughout the vegetative growth stage of wheat (Table IV). The exception to that trend occurred in fall (16 - 21 Nov.) when maximum soil temperatures under no-tillage were equal to those under the plow system. In contrast, minimum soil temperatures under no-tillage varied in comparasion to the plow system depending upon the season. The minimum soil temperatures under no-tillage were cooler during early fall, warmer in fall or early winter, and were equal in spring as compared to those under moldboard plow system. The effects of tillage system upon mean soil temperatures and GDD also varied throughout the year. The mean soil temperatures and GDD were lower in summer, higher in early fall, equal in early winter, under no-tillage than under plow system, but no consistent trend was found in early spring.

Soil temperature fluctuations during early fall are shown in Figure 1a. There was an abrupt decline in soil temperatures that occurred in the last few hours of measurement when the plots received rainfall of 5.5 mm, and the temperature differences between tillage systems disappeared. Rosenberg et al. (1983) suggested that water in soil tends to moderate or equalize the soil temperature differences. Significant difference in maximum soil temperatures occurred between no-tillage and plow system (Table IV). Maximum soil temperatures were an average of 31.36 C and 24.05 C under plow and no-tillage system repectively, with the difference of 7 C. During this time period the effect of residue was large. In contrast to the great differences in maximum soil temperatures between no-tillage and plow system during summer, small differences in minimum soil temperatures were observed between plow and no-tillage system during the same periods of observation (Table IV). Minimum soil temperatures under no-tillage were decreased in an average of 1.4 C as compared to those under plow system. Mean soil temperatures were 26.52 C and 22.17 C under plow and no-tillage system, respectively, with difference of 4.4 C observed during summer season in the first study. Accumulation of heat unit presented in terms of GDD under no-tillage were significantly lower than under plow system during summer time in the first study. In short, soil temperatures and GDD were always lower under no-tillage than moldboard plow system in summer observation.

The phenomena mentioned above are believed to be related to the role of residue cover, which was associated with a difference in net solar radiation reaching the soil surface, and water content. The result is a difference in the heat accumulation in the soil surface. When plant residues are placed in the soil surface, they can exert a significant influence on soil temperature. Surface residues (or their absence) affect most strongly the reflectance coefficient (ALBEDO) of the surface. The primary mechanism of the residue effect is the change in the radiant energy balance. The balance of radiant energy (RNET), can be broken into flux density components for heating the air (A), heating soil (S), or evaporation (LE) (Van Doren, Allmaras, 1978). The amount of residue cover left on the soil surface influences the partitioning of RNET into the components mentioned above. Any influence of residue cover on S, such as residue cover, and water content of the soil surface, has an influence on soil temperature. For example, soil water content influences RNET partitioning. When soil is moist (Stage I evaporation), most of RNET is partitioned to LE.

Stage I evaporation occurs from wet soil surface during first of drying. When the soil surface is dry enough for Stage II or III evaporation, more of RNET is partitioned to A and S. Stage II evaporation begins when the soil surface becomes visibly dry, generally, it occurs 1 - 5 days after irrigation or precipitation. The third stage drying begin when the adsorption forces at the soil particle-liquid interfaces exert control over the evaporation.

Many characteristics of both surface residue and soil influence the reflectance coefficient (ALBEDO) for incoming radiation. Among these factors are residue age, color, and the amount of residue cover left on the soil surface. Residue cover in this study, categorized as a highly reflective material, could have the effect of lowering soil temperatures by reducing the radiant flux reaching the soil surface (Hillel, 1980). Even though this amount of radiant flux was not quantified, we could assume that the amount of radiant flux reaching the soil surface was reduced under the no-tillage system with 97 % residue cover, compared to the plow system with 4 % residue cover. Since the radiant flux reaching the soil surface was reduced by residue cover in no-tillage plots, the soil surface then absorbed less radiant energy. As a result, there was less energy available to raise soil temperature in the no-tillage treatment. In summary, soil temperatures were cooler under high percentage of residue cover compared to those under low percentage of residue cover in early fall. This conclusion was parallel to the conclusion drawn by Unger (1978), and Griffth et al. (1973) that the coldest soil temperatures were found under tillage system that left the most residue cover on the soil surface.

As far as the big difference in maximum soil temperature between no-tillage and plow system is concerned, it is assummed that the water content of soil, in addition to differences in amount of radiant energy reaching the soil surface, had an significant input to explain those phenomena. Residue cover left on the surface also had an affect on the amount of water content of that surface. The amount of water content under no-tillage was higher than plow system (Corr, 1986). In a rather dry bare top soil, such as under moldboard plow system, evaporation of water (LE), assummed at stage III evaporation, from the soil surface is negligible, leaving nearly all the energy available (RNET) for heating the air (A), and soil (S). At the same time, the heat penetrates into the soil only slowly, due to the low values of heat diffusivity caused by low water content and tillage in increasing soil porosity - which has the insulating effect of the pore space filled with air. This combination of circumstances causes a large accumulation of heat in the surface layer with a relatively low heat capacity, resulting in rapid rise of soil surface temperature during daytime (Figure 1a). This effect was observed under plow system where the variation of diurnal (day-night) soil temperatures during 5 - day periods were an average of 10 C. In contrast, in a more moist soil such as under no-tillage system, evaporation of water (LE), assummed at stage II evaporation, consumes a significant part of the net radiation flux. The RNET was also consumed to warm up the air (A), and soil (S). The RNET for no-tillage was lower than under plow system, as we discussed earlier. As a result, the soil temperature changes little over a complete diurnal cycle (Figure 1a). This effect was observed under no-tillage system where the variation of diurnal soil temperatures during 5 - day periods were an average of 4 C.

Since early fall observation occurred when the day time was longer than night, the absorbtion on radiant energy during day time was longer than the reradiation or the release of energy during night. That means the radiation played more important role than reradiation. Figure 1a tells us that the cooling down process under plow system was faster than under no-tillage. The proposed explanation is that there was not enough time during the night to allow the declining of minimum soil temperature under plow system. When the night is getting longer than day time, as observed in fall, the reradiation seems more important than the radiation in affecting minimum soil temperature, which will be discussed later.

As far as small differences in minimum soil temperatures between no-tillage and plow system is concerned, the air temperature near the soil surface might contribute to this small differences. During the night, air in contact with the surface loses energy to the surface until to the point where air and soil temperature reach about the same values. As a results the differences in minimum soil temperature between no-tillage and plow system was small. This finding was also observed in fall and early winter.

Soil temperatures observed in fall, from 16 to 21 Nov. and from 21 to 26 Nov. are given on Figure 1b, and 1c, respectively. The average of maximum, minimum, mean soil temperatures and GDD observed in fall season are summarized on Table IV. Maximum soil temperatures under no-tillage were cooler than under plow system, except on our first observation in fall, when maximum soil temperatures were equal between no-tillage and plow system. Minimum soil temperatures under no-tillage were significantly warmer than under plow system. However, mean soil temperatures and GDD were equal under both no-tillage and plow system.

In fall observation, the influence of residue covers upon soil temperatures and GDD were different from those observed in early fall. Maximum soil temperatures under no-tillage were decreased compared to plow system, but minimum soil temperatures were increased. Maximum soil temperatures under no-tillage were 1C cooler than under plow system. That means the magnitude of differences in maximum soil temperatures between no-tillage and plow system declined in fall as compared to those in early fall. This phenomena suggested that the role of residue cover upon maximum soil temperatures decreased during fall. Figure 1c shows that gap of maximum soil temperatures between no-tillage and plow system is smaller than those observed in early fall (Figure 1a). Decreasing in the role of residue cover upon maximum soil temperatures was due to reducing day lengths in fall. The smaller amount of the net radiation flux at lower sun angles, irrespective of cover, would reduce the effect of plant residues on soil temperatures. This is because the incoming solar radiation would be reflected more with lower sun angle in fall than high sun angle in summer. Therefore, it was expected that the magnitude of differences for soil temperatures and GDD observed in fall would be smaller than in early fall.

In the first fall observation, maximum soil temperatures were equal under both no-tillage and plow systems. It seem that there was not enough solar radiation reaching the surface, to cause the significant role of residue cover in affecting soil temperature differences under no-tillage and plow system. The general characteristics of soil temperature fluctuations on Figure 1b and 1c were different from those on Figure 1a. The exception was when there were some rainfall, and cloudiness. According to daily rainfall record at Agronomy Station in Stillwater, during our first fall observation (Fig.1b), there was 17 and 21 mm rainfall on 17 and 18 of November, respectively. The effect of rainfall is to moderate the soil temperature differences. The first three-days of observation (Fig. 1b) were assumed under cloudy sky, which naturally occurs when there is rainfall. Clouds may absorb as much as 30 - 40 % (Liou, 1976) or 80 - 90 % of solar flux depending on type or cloud thickness (Rosenberg et al, 1983). According to Shul'gin (1965), cloudiness reduces the daily amplitudes of soil temperatures. This can be observed from Figure 1b. In general, soil temperatures under no-tillage, under cloudiness and rainfall, appeared warmer than under plow systems (Figure 1b). Under these circumstances, the residue mulch, through reduced reradiation, had an effect to slow the decline in soil temperatures under no-tillage system compared to plow. This was because the release of energy (reradiation) from soil covered with mulch except at the extreme upper surface of mulch, was reduced due to role of mulch as an insulator and as well as reradiating back to the soil surface. Later on 21 - 26 Nov. assumed under clear sky, the influence of residue cover upon maximum soil temperatures was significant. The maximum soil temperatures under no-tillage system were significantly lower than those under plow system. In contrast to the early fall when the minimum soil temperatures were significantly cooler under no-tillage than plow system, minimum soil temperature observed in fall season were significantly warmer under no-tillage than plow system. This suggested that the residue cover under no-tillage had an effect in increasing minimum soil temperature during fall. These phenomena was associated with the change in day lenghts to longer nights. During daylight, most of the incoming direct and indirect short-wave radiation is absorbed by the soil surface, the remainder is reflected back into the atmosphere. Normally, during the day the net radiation flux is greater than zero. During the night or early morning, the soil temperatures at the surface fall rapidly because of radiational cooling (Rosenberg et al., 1983), and normally, the net solar flux is less than zero. Therefore, during night, more negative net radiation occurred under plow system than no-tillage system. This is because reradiation under no-tillage was lower due to the barrier effect of the residue cover. So the cooling process that occurred under no-tillage was small compared to plow system. Therefore, more energy remains in on no-tillage plots, resulting in the minimum soil temperatures being higher than under plow system. The magnitude of differences in mean soil temperature and GDD between no-tillage and plow system were decreased in fall compared to those observed in summer time.

In summary, it appeared that the residue cover influenced soil temperatures in fall differently than in early fall. Residue cover decreased maximum soil temperatures, but increased minimum soil temperatures under no-tillage compared to plow system in fall. The day lengths, cloudiness, and water content from rainfall, contributed the decreasing role of residue cover upon maximum soil temperatures and GDD during fall observation.

Soil temperatures during 5-day period observed from 27 Nov. to 2 Dec. are given on Figure 1d. The average of maximum, minimum, mean soil temperatures and GDD in early winter (27 Nov. - 2 Dec.) are summarized on Table IV. Maximum soil temperature under no-tillage were 2 C cooler than under moldboard plow system. In contrast, minimum soil temperatures were 1.7 C warmer under no-tillage than plow system. It seem that the effects of residue cover, associated with tillage systems, still existed till early winter. In general, the trend of the influence of residue cover in early winter was similar to those observed in fall. The exception was that the magnitude of differences for maximum and minimum soil temperatures were higher than those observed in fall (Table IV). The differences between no-tillage and plow system for maximum soil temperature were higher observed in early winter, with 2.0 C difference, than those monitored in 21 - 26 Nov. in fall season, with 1.3 C difference. The differences in the minimum soil temperature between plow and no-tillage system in early winter were higher compared to those observed in fall season. Mean soil temperatures and GDD under no-tillage were not different from plow system. This finding was similar to those observed in fall.

The higher difference for maximum and minimum soil temperatures in early winter compared to those in fall were related to the amplitude of soil temperature variation in both seasons. The amplitude of soil temperature variation in early winter was higher than in fall. There were 7 C, and 4 C difference for day and night soil temperature under plow and no-tillage system, respectively (Figure 1d). Those values were higher compared to 6 C and 3 C difference observed in fall (Figure 1c). The greater amplitude in winter than fall was probably due to cloudiness and therefore less solar radiation in fall and drier soil surface in winter. The total rainfall during first and second fall observation were of 38 mm, and 4 mm, respectively, while no rainfall occurred in early winter. Having no rainfall during early winter, water content of the surface soil was drier than in fall. Hillel (1980) suggest that in dry soil the amplitude of soil temperature variation is bigger than rather wet soil. Therefore, lower soil moisture can attributed for the higher amplitude of soil temperatures in early winter (Figure 1d) than in fall (Figure 1c).

Residue cover no longer had as big control upon maximum soil temperatures and GDD in fall and early winter as it had in early fall. The declining of the residue cover influence upon these parameters was mainly due to the decreasing of day lenghts during fall and early winter. It was expected that later on spring when the day lenghts are getting longer than in early winter, that the influence of residue cover upon those parameters will increase. However, observation in spring show that the influence of residue cover upon soil temperatures and GDD was overwhelmed by wheat canopy.

Soil temperature data in early spring, 21 - 25 Feb. 1985 are on Figure 2a. We assumed from 21 to 23 Feb. the sky was cloudy and from 23 to 25 Feb. the day was clear (Fig. 2a). Besides, there was rainfall of 38 mm, 4 mm, 6 mm, and 5 mm on 20, 22, 23, and 24 February respectively. The interesting point was that soil temperatures under cloudy day, associated with rainfall, was warmer under plow and disk as compared to no-tillage and v-blade systems (from 21 to 23 Feb.). This situation was the reverse of the phenomena shown on Figure 1b. Along with the argumentation relating to the phenomena shown in Figure 1b, it seems that the effect of water (rainfall) and cloudiness were different during the periods of increasing as compared to those during the periods of decreasing soil temperatures. The differences between phenomena shown on Figure 1b and Figure 2a, might be supported the findings of Van Duin (1956). He concluded, during the periods of increasing soil temperatures, soil are warmer near the surface when tilled and cooler when left undisturbed.

Maximum soil temperature under no-tillage were 2 C lower than under plow system in early spring (21 - 25 Feb.). This difference, for maximum soil temperatures between no-tillage and plow system observed in early spring, were similar to those observed in early winter. This might be expected since the day lengths and solar radiation are similar between early winter and early spring. That means the perfomance of the residue cover in affecting soil temperature, at maxima level, between no-tillage and plow system that occurred in early spring were equal to those observed in early winter.

The role of residue cover, associated with tillage systems had an effect in reducing maximum soil temperatures to a different degree from early fall through early winter. Later on spring the affect of residue cover upon maximum soil temperatures under both tillage systems were not consistent. Maximum soil temperatures under no-tillage were not different during period of 11 - 16 March (Figure 2b), and then were statistically different in period of 16 - 21 March (Figure 2c), and finally were similar during 21 - 26 March (Figure 2d).

Residue cover had an effect of reducing minimum soil temperatures in summer and of increasing minimum soil temperatures in fall and in early winter. In early spring, minimum soil temperatures were not affected by tillage systems. This definite trend continued through the spring.

Mean soil temperatures and GDD were not consistently affected by tillage systems during the spring observations. Observation on 21 - 26 November 1984 and 16 - 21 March 1985 revealed that mean soil temperatures and GDD under no-tillage were lower than plow system. Growing degree days (GDD) under no-tillage were 7.07 and 3.34 degree lower than plow system during these two spring observations. On daily basis, GDD under no-tillage were 1.4 and 0.7 degree days lower than plow system. Those values were not meaningful in reference to wheat growth and development considering it takes 80 - 100 GDD to produce a wheat leaf.

The maximum soil temperature differences in early spring, with 2.0 C differences between no-tillage and plow system, did not exist in the later periods of spring season. During early spring observation, the solar radiation reaching the soil surface, was not reduced as much as in later periods of spring season, since the wheat canopies in early spring were not as wide as those in later season. To explain this, a classical description according to Gates (1965) revealed that if the single leaf is exposed to light, in the visible wavelengths, approximately 85 - 90 % of the light is absorbed, 5 - 10 % is reflected, and 5 % is transmitted. So the more leaves we have the less solar radiation will be transmitted. The illustration mentioned above, might be valid to get an idea how the wheat canopy was overwhelming the role of residue cover in affecting soil temperatures. Another reason was that the age of residue cover which might not have as high a reflectance as it used to be in the past season. Therefore, under those circumstances, the process of warming the soil surface was sluggish. So it was expected that the magnitude differences for soil temperatures and GDD in later periods of spring season were smaller than those monitored in early spring time. Finally, high soil water content from rainfall or snow, might contribute to the inconsistency of the results too.

The effect of tillage systems, associated with residue cover, upon soil temperatures and GDD was mainly dependent on season, related to day lenghths. The rainfall, cloudiness, and the canopy were also attributed the fluctuation of these parameters. The great influence of residue cover was observed in early fall, then decreased in fall and early winter. In spring, the role of residue cover upon these parameters was overwhelmed by the plant canopy. The magnitude of differences in maximum soil temperatures between no-tillage and plow systems decreased in fall compared in early fall. In contrast, the magnitude of differences in minimum soil temperatures were greater in early fall. The observations show a decrease in magnitude of differences in mean soil temperatures and GDD in fall compared to early fall.

Soil Temperatures and GDD Under Different Tillage Systems and Planting Dates

The percentage of residue covers are given on Table V. The highest amount of residue cover was under no-tillage system at August planting. In general, residue covers were higher under no-tillage compared to conventional tillage system within planting dates. The amount of residue cover was less than 10 percent among planting dates within conventional tillage and over 80 percent in no-tillage. Even though the residue covers were statistically different, these differences do not seem to be meaningful in reference to soil temperatures and GDD. In the results of first year study, where plow and disk system had 4 and 31 percent residue cover, respectively, yet the residue performances in terms of soil temperatures and GDD were frequently not different. Therefore, it will not be discussed on how the planting date within a tillage system, associated with the different amount of residue covers, effected soil temperatures and GDD. Rather the discussion will focus on how the planting dates, influence the soil temperatures and GDD under conventional and no-tillage system.

The interaction of planting date by tillage system, upon soil temperatures and growing degree day (GDD) was significant in some cases. The magnitude and/or the directions of the effects on these parameters varied throughout the seasons and will be discussed individually.

The discussion on soil temperatures and growing degree days (GDD) were based on 4-day period of observation. There were two blocks of 4-day periods observed in summer time -- from 24 - 28 Aug. and from 28 Aug. - 1 Sep. 1985. The third and fourth block were monitored from 15 - 19 Oct and 25 - 29 Nov. in early and late fall, respectively. The fifth and sixth blocks of 4-day periods were detected from 5 - 9 Feb. and 12 - 16 Feb. 1986 in early spring season.

The general characteristic of soil temperature fluctuation monitored during summer in the first (Figure 1a) and second year of study were similar (Figure 3, 4). In our first observation in summertime, only August planting date was used, therefore our discussion would be concentrated on the effect of no-tillage and conventional tillage system upon soil temperatures and GDD. Tillage systems significantly affected soil temperatures and GDD (Table VI). Maximum soil temperature difference in summer of this second year of study (24 - 28 Aug; and 28 Aug.- 1 Sep.), were even higher than those observed in summer on the first study. The average of maximum soil temperatures were 35.6 C and 27.7 C, with difference of 8 C (in the first observation); and 38.1 C and 29.1 C, with difference of 9.0 C (on the second observation in summer) under conventional tillage and no-tillage system, respectively. These findings were consistent with the findings of Krenzer et al. (1987) that the soil temperatures on no-tillage were as much as 8.0 C cooler at the highest level than under plow system.

In contrast to maximum soil temperatures, there was a small difference in minimum soil temperature between no-tillage and conventional tillage system. Minimum soil temperatures under no-tillage were 1.7 C cooler than under conventional system during Aug. - Sept. 1. This finding was consistent with our results in the first year study where minimum soil temperatures under no-tillage were an average of 1.4 C cooler than conventional tillage system. Earlier observation during Aug. 24 - 28 revealed that minimum soil temperatures under no-tillage were not different compared to conventional tillage system due to the rainfall received the day before monitoring. Similar to the result mentioned earlier in first year study for mean soil temperatures, our findings on the second study during summertime for mean soil temperature were an average of 5.3 C cooler under no-tillage than conventional tillage system. This was slightly higher than that of the first study (4.4 C). Our observation on the second study was held in summer, while in year one was held in early fall (21 - 26 Sep. 1985). Growing degree day (GDD) accumulated during 4-day period under no-tillage system were 21.4 lower than under conventional tillage system observed in this second study. This value was higher than those observed in year one. In year one the plow system accumulated 4.4 GDD per day more than no-tillage system while in year two it was 5.4 GDD per day more.

In summary, tillage system, associated with residue cover, affected soil temperatures and GDD during summer. The effect of tillage systems, conventional and no-tillage system, upon these parameters were similar to what those observed in summer of year one. The exception was that the value of maximum, mean soil temperatures and GDD were higher in the second year of study than in first one. This was attributed to the time of observation was made.

Statistically many of planting date by tillage system interaction were significant (Table VII). Therefore, the discussion will focus on main effects, planting date and tillage systems, only when the interaction is not significant and individual interactions will be discussed where they occur.

Observation in early fall (15 - 19 Oct.), revealed that the interaction between planting dates and tillage systems for maximum soil temperatures was significant (Table VII). This interaction occurred because of the change in magnitude of soil temperature differences between conventional tillage and no-tillage system in August compared to those observed in September planting (Figure 5a). In both planting dates no-till was cooler than plow but differences were greater for the September than August planting.

Soil temperatures under different planting dates are shown on Figure 6. In general, September followed by August planting under conventional tillage system had warmer soil temperatures than under no-tillage system. September planting had higher maximum soil temperature than August planting within conventional tillage and within no-tillage system (Table VIII). This was probably due to the differences in percent of soil surface shaded by wheat canopy on October 15 - 19. Since the percentage of soil surface shaded by wheat was not quantified, this relationship can be best show through the amount of forage clipped. Forage yield on 24 October were 869 and 700 lb/A under August no-tillage and conventional systems, respectively, while there was not enough forage to clip on the September plantings. Since the soil temperatures were monitored on 15 to 19 October, about one week before clipping, those forage yields give us an idea of the wheat canopy for the August and September plantings. Thus, the reduction of solar radiation reaching the soil surface due to canopy were greater under August than September plantings. As a result, soil temperatures were higher under September than those under August date.

Differences of maximum soil temperatures between August and September planting date, associated with the canopy, within no-tillage were smaller than within conventional tillage systems. This fact told us that the role of residue cover had more influence than the canopy over maximum soil temperatures during this time period. The amount of residue cover were greater under no-tillage system, with 92 %, compared to those under plow system, with 4 % residue cover. With 92 % residue cover, the effect of planting dates, associated canopy, within no-tillage system was decreased. However, the reverse is true within conventional tillage system with 4 % residue cover. This small differences can actually be observed from the average daily soil temperature variation which was smaller under no-tillage than conventional tillage system. In summary, the effect of plant canopy mentioned earlier upon maximum soil temperatures between August and September within no-tillage system was small compared to those observed within conventional tillage system.

Since the interaction of planting dates by tillage systems for minimum, mean soil temperatures and GDD were not significant in early fall, our discussion will focus on the effects of planting dates across the tillage and tillage across planting dates. Minimum, mean soil temperatures and GDD are summarized on Table IX. Planting date did not affect minimum soil temperatures, but did affect mean soil temperatures and GDD ($P = 0.01$). Mean soil temperatures and GDD were higher under September than August planting. In contrast, tillage system, associated with residue cover, affected minimum, mean soil temperatures and GDD. Mean soil temperatures and GDD were cooler under no-tillage than conventional tillage system. Minimum soil temperatures were warmer under no-tillage than conventional-tillage system. This was due to the mulch effect on reradiation. Another reason was that under no-tillage there was more soil moisture (Heer, 1986), because residue cover may enhance soil water storage and reduce the evaporation. In rather wet soil, such as under no-tillage system the minimum soil temperatures were higher than in rather dry-bared soil. This was also observed in year one study, especially in fall or early winter.

Basically, the influence of planting dates upon soil temperatures and GDD were related to the canopy. However, the degree of this effect was dependent on the influence of residue cover left on the soil surface. For example, the influence planting date, associated with canopy, was higher within conventional tillage, with 2.0 C difference, than no-tillage system, with 1.0 C difference between August and September planting.

The general characteristics in Figure 7 were similar to those shown in Figure 1b, observed in fall of first study. It appeared that during the periods of falling soil temperatures, soil surface were warmer when left undisturbed and cooler when tilled. To explain these apparent similarity, it was assummed the influence of canopy, coupled with residue cover, of the soil surface decreased the heat intake and loss of a soil, caused less heat exchange to take place in the surface soil.

Planting date by tillage system interaction was significant for minimum, maximum, mean soil temperatures and GDD in fall, 25 - 29 Nov., (Table VII). The interactions occurred because the differences in those parameters between conventional and no-tillage system within October planting was small, as compared to those in August and September planting (Figure 8a, 8b, 8c, and 8d). In general, at maximum, minimum, mean soil temperatures and GDD under August planting were equal to September planting, but were statistically warmer than October planting within tillage system. The exception to those was for maximum soil temperatures which were equal among August, September, and October planting within conventional tillage system (Table VIII).

When soil temperatures were monitored on 25 - 29 November the wheat planted on August 16 has been clipped on October 24, while wheat crop planted in September 17 has not been clipped at all. The speculation was that the wheat canopy under both August and September planting were about the same when we monitored 25 - 29 November. So it could be assumed that the amount of solar radiation reduction under both planting date within tillage system was equal. Therefore, the soil temperatures and GDD under both planting dates were similar.

Soil temperatures and GDD were significantly warmer either under August or September planting as compared to October planting within tillage systems, if the same arguments mentioned above were applied, we assumed that the canopy development of wheat planted in October 27 was not as much as those under August or September planting within tillage systems. When soil temperatures were monitored on 25 - 29 November, the wheat plants planted in October 27 were about 1 month old, so the soil temperatures under October planting were expected to be warmer than those under August or September planting within tillage systems. However the reverse is true. Daylengths had shortened to the point where reradiation was more important than radiation. Therefore, there was not enough canopy to prevent reradiation, so the soil temperatures cooled faster in the October 27, planted plots.

Within a planting date, maximum, minimum, mean soil temperatures were warmer and GDD was higher within no-tillage than conventional tillage system, with the greatest differences in September followed by August, and October planting (Table VIII). The only exception was observed for maximum soil temperatures which were equal under conventional and no-tillage system within October planting. Those phenomena tell us that the influence of planting dates, through the canopy, upon maximum, minimum, mean soil temperatures and GDD still existed. However, the effect of tillage systems, associated with residue cover, upon these parameters overshadowed the canopy's influence. For example, the influence of planting date upon soil temperatures and GDD were higher within no-tillage than within conventional tillage system. Differences of minimum and maximum soil temperatures between August and September planting were higher within no-tillage than conventional tillage system. The trend also applied to mean soil temperatures and GDD during this time period. It was believed that the effect of residue cover and canopy on reradiation were attributed to those phenomena.

Soil temperatures observed in spring are given on Figure 9. Planting date by tillage system interaction (Table VII), for minimum soil temperatures were significant in early spring from Feb. 5 to 9 and from Feb. 12 to 16. These interactions occurred because of change in magnitude of minimum soil temperature differences between conventional and no-tillage system in December planting compared to August, September, and October planting dates (Figure 5b, and 5c). Minimum soil temperatures under no-tillage were higher than under conventional tillage system, except in December plantings where this parameter under no-tillage was equal to under conventional tillage system. However, the differences of minimum soil temperatures between no-tillage and conventional tillage system were higher in October than other plantings, except during Feb. 12 - 16.

In our first spring observation, minimum soil temperatures (Table VII) under August planting were similar to those under September plantings, but statistically higher than October and December plantings within conventional tillage. Since the forage under August and September plantings was clipped on the same time (Jan. 21), the wheat canopy under both plantings would have similar development, so reradiation through the canopy would be the same. Therefore, it was expected that the minimum soil temperatures under both plantings, August and September, would be equal within tillage system. Minimum soil temperatures under October planting were equal to those under December planting within conventional tillage systems, but not within no-tillage system. In our second spring observation these trends also existed. The exception was that minimum soil temperatures under October planting were equal to December planting within conventional tillage system in first spring observation, but different in the second observation.

In general, no-tillage system had significantly warmer minimum soil temperatures than conventional tillage system within planting dates (Table VII). The only exception occurred within December planting when no-tillage system had the same minimum soil temperatures with those under conventional tillage system during both spring observations. If we recall the results of our first study, minimum soil temperatures were not affected by tillage systems during spring observation. In contrast, this parameter was affected by tillage system within planting dates in spring of second study, and minimum soil temperatures were warmer under no-tillage than conventional tillage system.

For the remaining temperature and GDD data collected in spring, the discussion will be concentrated on main effects because the interaction was not significant. Our first observation in spring (Table X) suggested that maximum soil temperatures were not affected by tillage system or by planting date. Mean soil temperature and GDD were not significantly affected by tillage systems, but planting dates did. Mean soil temperatures were significantly warmer under September as compared to those under August, October, and December planting across tillage systems.

In our second observation in Spring (Table XI), maximum, mean soil temperatures and GDD were significantly higher under no-tillage than conventional tillage systems. Figure 10 suggested that soil temperatures were wamer under no-tillage than conventional tillage system during first coupled days. These views were similar to Figure 2a of first study where warmer soil temperatures were under no-tillage than conventional tillage system.

Similar to fall observations, minimum soil temperatures among planting dates were higher within no-tillage than within conventional tillage system during spring observation. However, the role of tillage systems, associated with mulch, in affecting minimum soil temperatures was decreased in spring compared to in fall. Plant canopy appearently contributed to the decreased influence of the residue cover in spring through the reduction of the incoming solar radiation to the surface, since the wheat plant already developed complete leaves. The influence of the canopy applied under both tillage systems. These spring phenomena can be observed on Table VIII where the effect of planting dates were not consistent in influencing minimum soil temperatures under both tillage systems.

The conclusions were tillage system, associated with residue cover, did affect soil temperatures and GDD. The magnitude of differences for soil temperatures and GDD between no-tillage and conventional tillage systems were higher in summer, and declined in fall and early winter as the day lengths becomes shorter than night. In spring those trends were not found because the wheat canopy played more important role in affecting soil temperatures and GDD than the residue cover.

Planting date effects on soil temperatures and GDD under no-tillage and conventional tillage were different at the time of observation. In fall observation, delaying planting until mid September resulted in a greater effect on the soil temperature at maxima level because less leaves were developed under September compared to August planting. So the accumulation of heat were assumed greater under September than August planting. Later in late fall, August and September planting had equal maximum, minimum, and mean soil temperatures and GDD, but both dates were warmer than October planting under no-tillage and conventional tillage systems. That means delayed planting in October would lower maximum, minimum, and mean soil temperatures and GDD under no-tillage and conventional tillage systems. In spring, the effect of planting dates upon minimum soil temperatures was minimal and inconsistent.

CHAPTER IV

CONCLUSIONS

Soil Temperature Differences under Tillage Systems

Different tillage systems, associated with the percentage of residue cover, affected soil temperatures and GDD. The effect on these parameters was highly dependent on the season. The four tillage treatments generally can be divided into two categories. The moldboard plow and disk system were very similar and frequently were not significantly different in affecting soil temperatures, and v-blade and no-tillage system were likewise.

Maximum soil temperatures were always cooler or equal under no-tillage than those under plow system throughout the season in year one. In contrast, minimum soil temperatures under no-tillage varied in relationships to plow system depending upon the season. The minimum soil temperatures were cooler during early fall, warmer in fall and early winter, and were equal in spring under no-tillage as compared to those under moldboard plow system. The mean soil temperatures and GDD were always cooler under no-tillage than under plow system throughout the year.

Observation during early fall revealed that, in general, we had great differences in maximum soil temperatures, moderate differences in mean soil temperatures and GDD, and small differences in minimum soil temperatures between no-tillage and moldboard plow system.

The magnitude of differences in maximum soil temperatures between no-tillage and plow system decreased in fall as compared to in early fall. In contrast, the magnitude of differences in minimum soil temperatures were greater in fall than in early fall. We also observed a decrease in magnitude of differences in mean soil temperatures and GDD in fall season as compared to in early fall season. Decreasing in day lengths due to lower zenith sun angle in fall compared to early fall, coupled with cloudy sky and rainy days, reduced the role of residue cover in affecting soil temperatures and GDD under no-tillage in relationship with plow system.

In early winter, the magnitude of differences in maximum and minimum soil temperatures were higher as compared to those in fall season under no-tillage and plow system. The differences in mean soil temperatures and GDD between no-tillage and plow system observed in early winter were equal to those observed in fall.

The differences in maximum soil temperatures in early spring were similar to the differences in maximum soil temperatures in late fall or early winter between no-tillage and plow system. Minimum soil temperatures under no-tillage were equal to those under plow system in early spring. Mean soil temperatures and GDD differences between no-tillage and plow were higher in early spring than in late fall or early winter.

The greater differences in maximum soil temperatures between no-tillage and plow system in early spring were not found in later periods on the spring. Since the wheat canopies in early spring were not as wide as those in later period in spring, the solar radiation reaching the soil surface in early spring was not reduced as much as in the later periods of spring season. In respect to that phenomena it was expected that the magnitude of differences in soil temperatures and GDD later on the spring would be smaller than those in early spring season.

The role of residue covers, associated with tillage systems in influencing the soil temperatures and GDD, was greater in summer time than in fall, early winter, and spring. In fall, and early winter residue cover still had major influence upon soil temperatures and GDD. In spring, the wheat canopy was predominant besides the environmental factors such as day length in affecting soil temperatures and GDD than residue cover.

The influence of Planting Date upon Soil Temperatures and GDD under Tillage Systems

The magnitude of differences for minimum, maximum, and mean soil temperatures and GDD observed in summertime in this second study were similar to those observed in the first study. Planting date by tillage system interaction for soil temperatures and GDD was significant. However, the cause of the interactions varied throughout the seasons.

The interaction between planting dates and tillage systems for maximum soil temperatures occurred because of change in magnitude of differences between no-tillage and conventional tillage system in August compared to September plantings in early fall. In both dates, soil temperatures were warmer under conventional tillage than no-tillage system, but the differences were greater in September than August planting.

In late fall, planting date and tillage system interactions were observed on minimum, maximum, mean soil temperatures and GDD. These interactions occurred because the change in magnitude of differences between no-tillage and conventional tillage system in October compared to August and September plantings. Among planting dates, maximum, minimum, mean soil temperatures and GDD were warmer under no-tillage than conventional tillage system, but the differences were greater in September than August or October plantings.

In two spring observations, planting date by tillage system interaction occurred only for minimum soil temperature. This is because tillage system did not affect minimum soil temperatures for December planting date, but did affect August, September, and October planting. Among dates, minimum soil temperatures were greater under no-tillage than conventional tillage system, but differences were greater in October than other plantings, except in December planting where minimum soil temperatures were similar between no-tillage and conventional tillage system.

The planting date by tillage system interaction occurred for different soil temperature parameters at different times. The interactions might be related to several factors and/or the combination of the factors such as wheat canopy, the net radiation flux, and rainfall.

Planting date effects on soil temperatures and GDD under no-tillage and conventional tillage were different at the time of observation. In fall observation, delaying planting until mid September resulted in a greater residue effect on the soil temperature at maxima level because less leaves were developed under September compared to August planting. So the accumulation of heat were assumed greater under September than August planting. Later in late fall, August and September planting had equal maximum, minimum, and mean soil temperatures and GDD, but both dates were warmer than October planting under no-tillage and conventional tillage systems. That means delayed planting in October would lower maximum, minimum, and mean soil temperatures and GDD under no-tillage and conventional tillage systems. In spring, the effect of planting dates upon minimum soil temperatures was minimal and inconsistent.

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APPENDIX

TILLAGE DATES, PERCENT GROUND COVER, AND RESULTS

TABLE I

SUMMARY OF DATES AND RATES OF APPLICATION OF HERBICIDES TO TILLAGE STUDIES

Cropping Season	Date	Chemical Applied	Rate kg (ai) ha^{-1}
1984 - 1985	7 - 10	Glyphosate	1.12
	8 - 28	Glyphosate	1.12
	10 - 08	Glyphosate	0.28
	11 - 08	Tycor	1.12
	3 - 14	Sencor	0.42
1985 - 1986	6 - 28	Landmaster	
		Glyphosate	2.42
		2,4 - D	0.75
		Surfactant	1.12
	8 - 02	Glyphosate	1.12
		2,4 - D	1.12
	9 - 03	Glyphosate	0.28
	10 - 28	Glyphosate	0.28
	3 - 03	Sencor	0.42

TABLE II

SUMMARY OF PLANTING DATES, AND SEEDING RATES

Cropping Season	Planting Dates	Seeding Rate
		kg ha -1
1984 - 1985	10 - 17	67
1985 - 1986	8 - 16	70
	9 - 17	70
	10 - 27	70
	12 - 11	100

TABLE III

PERCENT RESIDUE COVER AFTER PLANTING AS AFFECTED BY TILLAGE IN 1984-85

Tillage Sytems	Percent Cover
Moldboard Plow	4
Disk	31
V-blade	75
No-tillage	97

LSD (0.05) = 3.193
LSD (0.01) = 5.861

TABLE IV

TILLAGE EFFECT UPON SOIL TEMPERATURES AND GROWING DEGREE DAYS (GDD) FOR 1984-1985

Tillage Systems	Average Soil Temperature (C) Means	Maximums	Minimum	GDD
20 - 25 September 1984.				
Plow	26.52 a[+]	31.36 a	21.67 a	132.60 a
Disk	25.88 b	30.32 a	21.45 a	129.42 b
V-Blade	23.52 c	26.49 b	20.55 b	117.61 c
No-Till	22.17 d	24.05 c	20.28 b	110.85 d
16 - 21 November 1984.				
Plow	6.96 b	9.05 a	4.87 b	34.81 b
Disk	6.97 b	8.87 a	5.06 b	34.84 b
V-Blade	7.39 ab	8.84 a	6.15 a	36.95 ab
No-Till	7.64 a	8.63 a	6.44 a	38.21 a
21 - 26 November 1984.				
Plow	7.33 ab	10.15 a	4.51 b	36.65 ab
Disk	7.16 b	9.65 b	4.67 b	35.81 b
V-Blade	7.31 ab	8.98 c	5.73 a	36.57 ab
No-Till	7.50 a	8.89 c	6.02 a	37.52 a
27 Nov. - 2 Dec. 1984.				
Plow	6.89 a	10.68 a	3.10 b	34.50 a
Disk	6.70 a	10.02 ab	3.38 b	33.51 a
V-Blade	6.58 a	8.82 b	4.34 a	32.91 a
No-Till	6.80 a	8.79 b	4.80 a	33.99 a
21 - 26 February 1985.				
Plow	10.55 a	13.58 a	7.53 a	52.77 a
Disk	10.30 a	13.35 a	7.24 a	51.50 a
V-Blade	9.26 b	11.20 b	7.33 a	46.32 b
No-Till	9.14 b	10.89 b	7.38 a	45.70 b

TABLE IV(Continued)

Tillage System	Average of Soil Temperature (C) Means	Maximums	Minimums	GDD
11 - 16 March 1985.				
Plow	10.93 a	13.98 ab	7.87 a	54.56 a
Disk	11.35 a	14.27 a	7.69 a	56.74 a
V-Blade	10.34 b	12.39 b	8.29 a	51.71 b
No-Till	10.83 ab	13.73 ab	7.93 a	54.16 ab
16 - 21 March 1985.				
Plow	10.49 ab	13.45 a	7.53 a	52.45 ab
Disk	10.98 a	14.27 a	7.69 a	54.92 a
V-Blade	10.02 bc	12.16 b	7.87 a	50.09 bc
No-Till	9.82 c	11.85 b	7.79 a	49.11 c
21 - 26 March 1985.				
Plow	10.79 ab	13.56 ab	8.02 a	56.65 ab
Disk	11.33 a	14.46 a	8.20 a	53.97 a
V-Blade	10.61 ab	12.89 ab	8.33 a	53.07 ab
No-Till	10.37 b	12.42 b	8.31 a	51.85 b

+ Within column values for a tillage system followed by the same letter were not significantly different at 5 % probability level according to Duncan's Multiple Range Test.

TABLE V

PERCENT RESIDUE COVER AFTER PLANTING AS AFFECTED BY TILLAGE AND PLANTING DATES IN 1985-86

Tillage Systems	Planting Dates Aug.	Sep.	Oct.	Dec.
Conventional	4	8	6	6
No-tillage	95	92	86	84

LSD (0.05) for tillage at the same planting date is 2.278
LSD (0.05) for planting date at the same tillage is 1.067

TABLE VI

TILLAGE EFFECT UPON SOIL TEMPERATURES AND GROWING DEGREE DAYS (GDD) IN SUMMER 1985

Treatments	Average Soil Temperature (C) Minimums	Maximums	Means	GDD
Tillage Systems				
24 - 28 Aug. 1985.				
Conventional	21.94 N.S	35.58 **	28.76 **	115.04 **
No-tillage	21.87	27.66	24.76	99.04
28 Aug. - 1 Sep.				
Conventional	24.48 **	38.10 **	31.29 **	125.16 **
No-tillage	22.80	29.11	25.95	103.80

N.S, ** = Not significant, Significant at 1 percent level according to F test, respectively.

TABLE VII

STATISTICAL SUMMARY OF PLANTING DATE BY TILLAGE SYSTEM INTERACTION FOR SOIL TEMPERATURES AND GDD

Season	Minimum	Maximum	Mean	GDD
Early Fall	N.S	**	N.S	N.S
Fall	*	*	**	**
Early Spring	**	N.S	N.S	N.S
Spring	*	N.S	N.S	N.S

N.S, *, ** = Not significant, Significant at 5 percent, Significant at 1 percent according to F test, respectively.

TABLE VIII

EVALUATION OF AVERAGE SOIL TEMPERATURES AND GROWING DEGREE DAYS (GDD) FOR CASES WITH SIGNIFICANT PLANTING DATE BY TILLAGE SYSTEM INTERACTIONS

Date	CONV.	NO-TILL		CONV.	NO-TILL	
15 - 19 OCT. 1985						
<u>Max. soil temperatures (C)</u>						
AUG.	19.07 a+	17.59 y	*	--	--	-
SEPT	20.97 b	18.46 x	*	--	--	-
				25 - 29 NOV. 1985.		
<u>Min. soil temperatures (C)</u>				<u>Max. soil temperatures (C)</u>		
AUG.	3.26 a	5.64 y	*	6.01 a	7.63 y	*
SEP.	3.22 a	5.86 y	*	6.09 a	7.79 y	*
OCT.	2.01 b	3.99 x	*	5.89 a	6.56 x	N.S
<u>Mean soil temperatures (C)</u>				<u>Growing Degree Days (GDD)</u>		
AUG.	4.63 a	6.64 y	*	18.52 a	26.56 y	*
SEPT.	4.65 a	6.83 y	*	18.60 a	27.32 y	*
OCT.	3.95 b	5.27 x	*	15.80 b	21.08 x	*

TABLE VIII (Continued)

Date	CONV.	NO-TILL		CONV.	NO-TILL	
5 - 9 Feb. 1986. Min. soil temperatures (C)				12 - 16 Feb. 1986. Min. soil temperatures (C)		
AUG.	5.43 a	6.32 yx	*	0.52 a	1.65 yx	*
SEPT.	5.76 a	6.63 y	*	0.70 a	2.02 y	*
OCT.	4.61 b	6.12 x	*	-0.19 b	1.36 x	*
DEC.	4.75 b	4.74 z	N.S	-0.48 c	-0.36 z	N.S

+ = within column values planting date within a tillage system followed by the same letter were not significantly different at 5 percent probability according to LSD.

N.S, * = Not significant, Significantly different at 5 percent levels according LSD, between tillage system within a planting date.

TABLE IX

TILLAGE AND PLANTING DATE EFFECT UPON SOIL TEMPERATURES AND GROWING DEGREE DAY (GDD) FOR OCT. 15-19, 1985.

Treatment	Average Soil Temperature (C)			GDD
	Minimums	Maximums	Means	
Tillage Systems				
Conventional	14.58 *	-- [1]	17.30 *	69.20 *
No-tillage	15.15	--	16.59	66.36
Planting Times				
August	15.02 N.S	--	16.68 **	66.72 **
September	14.71	--	17.21	68.84

1 = Planting date x tillage system interaction was significant at 1 percent according to F test.

N.S, *, ** = Not significant, Significant at 5 percent, Significant at 1 percent according to F test, respectively.

TABLE X

TILLAGE AND PLANTING DATE EFFECT UPON SOIL TEMPERATURES AND GROWING DEGREE DAYS (GDD) FOR FEB. 5 - 9, 1986

Treatments	Average Soil Temperature (C)			GDD
	Minimums	Maximums	Means	
Tillage Syatems				
Conventional	--[1]	7.66 N.S	6.40 N.S	25.60 N.S
No-tillage	--	7.57	6.76	27.04
Planting Dates				
August	--	7.44 a+	6.66 b	26.64 b
September	--	7.72 a	6.96 a	27.84 a
October	--	7.78 a	6.57 b	26.28 b
December	--	7.53 a	6.14 c	24.56 c

1 = Planting date x tillage system interaction was significant at 1 percent according to F test.

N.S = Tillage systems across planting dates were not significant different according to F test.

+ Within column values for a planting date across tillage systems followed by the same letter were not significantly different at 5 % probability level according to Duncan's Multiple Range Test.

TABLE XI

TILLAGE AND PLANTING DATE EFFECT UPON SOIL TEMPERATURES AND GROWING DEGREE DAYS (GDD) FOR FEB. 12-16, 1986

Treatments	Average Soil Temperature (C)			GDD
	Minimums	Maximums	Means	
Tillage Systems.				
Conventional	--[1]	3.03 **	1.58 **	6.32 **
No-tillage	--	3.53	2.35	9.40
Planting Dates				
August	--	3.37 a+	2.23 a	8.92 a
September	--	3.42 a	2.39 a	9.56 a
October	--	3.56 a	2.07 a	8.28 a
December	--	2.77 b	1.18 b	4.72 b

1 = Planting date x tillage system interaction was significant at 5 percent according to F test.

** = Tillage means significantly different at 1 percent according to F test.

+ Within column values for a planting date across tillage systems followed by the same letter were not significantly different at 5 % probability level according to Duncan's Multiple Range Test.

TABLE XII

PERIOD OF SOIL TEMPERTURE MEASUREMENTS
IN RELATION TO WHEAT GROWTH STAGES
BASED ON FEEKES SCALE

Season	Period	Growth Stages
First Study (1984 - 1985)		
Early fall	20 - 25 Sep. 1984	-
Fall	16 - 21 Nov. 1984	2
Late fall	21 - 26 Nov. 1984	2
Early winter	27 Nov. - 2 Dec. 1984	3
Early spring	21 - 26 Feb. 1985	4
Spring	11 - 16 Mar. 1985	5
Spring	16 - 21 Mar. 1985	5
Spring	21 - 26 Mar. 1985	6

Season	Period	Planting Dates Aug.	Sep.	Oct.	Dec.
		..........Growth Stages...........			
Second Study (1985 - 1986)					
Late summer	24 - 28 Aug.	1	-	-	-
Early fall	28 Aug. - 1 Sep.	2	-	-	-
Fall	15 - 19 Oct.	3	2	-	-
Late Fall	25 - 29 Nov.	3	3	2	-
Spring	5 - 9 Feb.	3	3	3	1
Spring	12 - 16 Feb.	4	4	3	2

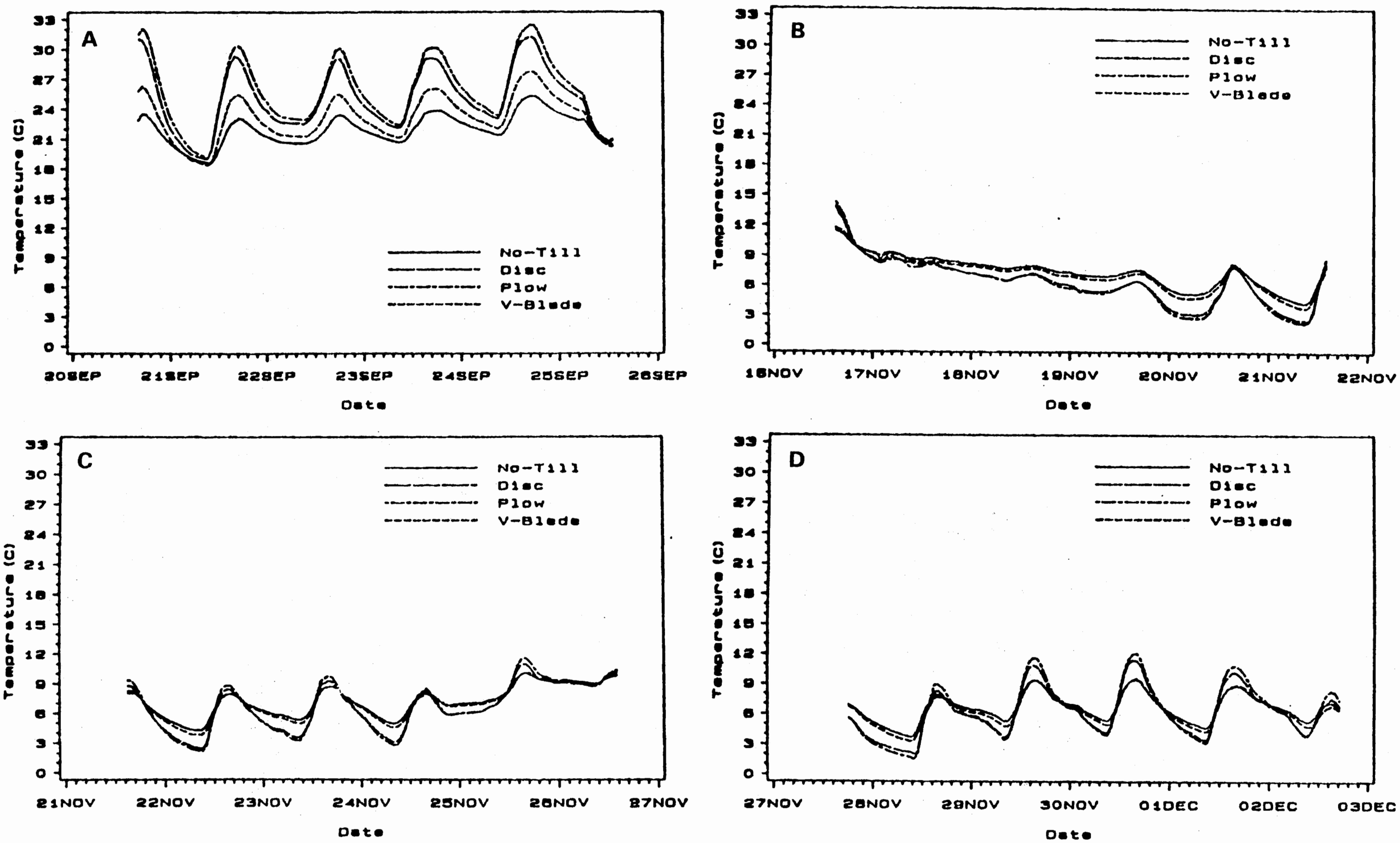

Figure 1. Soil Temperatures Under Different Tillage Systems; a) summer; b), c), d), fall 1984

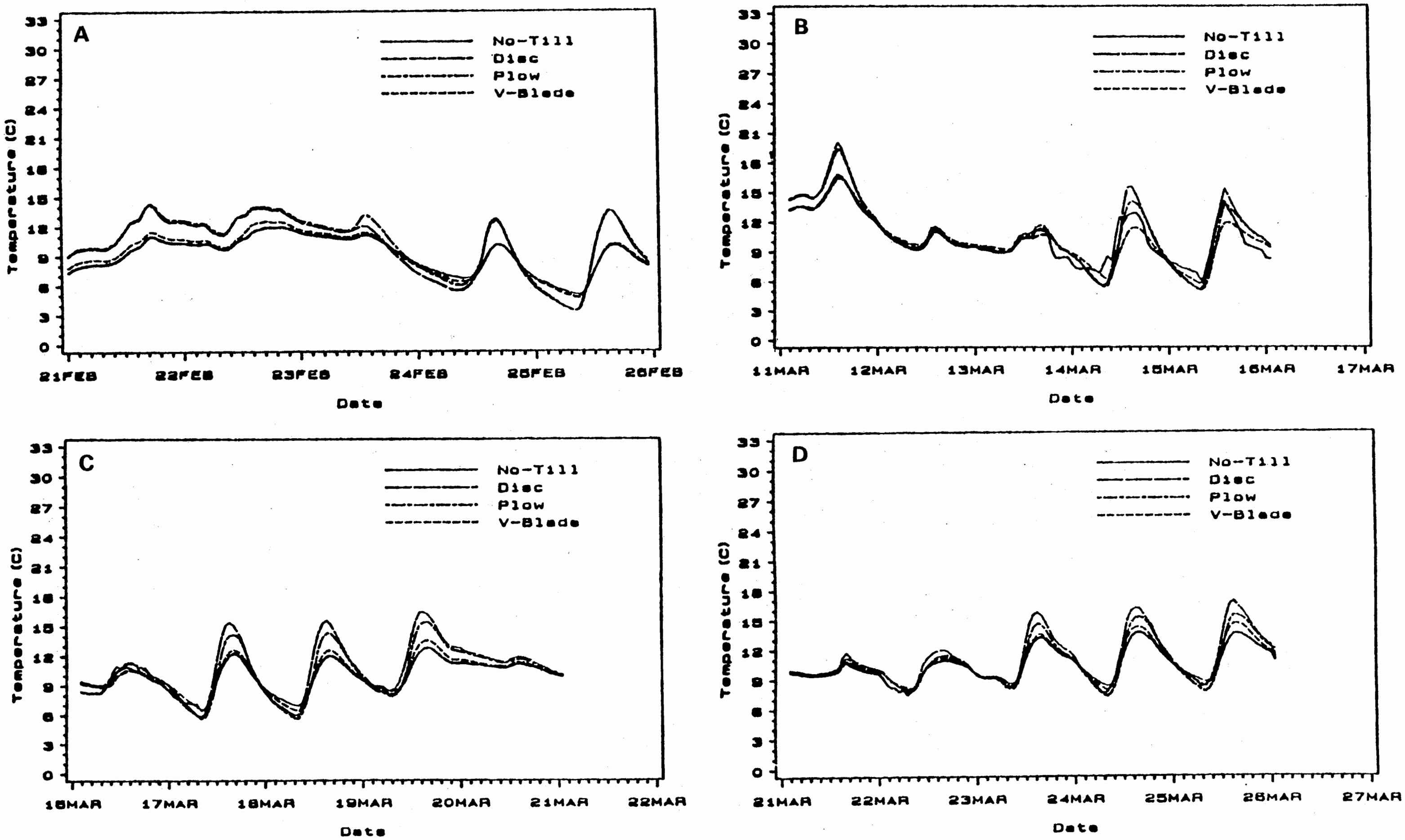

Figure 2. Soil Temperatures Under Different Tillage Systems; (a) early spring, (b), (c), (d), spring 1985.

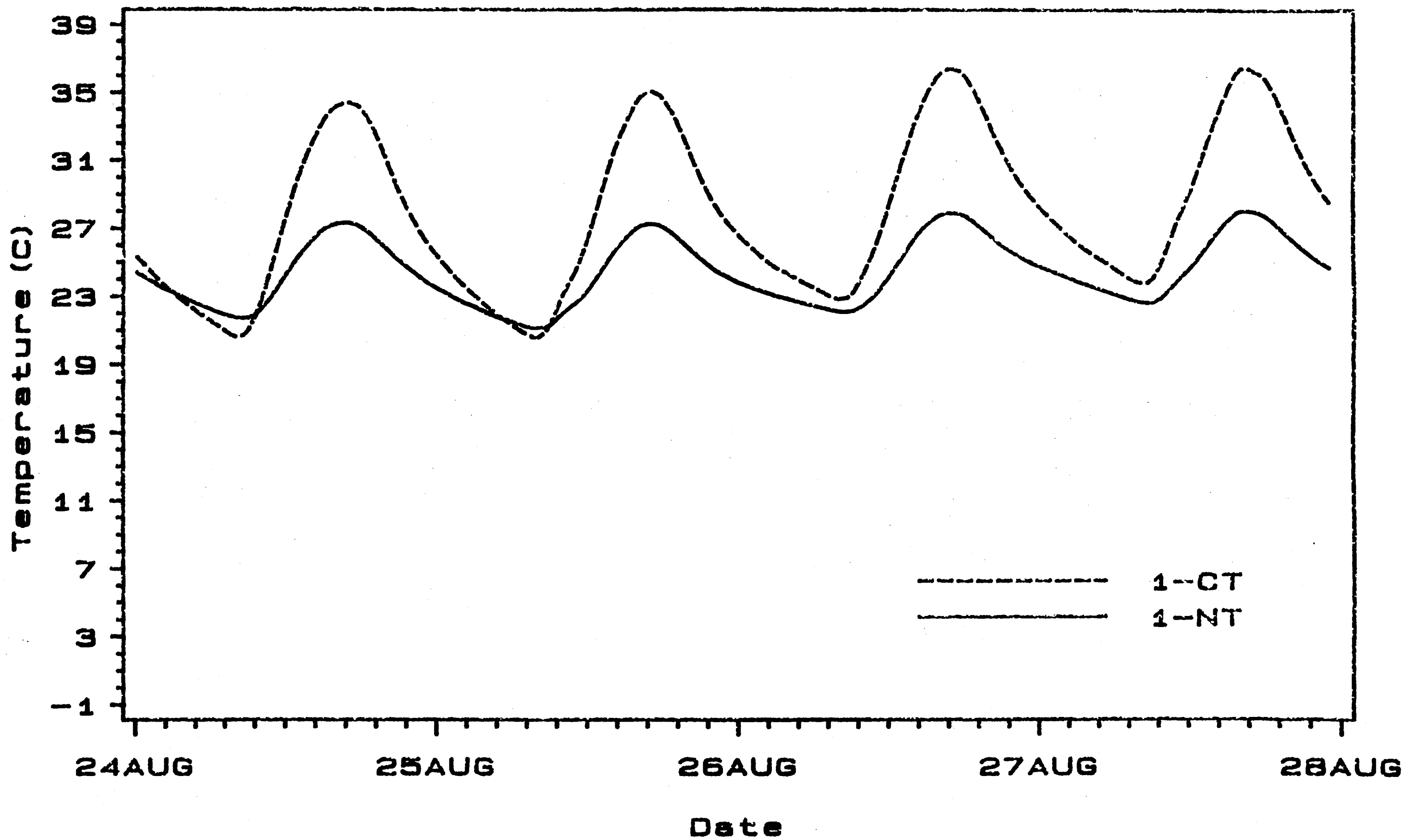

Figure 3. Soil Temperatures Under Different Tillage Systems in Summer 1985.

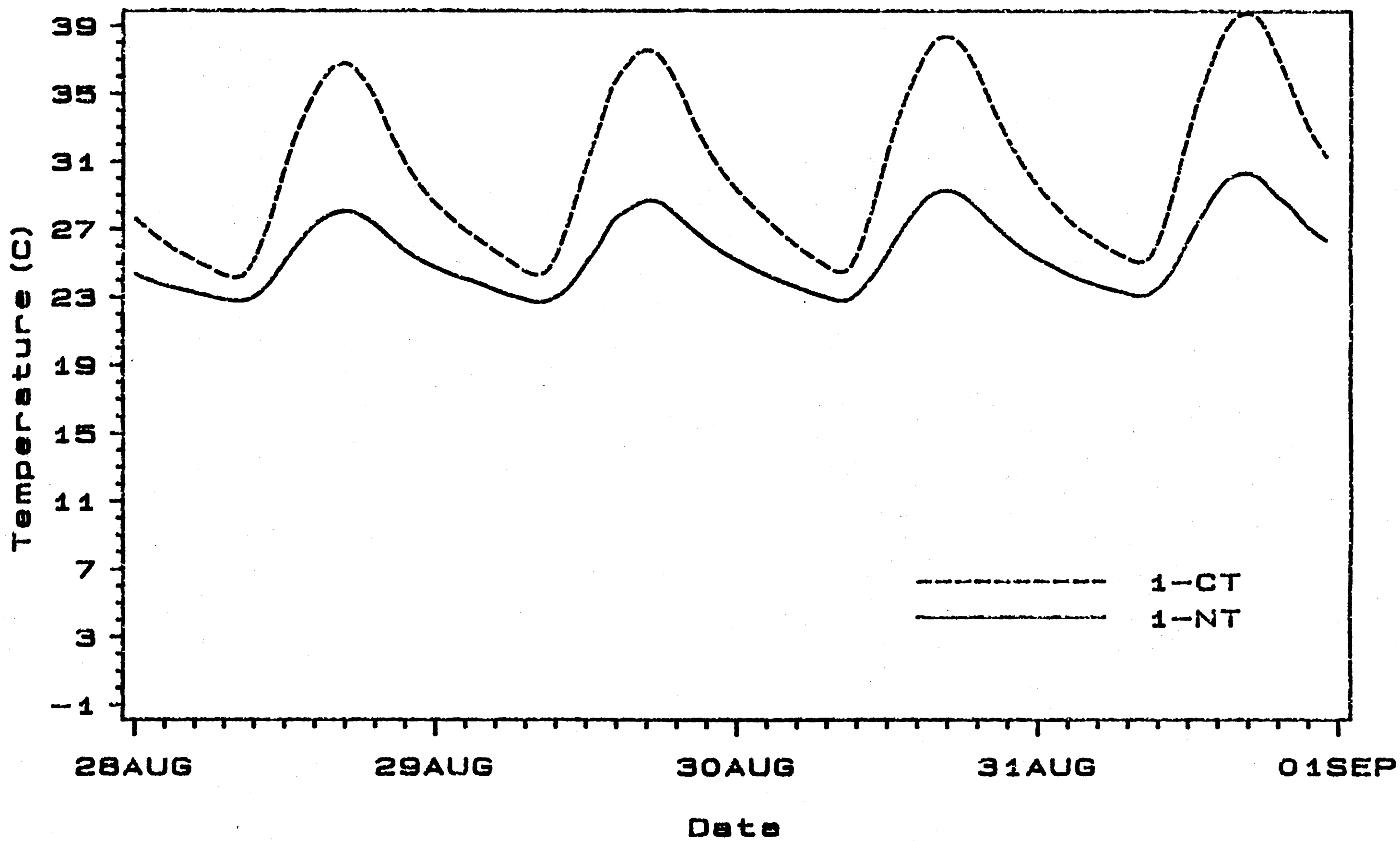

Figure 4. Soil Temperatures Under Different Tillage Systems in early fall 1985.

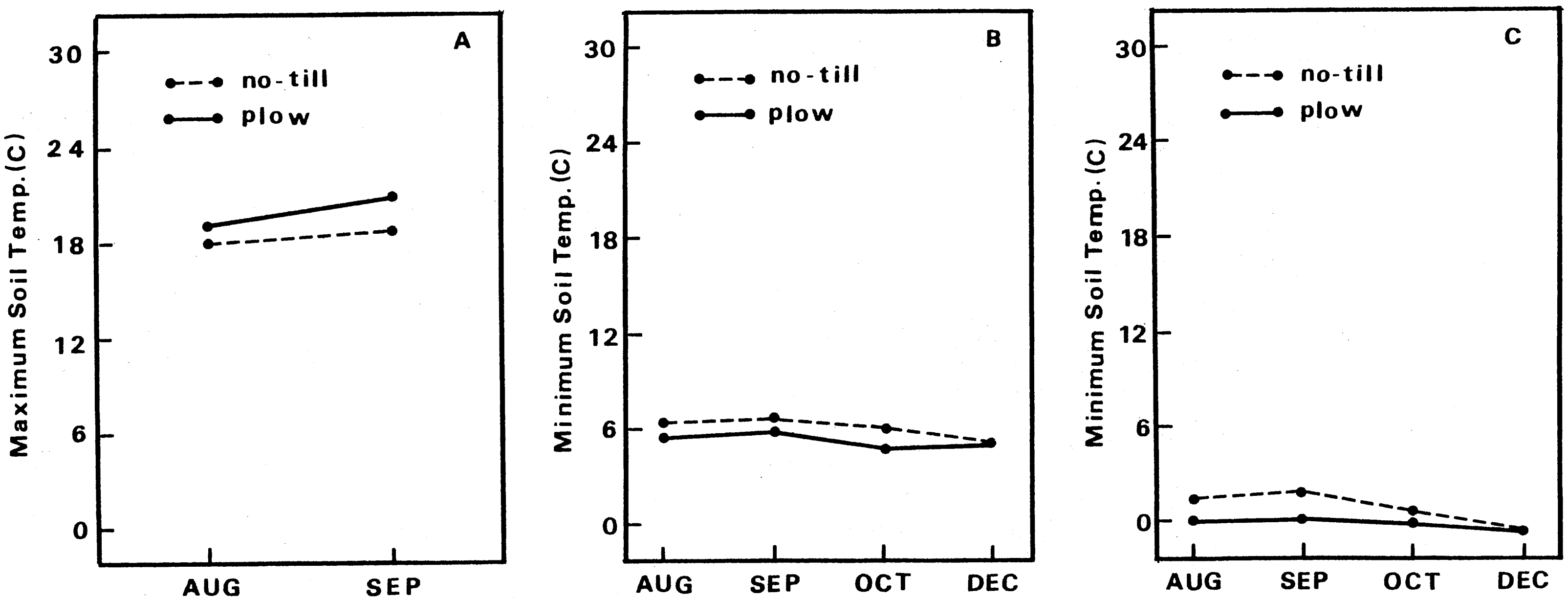

Figure 5. The Effect of Planting Date and Tillage System Upon Soil Temperatures; (a) summer; (b), (c) spring 1985 - 1986

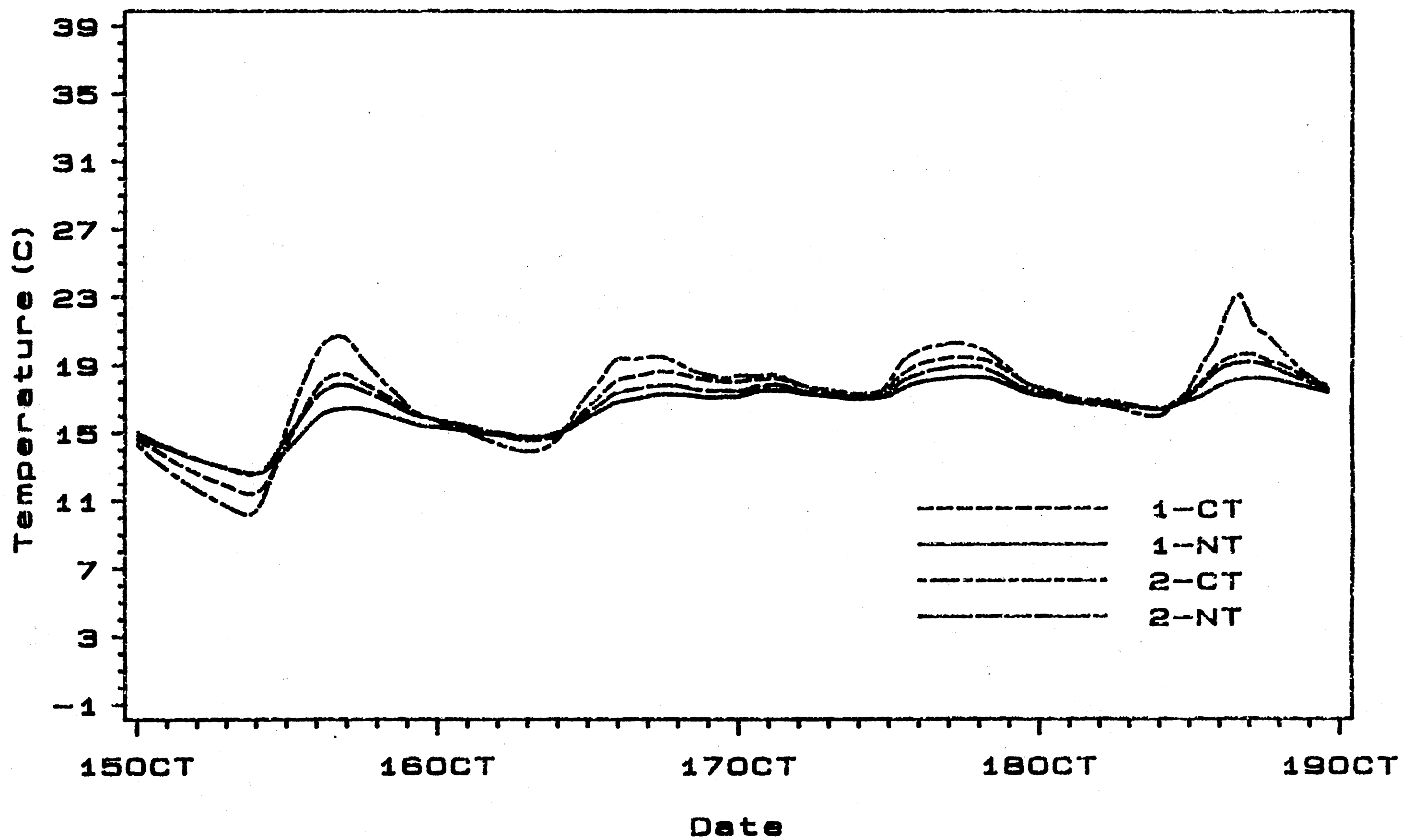

Figure 6. Soil Temperatures Under Different Tillage Systems and Planting Dates in fall 1985

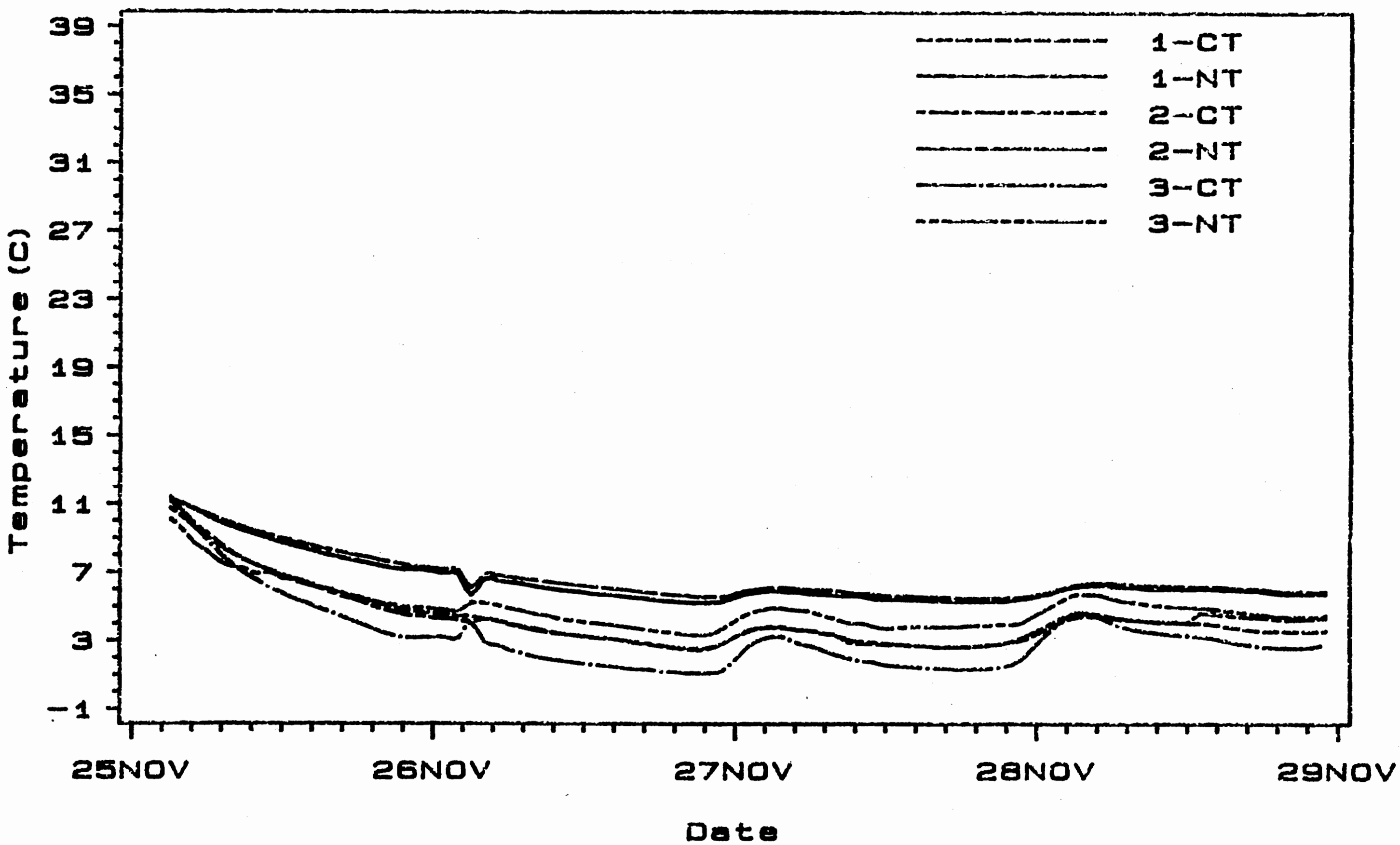

Figure 7. Soil Temperatures Under Different Tillage Systems and Planting Dates in late fall, 1985

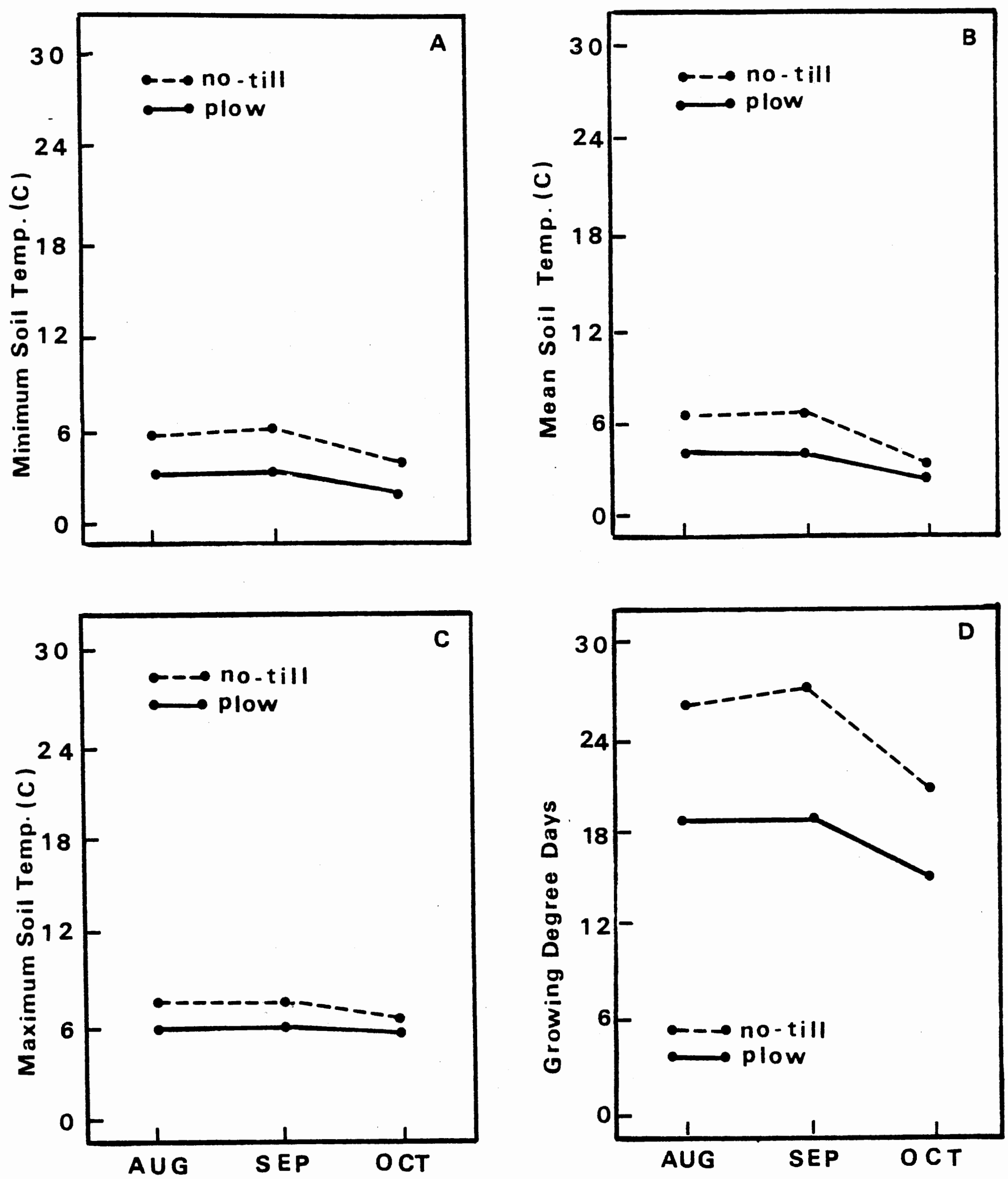

Figure 8. The Effect of Planting Date and Tillage System upon Soil Temperatures and GDD; (a), (b), (c), (d) in 25 - 29 Feb., 1986

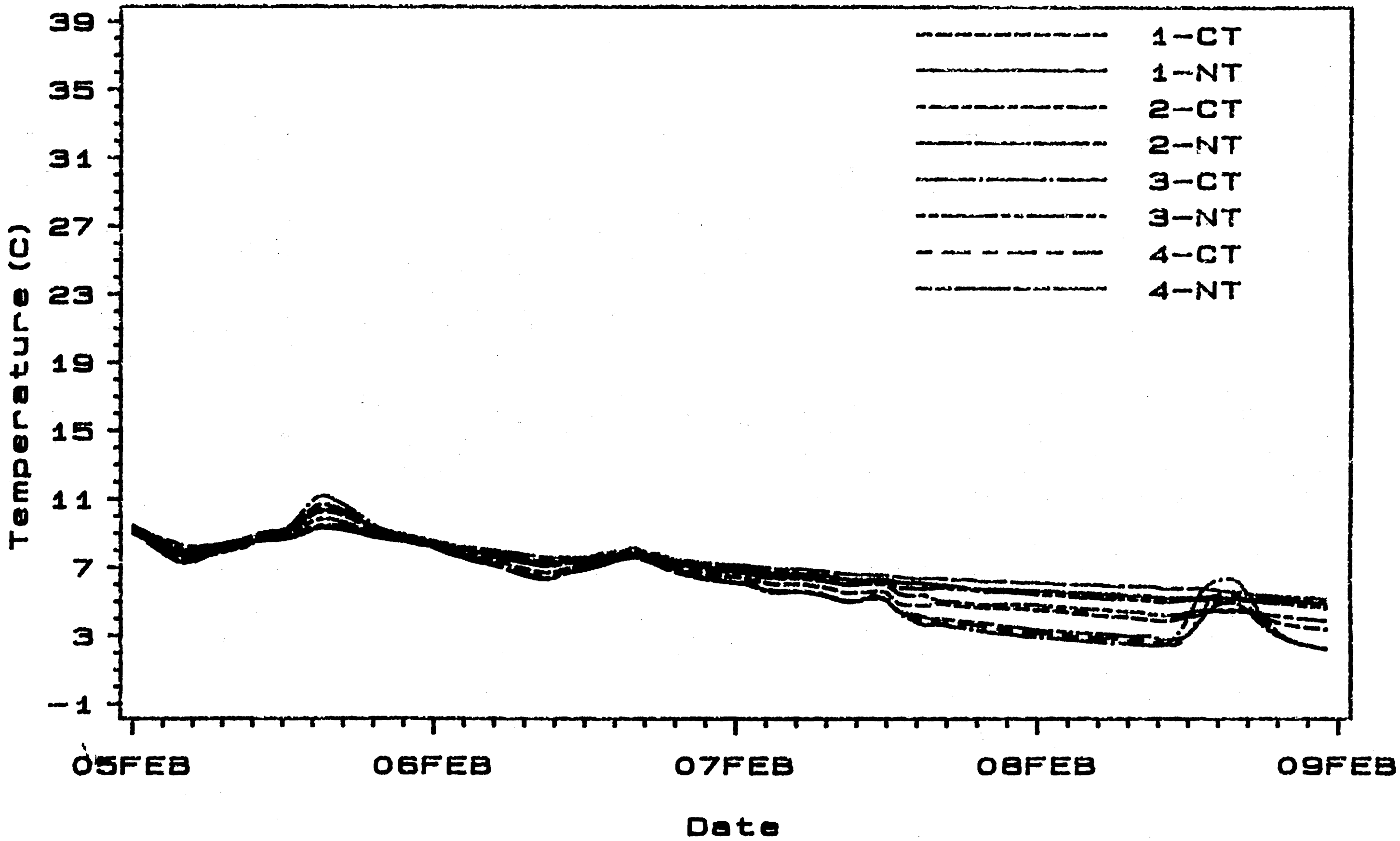

Figure 9. Soil Temperatures Under Different Tillage Systems and Planting Date in first spring 1986

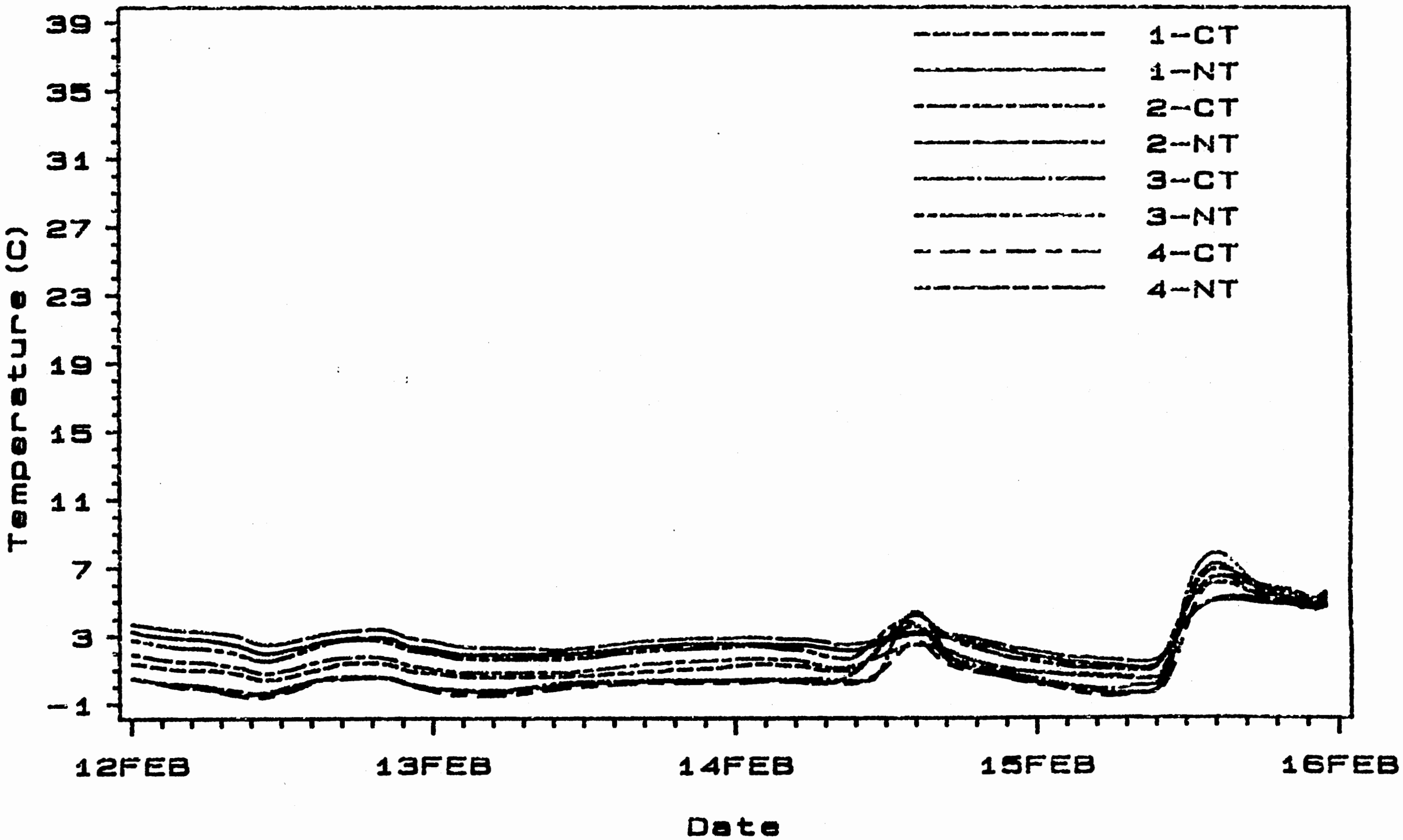

Figure 10. Soil Temperatures Under Different Tillage Systems and Planting Dates in second Spring 1986

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VITA

Ismeth Firdaus

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF PLANTING DATES AND TILLAGE SYSTEMS UPON SOIL TEMPERATURES.

Major Field: Agronomy

Biographical:

Personal Data: Born in Palembang, South Sumatera, Indonesia, October 16, 1952, the son of Mr. and Mrs. Ishak Lufty Natanegara. Married to Pudji Wijati on November 23, 1984.

Education: Received the degree of Sarjana from Fakultas Pertanian, Universitas Sriwijaya, Palembang, Indonesia in 1982; completed requirements for Master of Science degree at Oklahoma State University in December, 1988.

Professional Experience: Lecturer, Department of Soil Science, University of Sriwijaya, 1978 to 1983.

Member: American Society of Agronomy, Soil Science Society of America, Crop Science Society of America.