SOIL TEMPERATURE AND MOISTURE OF CONVENTIONAL AND ZERO TILLED SOILS IN MANITOBA

by

Lillian Elaine Gauer

A Thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
Department of Soil Science

Winnipeg, Manitoba, 1980

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ABSTRACT

Soil temperature and moisture were investigated under conventional and zero tilled soils in Manitoba. The soil types included a heavy clay, a clay loam, and a sandy loam. In conjunction with the tillage treatments, three straw management practices were imposed to determine if they could affect soil temperature or moisture in relation to tillage.

Tillage and straw management were found to have compounded effects. When the straw was spread on the surface, zero tilled soils were found to be cooler than those conventionally tilled. The opposite was true at seeding time when the straw was removed by raking. No significant differences in temperature occurred after the straw had been burned.

Soil moisture was higher under zero tillage than under conventional especially when the straw was spread, as well as when the straw was removed by raking. After burning, no significant differences in moisture occurred between conventional and zero tillage.

All differences found between tillage treatments were most significant early in the season. As the crop canopy developed, and the straw trash disintegrated, the two tillage treatments became similar in soil moisture and temperature trends.

ACKNOWLEDGEMENTS

The author wishes to gratefully acknowledge the guidance and assistance of Dr. Carl Shaykewich for never giving up when things looked impossible and for always being available to help when needed.

The efforts of Dr. Stobbe and David Rourke are sincerely appreciated, for without their efforts, none of this would have come about.

To Jim McCutcheon especially, for the use of his land, and to the other farmers interested in the advancement of farm management, the author extends a heartfelt thanks. Without their interest, there would be no government support for such studies.

Grateful acknowledgements are extended to the Canadian Department of Agriculture and the Natural Sciences and Engineering Research Council for financial support of the project.

The fine quality and dedication shown by the summer students of Martha Taylor and Leesa Sereda will not be forgotten, nor the support by friends and faculty in the Department of Soil Science. Special thanks are extended to Jim Griffiths for his significant contribution of his excellent drafting skills.

Finally, and most of all, the author is deeply appreciative for the encouragement and assistance of her family, especially of her husband John. Without his patience and understanding, the author surely would have abandoned hope sometime during the first summer.

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INTRODUCTION

"Let us not forget that the cultivation of the earth is the most important labor of man. Man may be civilized in some degree without great progress in manufacture and with little commerce with his distant neighbors. But without the cultivation of the earth, he is in all countries a savage. Until he gives up the chase and fixes himself in some place, and seeks a living from the earth, he is a roaring barbarian. When tillage begins, other arts follow. The farmers, therefore, are founders of civilization."

Daniel Webster

Zero tillage is being used on an increasing scale for crop production in Manitoba. This has occurred in conjunction with a general reduction in the level of cultivation. More farmers are now questioning the belief that a well tilled seedbed is the only acceptable method of ensuring rapid and even crop emergence in spring. The man hours involved in preparing a field are significant, especially when the farm is a one man operation, so that the few times over the field which are required in a zero till system can be considered as being quite a saving in time.

Soil erosion has removed much of the topsoil, especially on rolling, hilly land. Unfortunately, erosion has not been recognized as a serious problem on the Prairies. Conventional tillage methods promote conditions most suitable for erosion, not only due to spring run off, but also during early summer and winter when the soil surface remains unprotected. Zero tillage can eliminate almost all the loss of topsoil without reducing crop production levels (Lal, 1976; Richey et al., 1977).

This could go a long way in preventing the further deterioration of an important natural resource.

Zero tillage is a management intensive system which requires the farmer to have specific knowledge as well as management skills. By applying what is known, a good farmer can go a long way towards running a labor and fuel efficient operation. Since zero tillage is increasing in use, it seems appropriate at this time to evaluate some of the aspects associated with it in a more intensive manner. In this way, associated problems that might occur can be evaluated more effectively in the future.

In 1978 and 1979, a study was undertaken to investigate the temperature and moisture conditions on zero and conventionally tilled soils in Manitoba. The study was designed to show the changes in the soil environment brought about by the use of the zero tillage system. Three soil types, differing in drainage and texture were involved. Three straw management practices were used in an evaluation of their effects in relation to tillage. Soil temperature and moisture within the soil were considered in relation to the climate and levels of production for the area. The data collected were evaluated to determine the potential, and problems associated with zero tillage crop production.

Chapter II

LITERATURE REVIEW

2.1 SOIL TEMPERATURE

2.1.1 The Energy Balance

The distribution of solar energy ranges from the ultra-violet to the infra-red bands of the radiation spectrum. The earth's atmosphere allows the passage of radiation only at certain wavelengths and restricts that at others. Radiation is absorbed and scattered by the atmosphere. In the visible region scattering is more important, whereas, in the infra-red, the opposite is true. Solar radiation is short-wave in nature. About 15% of incoming radiation is absorbed directly by ozone and water vapor. Ozone absorbs ultra-violet while water vapor absorbs in the longer wavelength bands (Barry and Chorley, 1975).

Clouds act to reflect as well as absorb radiation. Under an overcast sky the solar radiation received at the surface is almost entirely diffuse. The total amount of energy may be reduced, although the cloud acts as a heat reservoir, reradiating energy in the long wave form back into the atmosphere. The earth reradiates energy in long wave form which is absorbed by water vapor, and carbon dioxide in the atmosphere. Nearly 40% of incoming energy is immediately reflected back from the atmosphere, clouds, and ground surface, leaving only about 60% for use within the system. In total, of the 100% of incoming radiation at the top of the atmosphere, only 47% is absorbed by the earth's surface (Barry and Chorley, 1975). 27% is from incoming short wave radiation while 20% comes from long wave energy reflected or absorbed by the atmosphere. This incoming energy is used to heat the ground and atmosphere and to evaporate water. The fraction of incoming radiation in the visible range is assumed to be 45% of total (Moon, 1940;from Monteith, 1973). The wavelengths important for chlorophyll production and absorbtion are found in this visible region.

2.1.2 Soil Temperature Response

The amount of solar radiation which is available for heating or evaporation depends on the amount which is reflected at the surface, as well as the total available. The total is affected by such factors as season, time of day, humidity, and cloud cover. The quantity of light reflected depends upon the reflection coefficient of the surface, which is known as the "albedo". A surface light in colour has a higher albedo than one which is darker. A higher albedo value is found on a straw covered soil than on a tilled surface. Van Wijk et al.(1959), reported a value of 8% for a bare soil compared to 18% for one having a straw cover. This condition results in less energy being available for use within the system, i.e. lower net radiation (Hanks et al., 1961).

The reflectivity of soils depends mainly on organic matter content, particle size, and angle of incidence of incoming radiation. A decrease in the organic matter content increases the albedo. The radiation is trapped by internal reflection at the air-water interfaces formed by the menisci in the soil pores (Monteith, 1973). This trapping results in lower albedo values with increasing water contents.

During daylight hours, the soil surface can be heated to temperatures higher than those in the air or deeper soil. From the surface, heat is conducted to the cooler regions above and below. The amount of energy which penetrates the soil depends upon such factors as structure, water content, and the thermal properties of the soil constituents, as well as the nature of the surface (Carson and Moses, 1963). Increasing soil moisture increases conductivity as well as heat capacity so that the temperature response is reduced. This means that actual temperature changes in response to a given change in available energy are greater in dry soils. (Barry and Chorley, 1975). Packing of soil particles results in better heat flow, due to the greater amount of particle to particle contact (Nakshabandi and Konke, 1965). This can result in a greater temperature response with increased compaction.

Soil temperature varies in a regular pattern reflecting both the diurnal and annual cycles of solar heating. Effects of changing weather conditions are superimposed on these regular trends. The soil temperature cycle follows a damped, lagging wave pattern, so that as the wave moves deeper into the soil, maximum temperatures are reached increasingly later in the day or year. Maximum heat flux into the ground coincides with the time of maximum solar and net radiation, although maximum air-soil interface temperatures are reached about an hour later (Carson and Moses, 1963; Carson, 1963).

The temperature wave is not symmetrical. The cooling portion is approximately twice as long as the heating (Carson, 1963), although the heating portion is more intense(Carson and Moses, 1963). During the day, vertical temperature gradients show a strong downward trend. In summer, a downward trend exists down to 100 cm. indicating that heat is being transferred into the underlying soil. At night, the temperature gradient in the top 20 cm. is reversed, as heat flows upwards towards the cooler surface (Carson and Moses, 1963).

Maximum heat exchange between the atmosphere and soil occurs in June and November, a month or two before extremes in solar radiation and surface temperatures. Heat exchange is minimal between the surface and lower soil in March and September (Carson and Moses, 1963).

At 305 cm. only minor departures from annual trends are observable whereas, at 884 cm. the seasons are reversed, with the warmest months being February and March, and the coldest occuring in July and August (Carson, 1963).

2.1.3 Soil Temperature as Related to Tillage

Zero tilled fields are often covered by a layer of straw or stubble. Because of this, the soil tends to be cooler than under conventional tillage (Lal, 1976; van Wijk et al., 1959; Hanks et al., 1961; Moody et al., 1963). The more straw that is left on the surface, the more the soil temperature is depressed (Griffith et al., 1973). The effect of the straw mulch is greater on maximum temperatures than on minimum. Minimum temperatures are the same or slightly higher than those on conventionally tilled soils. This occurs because the amplitude of the temperature wave is decreased when a straw mulch is present (van Wijk et al., 1959).

As the crop grows, the canopy intercepts more radiation and shades the soil (Lal, 1976). Also, the straw mulch disintegrates and darkens as the season progresses, so that differences due to its presence become less significant (Hanks et al., 1961).

Under some circumstances, a mulch cover can actually increase soil temperature. The transfer of heat to the atmosphere is mainly by turbulent air movement, so that management practices which cause a decrease in air movement at the surface should also decrease heat transfer to the atmosphere. Leaving stubble on the surface increases the surface roughness and usually causes a corresponding increase in turbulent air movement. At times, the straw can have an opposite effect, so that wind velocities at the soil surface are actually less. This results in a heat build-up, causing higher soil temperatures to occur under a mulch, which was illustrated by a 1953 study in Texas. Net radiation measurements showed that the mulch did not change the amount of energy available, but acted instead as a heat pump, increasing the transfer of heat into as well as out of the ground surface (Lemon, 1956).

2.1.4 Winter Temperatures

In winter, net radiation and mean air temperature are negatively correlated; the opposite to summer conditions. Minimum net radiation periods occur during sunny cloudless days, when mean air temperatures are below normal. (Monteith, 1973).

Winter soil temperatures are less subject to diurnal fluctuations than those in the summer, with the daily cycle not penetrating past 20 cm. in depth. Solar radiation is much lower in intensity and shorter in duration. As well, the ground cover acts to prevent energy from leaving or entering the soil (Carson and Moses, 1963; Hay, 1977). Fresh snow can reflect up to 85% of incoming radiation (Barry and Chorley, 1975), which greatly reduces the amount of available energy.

Snow is a very good thermal insulator, so that in winter it prevents the rapid cooling of the soil surface, and reduces heat loss to the atmosphere. When a snow cover is present, the loss of heat from the soil to the atmosphere begins later in the fall and is much more gradual, penetrating less deeply than if the soil was bare. Because of this, the depth of freezing is inversely related to the depth of snow present (Anonymous, 1962).

If water is present in the soil, its presence tends to decrease the rate of soil cooling due to its large volumetric heat capacity and relatively large heat of fusion (Carson, 1963). These factors are believed to be responsible for higher soil temperatures found under the zero tillage than those under conventional in Scotland. Poorer conditions at seeding time due to a reduction in frost action over winter gave less favorable structure in spring under zero tillage (Hay, 1977).

2.1.4.1 Effects of Stubble on Snow Cover

Straw residue strongly affects the amount of snow cover as well as its distribution in the field. Schneider et al. (1978) demonstrated that the depth of snow cover was directly related to the height of stubble, and that with increased levels of snow the soil temperatures remained warmer. This caused higher soil temperatures to occur in the zero tilled as compared to the conventionally tilled soils in winter.

2.2 TEMPERATURE EFFECTS ON PLANT DEVELOPMENT

Species differ in their temperature reguirements for germination and growth. The stage of development, genotype, age of seed, and water potential as well as other factors, all affect temperature responses. Growth occurs over a range of temperatures which include a minimum, optimum, and maximum. These cardinal temperatures are influenced by factors controlling development, therefore are not well defined (Mayer and Poljakoff-Mayer, 1975; Naylor and Fedec, 1978).

2.2.1 Germination Requirements

Germination rate decreases with decreasing temperature, so that at lower temperatures the minimum may not be well defined if the rate is extremely slow (Mayer and Poljakoff-Mayer, 1975). Cereals are in this category because they are capable of germinating at temperatures just above 0C. Wheat will emerge at a minimum of 1.3C when moisture is not limiting. The optimun temperature range for wheat growth is from 20-25C while the maximum is around 35C (Peterson, 1965).

Germination involves physical as well as chemical processes. Over the range of temperatures experienced in summer on the Prairies, the germination rate can be considered to be essentially a linear function of temperature. Higher rates than predicted from a simple linear relationship have been found under a fluctuating temperature regime, suggesting that the physical processes may not be inhibited to the same extent as the chemical at the lower temperature range (Haydecker, 1972).

The speed of germination is partially determined by the chemical processes in the seed. Kotowski (1926) demonstrated the Q_{10} values were higher at lower temperatures. This meant that a change in temperature in the cooler end of the range had more effect on the germination rate than the same change at the warmer end.

Crops having lower temperature requirements are able to germinate earlier in the spring. Blackshaw (1979) demonstrated that the higher temperature requirement of green foxtail was responsible for its poor competitive ability with spring wheat. The wheat was able to germinate and emerge at lower temperatures than the green foxtail.

Corn has a much higher heat requirement than cereal crops, being totally unable to germinate below 10C (Hough, 1972; Mayer and Poljakoff-Mayer, 1978). If planted too early, the corn seeds deteriorate (Martin et al., 1935). They can be attacked by fungus parasites such as Pythium spp., Diplodia zeae, Gibberella zeae, and others (Arnon, 1975).

2.2.2 Emergence Requirements

Relative speed of establishment is important in determining the ability of the crop to compete against weeds and produce high yields. The time required for emergence depends on factors controlling germination as well as coleoptile growth. The temperature response is similar to that of germination, in that increasing temperatures increase emergence up to an optimum point. Except under severe moisture stress, the temperature effect on the emergence of most crops is much greater than the effect of limiting moisture (Haydecker, 1972).

Low soil temperature may have a detrimental effect on crops planted too early in the spring. Plant populations can be reduced and yields lowered due to slower plant development (Scarisbrick et al., 1976).

Corn growth is controlled by soil temperature up until the six-leaf stage since the shoot apex remains slightly below ground. Lower soil temperatures can lengthen the time required for tasselling to occur (Beauchamp and Lathwell, 1967; Beauchamp and Torrance, 1969).

Deeper planting to obtain better use of the soil moisture may result in delayed growth due to lower temperatures (Lindstrom et al., 1976; Sepaskhah and Ardekani, 1978; de Jong and Best, 1979). De Jong and Best

(1979), found that the heat sum necessary for 50% emergence increased linearly as seeding depth increased from 76 degree days above 5C at 1.25 cm. to 150 degree days at 10 centimeters.

Alessi and Power (1971), discovered 60-85 degree days above 10C were required for corn emergence. Similar results were found for sorghum (Kanemasu et al., 1975).

2.2.3 Growth Requirements

Between the minimum and maximum temperatures, the rate of growth is a sigmoidal function. For corn, this range is from 12 to 26C (Walker, 1969). Small changes in temperature result in noticeable differences in the growth rate between these two points.

Lower soil temperatures caused by a mulch cover can depress yields by slowing plant development (Watts, 1972; Power et al., 1970; Scarisbrick et al., 1976). Decreased soil temperatures due to the presence of a mulch affects yields more in the cool climates than in the warm. The mean soil temperature in northern areas is lower than in southern climatic regions, which have conditions closer to optimum for corn growth. Because of this, a small temperature decline in the south is not as detrimental to corn as in the more northerly areas (van Wijk et al., 1959).

2.2.4 Acclimatization of Winter Wheat

The survival of winter wheat is dependant upon the level of cold hardiness of the variety as well as the climatic conditions which exist between seeding and the last spring frost. Because "hardening off " is an active process, the sequence of temperature changes is important in determining whether or not the plant will live through the winter. If exposed to a gradual temperature decline, the plant will be able to survive the cold. On the other hand, rapidly declining or widely fluctuating temperature conditions will destroy the crop (Fowler et al., 1975).

During hardening off, there is a gradual build up of compounds such as sugars, amino acids, and proteins, which protect the cell against freezing (Santarius and Heber, 1971). In addition, a shift in the total phytochrome occurs to forms less suseptible to frost induced dehydration. If the temperature fluctuates rapidly from day to day, the plant is unable to prepare for frost (Vincent, 1971). Maximum level of cold hardiness is attained prior to or at freeze up. From then until spring there is often a reduction in this level (Fowler et al., 1975).

Winter wheat survival on fallowed land is poor. Sowing the crop into grain stubble offers the best chance for survival. The stubble catches and holds the snow on the field, protecting the crop from temperature extremes and fluctuations. Zero tilled conditions provide a stubble cover to trap snow over the winter. This is why winter wheat has been able to survive on zero tilled fields when unable to on conventionally tilled fields (Halvorson et al., 1976).

2.3 SOIL WATER REGIME

2.3.1 Infiltration

Higher infiltration may be found on zero tilled soils. By leaving the straw on the surface, runoff is reduced, and root channels through which water can flow into the soil are stabilized (Shanholtz and Lillard, 1969; Triplett et al, 1968; Mannering et al., 1966; Richey et al., 1977). Increased earthworm activity on zero tilled soils results in an increase in the infiltration rate (Barley, 1954; from Baeumer and Bakermans, 1973).

Although water infiltrates rapidly into a plowed surface, the resistance to infiltration increases more quickly than under zero tilled conditions. Soil suction is quickly reduced to nearly zero on a tilled soil, whereas it remains high on a zero tilled field(Ehlers, 1972; from Baeumer and Bakermans, 1973). This allows more warer to infiltrate under zero tilled conditions.

2.3.2 Evaporation

Kolasew (1941) divided evaporation into three stages. The first stage is of rapid and steady water loss, depending upon the water transmission rate through the soil and above ground boundary layer. Such factors as wind speed, temperature, relative humidity, and solar radiation effect this stage, especially at the soil boundary. The end of the first stage is marked by the development of a dry diffusional barrier at the soil surface. This appears as a distinct break in the evaporation curve.

The second stage consists of a rapid decline in the evaporation rate as the soil moisture is depleted. The most important factors are not the above ground conditions, but are the factors controlling the rate of moisture supply from the soil to the surface.

The second linear stage gradually becomes the non linear third phase of extremely slow moisture loss. The third stage is governed by the absorbtive forces at the solid-liquid interfaces within the soil (Kolasew, 1941).

During the first stage, loss of soil moisture represents a thinning of the water film separating the aggregates. Moisture tensions are low and liquid movement alone is enough to account for the rapid loss. Vapor flow is insignificant.

As liquid movement becomes insufficient to meet evaporative demand, surface drying occurs. Soil suction continues to increase as the second stage is reached. The faster the initial rate proceeds, the sooner the second stage of evaporation begins. Mechanisms of moisture flow become more complex as vapor movement increases in importance. Net flow occurs towards the cooler regions as liquid moves to warmer, and vapor to cooler, in the process of capillary condensation (Gurr et al., 1952). Maximum movement occurs when the curvature of the water film is sufficient to alter the vapor pressure above it. This happens at a capillary radii of about 10^{-5} cm.(Lemon, 1956). As vapor flow becomes the dominant means of soil moisture loss, the third stage is reached.

Evaporation can be reduced by influencing the factors controlling the first two stages. To decrease the rate in the first stage, surface conditions can be altered. Any practice decreasing air turbulence at the ground will lead to reduced loss of soil moisture. A mulch cover is capable of depressing evaporation in this manner. The effects of the mulch increase with increasing thickness, although the most noticeable reduction occurs with the addition of the initial 5 mm. depth (Hanks and Woodruff, 1958).

The importance of the effect of turbulent air movement on the evaporation rate was demonstrated by Farrell et al. (1966). Turbulent diffusion of water vapor was as much as one hundred times greater than the molecular. This effect extended several centimeters below the mulch cover. Air turbulence contributed to evaporation of soil water even into the second stage of evaporation.

The evaporation rate during the first stage is depressed by lowering the soil temperature (Kimball and Lemon, 1970; Hanks, 1958). A mulch cover can decrease soil temperature and lower the evaporation rate.

The presence of a mulch was found to have the opposite effect in one study. The straw actually decreased air movement at the surface so that heat was not being lost as quickly. This resulted in higher temperatures during calm periods, which increased the evaporation rate (Lemon, 1956).

2.3.2.1 Evaporation in Field Situations

The effects of the plant-soil moisture regime are strongly influenced by the atmospheric demand for water. Aerial parts of the plant permit vapor transfer throughout a significant thickness of air. The roots withdraw moisture for transpiration from a considerable depth, thereby changing the soil moisture profile (Penman, 1947).

Under field conditions, there may be no direct relationship between soil temperature and evaporation, since other factors may be limiting. In sub-humid areas where moisture is not readily available at the soil surface, evaporation has little relation to soil temperature. Moisture loss is governed by factors controlling the second stage (Hanks et al., 1961). As well, the presence of a dry soil layer at the surface acts to prevent evaporation during the second stage (Hanks and Woodruff, 1958).

Water use is controlled by the net amount of energy reaching the soil and crop surfaces. The ground is completely exposed on a conventionally tilled field during the first few weeks of the growing season. During this time, evaporation is the dominant means of soil moisture loss. As the crop canopy develops, transpiration becomes increasingly important (Shanholtz and Lillard, 1968). When moisture is sufficient, water loss proceeds both by evaporation and by transpiration at a rate closely approximating potential use (Peters and Russell, 1959).

2.3.3 Soil Moisture and Tillage

Zero tilled fields are usually covered by a straw mulch which persists into the growing season. This mulch decreases the evaporation rate, thereby maintaining a higher level of moisture than under conventionally tillage (Moody et al, 1963; Shanholtz and Lillard, 1968, 1969; Blevins et al., 1971; Lal, 1976; Pidgeon and Soane, 1977). The straw also decreases surface runoff and increase infiltration (Moody et al., 1963; Shanholtz and Lillard, 1968). As well, Schneider et al. (1978) found that the additional amount of snow retained by the standing stubble was important in determining the level of available moisture at seeding time. As the height of stubble increased, so did the level of soil moisture in the spring. Lal (1976) demonstrated that under tropical conditions, increased organic matter content in the surface soil as well as structural differences resulting from the elimination of tillage contributed to the higher levels of moisture found under zero tilled conditions.

Increased available moisture resulting from zero tillage may be found throughout the entire growing season. Differences are greatest at seeding time, decreasing in significance as the season progresses (Moody et al., 1963; Blevins et al., 1971).

Zero tillage increases moisture more at the surface than in the lower profile. Pidgeon and Soane (1977) demonstrated that the level of moisture in the 18-30 cm. depth of conventional and zero tilled soils was similar, although the zero till did maintain a significantly higher level close to the surface.

Soil water potential is affected by tillage. Ehlers (1972;from Baeumer and Bakermans, 1973) demonstrated the soil suction was affected down to 220 cm. and that this difference due to tillage was more significant than that of water content. The zero tilled soil maintained a lower suction at the same water content as was found on the conventional. This indicated a lower resistance to water uptake by the roots, as well as higher moisture conductivity under zero tillage.

Shanholtz and Lillard (1969) compared the water use efficiency of conventional and zero tilled corn. The efficiency is a measure of actual evapotranspiration per weight of dry matter produced. More vigorous growth on the zero tilled soil required additional water. Based on rainfall and soil moisture data, water use efficiencies of 57% for the conventional and 81% for the zero tilled corn were calculated. The zero tilled system was 24% more efficient.

The effects of low moisture stress during drought periods were not as great under zero tilled conditions. Leaf curling and reduced yields were more evident on conventional as compared to zero till (Lal, 1976; Blevins et al ., 1971). Although damage resulted under either tillage system during prolonged drought,it was less evident on zero tilled soils. The greatest advantage was during short drought periods, when the zero tillage system prevented crop failure by maintaining higher soil moisture (Shanhotz and Lillard, 1968).

On many soils in Great Britain excessive soil moisture has often been a problem. Because of the higher moisture levels found with the zero system system, crops have been more at risk at seeding time, than with conventional tillage. In Britain, burning of the straw is recommended to prevent high water content from causing aeration problems, and to increase tilth (Cannell et al., 1978).

A straw cover can decrease soil temperature and depress early growth. In the United States, slower growth early in the season has often been offset by the moisture advantage found with the zero tillage system (Moody et al., 1963; Shanholtz and Lillard, 1969).

2.4 THE EFFECTS OF WATER POTENTIAL ON DEVELOPMENT

2.4.1 Germination

The difference in the water potential between the soil and seed governs water uptake. As the seed approaches water contents necessary for germination, its hydraulic conductivity approaches that of the soil in the dry end of the available water range. The potential difference between the seed and soil decreases to the point where the soil potential governs further uptake by the seed (Shaykewich and Williams, 1971).

The critical water potential for germination varies with the species as the seeds differ in their ability to absorb water (Hunter and Erickson, 1952). FOr example, at a given potential, the water content of wheat seeds is higher than that of rapeseed, although the germination of rapeseed is much more sensitive to changes in water potential (Ward and Shaykewich, 1971; Shaykewich and Williams, 1971).

At high suctions, the rate of germination is affected by the area of contact between the seed and soil water, which is influenced by the hydraulic potential. As suction decreases, so too does the significance of the contact area (Collis-George and Hector, 1966).

The rate of germination increases as soil suction decreases. Species differ in the level of response to changing suction. Wheat germination is affected only slightly. Pawloski and Shaykewich (1972) showed that the germination rate of wheat was greatly reduced near the permanent wilting point, but not at higher potentials. Owen (1952) found that at water potentials below the permanent wilting point, total germination of wheat was neither greatly inhibited nor reduced.

Rapeseed germination is reduced below -2.8 bars and completely inhibited at -15.3 bars (Williams and Shaykewich, 1971). The difference between wheat and rapeseed germination is attributed to the higher rate of water uptake by the wheat seed (Pawloski and Shaykewich, 1972).

Water potential can affect the minimum temperature requirement for germination. De Jong and Best (1979) showed that decreasing the potential from -6 to -10 bars, lowered the minimum temperature requirement of wheat from 1.3C to 0.5C or 0.2C. Hough (1972) also found water potential to affect the temperature response of corn, finding a lower temperature requirement under wet conditions. It was suggested that this response was to help compensate against the effects of cool, wet soils (de Jong and Best, 1979).

2.4.2 Emergence

The rate of emergence is affected by soil water potential in much the same way as is the germination rate. A decrease in the potential can cause a decrease in the rate as well as in the final percentage. Although the rate of emergence is affected in cereals, the final percentage is not, until the potential drops to below the permanent wilting point (Sepaskah and Ardekani, 1971; Hanks and Thorpe, 1956).

Soil strength increases with increasing suction (Pidgeon, 1978). At lower potentials, restricted coleoptile and root growth occur due to high soil strength. Increasing soil strength can decrease the emergence of small seeded crops such as rapeseed if crusting occurs (de Jong and Rennie, 1967).

2.4.3 Growth

Before a complete crop canopy has developed, the relationship between yield and moisture use is nearly linear when water supply is limiting. Early moisture stress is more harmful than later, although vegetative growth can be closely correlated to water availability, because of leaf turgidity.

Cultivars which are capable of emerging quickly at low potentials are not necessarily the ones that will do well when subjected to dry conditions later on (Gul and Allan, 1976).

The main factors which determine how well the plant uses water are the root distribution pattern and the ability of the root to absorb water. Wheat is capable of withdrawing water at suctions greater than 15 bars (de Jong and Rennie, 1967). Work by Yang and de Jong (1968) indicates that this could be as dry as 40 bars.

2.5 POROSITY

Tillage may alter the total porosity of the soil. Zero tilled soils tend to have lower total porosities than those tilled by conventional methods (Gowman et al., 1978; Hamblin and Tennant, 1979; van Ouerkerk and Boone, 1970; Pidgeon, 1978). The extent of this reduction is partially determined by texture. Pidgeon (1978) found total porosity to be reduced more on a clay loam than on a sandy loam. Baeumer and Bakermans (1973) reported an average decrease in the total porosity ranging from 0% to 6% when zero tillage was adopted.

At other times, tillage may not effect the total porosity (Hamblin and Tennant, 1979) or may even cause a reduction. This reduction occurs on unstable soils subject to problems of compaction (Skidmore et al., 1975).

Total porosity decreases under conventional tillage as the season progresses, but remains at a higher level than found under zero till. The porosity on a zero tilled soil remains at an equilibrium level throughout the season (Burwell et al., 1963).

Pore size distribution is also affected by tillage. Use of zero till results in fewer large pores as well as a greater homogeneity in porosity (Gowman et al., 1978; van Ouwerkerk and Boone, 1970; Ehlers, 1972;

from Baeumer and Bakermans, 1973; Finney and Knight, 1973; Tomlinson, 1974).

For soils having lower than 3% total porosity, cultivation is recommended. A soil ideally suited to zero tillage should have over 10% of the volume occupied by pores greater than 60 microns in diameter (Gowman et al., 1978).

Over a long period of time, zero tillage may result in an increase in soil porosity. This can occur with the opening of natural channels due to frost action, and to the presence of intact roots (Baeumer and Bakermans, 1973).

Earthworms are also important in increasing porosity. Earthworm tunnels are continuous large pores, which are often connected to the surface. An estimate of the relative space occupied by them can be used as an indicator of pore continuity. Often this space on a zero tilled soil is more than double than that on conventional (Ehlers, 1972; from Baeumer and Bakermans, 1973) Increased earthworm activity is due to the increase in population. Populations have been reported to increase by factors of 1.6 (Wilkinson, 1967); 4-5 (Lal, 1976); and even up to 16 (Schwerdtle, 1969; from Baeumer and Bakermans, 1973). Along with the root channels, earthworm tunnels give a predominately vertical orientation of larger pores. This compensates for the reduction in the total volume of large pores, which occurs under zero tilled conditions (Ehlers, 1972; from Baeumer and Bakermans, 1973).

2.6 AERATION

The ability of the soil to supply the root with oxygen is known as the oxygen diffusion rate (ODR), and varies with total porosity, pore size distribution, and water content. Any management practice resulting in compaction or smearing of the soil can be expected to cause aeration problems when moisture levels are high. Soils having low porosity and high water holding capacity, such as clays, will have lower aeration than the better drained soils such as sandy loams (Wiegand and Lemon, 1958). If the majority of the pores are small, most will be occupied by water when conditions are wet, resulting in insufficient oxygen supply to the roots (Ehlers, 1972; from Baeumer and Bakermans, 1973).

The diffusion of oxygen from the atmosphere to the root increases linearly with the logarithm of the soil moisture tension, so that as the soil dries, the ability of the soil to transfer oxygen increases. A minimum value of 10% air filled porosity is believed to be necessary for adaquate gas exchange(Letey and Stolzy, 1964). A value of 12% was reported for corn (Grable, 1967; van Diest, 1962).

Oxygen requirements of the root vary with the species, temperature, age of plant, and moisture content of the soil. During germination and emergence, oxygen needs are higher than for later growth (Stolzy and Letey, 1964). Wheat requires an oxygen diffusion rate of 75 to 100 x 10^{-8} g/(cm^2 min) for emergence (Hanks and Thorpe, 1956).

Root respiration is the most sensitive aspect to soil aeration. The first effect of reduced oxygen supply is a reduction in root growth. Normal root elongation is suppressed below an ODR of 30 x 10^{-8} g/(cm^2 min) and completely inhibited below 20 x 10^{-8} (Stolzy and Letey,1964).

Ethylene produced in anaerobic respiration acts to suppress the growth of the roots, causing similar injury to plants as what occurs under flooding (Kramer, 1951). Ethylene is produced when the oxygen level in the soil atmosphere falls below 2%. The increase in the ethylene level mirrors the decrease in the level of oxygen (Smith and Restall, 1971). This effect is greater on sunny days when respiration proceeds at a rapid rate. (Fulton and Erickson, 1964).

The effects of ODR on vegetative growth are variable. The influence of aeration depends upon the species, stage of growth, root radius, and how well the crop is established. Above an ODR of 40, vegetative growth no longer increases, although reproduction continues to respond favorably with greater oxygen supplies (Letey et al., 1963).

An increase in temperature results in an increase in respiration. This higher demand for oxygen is partially offset by an increase in the ODR of 1-2% for one degree celcius (Letey et. al., 1963).

Aeration is altered by tillage. Plants growing on poorly drained soils respond favorably to increased levels of tillage (Grable, 1967). Because zero tillage causes a reduction in the number of large well-drained pores, a higher percentage of the pore volume is occupied by water than air. This can result in a limiting oxygen supply (Pidgeon and Soane, 1977; van Ouwerkerk and Boone, 1970; Ehlers, 1972; from Baeumer and Bakermans, 1973).

2.7 COMPACTION

The ability of the soil to resist or recover from compaction while maintaining satisfactory pore size distribution and drainage is important in determining the soil suitability for zero tillage (Pidgeon and Ragg, 1979).

During the preparation of a conventional seed bed, approximately 90% of the field is covered by tractor wheels (Soane and Pidgeon, 1975). Richey et al. (1977) suggested that with moderate and low energy systems, like zero tillage, compaction could be reduced, not only by decreasing the number of trips across the field, but by using lighter, lower powered equipment.

Tillage loosens the soil surface, thereby decreases bulk density (Pidgeon and Soane, 1977; Pidgeon, 1978). Zero tilled surfaces are higher in bulk density than those of conventional, deep plowing, or chisel plowing. Pidgeon and Soane (1977) found that the difference in bulk density decreased down to a depth of 20 cm., below which the conventional was the same as the zero tilled. Zero tilled soils also show higher resistance to penetration (van Ouwerkerk and Boone, 1970; Hamblin and Tennant, 1970; Pidgeon and Soane, 1977).

As the season progresses, recompaction of the tilled surface occurs due to subsequent wheel traffic (Soane et al., 1976; Rao et al., 1960) and rain drop impact (Hamblin and Tennant, 1979).

Under zero tilled conditions, an equilibrium level of compaction is reached within three years (Pidgeon and Soane, 1977; Soane et al., 1976). This level may be detrimental to crop growth. On soils having aeration problems, or high mechanical strength on drying, a decrease in emergence, root development, and yield may result (Hay et al., 1978; Soane et al., 1976). Bulk density values of 1.2 to 1.3 g/cc. on a silty clay loam, 1.3 to 1.4 on a silty loam, and 1.5 to 1.6 g/cc. on a sandy loam, can severely limit wheat emergence at field capacity (Hanks and Thorpe, 1956). These values are in the range found on zero tilled soils (Pidgeon and Soane, 1977).

2.7.1 Surface Crusting

Surface crusting occurs when surface aggregates are broken down, resorted, and repacked, so that a continuous layer of relatively fine particles covers the soil. On drying, this crust may limit emergence. A soil crust can often prevent the emergence of rapeseed, whereas wheat is able to penetrate it easily (de Jong and Rennie, 1967).

A finely worked seedbed is susceptible to crusting. Thus conventionally tilled fields suffer more crusting problems than zero tilled. Surface crusting occurs much less frequently on zero tilled soils, because the surface is more protected. The surface mulch protects the soil from raindrop impact preventing particle breakdown (Richey et al., 1977; Baeumer and Bakermans, 1973).

Higher modulus of rupture measurements on tilled soils indicate a higher susceptibitity to crusting (Skidmore et al., 1975).

2.7.2 Root Growth as Related to Compaction

Root growth follows the path of least resistance in a structured soil (Soane and Pidgeon, 1975). The presence of clods having high bulk density and mechanical strength decreases the volume of soil available for growth. As such, plant response is related to the strength of the soil, for an increase in strength will increase the resistance to root growth (Pidgeon and Soane, 1977).

Restricted root development may occur on zero tilled soils. Hamblin and Tennant (1979) found that wheat roots were restricted to shallow depths and that the growth pattern was affected under zero tillage. The main roots were thicker. All roots showed signs of distortion and proliferation of root hairs just behind the growing point. Fanged roots as well as broken off root tips resulting from high soil strength were also discovered (van Ouwerkerk and Boone, 1970).

Increased trafficability when using zero tillage has been attributed to increased soil strength (Gowman et al., 1978). Pidgeon and Ragg (1979) reported that the zero tilled areas could be seeded during a rain when conditions were too wet to seed conventionally tilled fields. Structural damage was avoided by using a light tractor.

Restricted root growth due to the presence of a plow pan may occur on conventionally tilled soils. The plow pan developes because of excessive traffic over the surface (Hamblin and Tennant, 1979; Lal, 1976; Rao et al., 1960).

The use of zero tillage may reduce or elimimate the effects of this compacted layer after a number of years (Hamblin and Tennant, 1979). This occurs from the effects of increased earthworm activity and the presence of roots, which add organic matter and structure to the soil (Rao et al., 1960).

2.7.3 The Characterization of Compaction

The characterization of soil compaction is a problem. Soane and Pidgeon (1975) pointed out that the main difficulty in properly assessing the relationship between plant growth and soil conditions was that the measurements easiest to make may not be the ones showing the greatest significance. Such is the case for bulk density. The effects of soil suction, pore size distribution, mechanical impedence, as well as bulk density, all interact on the development of the root. Bulk density in itself is an unreliable measure of the soil resistance to root penetration. Soil strength as measured by a cone penetrometer tends to be a much more useful measurement (Pidgeon and Soane, 1976; Milford et al., 1961).

At a constant water content, bulk density increases with soil strength, but if the water content should change this need not be the case (Pidgeon, 1978). Camp and Gill (1969) demonstated soil strength increased as water content decreased.

Cone resistance is related to soil strength and is independent of texture (Pidgeon, 1978). It is a better indication of root growth especially on soils having little structural development (Harrod, 1975). On the other hand, on structured soils roots tend to follow cracks, these being the natural avenues of least resistance. Penetrometer readings high enough to limit root growth have been recorded on zero tilled soils (Buhtz et al., 1970; from Baeumer and Bakermans, 1973). This may be offset by natural structural development (Baeumer and Bakermans, 1973).

2.8 LITERATURE SUMMARY

Lower soil temperatures are found under zero tillage at seeding time. This is attributed to the presence of a straw cover on the surface of the zero tilled soil (Lal, 1976; van Wijk et al., 1959). These lower temperatures cause a reduction in early corn growth because of this crop's high heat requirement (van Wijk et al., 1959).

Higher soil moisture levels are found under zero till management. The increase is attributed to the presence of the straw cover which acted to depress evaporation (Moody et al., 1963). As well, differences in pore size distribution help to maintain higher levels of moisture (Gowman et al., 1978).

An increase in available water is found to increase the germination rate of rapeseed and wheat in certain suction ranges (Shaykewich and Williams, 1971). The emergence rate of wheat can also increase with an increase in moisture (Hanks and Thorpe, 1956).

Differences in temperature and moisture become less significant as the season progressed and as the crop canopy develops (Moody et al., 1963; Blevins et al., 1971).

Reduced total porosity (Gowman et al., 1978) as well as increased compaction (Pidgeon and Soane, 1977) occurs on some soils under zero till management. This may result in aeration problems on poorly drained soils (Pidgeon and Soane, 1977).

The suitability of the soil for zero tillage management has been shown to depend on the ability of the soil to resist or recover from compaction and changes in porosity (Pidgeon and Soane, 1979). Decreased yields with zero tillage are attributable to poor soil conditions resulting from the elimination of tillage (van Ouwerkerk and Boone, 1970).

Chapter III

METHODS AND MATERIALS

3.1 SITE DESCRIPTION

Three soil types differing in texture and drainage were used.

3.1.1 Graysville

One site was located on the Plant Science Research Station (legal description 24-6-6W). The soil was a well drained Riverdale fine sandy loam (Ellis and Shafer, 1943) with the surface layer consisting of 76% sand, 15% silt, and 13% clay. The zero tilled plots had been established two years previous to the start of the investigation. The experimental area was seeded to wheat in 1977 and 1978, and to rapeseed in 1979. Measurements began in 1978.

3.1.2 Homewood

The Homewood site was located on the farm of Jim McCutcheon (legal description 6-7-3W). The soil was a poorly drained Sperling clay loam (Ehrlich et al., 1953), with the surface layer consisting of 57% clay, 25% silt, and 18% sand. Soil texture varied vertically with depth, so that the location of the winter wheat study was underlain by sandy clay at a depth of about 76 cm. The field had been under zero tillage management for three years previous to the study. Rapeseed was sown into cereal stubble in the spring of 1978. Winter wheat was sown the following autumn.

3.1.3 Sanford

The Sanford location was on a very poorly drained Osborne clay (Ehrlich et al., 1953) 10 miles west of the town of Sanford (legal decription 23-8-2W). The soil consisted of greater than 80% clay. The soil had not been tilled for two years prior to 1979. The area was not seeded in 1978, because excessive soil moisture prevented seeding. In 1979, rapeseed was sown into a volunteer wheat stubble.

In 1979, seeding was delayed at Sanford and Graysville because of spring flooding in the Red and Boyne River valleys.

3.2 TILLAGE METHODS

The type and amount of cultivations used on conventionally tilled plots are shown in Table 1. The zero tilled plots were undisturbed except by the seeding procedure. Plots at Sanford and Graysville were established and seeded by David Rourke from the Department of Plant Science. Cultivation and seeding were performed at Homewood by Jim McCutcheon, who used similar methods as listed for Rourke.

TABLE 1

Cultivation Methods for Conventionally Tilled Plots

Location	Operations	Number of Operations	Time
Graysville 1978	Double Disced	2	Fall
	Double Disced	2	Spring
	Harrowed	2	Spring
Graysville 1979	Double Disced	2	Fall
	Double Disced	2	Spring
	Harrowed	2	Spring
	Packed - prior to seeding	1	Spring
Sanford 1979	Deep Tilled	2	Fall
	Cultivated	1	Spring
	Harrowed	2	Spring

Operations performed by David Rourke, Dept. of Plant Sci., University of Manitoba.

3.3 SOIL TEMPERATURE

Soil temperature was measured during the growing season, as well as during the 78-79 winter at Homewood. Thermocouples positioned on wooden probes placed in the ground measured temperature at 2.5, 5., 10., and 20. cm. depths. The probes were placed facing north. This was to allow a truer measurement of the temperature within the soil by minimizing heat transferrence by the black electrical tape which held the thermocouples on the probes. The treatments which were tested are listed in Table 2.

Readings were taken periodically throughout the day by using automatic recording potentiometers. At Graysville, chart recording models(1) recorded temperatures every 4 or 6 hours, depending on the

TABLE 2

Straw-Tillage Treatments Tested

Location	Year	Tilled(T)	Zero Tilled(U)
Graysville	1978	Scattered(ST)	Scattered(SU) Removed(RU)
Homewood	1978	Scattered(ST)	Scattered(SU)
Graysville	1979	Scattered(ST) Removed(RT) Burned(BT)	Scattered(SU) Removed(RU) Burned(BU)
Sanford	1979	Scattered(ST) Removed(RT) Burned(BT)	Scattered(SU) Removed(RU) Burned(BU)

machine setting. At Homewood and Sanford, digital print out potentiometers(2) were used. They recorded temperatures every three hours, except during the winter, when they were set to record once daily.

Temperature probes were installed in duplicate on all plots except at Homewood where they were installed in triplicate. Periodic malfunction of the potentiometers resulted in some gaps in the data.

At mid season, deeper temperature probes were installed at Graysville and Sanford. These placed thermocouples at 50, 100, and 150 cm. in addition to the four shallower depths. Temperature measurements using these probes were taken weekly with a portable potentiometer.

3.4 SOIL DEGREE DAYS

Soil degree days above 5C and 10C were calculated for the seeding depths from the collected data. The depths of seeding were 2.5 cm. for the rapeseed and 5 cm. for the wheat. They were accumulated to determine the heat energy available in the seeding zone for crop germination, emergence, and early growth.

For a given day, the degree days were calculated according to the equation:

$$\sum_{i=1}^{n} (Ti - Tbase)/n$$

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(1)Honeywell mulitpoint recorder from Honeywell Industrial Products Group, Phila., Pa.

(2)Campbell CR-5 digital recorder from Campbell Scientific Inc., Logan, Utah

where Ti = Temperature at a given observation time
Tbase = base temperature:
5C for cereals and oilseeds
10C for corn
n = number of temperature readings per day

Daily totals were summed over the growing season.

By using information collected by Rourke concerning the dry weight of the wheat and rapeseed, accumulated dry weight was graphed against soil degree days above 5C to determine if the straw-tillage practice caused a difference in the growth response to soil heat.

3.5 EMERGENCE STUDY

From the literature, regression equations relating germination and emergence to temperature were developed for various crops (Table 3). An example of how the regression calculations were done can be found in the appendix.

Equations for wheat and rapeseed were developed after an emergence study was completed under controlled conditions. Rapeseed (Brassica campestris c.v. Torch) and wheat (Triticum aesitivum c.v. Sinton) were planted in soil maintained at constant temperatures. Days to 50% emergence were recorded and a regression equation of the form:

$$1/D = b(T - Tbase)$$

was calculated for each species. In this equation;

D = days to germination, emergence, or growth stage
b = calculated regression coefficient
T = temperature at given observation time
Tbase= calculated base temperature

The data for the wheat was combined with data from de Jong and Best (1979) to increase the accuracy in the lower temperature range. The regression equation calculated from the combined data was used in the study. By using these equations and the soil temperature data stored on computer files, days to germination or emergence for the various crops were predicted.

TABLE 3

Regression Equations Relating Time of Development (Days) to Temperature

CROP	STAGE FROM PLANTING	REFERENCES USED
	Time to 50% germination	
Wheat	1/D =.025(T + 4.024)	Pawloski and Shaykewich (1972) Blackshaw (1979)
Green Foxtail	1/D =.0083(T-4.9)	Blackshaw(1979)
	Time to 50% Emergence	
Wheat	1/D =.012(T - 1.8)	de Jong and Best (1979)
Rapeseed	1/D =.014(T - 1.2)	
Beans	1/D =.0232(T - 7.7)	Scarisbrick et al.(1976)
Corn		
-Moist soil	1/D =.0093(T - 5.9)	Hough(1972)
-Dry soil	1/D =.0093(T - 8.2)	
	Time to the 4th leaf stage	
Corn	1/D =.0026(T - 3.75)	Beauchamp and Lathwell (1967)

3.5.1 Corn Development

Because the temperature requirements of a crop change from one growth stage to the next, four different regression equations calculated from the data of Beauchamp and Lathwell (1967) were used for corresponding growth stages. It was assumed that using four separate equations would be more accurate than only using one equation to predict the time to the 6-leaf stage. These equations are listed in Table 4.

Using the given regression equations and the averages of all replicates at a given depth and observation time, the days to the end of each stage were predicted.

3.6 SOIL MOISTURE AND BULK DENSITY

Gravimetric soil moisture was taken in 5 cm. intervals to a depth of 20 cm. throughout the growing season. Three to four replicates were used for each straw-tillage treatment.

TABLE 4

Regression Equations used for Corn Development

Stage 1 : Planting to Emergence	$1/D = .0152(T - 9.4)$
Stage 2 : Emergence to 2-Leaf	$1/D = .0121(T - 3.9)$
Stage 3 : 2 to 4-Leaf	$1/D = .0051(T - 2.5)$
Stage 4 : 4 to 6-Leaf	$1/D = .0138(T - 10.6)$

Based on data from Beauchamp and Lathwell, 1967.

At seeding time, the samples were taken by using small cylinders of known volume. By pressing the cylinder into the soil and carefully removing the sample and cylinder, the sample could be trimmed to the volume of the surrounding cylinder. The samples were removed, weighed, oven dried and reweighed. Bulk density and volumetric water content were calculated at seeding time, using this technique. Six replicates were taken for each straw-tillage treatment for bulk density.

For the remainder of the growing season, only gravimetric water content was determined by using four replicates.

In 1978 volumetric water content was determined to a depth of 135 cm., using a neutron moisture meter. Access tubes were installed at mid season and readings were taken on a weekly basis until harvest.

3.7 AERATION

When the soil was wet in 1978, aeration measurements were taken at Homewood by using the platinum microelectrode method, as described by Letey and Stolzy (1964). Ten replicates per depth were used for both conventional and zero tilled soils. The number of replicates was high because of the nature of the measurements. The microscopic variability of the soil required that a large number of readings be taken, to ensure that a representative value was obtained.

Readings were not taken in 1979 because of low soil moisture. At low moisture levels, the surface of the electrode is not entirely covered by water. Oxygen diffusion rate decreases as the area covered becomes less, so that at low moisture contents, the readings are meaningless

(Birkle et al., 1964). As well, because of the delicate nature of the platinum electrode, installation is impossibe in hard, dry soils.

Chapter IV
RESULTS AND DISCUSSION

4.1 SOIL TEMPERATURE

Depending upon the type of straw-tillage practice, time of season, and variations in microclimate at the surface, zero tillage was found to either decrease,(Figure 1) increase (Figure 6) or have no effect on the soil temperature. The main emphasis is placed on the conditions which occurred at seeding time, although consideration also is given to soil temperature differences which occurred later in the growing season.

4.1.1 Straw Scattered Treatment

This kind of straw management is commonly used by farmers, so that it can be considered as being the normal. As well, most researchers have used this type of straw management when working on zero tillage.

Maximum daily temperatures were depressed by as much a 6C due to the presence of the straw mulch (Figure 1) (Figure 2). Minimum temperatures were only slightly affected, if at all. This resulted in a lower average daily temperature on the zero tilled soil as compared to the conventional. Average weekly temperatures were also lower on the zero till treatment at Graysville and Sanford, especially early in the growing season (Figure 3).(See appendix.)

A straw covering of 2.5 to 5 cm. in depth remained on the zero tilled surface after seeding had been completed. Fall and spring discing were used to work the straw into the conventionally tilled soil, so that the surface was essentially bare. The trashy zero tilled surface was lighter in colour than the tilled, so less radiation was being absorbed (Hanks et al., 1961).

As the season progressed, the straw mulch darkened in colour and disintegrated so that the effects of the straw covering decreased. The effects of this straw management practice did last well into the growing season, persisting much longer than those of other types. If the straw decomposed slowly, then the effects were even noticed to a small degree

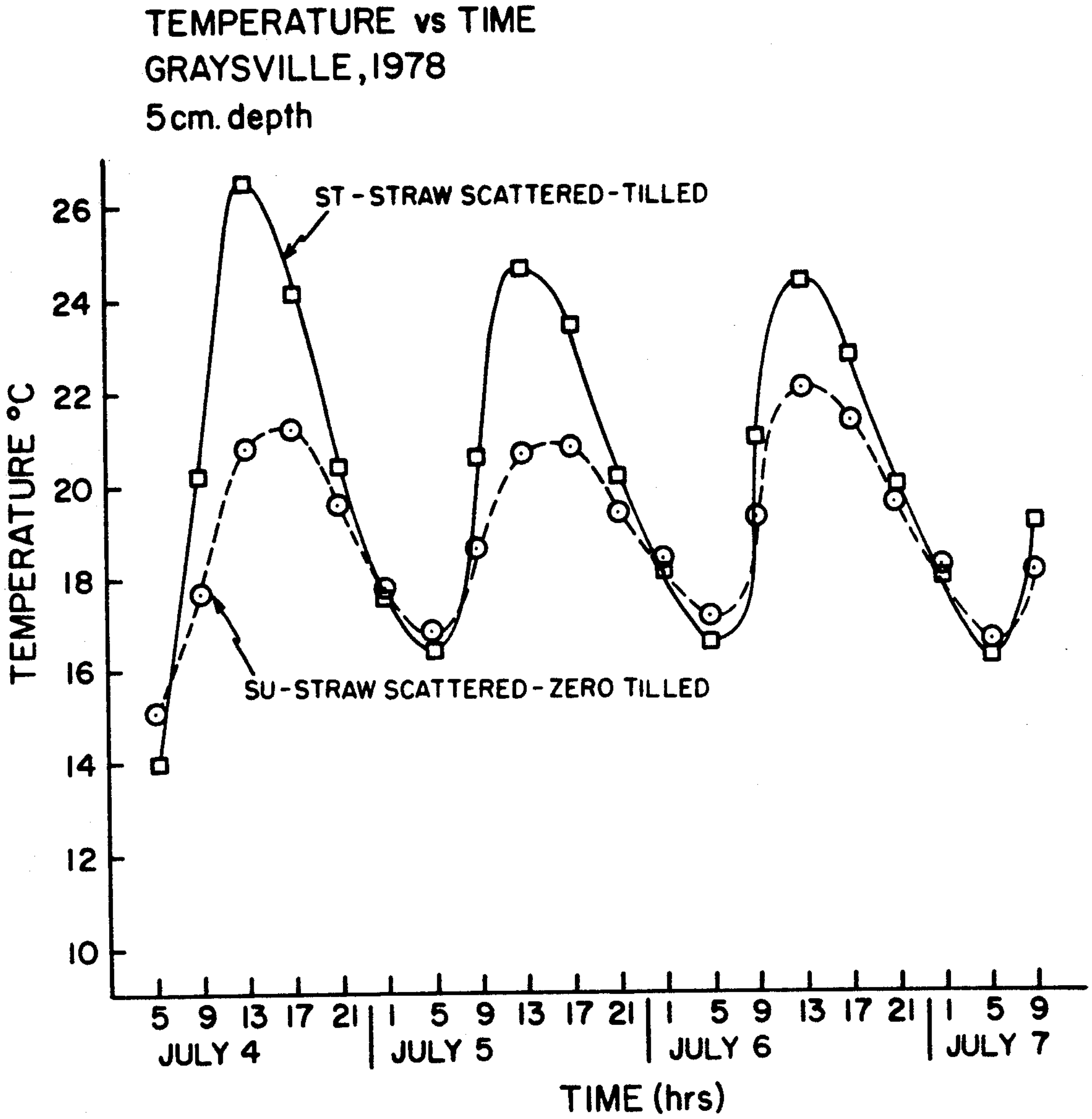

Fig. 1 The diurnal temperature variation under the straw scattered treatment at Graysville, 1978.

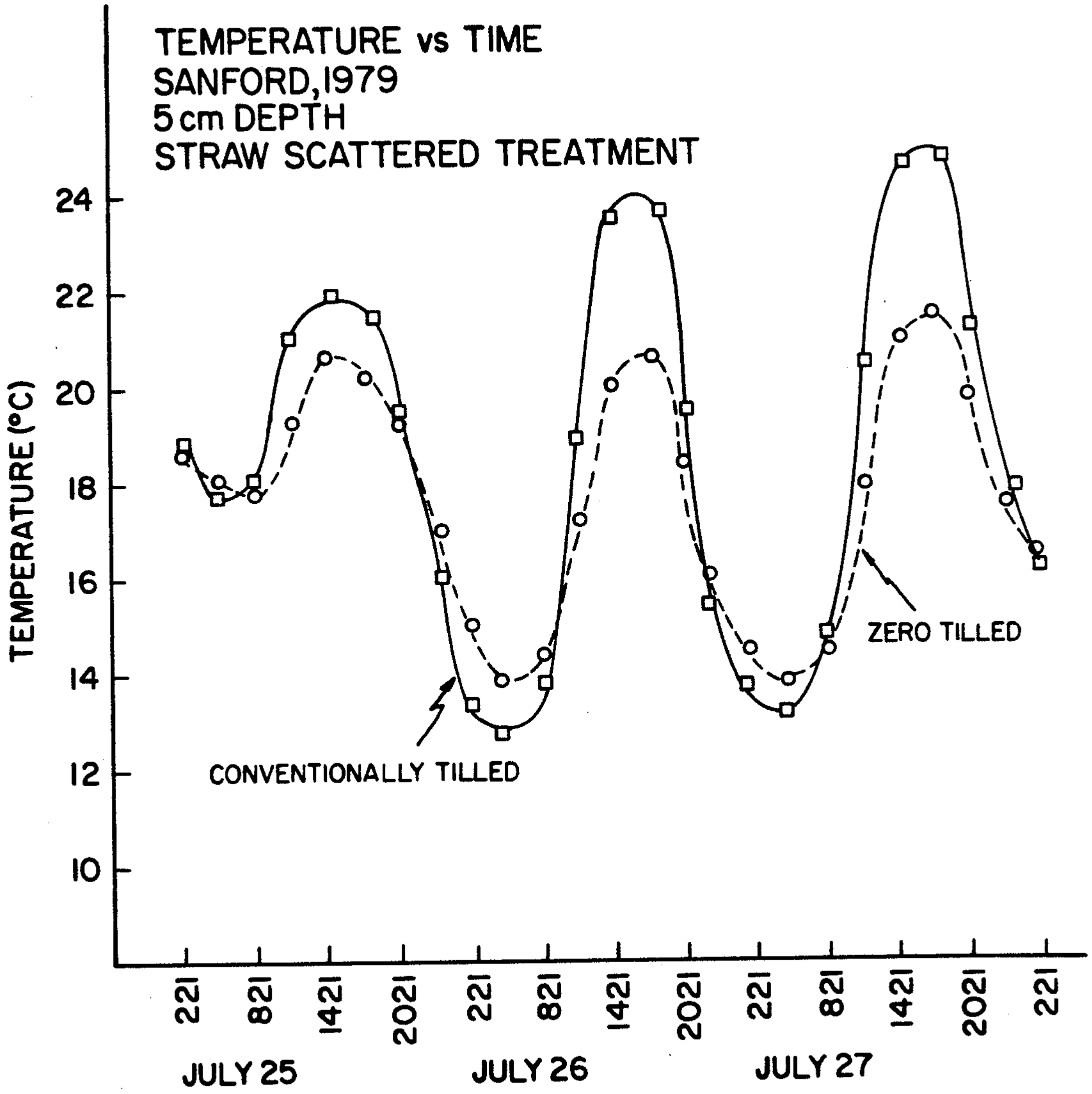

Fig. 2 The diurnal temperature variation under the straw scattered treatment at Sanford, 1979.

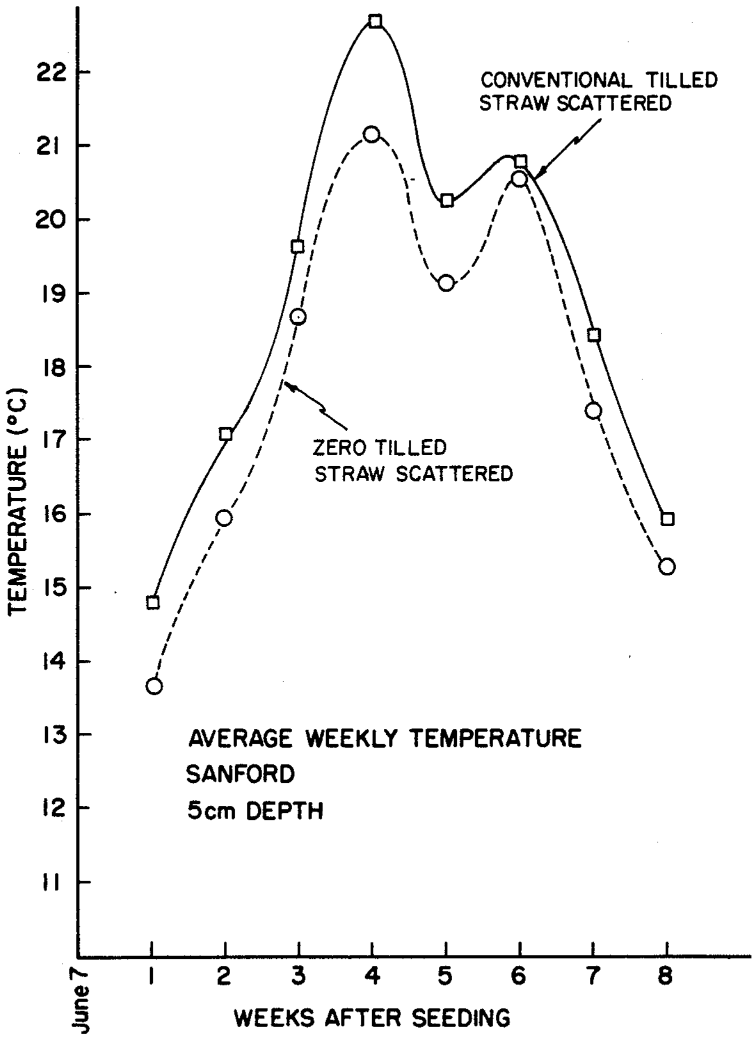

Fig. 3 Average weekly temperatures under the straw scattered treatment at Sanford, 1979.

at the end of the season, as occurred in 1978 at Graysville. Usually the differences were not noticeable after mid July.

In this study, no problems with straw persistence from one year to the next were encountered. The straw was from small grained cereals and tended to break down readily. Problems might be encountered with tougher stemmed crops such as rapeseed and corn, which break down at a slower rate. Removal of the straw may be desirable, especially if large amounts are involved, so that problems relating to drill penetration of the seedbed are kept to a minimum. As well, Griffith et al. (1973) demonstrated that the depression of soil temperature was directly related to the depth of the straw mulch. This study illustrated that even 5 cm. of straw could depress maximum soil temperature by as much as 6C (Figure 1). Care should be taken in preventing large straw build-ups from occurring. Some Manitoban farmers who have tried zero tillage, have encountered problems with crop emergence due to uneven spreading of the straw because of concentrations of straw in localized areas throughout the field. This can be avoided with proper management procedures. Straw chopper and spreader attachments can do much in the way of preventing localized build-ups, and resulting problems due to cold soil temperatures.

4.1.2 Straw Scattered Treatment at Homewood, 1978

During the early part of the growing season, higher soil temperatures were found under a straw mulch (Figure 4) on a frequent, but sporadic basis . At first, the possibility that the higher spring temperatures could have been caused by higher winter temperatures was considered. At mid season, maximum temperatures occurred at different times on the zero and conventional fields (Figure 5). This difference in phase between the two systems was similar to one reported by Lal(1976). At the time, it was considered that the phase difference might have been caused by a difference in the energy stored in the clay loam under the two management systems. Closer examination of the data revealed that when higher temperatures occurred under zero tillage than under conventional at the 2.5 cm. depth, they did not follow or occur at the same time as higher temperatures at the 5 cm. and 10 cm. depth. This meant that the temperature phenomena originated at the surface. Also, since there was no information in the literature supporting the first theory, a different approach was used.

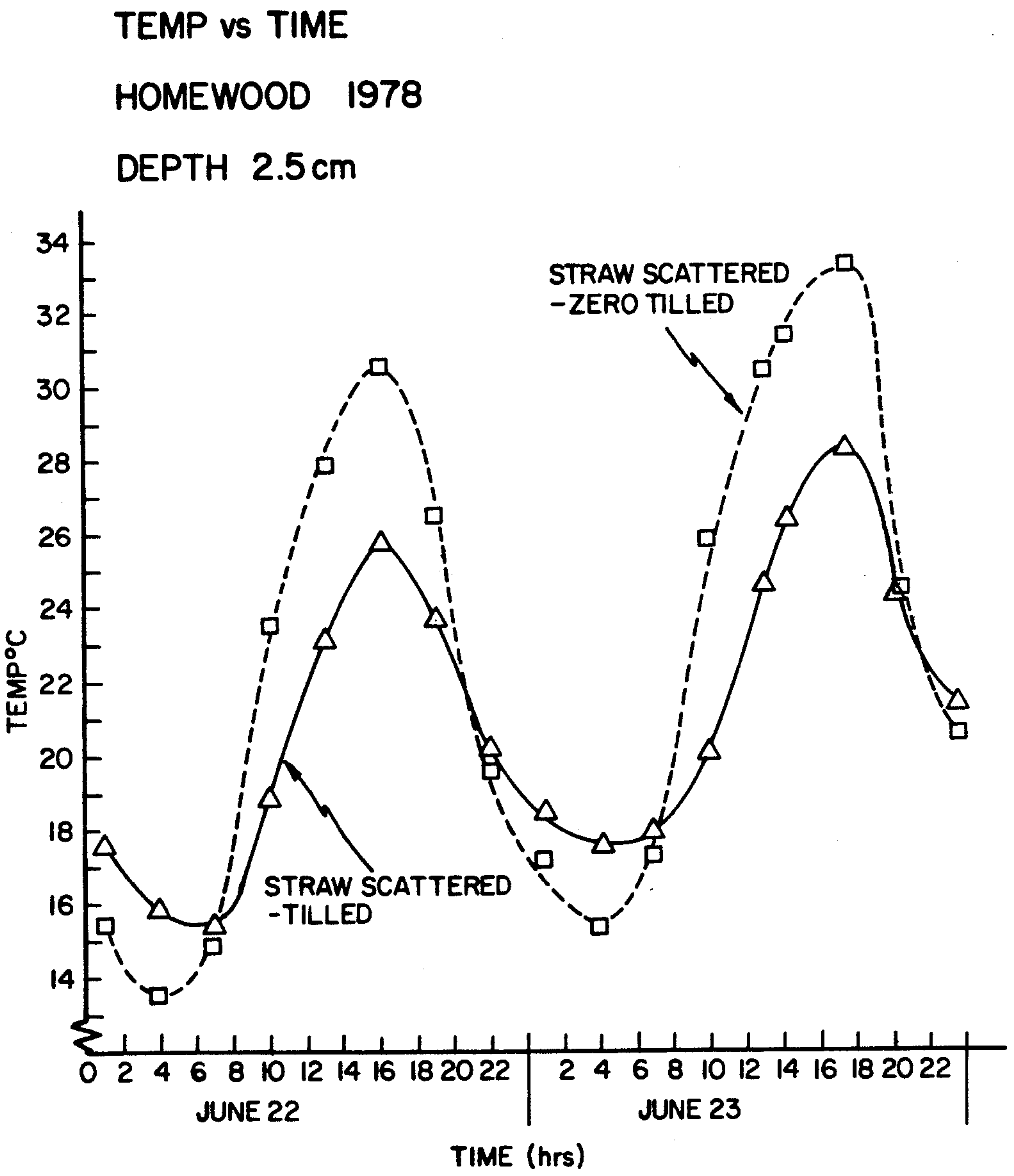

Fig. 4 The temperature variation found at Homewood under a straw cover, 1978.

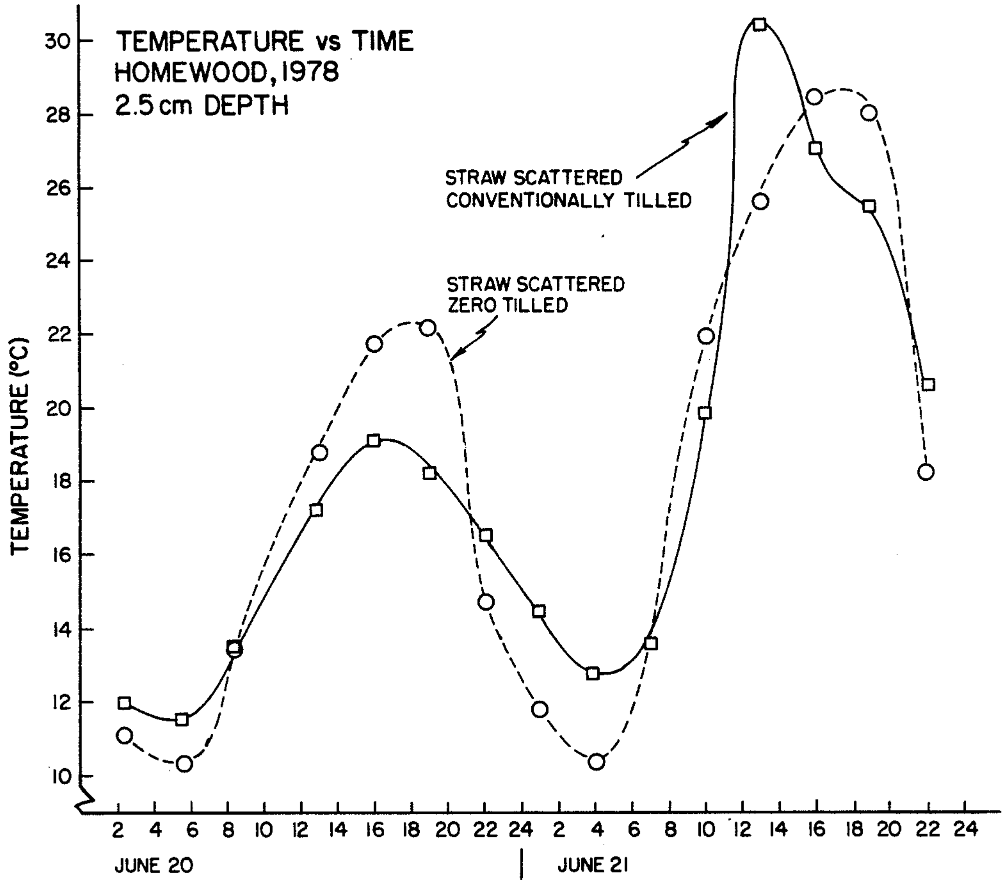

Fig. 5 Out of phase diurnal temperature variations under two tillage treatments at Homewood, 1978.

Conditions were similar to those found in a 1953 study in Texas. Lemon (1956) proposed a theory which could be applied to this study's results as well as to the study in Texas. He found that a straw cover increased the rate of soil water evaporation by increasing soil temperature. Higher temperatures resulted from the effects of the mulch cover on the wind patterns at the soil surface. The straw depressed turbulent air movement so that heat loss to the atmosphere was also depressed. At these times, the straw cover acted as a heat pump, increasing the amplitude of the diurnal wave. Maximim temperatures were higher while minimum were lower. Similar temperature patterns occurred in the 1953 study.

Although no air movement data was collected, the sequence of events leading to the phenomena described by Lemon (1956) could have caused a similar occurrence at Homewood. The higher temperatures occurred sporadically, but frequently under a straw cover during the early to mid season period. The event may have been related to surface air patterns, as described by Lemon, explaining its transitory nature.

The occurrence of higher temperatures under a straw mulch was not expected. The event has been found and recorded, but only infrequently. The conditions leading to it were brought about by a unique microclimatic situation at the surface. Possibly, these surface conditions interacted with local wind patterns in such a way that was only possible for that particular mulch and particular wind pattern.

This event should not be considered in the same light as the tillage study, because it was an unusual occurrence. Zero tillage cannot be expected to increase soil temperatures when the straw remains on the surface, under normal conditions.

4.1.3 Straw Removal Treatment

Straw removal simulated the effects of baling. Quite different temperature effects resulted between zero and conventional tillage systems at seeding time, as compared to when the straw was scattered on top of the surface. Whereas the zero tilled soil was lower in temperature in the presence of a mulch at seeding time, it was higher when a mulch was absent (Figure 6). At Graysville and Sanford when the straw was removed in 1979, the temperatures were higher on the zero than on the conventionally tilled system. On the sandy loam, the increase mainly affected the maximum daily temperatures (Figure 6) but on the clay, temperatures were affected throughout the day (Figure 7), even though the moisture content was higher (Figure 19). This difference in soil temperature lasted until late June on the clay, but only occurred for a couple of weeks after planted on the sandy loam.(See appendix.)

The greater amount of compaction which occurred under zero tillage was probably responsible for the difference. The greater amount of particle to particle contact within the soil increased heat flow into the untilled surface (Nakshabandi and Konke , 1965). As the season progressed and the plowed surface became compacted by successive wetting and drying cycles, the differences became less noticeable and finally disappeared.

When the straw was removed, a layer of chaff often remained on the zero tilled surface. The chaff did not depress soil temperature like the straw had. However, the thickness involved was much smaller, so that any effect would have been less. If the chaff had been the same depth as the straw, then similar results would have been found. The chaff would have acted in the same way as the straw. Under normal farming conditions, problems with chaff build-ups may occur in localized areas throughout the field. If these conditions act to depress emergence and early growth, then the placement of a chaff saver on the combine could be helpful. This would remove the problem of having to deal with the finely divided material, and would also help to remove unwanted weed seeds from the trash.

When the straw was removed, no depression of soil temperature occurred on the zero tilled soil. In fact, temperatures were somewhat increased. The literature contains no information on the effects of straw removal on soil temperature differences under zero and conventional tillage. Hopefully by examining this possibility a little more closely, the recommendations will be able to be widened so as to be more specific for the different straw management practices for the various soil and climatic areas.

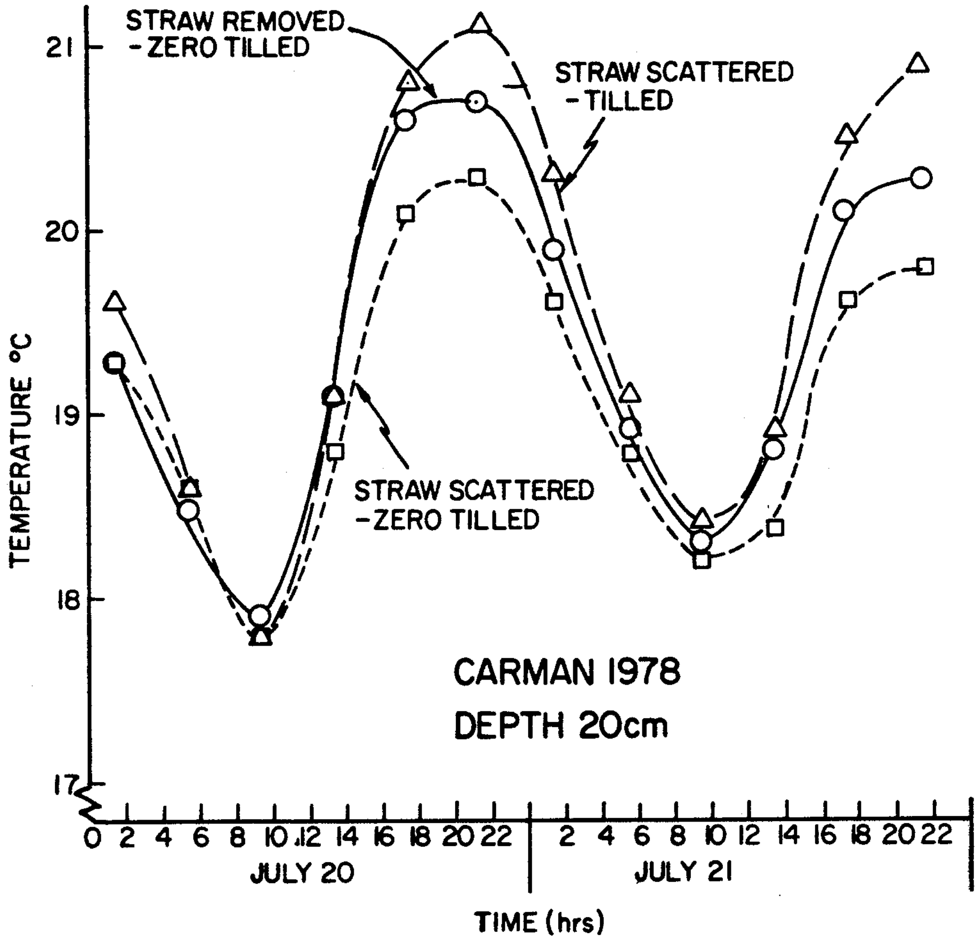

Fig. 6 The diurnal temperature variation under the straw removed treatment at Graysville, 1978.

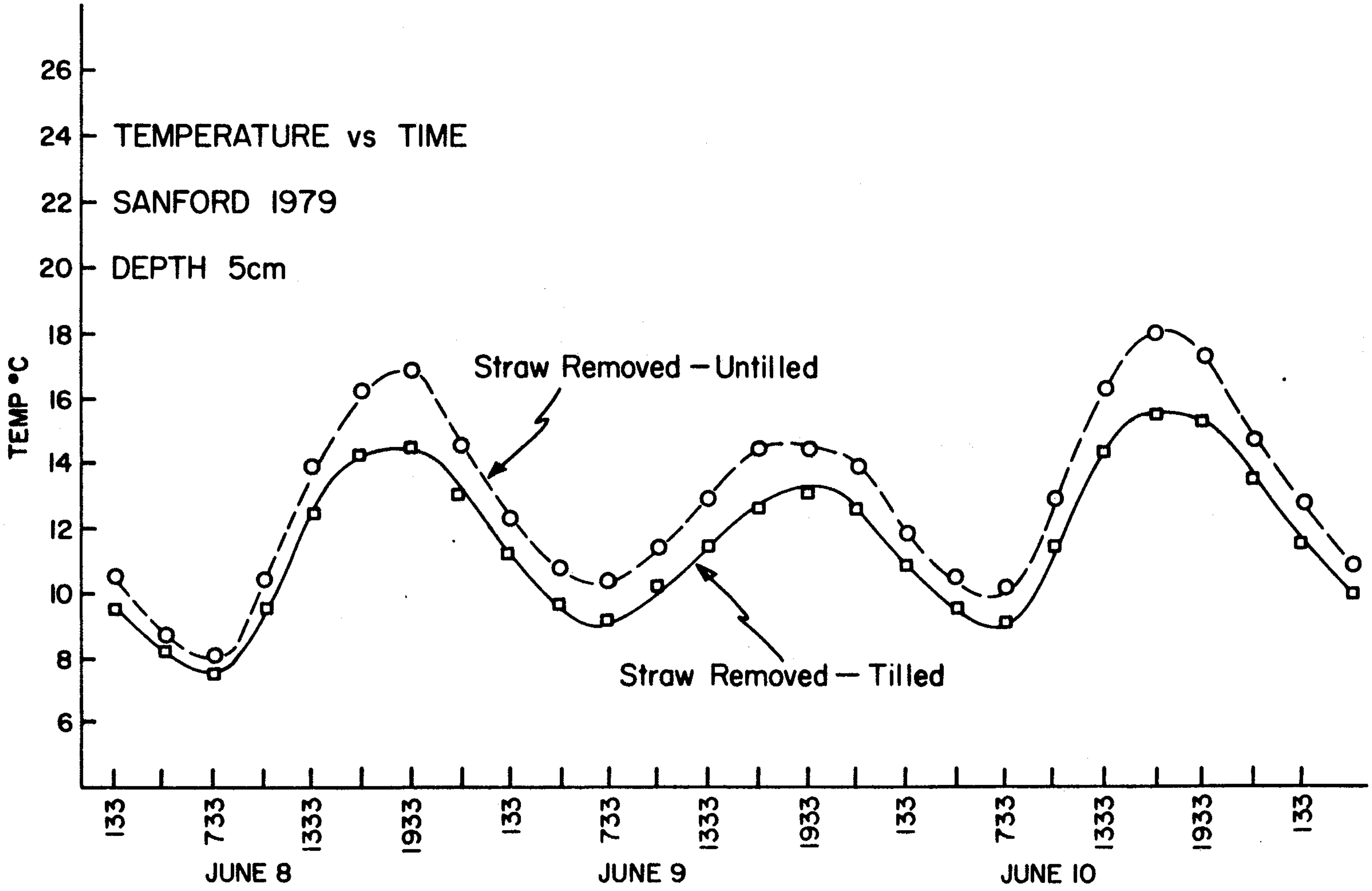

Fig. 7 The diurnal temperature variation under the straw removed treatment at Sanford, 1979.

4.1.4 Straw Burned Treatment

When the straw was burned, the zero tilled surface was dark in colour, similar to the colour of the conventionally tilled soil. This meant that both tillage systems produced surfaces that absorbed similar amounts of incoming radiation. At Graysville and Sanford the difference in soil temperature between the two tillage treatments was very slight. Conventional and zero tillage produced almost identical maximum and minimum temperatures at Graysville (Figure 8).

At Sanford there was a more noticeable difference in soil temperature patterns due to tillage practices, although it was still quite small (Figure 9). At seeding time, the zero tilled soil was .5 to 1C warmer at all times of the day. This was probably due to the higher bulk density of the zero tilled soil. This difference did not persist long after seeding, so that it was of minor importance.

Of all the straw management practices, the straw burned-zero tilled produced the most similar temperature conditions to the conventional tillage system. The effects of burning on the soil organic matter and structure are not well known. Removal of the straw makes the soil more susceptible to erosion (Lal, 1976). As well, burning the straw residue can result in unfavorable environmental conditions due to air pollution. Caution is needed in approaching the possiblity of using this somewhat drastic but effective method of trash management.

4.1.5 Winter Soil Temperatures under Zero Tillage

Soil temperatures remained higher and fluctuated less under the zero tilled conditions as compared to those under conventional (Figure 10). The difference in temperature varied less at the lower depths, which were less subject to atmospheric influences (Figure 11). Because of the wide temperature fluctuations and the very low temperatures involved, the survival rate of the winter wheat was less than 1% under conventional tillage. On the zero tilled field, the temperature decline was gradual and fluctuations were relatively insignificant, so the rate of survival was high. The zero tilled conditiond rarely produced severely low soil temperatures. The lowest readings obtained from the end of November to the end of January are listed in Table 5. Conditions were favorable for winter wheat acclimatization under zero tillage. This has been supported by similar findings of Halverston et al. (1976).

TABLE 5

Lowest temperatures(C) recorded during the winter

DEPTH (cm.)	CONVENTIONAL	ZERO TILLED	DIFFERENCE
0.0	-21.1	-12.8	8.3
1.0	-20.2	-10.2	10.0
2.5	-19.2	-9.8	9.4
5.0	-17.8	-8.5	9.3
10.0	-16.1	-7.2	8.9
20.0	-13.8	-7.0	6.8

Average difference = 8.8C

Snow cover was the factor controlling soil temperature. Schneider et al. (1978) demonstrated the importance of leaving the stubble on the field to maintain the snow. They demonstrated that the depth of snow was directly related to the height of stubble and that increased amounts of snow produced higher soil temperatures. The rapeseed stubble in this study was left at a height of 15 cm. so that it did have good snow holding potential, and was able to maintain the snow on the field. The snow cover insulated the soil against rapid heat loss and large temperature variations. The covering of snow on the conventionally tilled field was poor, most of it having been blown away. Where the snow had blown off of the borders of the zero tilled field, the winter wheat had died as under conventional tillage.

The use of reduced tillage in our climatic area could make winter wheat production possible in spite of extemely low air temperatures. As long as the snow remains on the field, the crop is protected from extreme environmental conditions. This is not usually possible with a conventional system, because the wind blows the snow off of the field. Zero tillage eliminates this problem by the use of stubble. The severity of the winter need not be considered as a hinderance to winter wheat production, unless snowfall is greatly below average or only occurs late in the winter. In these cases, soil temperatures would be similar on the conventional and zero tilled areas.

4.1.6 Soil Temperature :General Observations and Remarks

The type of straw-tillage practice influenced soil temperature, separately and together, especially at seeding time. As the season progressed, the crop increasingly shaded the soil surface from incoming

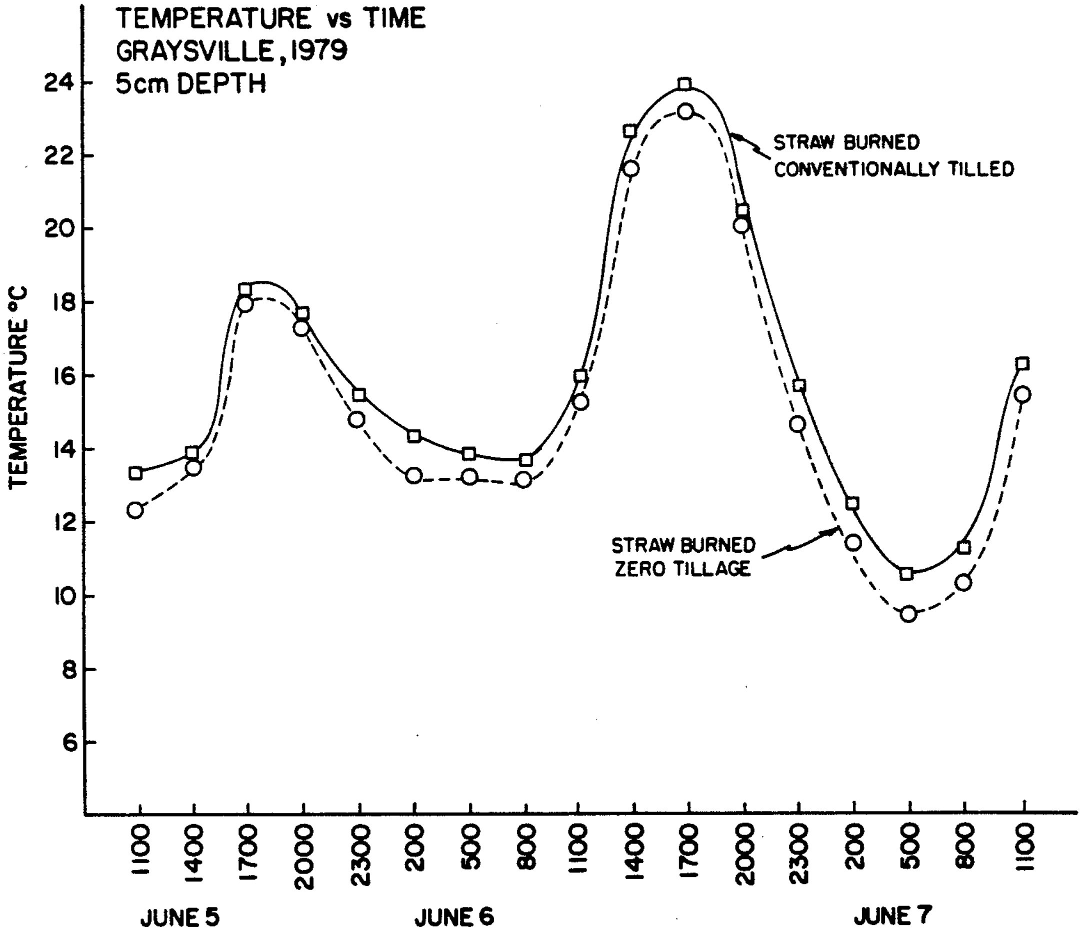

Fig. 8 The diurnal temperature variation under the straw burned treatment at Graysville, 1979.

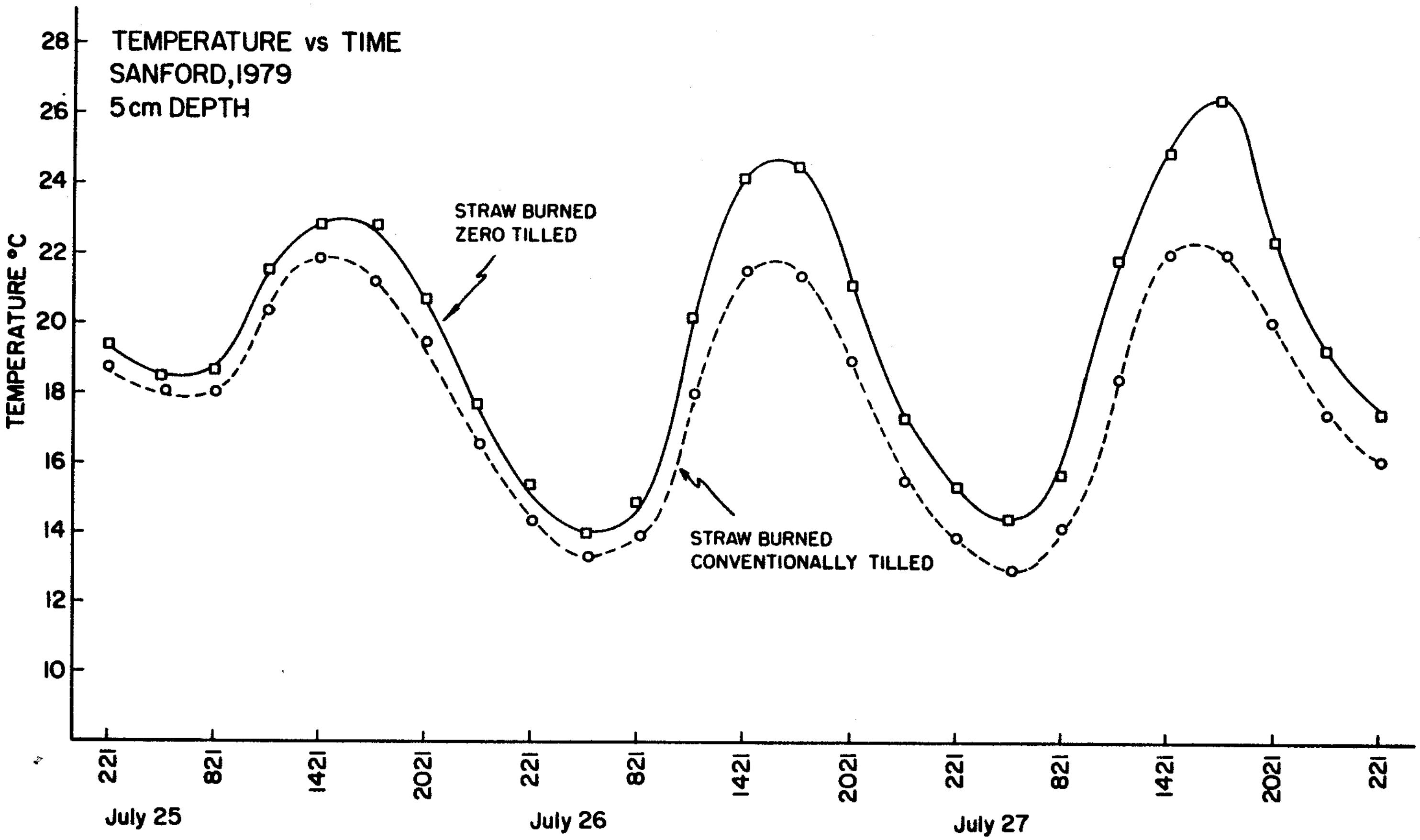

Fig. 9 The diurnal temperature variation with the straw burned treatment at Sanford, 1979.

radiation, so that differences due to surface conditions became less important. This is in agreement with similar observations made by Lal (1976).

As explained by Carson and Moses (1963), the temperature wave moved into the soil as a damped, lagging wave. As the amplitude decreased, surface conditions became less important in determining soil temperature differences. During the early part of the season, differences in soil temperature were found consistantly down to 20 cm. When readings were taken using the deeper probes, the effects of the straw-tillage practice might or might not extend to the 50 cm. depth.(See appendix for temperature data.) At these lower depths, any differences which occurred were not consistant with those found closer to the surface. Also, temperature trends relating to tillage practice were inconsistant at lower depths, whereas they often persisted well into the season within the top 50 centimeters.

Greatest differences occurred during periods of high solar radiation, i.e. during cloudless periods. As well, differences were more noticeable when the soil was dry, because the effects due to different ground conditions decreased as the amplitude of the temperature wave was depressed.

At seeding time, the water content was higher on the clay and clay loam soils than on the sandy loam. This caused the clay soils to heat more slowly than the sandy soil, and to have a smaller diurnal temperature variation. At Graysville, on the sandy loam the amplitude of the diurnal temperature wave was greater than that found on the clays (Figures 1 and 2).

Maximum temperatures were affected the greatest, so that the most significant differences in temperature occurred at the time when the soil was the warmest. Minimum temperatures were not significantly affected. So that, in contrast to results reported by van Wijk et al.(1959), there was no increase in minimum temperatures due to the presence of a straw layer (Figures 1 and 2). The differences which occurred were due to the effects on the maximum temperatures, to a great extent. Maximum temperatures were depressed, but minimum temperatures were not usually increased by a straw mulch.

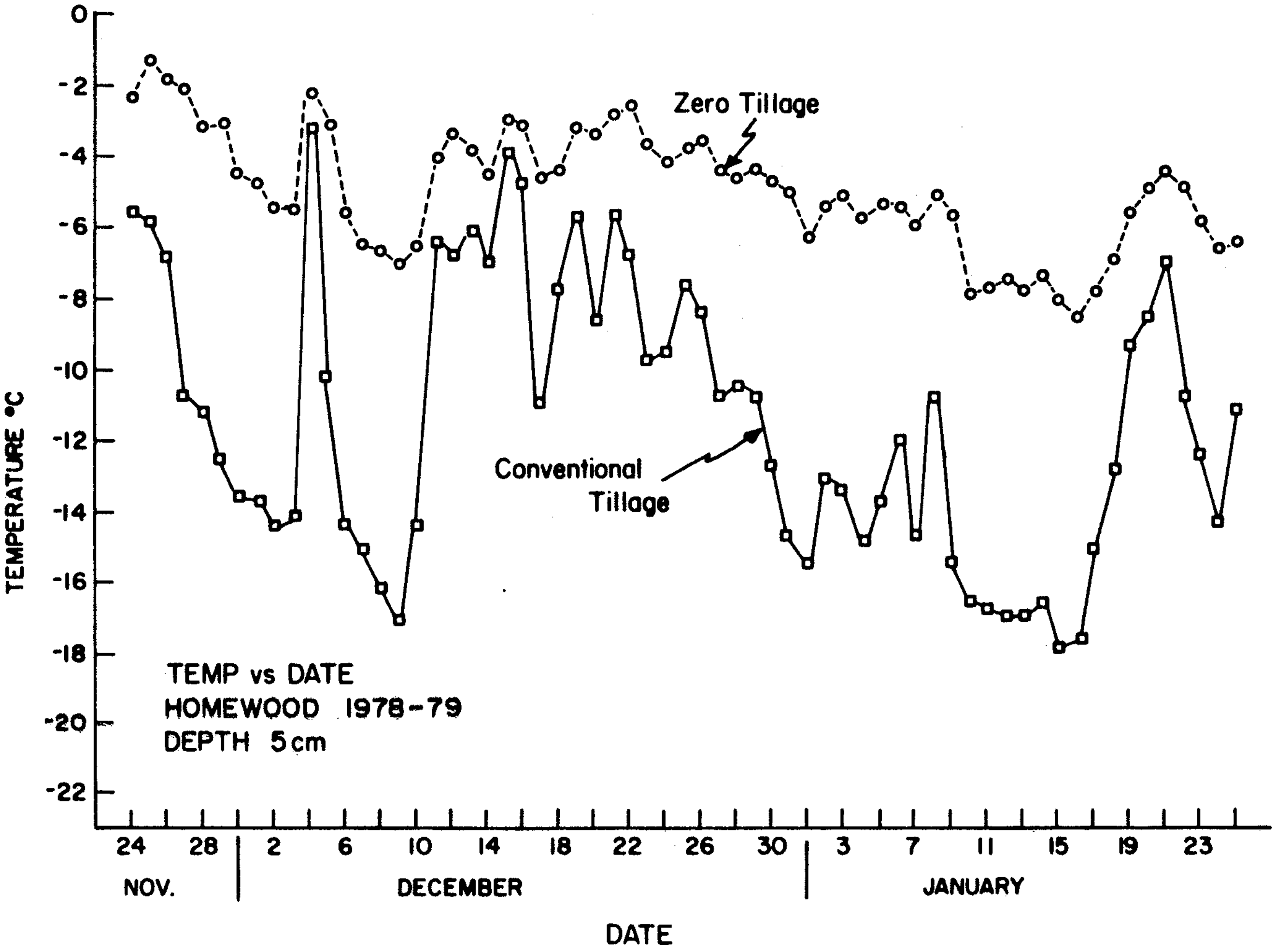

Fig. 10 Winter temperature variations at the 5 cm. depth at Homewood, 1978-1979.

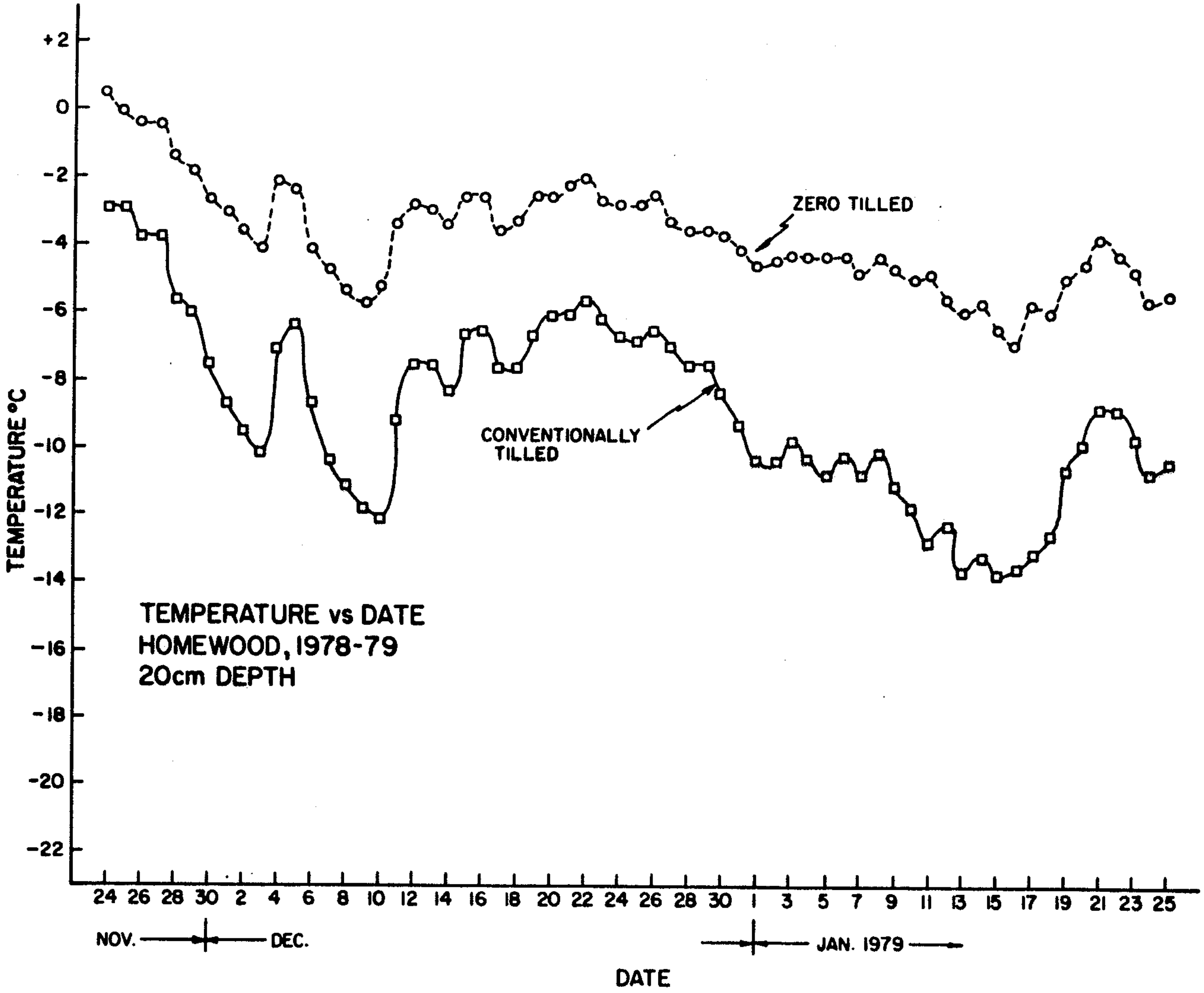

Fig. 11 The winter temperature variations at the 20 cm. depth at Homewood, 1978-1979.

4.2 SOIL DEGREE DAYS

Soil degree days can be used as an indication of the heat energy available for plant development. Several factors may influence the response of the crop to this energy. These include soil moisture, texture, fertility and plant population, to name a few. For example, low moisture at seeding time delays maturity. Low moisture late in the season can have the opposite effect (Edey, 1977).

Accumulated degree days above 5C and 10C were calculated for the period from seeding to harvest (Tables 6, 7, 8, 9). The differences between accumulated degree days for the entire growing season for various straw-tillage practices sometimes reflected the soil temperature trends at seeding time. For example, the accumulated degree days for the straw scattered treatment were higher on the conventionally tilled soil. On treatments where straw was removed, the accumulated degree days were greater on the zero tilled treatment than on the conventional at the beginning of the season. This trend persisted until the end of the season, when they became similar (Figure 12). Even if significant differences in accumulated degree days occurred early in the season, no difference might be found by the end of the season. Or in the case of the burned treatment, where little difference was found early in the season, the zero tilled plots had more soil degree days accumulated by the end of the season.

TABLE 6

Accumulated soil degree days at the 5 cm. depth at Homewood, 1978.

DEGREE DAYS ABOVE	STRAW SCATTERED TREATMENT	
	TILLED	ZERO TILLED
5C	1024.9	1027.4
10C	623.5	620.7

From 29 May, to 8 August, 1978.

When considering the three zero tilled straw treatments, a pattern emerges. The straw scattered treatment was lowest in accumulated degree

TABLE 7

Accumulated soil degree days at the 5 cm. depth at Graysville, 1978.

SOIL DEGREE DAYS ABOVE	STRAW SCATTERED TREATMENT		STRAW REMOVED TREATMENT
	TILLED	ZERO TILLED	ZERO TILLED
5C	1238.1	1200.2	1209.7
10C	785.5	743.7	753.4

From 4 May to 7 August, 1978.

TABLE 8

Accumulated soil degree days at Graysville, 1979.

SOIL DEGREE DAYS ABOVE	STRAW SCATTERED TREATMENT		STRAW REMOVED TREATMENT		STRAW BURNED TREATMENT	
	CT	ZT	CT	ZT	CT	ZT
5C	962.5	894.6	962.5	950.5	894.6	950.5
10C	515.5	451.2	497.9	452.0	505.0	521.4

CT -conventional tillage
ZT - zero tillage

From 24 May to 17 August, 1979.

days, followed by the straw removed. The highest values were obtained on the burned treatment (Tables 8 and 9).

Accumulated dry matter as measured on a biweekly basis by D. Rourke, was graphed against accumulated degree days above 5C for rapeseed grown at Sanford in 1979 (Figure 13) and for the wheat grown at Graysville in 1978 (Figure 14). At both locations, more dry matter was produced early in the season on the straw scattered treatment under zero tillage than under conventional. This may have been caused by higher available moisture on the zero tilled soils (Figures 18, 19).

TABLE 9

Accumulated soil degree days at the 5 cm. depth at Sanford, 1979.

SOIL DEGREE DAYS ABOVE	STRAW SCATTERED TREATMENT		STRAW REMOVED TREATMENT		STRAW BURNED TREATMENT	
	CT	ZT	CT	ZT	CT	ZT
5C	807.9	747.2	794.8	789.4	801.9	820.6
10C	581.2	512.6	603.9	567.9	567.0	649.6

CT -conventional tillage
ZT - zero tillage

From 7 June to 29 August, 1979.

The zero tilled plot at Sanford with straw removed by burning accumulated higher amounts of dry matter during early and mid season growth (Figure 15). As no moisture advantage existed under burning, other factors such as plant population or fertility must have been influential in determining this response. Possibly yields were higher because there was no immobilization of nitrogen by the decaying straw.

When the straw was removed, no difference in dry matter response to accumulated degree days was found between tillage treatments (Figure 16). This was in spite of higher moisture on the zero tilled plots (Figures 21, 22).

After emergence, the plant is strongly influenced by atmospheric conditions so that soil degree days per se. are not important for most crops. This is especially true when considering the cereals and small seeded crops whose growing points are above ground shortly after emergence. For corn, soil heat energy is significant in determining development, for the growing point remains below ground until the end of leaf initiation at the 6th leaf stage (Beauchamp and Lathwell, 1967).

4.3 PREDICTED DAYS TO EMERGENCE

The purpose of this study was to determine if crop production would be limited by the lower soil temperatures often associated with zero tillage, and to determine whether these colder soil temperatures would result in slower crop development. Soil temperatures were found to be

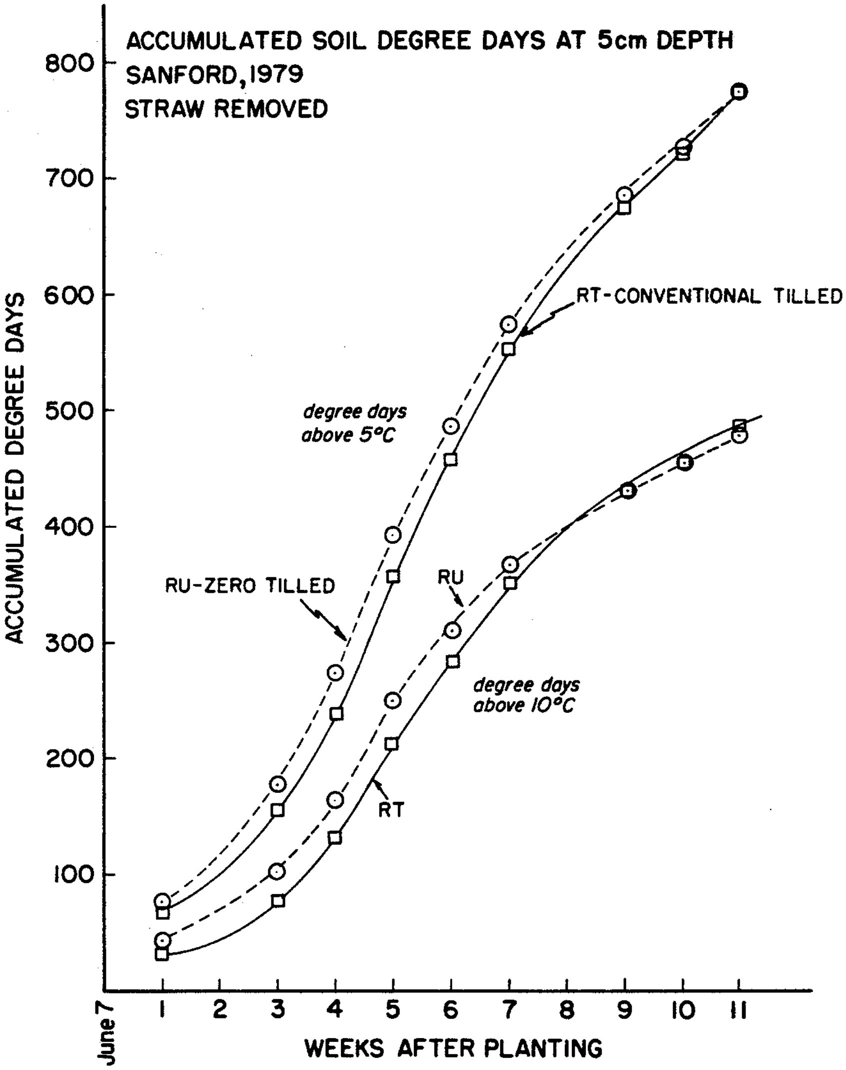

Fig. 12 Accumulated degree days of the conventional and zero filled straw removed treatments at Sanford, 1979.

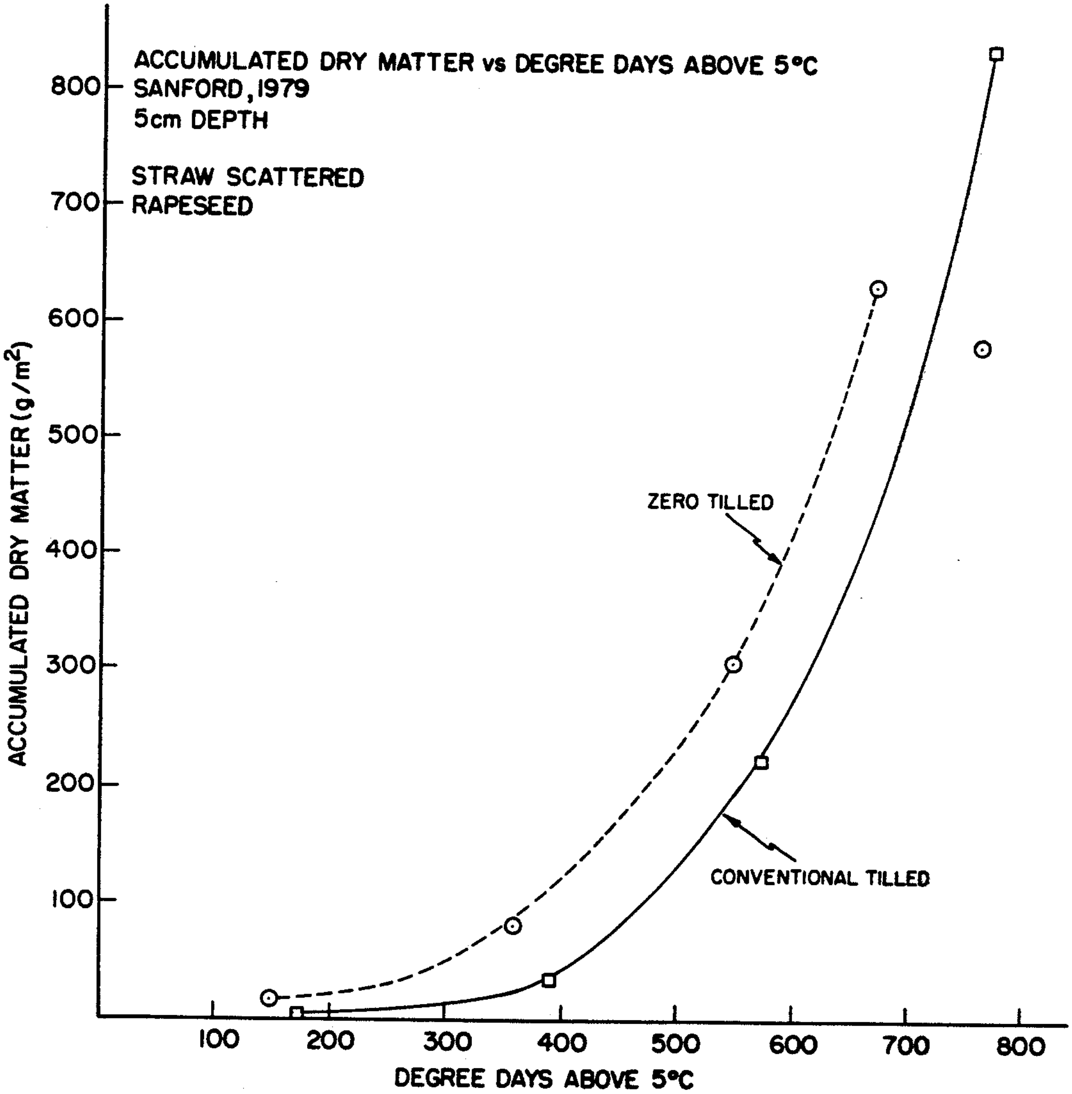

Fig. 13 Accumulated dry matter of rapeseed versus soil degree days at Sanford, 1979, straw scattered treatment.

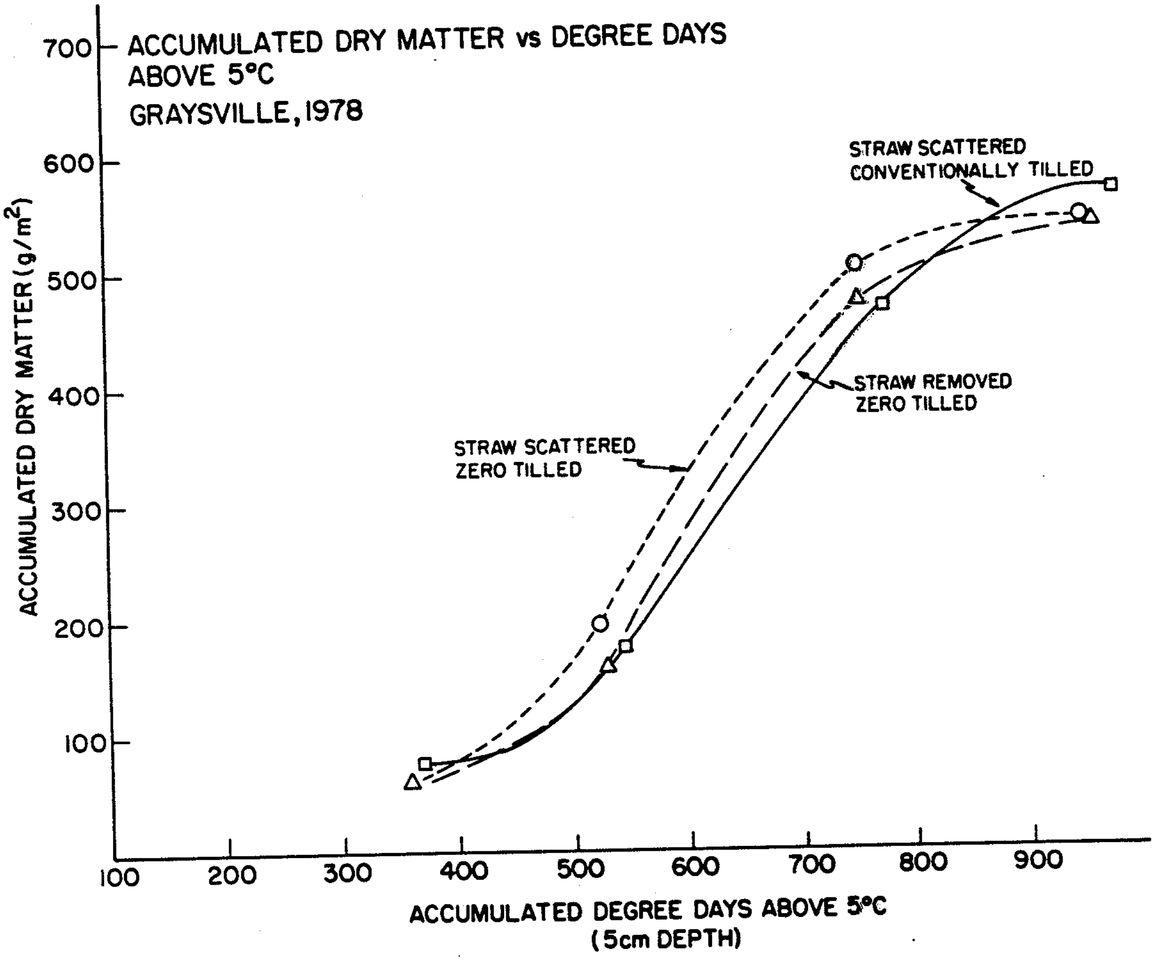

Fig. 14 Accumulated dry matter of wheat at Graysville, 1978.

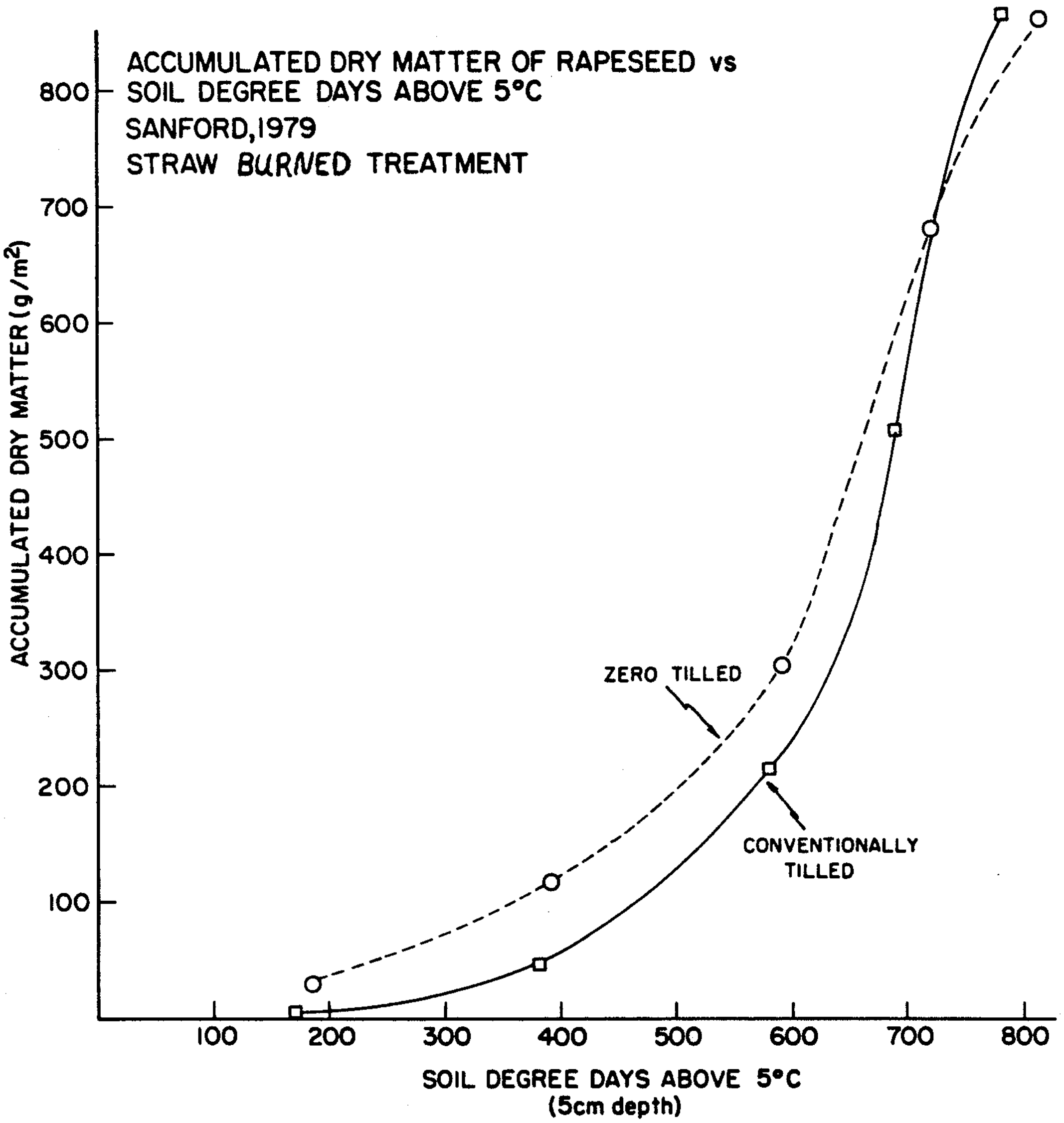

Fig. 15 Accumulated dry matter of rapeseed versus soil degree days at Sanford, 1979, straw burned treatment.

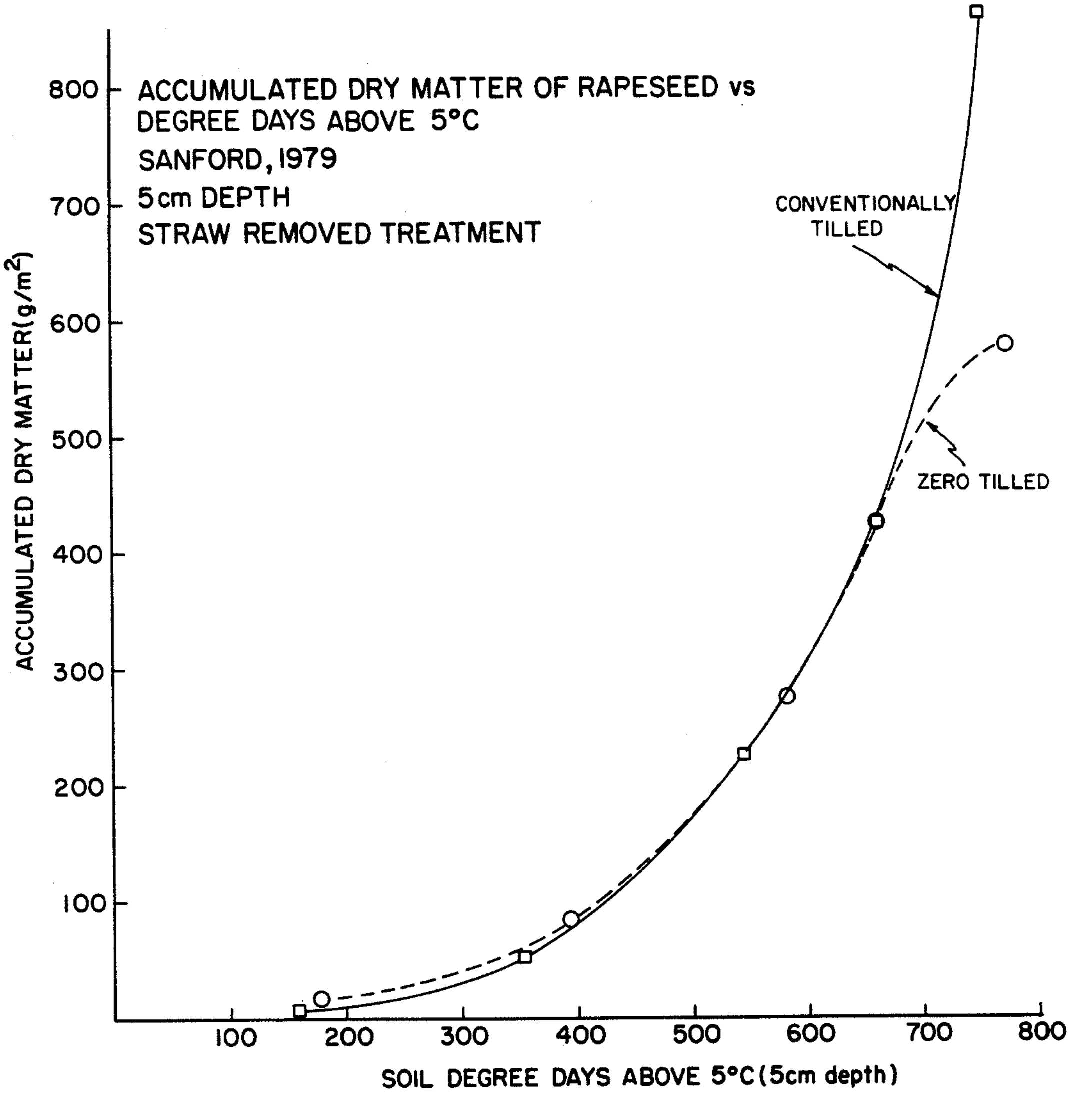

Fig. 16 Accumulated dry matter on the zero and conventional straw removed treatment at Sanford, 1979.

lower under zero tillage when a straw cover remained on the surface (Figures 1 and 2). By using regression equations developed from the literature and experimental work, in combination with the collected soil temperature data, predictions were made for time to germination or emergence for various crops. These predicted values are listed in Tables 10, 11, 12, and 13.

For the majority of the crops tested in this study, the differences in development found between the tillage treatments were small and insignificant, so that no large delay in germination or emergence was found. Therefore, with proper straw management, emergence should be as rapid under zero tilled conditions as under conventional tillage.

Poor emergence occassionally reported by farmers is probably associated with improper straw management procedures. Accumulations of straw may cause abnormally low temperatures in spring resulting in delayed emergence. As well, the straw may shade the young seedlings so that they die before reaching light. Our data suggests that careful management should alleviate any problems.

For corn, emergence was found to be delayed 2 to 3 days due to the presence of the mulch. Although this does not seem to be a very great delay, in field conditions the delay could even be more. It is important to remember that corn seeds are subject to microbial destruction by fungi in cool wet soils (Martin et al.; 1935, Arnon, 1975). This means that before growth begins, delayed germination can cause losses in the number of viable seeds. This effect is not accounted for by the regression equation relating growth to temperature.

4.3.1 Corn Development

Temperature requirements of the plant change as development progresses. By using data from Beauchamp and Lathwell (1967) a four stage procedure based on the number of leaves was developed. Soil temperature data, stored on the computer, was used with the regression equation to predict development to the 6-leaf stage for corn. These values are listed in Tables 14, 15, 16, and 17.

TABLE 10

Predicted time for plant development at Homewood

CROP	STRAW SCATTERED TREATMENT TILLED	 ZERO TILLED
GERMINATION		
WHEAT	1.63	1.75
GREEN FOXTAIL	10.25	10.63
EMERGENCE		
WHEAT	5.50	5.75
RAPESEED	4.25	4.13
BEANS	4.50	4.50
CORN: dry soil	12.13	12.50
CORN: moist soil	10.13	10.38

Planting Date 29 May, 1978.

TABLE 11

Predicted time for plant development at Graysville, 1978

CROP	STRAW TREATMENT Scattered Tilled	 Zero Tilled	 Removed Zero Tilled
GERMINATION			
WHEAT	2.0	2.17	2.17
GREEN FOXTAIL	13.67	16.00	14.30
EMERGENCE			
WHEAT	8.83	9.33	9.00
RAPESEED	6.50	7.00	6.67
BEANS	10.17	11.83	11.00
CORN: dry soil	18.0	20.00	18.83
CORN: moist soil	13.83	16.33	14.50

Planting date 4 May, 1978.

TABLE 12

Predicted time for plant development at Graysville, 1979

CROP	STRAW TREATMENT Scattered Tilled	Scattered Zero Tilled	Removed Zero Tilled
GERMINATION			
WHEAT	1.83	2.00	1.83
GREEN FOXTAIL	10.67	12.67	11.50
EMERGENCE			
WHEAT	5.83	7.00	6.67
RAPESEED	4.17	4.83	4.50
BEANS	4.67	8.00	6.83
CORN: dry soil	13.83	17.33	15.67
CORN: moist soil	10.50	12.67	11.33

Planting date 24 May, 1979.

TABLE 13

Predicted time for development at Sanford, 1978

CROP	STRAW TREATMENT Scattered		Removed		Burned	
	T	ZT	T	ZT	T	ZT
GERMINATION						
WHEAT	2.5	2.5	2.4	2.5	2.5	2.4
GREEN FOXTAIL	11.1	12.3	10.9	12.3	11.3	11.0
EMERGENCE						
WHEAT	6.4	7.3	6.5	7.0	6.8	6.5
RAPESEED	5.4	6.1	5.3	5.3	5.4	5.3
BEANS	6.5	7.1	6.3	7.1	6.6	6.3
CORN: dry soil	13.7	15.4	13.4	15.4	14.3	13.5
CORN: moist soil	11.0	12.3	10.6	12.3	11.3	10.8

Planting date 7 June, 1979.

TABLE 14

Predicted days from planting to stage of development for corn,Homewood

Planting Date May 29, 1978

STAGE	STRAW SCATTERED	
	Tilled	Zero Tilled
Emergence	9.88	10.25
* moist soil	10.38	10.13
* dry soil	12.50	12.13
2-Leaf	15.75	16.50
4-Leaf	27.50	27.38
6-Leaf	38.50	37.88

* - based on Hough's equations(1972)

TABLE 15

Predicted days from planting to development for corn, Graysville, 1978

Planting Date May 4

STAGE	STRAW TREATMENT		
	Scattered		Removed
	Tilled	Zero tilled	Zero Tilled
Emergence	18.00	19.83	18.83
* moist soil	13.83	16.33	14.55
* dry soil	18.00	20.00	18.83
2-Leaf	24.83	27.83	25.83
4-Leaf	44.17	46.00	45.33
6-Leaf	55.50	56.83	56.67

* - based on Hough's equations (1972)

Table 18 lists the predicted date to the 6th leaf stage for conventional and zero tillage for the various planting dates involved on the straw scattered treatment, as well as days to emergence. Soil temperatures were found to influence corn development for a considerable length of time. The earlier the planting date, the longer development was influenced.

TABLE 16

Predicted days from planting to development for corn, Graysville, 1979

Planting Date May 24

STAGE	STRAW TREATMENT Scattered Tilled	 Zero tilled	 Removed Zero Tilled
Emergence	15.00	17.83	16.17
* moist soil	10.50	12.67	11.33
* dry soil	13.83	17.33	15.67
2-Leaf	21.83	25.33	23.67
4-Leaf	44.17	41.17	38.83
6-Leaf	47.17	54.17	50.33

* - based on Hough's equations (1972)

TABLE 17

Predicted days from planting to development for corn,Sanford

Planting Date June 7, 1979

STAGE OF DEVELOPMENT	STRAW TREATMENT Scattered T	 ZT	 Removed T	 ZT	 Burned T	 ZT
Emergence	9.38	11.38	10.63	9.13	9.75	9.25
*moist soil	10.63	11.00	11.25	12.25	12.25	10.75
* dry soil	13.38	13.75	14.25	15.37	15.38	13.50
2-Leaf	15.38	17.25	16.75	15.00	15.75	15.00
4-Leaf	25.63	27.88	27.38	25.25	26.00	25.25
6-Leaf	32.50	36.00	35.13	32.13	33.25	32.75

T - conventional tillage
ZT - zero tillage
* - based on Hough's equation (1972)

With the earlier planting date, the seed remains in the soil for a longer time, so that damage may occur. Planting should not take place until soil temperatures are high enough to promote rapid development. As predicted from the collected soil temperature data, zero tillage could have resulted in a delay in development to the 6-leaf stage. this was as much as seven days in one case (Table 15).

TABLE 18

Days to emergence and predicted date of development to the 6-leaf stage for corn

Planting Date	Days to Emergence		Predicted Date for Development to the 6-Leaf Stage	
	Tilled	Zero Tilled	Tilled	Zero Tilled
Graysville, 1978				
May 4	18.0	19.8	June 29	June 30
Graysville, 1979				
May 24	15.0	17.8	July 10	July 17
Homewood, 1978				
May 29	9.9	10.3	July 7	July 6
Sanford, 1979				
June 7	9.3	11.3	July 9	July 13

On the sandy loam, predicted days to emergence based on the four stage study developed from data of Beauchamp and Lathwell (1967), agreed closely with results using Hough's equation for dry soil(1972) (Tables 15 and 16). On the clay and clay loam soils, the predicted values using the four stage method agreed closely with results using Hough's equation for moist soil (Tables 14 and 17). These findings for the different soil types were in agreement with the soil moisture conditions that existed at seeding time (Figures 17, 18, and 19).

4.3.2 Weed Competition

When the soil temperatures were lower due to the mulch, there was a predicted delay in the germination of green foxtail. The results indicated that wheat, beans, and rapeseed would be good competitors with this weed, because of their ability to germinate and emerge at lower soil temperatures. These crops should develop earlier and compete more favorably against the green foxtail for light and moisture.

4.4 SOIL MOISTURE

4.4.1 Straw Scattered Treatment

When the straw had been scattered on top of the ground at harvest time, higher moisture levels were found early the next growing season on the zero tilled soils (Figures 17, 18, 19). The moisture advantage was greater on the clay and clay loam soils than on the sandy loam, because of the greater water holding capacity of the clay.

Neutron moisture meter readings in 1978 indicated higher volumetric water contents consistantly occurred on the zero tilled soil from 30 to 60 cm. on both soil types.(See appendix.) Soil moisture was higher on the conventionally tilled plots below the 60 cm. level. A sampling of root distribution patterns down to 150 cm. would have been useful in determining the uptake of water within the profile. Tillage could have affected the root distribution which would in turn affect the soil moisture use (Hamblin and Tennant, 1979).

The main moisture advantage for zero tillage was within the 0-5 cm. depth. As well, soil moisture within 0-20 cm. was distributed more evenly in the profile on the zero tilled soils (Figure 20). Where moisture was especially low at the surface of the conventionally tilled soil, it was considerably higher under zero tillage. This is in agreement with previous findings in other climatic areas (Pidgeon and Soane, 1977).

Increased available moisture probably decreased soil strength, helping to alleviate emergence problems due to high bulk density values under zero tillage (Camp and Gill, 1969). As well, increased moisture aided in the more rapid and even germination of rapeseed on the clay and clay loam soils by decresing soil suction.

Soil temperatures were depressed on the zero tilled plots due to the presence of the straw mulch, so that evaporation was reduced (Hanks and Woodruff, 1958). This aided in moisture conservation.

4.4.2 Straw Removal Treatment

Zero tilled soils at Sanford and Graysville were found to be equal or higher in available water throughout the early and mid growing season (Figures 21 and 22). At Sanford, on the heavy clay, this advantage occurred throughout the entire season although it was only significant for the first few weeks (Figure 22). At Graysville, on the sandy loam, the zero tilled soil was higher in moisture during the early part of July, when the greatest differences between tillage treatments also occurred on the straw scattered treatment. The dry period in early July

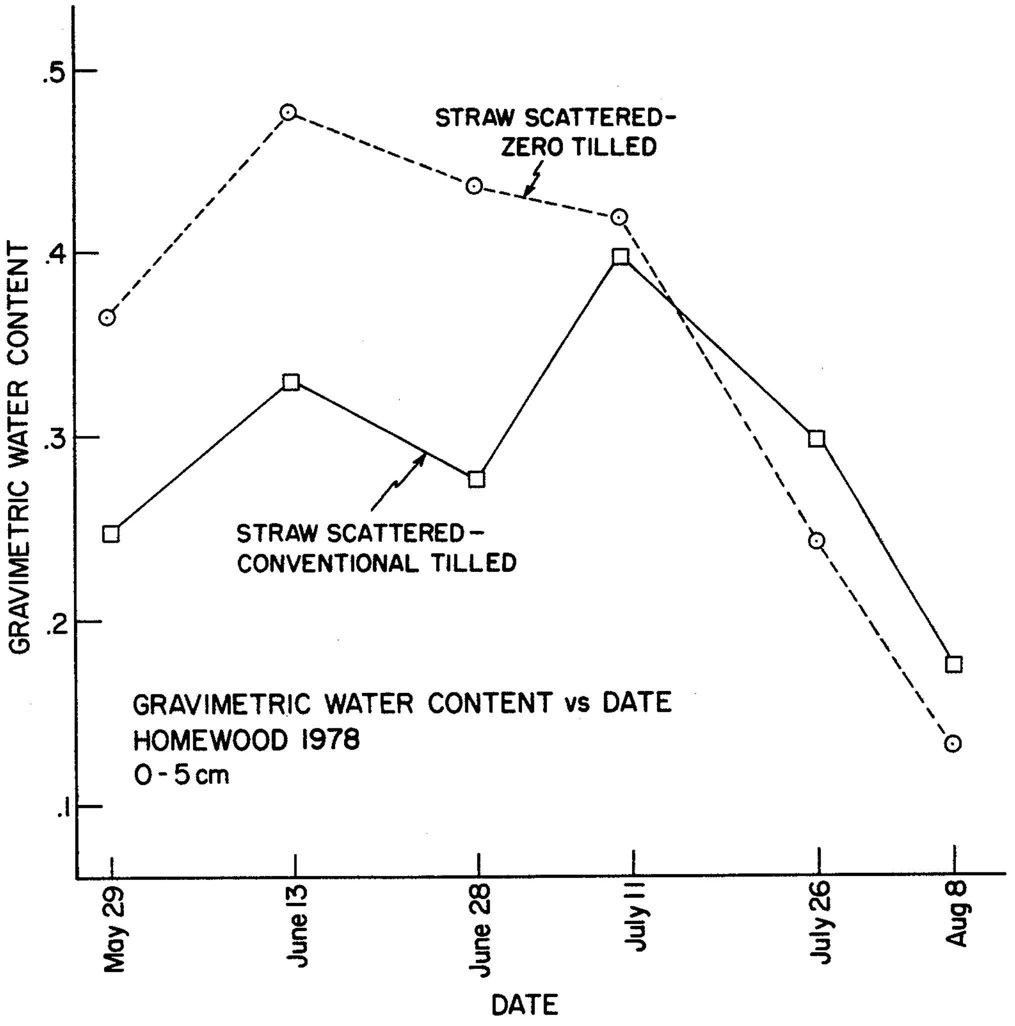

Fig. 17 Gravimetric soil moisture throughout the growing season at Homewood, 1978

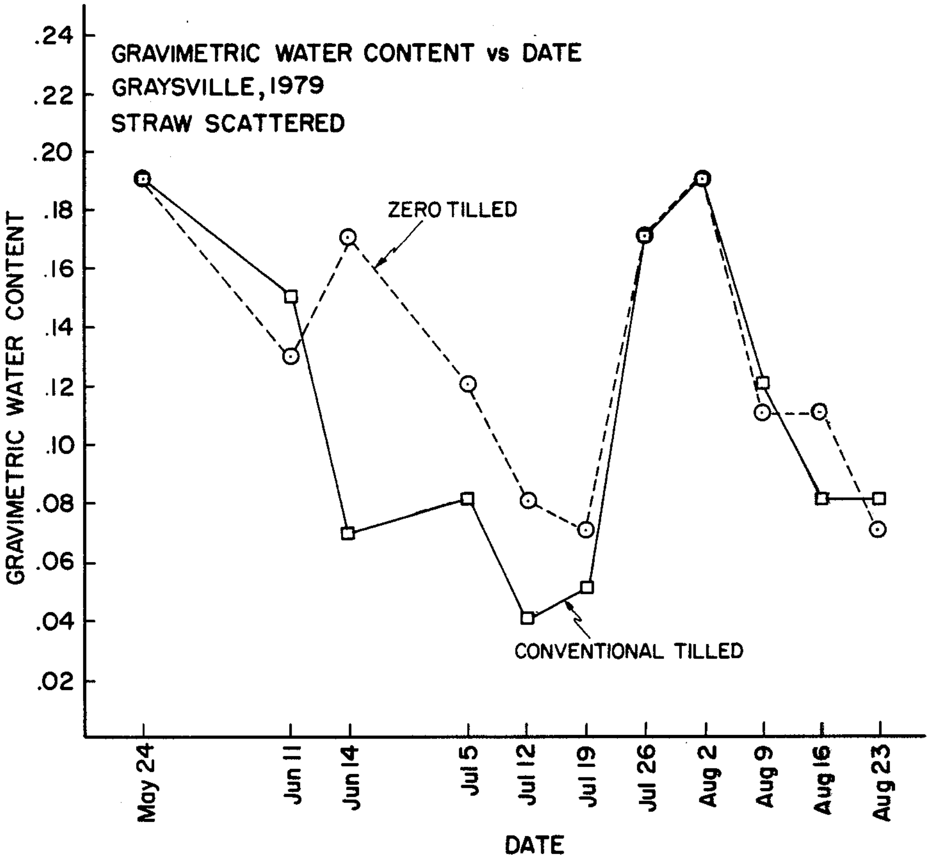

Fig. 18 Gravimetric soil moisture throughout the growing season at Graysville, 1979, straw scattered treatment.

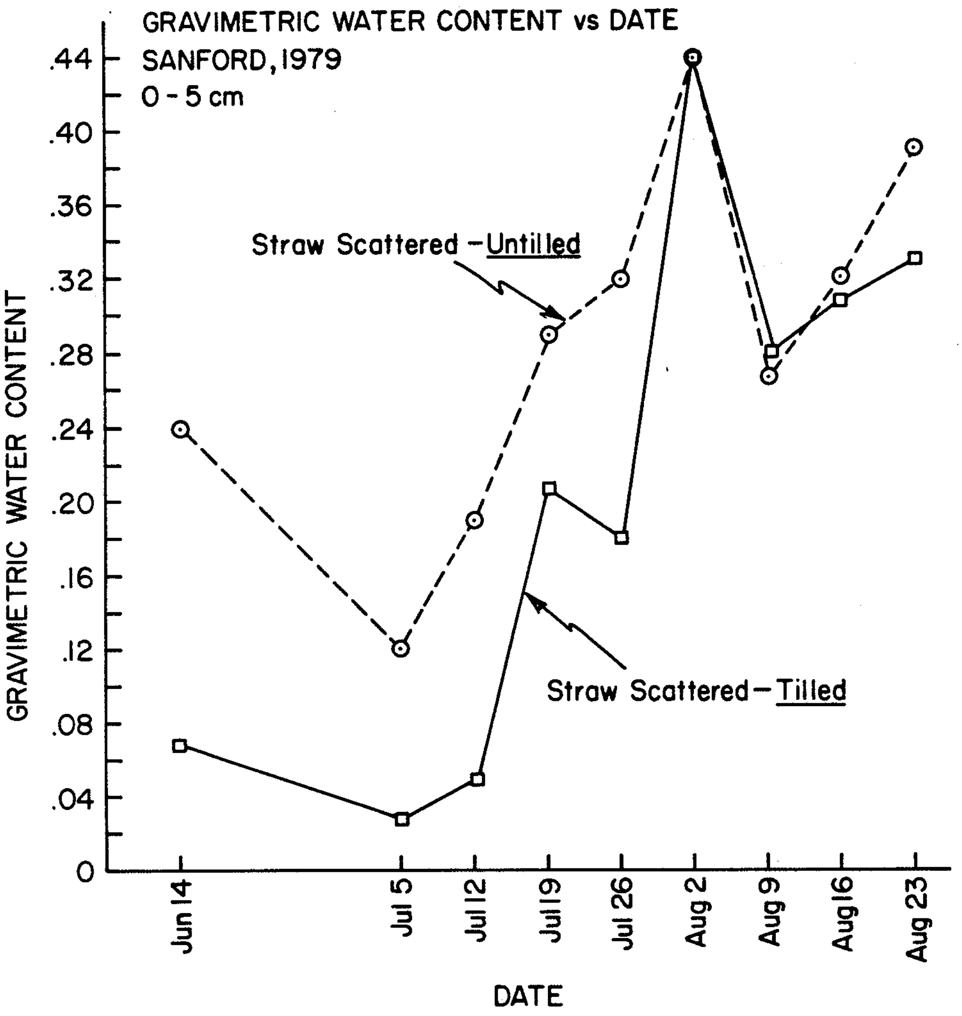

Fig. 19 Gravimetric soil moisture throughout the growing season at Sanford, 1979, straw scattered treatment.

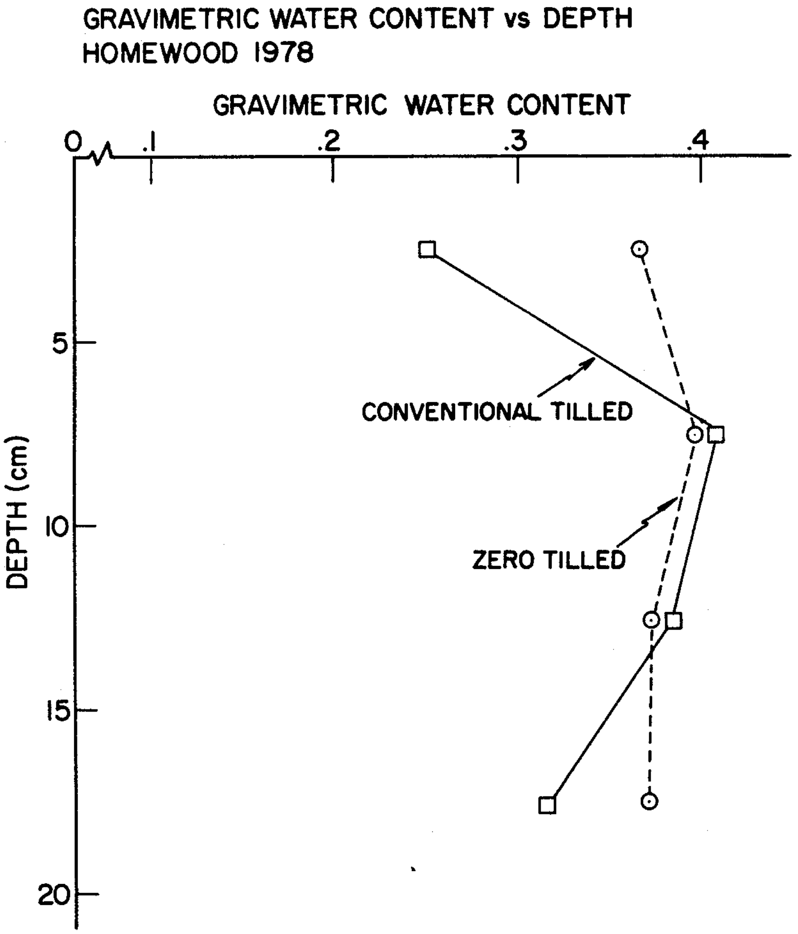

Fig. 20 Gravimetric soil moisture distribution in the profile, Homewood, 1978.

of 1979 quickly depleted the soil moisture on the conventionally tilled plots, but not on the zero tilled plots. This demonstrated that zero tillage was useful in preventing moisture stress from occurring during short drought periods as reported by Shanholtz and Lillard (1968).

The higher available moisture even with straw removal could have been caused from an alteration in pore size distribution. Zero tilled soils are reported to have a greater percent of smaller sized pores which are less subject to water loss by drainage or evaporation (Gowman et al., 1978; van Ouwerkerk and Boone, 1970). Also, because some stubble was remaining, moisture may have been higher due to greater amounts of snow cover (Schneider et al., 1978).

Difficulties in chaff removal resulting in a thin residue covering could have helped to maintain higher water contents, although soil temperatures were not depressed on these plots by the chaff (Figures 6 and 7).

4.4.3 Straw Burned Treatment

Although no significant differences occurred between the tillage treatments, some noticeable trends were found. Higher moisture was found under zero tillage than conventional at various times throughout the season (Figures 23 and 24).

At Graysville, soil moisture depletion during early July and late August was slower under zero tillage (Figure 23). At Sanford the pattern was similar for late August (Figure 24). The higher moisture levels at these times could have been caused from factors relating to an alteration in pore size distribution, as mentioned earlier for the straw removed treatment.

Of the three straw management practices used, burning produced the lowest soil moisture on the zero tilled soil at seeding time. Burning is a recommended practice in some areas of Great Britain where excessive moisture conditions produce problems during seeding and early growth. The British climate is much more humid than that found on the Canadian Prairies. In this region, higher moisture levels on zero tilled fields may cause a delay in seeding of only 2 to 3 days, compared to 1 to 2 weeks in Britain. The convenience of managing excessive straw by this

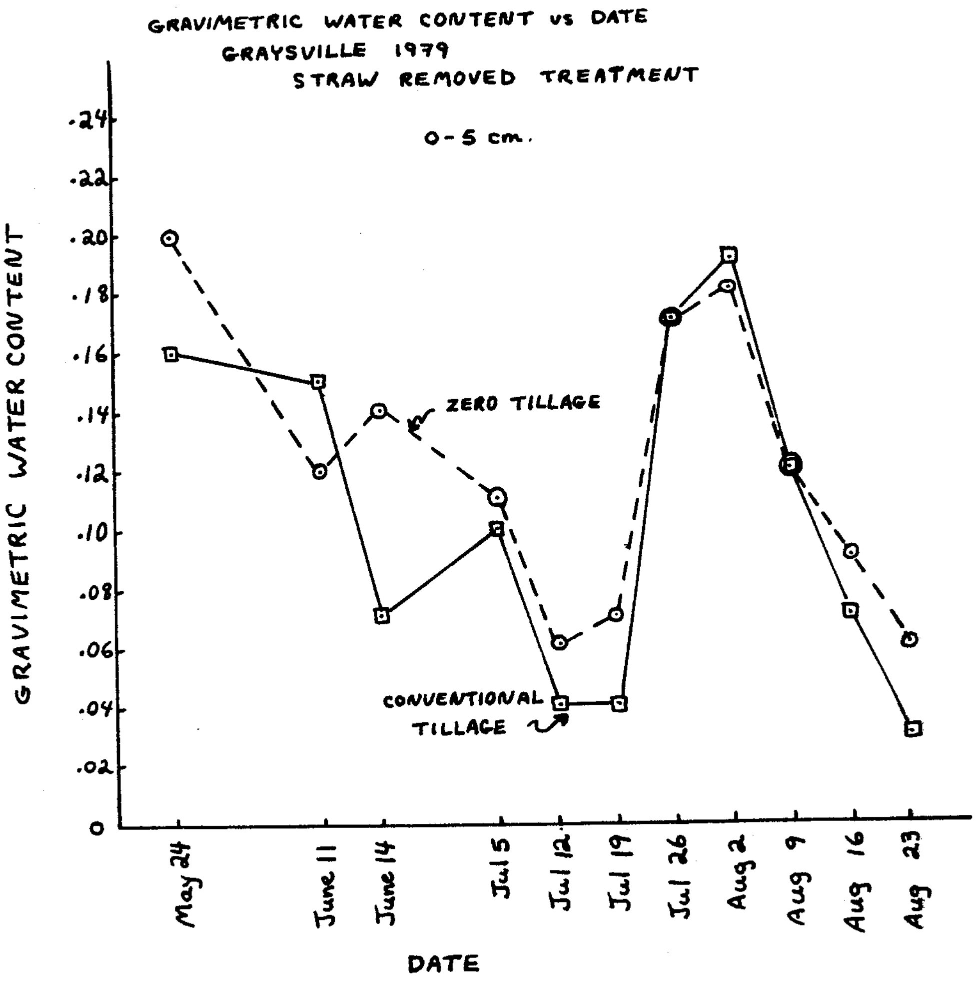

Fig. 21 Gravimetric soil moisture throughout the growing season on the straw removed plots, Graysville, 1979.

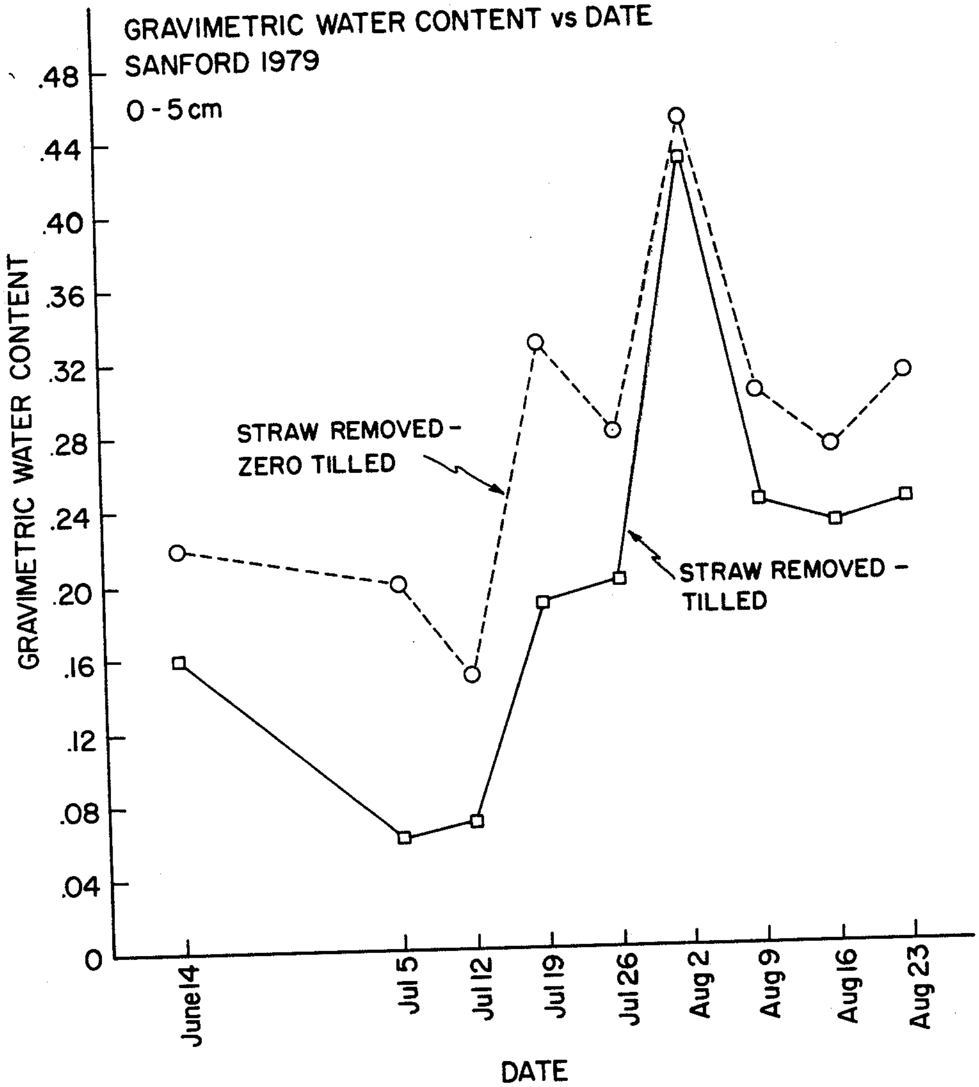

Fig. 22 Gravimetric soil moisture at Sanford, 1979 on the straw removed plots.

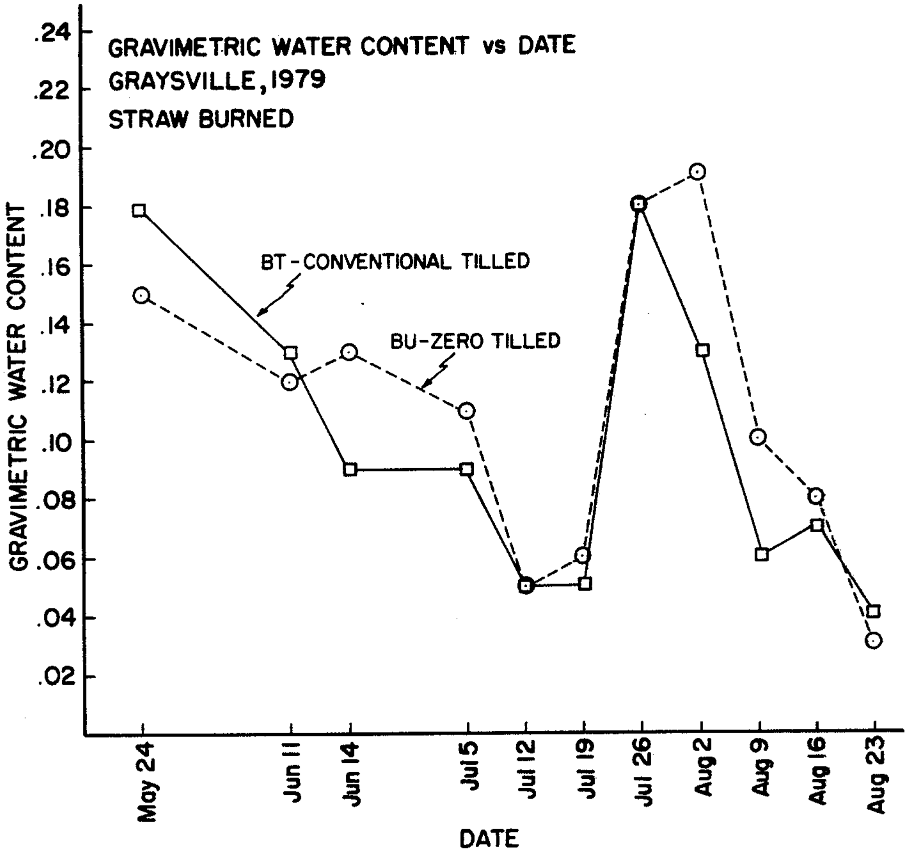

Fig. 23 Gravimetric soil moisture throughout the season on the burned plots at Graysville, 1979.

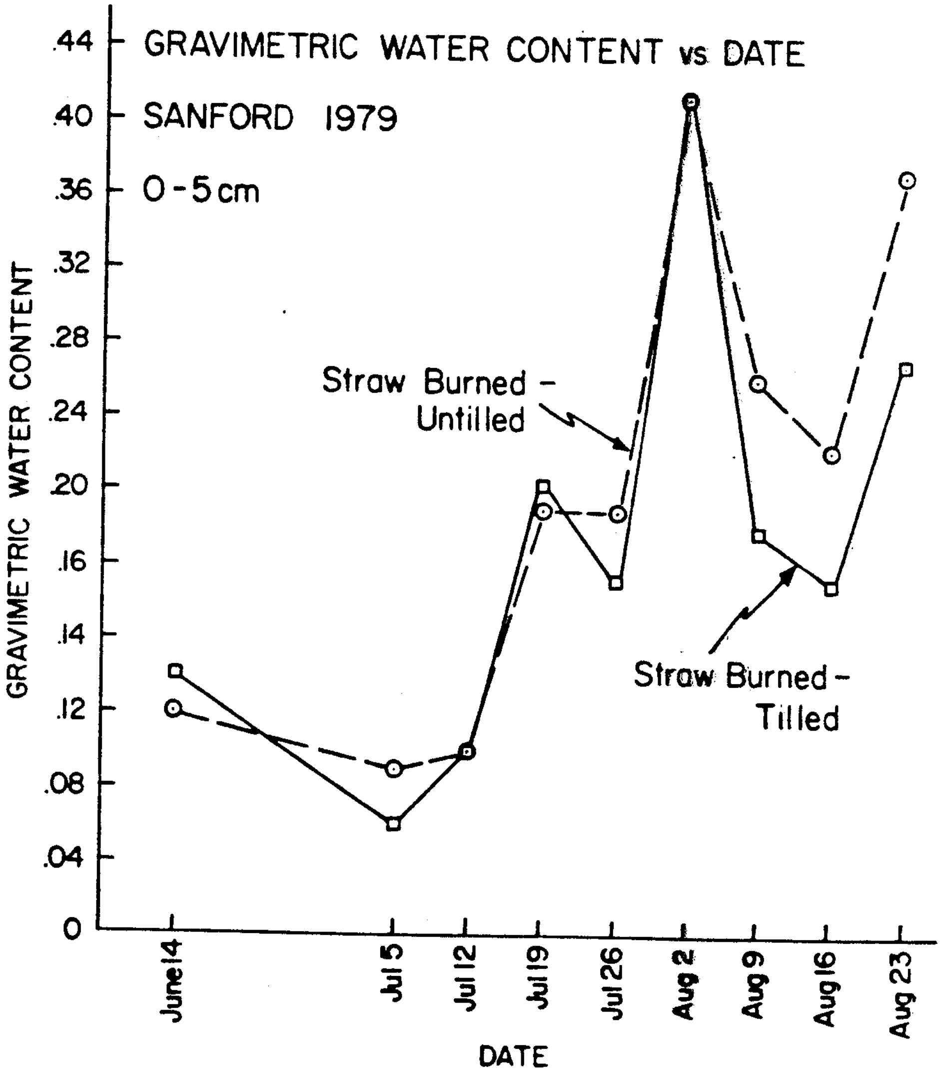

Fig. 24 Gravimetric soil moisture throughout the growing season at Sanford, 1979 on the burned plots.

method cannot be denied, for it takes a minimum of equipment and knowledge. Caution has to be used in approaching the procedure though, because burning does have undesirable effects on the environment, especially on the air. As well, the effects of burning on the soil organic matter and microstructure are not well known. One of the main advantages of using zero tillage in the prairie climate is the increase in available moisture. Wise straw management procedures must be used to ensure the maximum benifits of zero till are obtained without sacrificing in the way of field time or economics.

4.4.4 Soil Moisture Summary

The differences found in soil moisture between conventional and zero tilled plots were most significant early in the growing season, when evaporation was the dominant means of soil moisture loss. During the early and mid season periods, ground surface conditions were important in determining surface energy use, including the use of heat to evaporate water. The presence of the straw and stubble decreased evaporation, resulting in higher available moisture under zero tillage.

The amount of stubble and snow cover on the plots helped to determine the amount of available moisture in spring. The zero tilled plots where the stubble remained were able to hold the snow better (Schneider, 1978). As well, run off was slowed down by the straw, allowing greater infiltration (Shanholtz and Lillard, 1969).

4.5 BULK DENSITY

4.5.1 Graysville: Riverdale Sandy Loam

Values obtained in the first year of the study, (Table 19) showed a much different trend from those obtained in the second (Table 20). This indicated that the soil had not reached an equilibrium level in the second year of zero tillage management. Pidgeon and Soane (1977), found that it took three years to reach the equilibrium level on zero tilled soils. Because the values changed from one year to the next, the bulk density data cannot be considered as being representative of any long term indication of soil strength, but just of the conditions at seeding time.

In 1978, bulk density values taken on the sandy loam indicated that the straw scattered zero tilled was more compacted than the straw scattered conventional and the straw removed zero tilled treatments. In 1979, all zero tilled plots were found to be less compacted than the conventional treatments having similar straw management practices. The bulk density values were lower than in the previous year, which was opposite to the compaction which was expected under zero tillage (Pidgeon and Soane, 1977). Of the three straw management practices, the highest bulk density values were obtained on the straw scattered plots, and the lowest on the zero tilled straw burned. This could have been related to the amount of traffic that was involved in preparing the plots, for the burned treatment required fewer "trips over the field" to prepare.

No true compaction problems could be ascertained from the data. Relatively high bulk density values (1.3 g/cc.) were found on the straw scattered tilled soil, but higher moisture levels occurred as well, which would tend to decrease increased soil strength, commonly associated with higher bulk density values.

TABLE 19

Bulk density (g/cc.) on May 4, Graysville, 1978

DEPTH (cm.)	STRAW TREATMENT Scattered		Removed
	T	ZT	ZT
0 - 5	1.22	1.36	1.21
5 - 10	1.24	1.26	1.28
10 - 15	1.27	1.32	1.22
15 - 20	1.30	1.39	1.42

T - tilled : ZT - zero tilled

4.5.2 Homewood: Sperling Clay Loam

The zero tilled soil was higher in bulk density than the conventional within the top 20 cm. (Table 21). Bulk density increased with depth on both types of tillage systems (Figure 25). All values were below 1.3 g/cc. suggesting that relatively little compaction occurred (Table 21).

TABLE 20

Bulk density (g/cc.) on May 24, Graysville, 1979

	STRAW TREATMENT					
	Scattered		Removed		Burned	
DEPTH (cm.)	T	ZT	T	ZT	T	ZT
0 - 5	1.18	1.09	1.09	1.02	1.20	0.98
5 - 10	1.28	1.11	1.23	1.06	1.23	0.88
10 - 15	1.23	1.09	o.98	1.26	1.19	0.92
15 - 20	1.34	1.08	1.20	0.98	1.20	0.95

T - tilled : ZT - zero tilled

4.5.3 Surface Crusting

The zero tilled soil did not suffer from surface crusting problems which did exist under dry conditions on the conventionally tilled soil. Zero tillage produced a more friable seedbed, higher in moisture with better soil-seed contact. On drying, the conventional surface formed hard clods detrimental to the emergence of the rapeseed. Even if the zero tilled plots were higher in bulk density, the conditions for early seedling growth were more favorable.

4.5.4 Sanford: Osborne Clay

The plots were established in 1978, so had not reached an equilibrium level of compaction by 1979. Bulk density values are listed in Table 22. Some amount of relative compaction was found on all of the zero tilled plots, but not at all depths. The bulk density was higher at the surface under zero tillage for all straw management practices . This was not detrimental to early growth, due to the better structural conditions on the zero till than on the conventional. On drying, the conventionally tilled surface formed hard clods which impeded crop emergence. A measure of soil strength from a penetrometer would have been more useful in this case in demonstrating compaction.

4.5.5 Bulk Density Summary

Bulk density values were taken as an indication of soil compaction within the surface 20 cm. Conditions were found to vary from one location to another as well as from one year to the next (Tables 19, 20, 21,

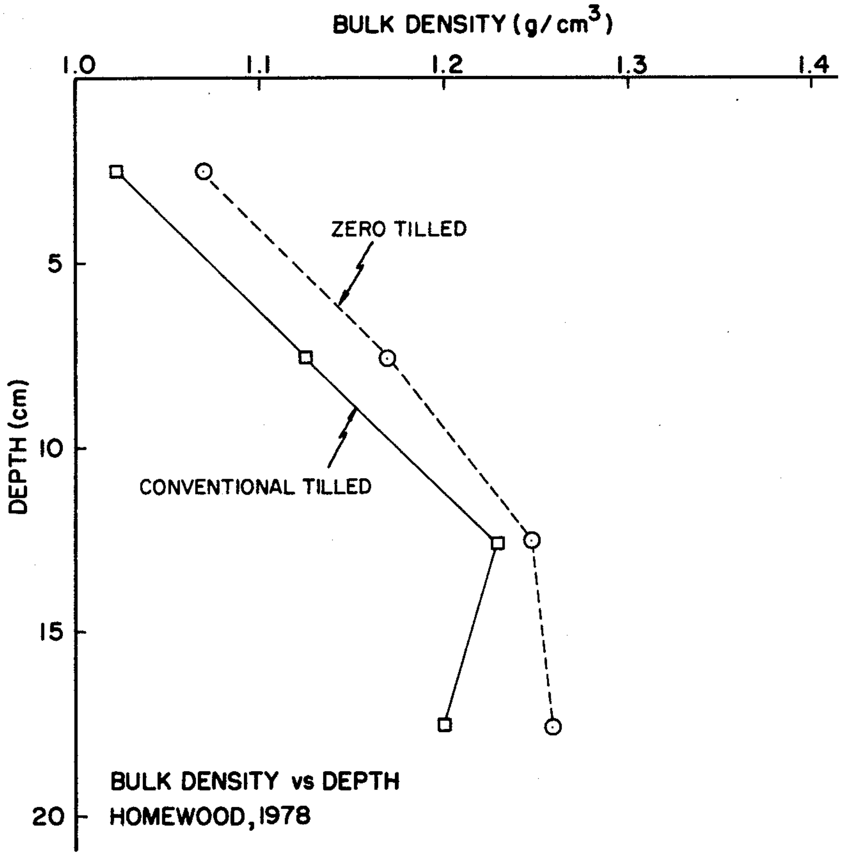

Fig. 25 Bulk density in the profile at Homewood, May 29, 1978.

TABLE 21

Bulk density (g/cc.) on May 29, Homewood, 1978

DEPTH (cm.)	STRAW SCATTERED Tilled	Zero tilled
0 - 5	1.02	1.07
5 - 10	1.13	1.17
10 - 15	1.23	1.25
15 - 20	1.20	1.26

TABLE 22

Bulk density (g/cc.) on June 7, 1979, at Sanford

DEPTH (cm.)	STRAW TREATMENT Scattered		Removed		Burned	
	T	ZT	T	ZT	T	ZT
0 - 5	0.99	1.05	0.97	1.07	0.85	0.87
5 - 10	1.14	1.25	1.24	1.33	1.20	1.15
10 - 15	1.28	1.20	1.25	1.24	1.20	1.31
15 - 20	1.18	1.24	1.30	1.26	1.28	1.25

T - tilled; ZT - zero tilled

and 22). Actual bulk density values obtained were not as useful as the measurement of relative values in comparing the various treatments, although they did serve as an indication of compaction in themselves.

4.6 OXYGEN DIFFUSION RATE

4.6.1 Homewood clay loam

Oxygen diffusion rate (ODR) was measured during periods of excessive soil moisture, when aeration would be limiting to plant growth. Limiting levels of ODR according to Stolzy and Letey(1964), as measured by the platinum electrode apparatus occurred under both tillage systems. The greatest difference between tillage treatments was found near the surface at the 2.5 cm. depth (Figure 26), where the conventional was considerably higher in ODR than the zero tilled. At the 5 cm. depth, readings taken throughout the season showed that the zero tilled soil was less able to supply oxygen to the roots (Figure 27). At the 10 cm. depth (Figure 28), the zero tilled soil was higher in ODR for most of the season.

The difference found at the surface could have been due to greater compaction (Table 25) or by the relatively higher moisture content on the zero tilled soil (Figure 17).

In the deeper layers, structural differences may have caused the better aeration under the zero till system. At these depths, the zero tilled soil was quite different structurally from the conventional, for it had stabilized into small, blocky aggregates, having many natural cracks for water and oxygen movement even under wet conditions. The conventional, on the other hand, had little structural development.

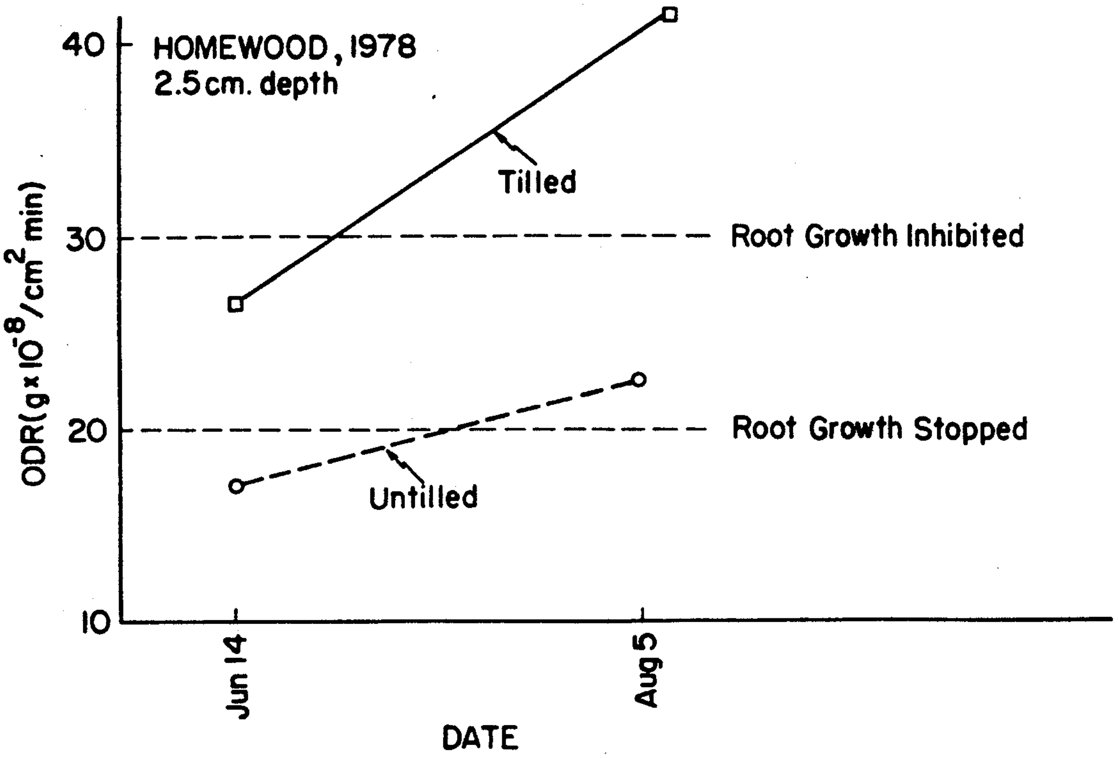

Fig. 26 Oxygen diffusion rate at the 2.5 cm. depth.

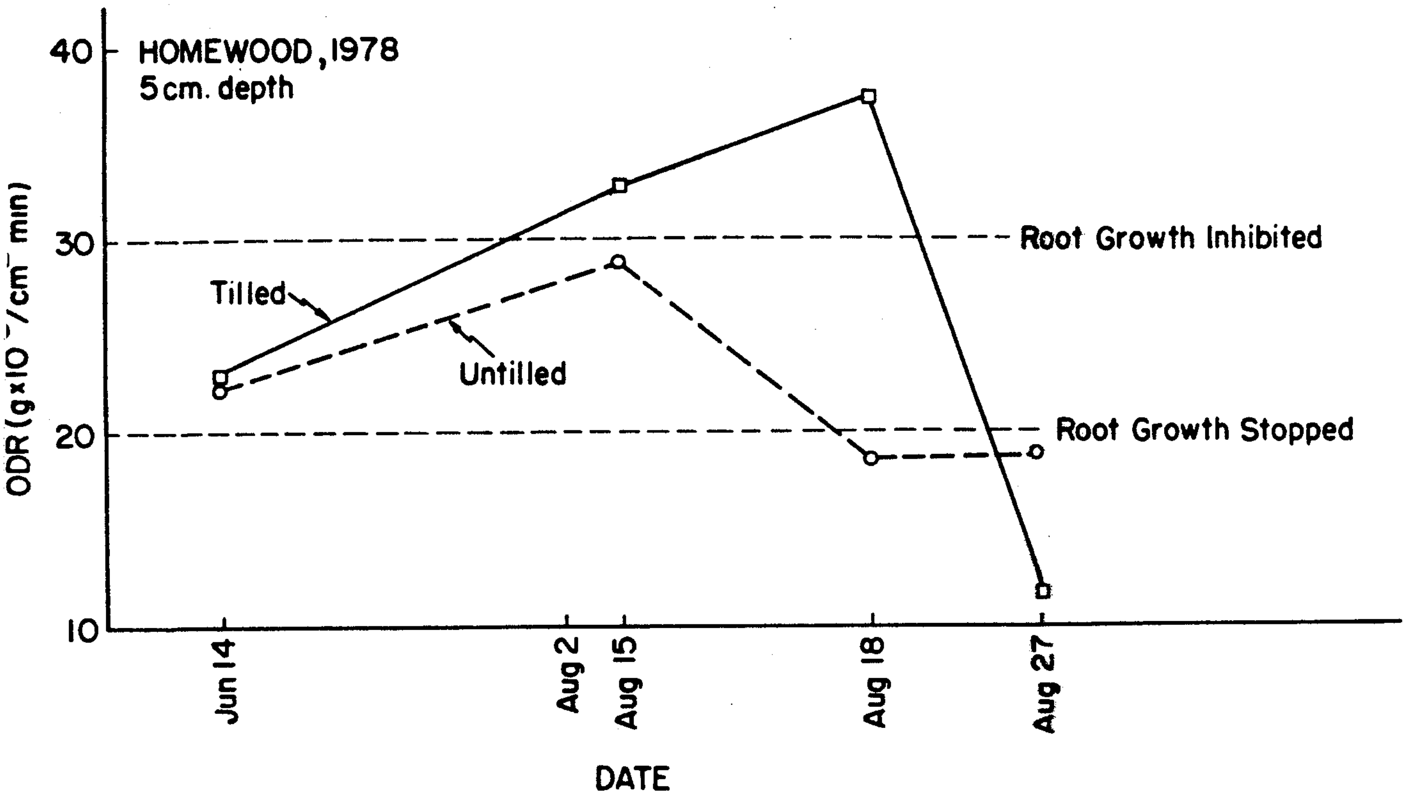

Fig. 27 Oxygen diffusion rate at the 5 cm. depth.

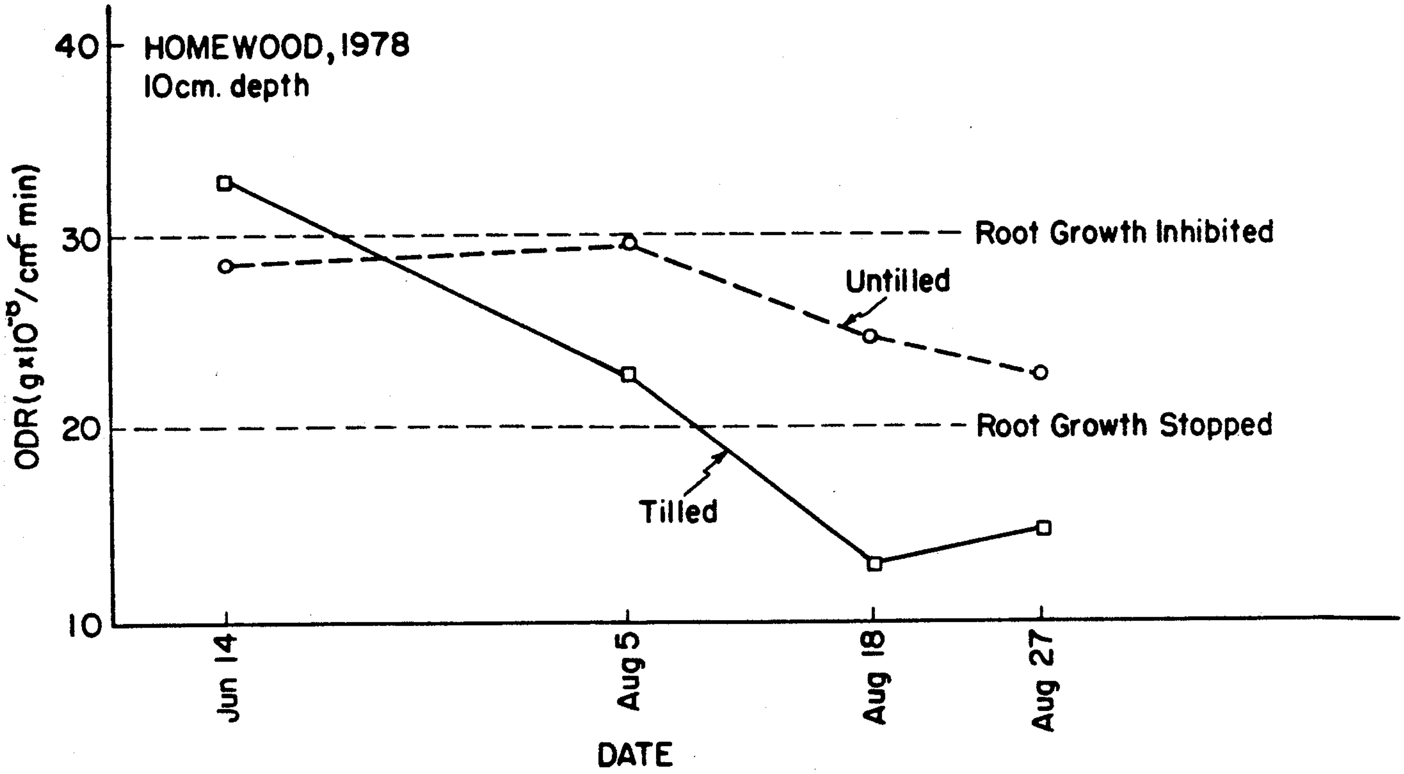

Fig. 28 Oxygen diffusion rate at the 10 cm. depth.

Chapter V
CONCLUSIONS

The future of zero tillage on the Canadian Prairies depends to a great extent on the acceptance of it by farmers. All indications point toward the feasibility of using the system in this climatic area. The more innovative farm owners have already shown that zero tillage is an acceptable if not superior system which can be adopted totally or along with conventional tillage practices now used. Concern over rising fuel costs as well as deteriorating top soil conditions has led a few farmers into totally abandoning conventional tillage in favor of zero till methods. In this, the farmer is more advanced than the researcher, for he has had to answer many of his own problems as they occurred.

Our study into soil moisture and temperature revealed that zero tillage could not be considered separately from the three straw management practices used. If the straw was scattered on top of the soil in the fall, lower soil temeratures (Figures 1 and 2) and increased soil moisture (Figures 17 , 18 and 19) were found the following spring. If the straw was removed, soil temeratures were similar or higher under zero tillage (Figures 6 and 7) and moisture tended to be greater (Figures 21 and 22). Straw burning produced similar temperature (Figures 8 and 9) and moisture trends (Figures 23 and 24) on conventional and zero tilled soils.

Winter temperatures were found to be considerably more favorable to the survival of winter wheat under zero tillage (Figures 10 and 11). This indicated the possibility of increasing winter wheat acreages on the Prairies, just by changing tillage methods.

In one case, higher soil temperatures were found under a mulch cover due to the unique microclimatic factors which existed (Figure 4).

Predicted days to emergence for various crops based on a regression equation study failed to show any significant differences due to the straw-tillage practice. No significant delays were found in emergence of cereals and oilseed crops. Corn showed a small delay of 2 to 3 days.

A greater delay in development to the 6-leaf stage was predicted. More reasearch is required to investigate the use of zero tillage for corn production. At this point, straw removal should be recommended for corn production to prevent low soil temperatures. Cereal straw could be put to good use as bedding for livestock.

Hopefully, this study will have helped to answer a few questions, although at this point, it has created a more. Work needs to be done on soil strength and compaction on silt and clay soils. Root distribution patterns should be investigated. Possible phytotoxicity of straw residues should be studied to determine if this might be a deterrent to zero tillage production. As well, germination and emergence as related to low soil temperatures need to be closely examined, keeping in mind that the crop breeder could be a valuable asset here.

Innovation seems to be the key behind the farmers who have tried and succeeded with the zero till system. Zero tillage does offer a few very significant advantages to the farmer, including reduced time on the field, reduced labor and fuel costs, higher soil moisture, and decreased soil erosion. It is up to the agricultural researchers and technicians to fully evaluate the zero till method. There is no better time to promote soil conservation, for zero tillage now makes it possible to separate the farmer from his plow. This alternative exists.

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APPENDIX

AVERAGE WEEKLY SOIL TEMPERATURES (°C)

GRAYSVILLE, 1978

SEEDING DATE - MAY 4

WEEK	TREATMENT	2.5 cm	5.0 cm	10.0 cm	20.0 cm
1	[1]ST	12.0	11.8	12.3	10.2
	[2]SU	11.2	10.8	10.3	9.4
	[3]RU	11.9	11.2	10.7	9.5
2	ST	16.4	15.8	14.8	13.2
	SU	14.8	14.0	13.1	11.7
	RU	16.0	14.9	14.0	12.3
3	ST	17.5	17.3	17.1	16.0
	SU	17.0	16.6	16.0	14.8
	RU	17.8	17.2	16.7	15.4
4	ST	17.2	17.6	17.8	17.5
	SU	17.5	17.5	17.5	17.1
	RU	18.3	17.4	17.4	17.0
5	ST	14.9	14.9	14.9	14.5
	SU	15.4	15.3	14.9	14.4
	RU	15.9	14.8	14.6	14.2
6	ST	16.8	16.6	16.1	15.4
	SU	17.3	17.0	16.4	15.6
	RU	18.2	16.3	15.9	15.1
7	ST	18.6	18.4	17.9	17.2
	SU	19.0	18.3	17.9	17.1
	RU	19.7	18.1	17.7	16.9

[1] straw scattered conventionally tilled

[2] straw scattered zero tilled

[3] straw removed zero tilled

AVERAGE WEEKLY SOIL TEMPERATURES (°C)

GRAYSVILLE, 1978 (continued)

WEEK	TREATMENT	2.5 cm	5.0 cm	10.0 cm	20.0 cm
8	ST	20.5	20.3	19.6	18.5
	SU	20.7	20.2	19.5	18.2
	RU	22.1	20.0	19.5	18.3
9	ST	22.7	22.6	22.0	20.8
	SU	22.5	22.2	21.4	20.0
	RU	22.7	22.1	21.6	20.4
10	ST	18.3	18.5	18.4	18.3
	SU	18.3	18.3	18.2	17.9
	RU	18.2	18.3	18.4	18.1
11	ST	20.8	20.6	20.3	19.6
	SU	20.8	20.5	20.0	19.2
	RU	21.0	20.9	20.4	19.8
12	ST	20.3	20.3	20.0	19.4
	SU	20.3	20.0	19.7	19.1
	RU	20.8	20.9	20.6	19.9
13	ST	18.4	18.4	18.5	18.3
	SU	18.2	18.3	18.2	18.1
	RU	18.3	18.6	18.8	18.7

AVERAGE WEEKLY SOIL TEMPERATURES (°C)

GRAYSVILLE, 1979

SEEDING DATE - MAY 24

WEEK	TREATMENT	2.5 cm	5.0 cm	10.0 cm	20.0 cm
1	[1]ST	14.4	14.2	13.8	12.6
	[2]SU	13.2	12.8	12.3	11.1
	[3]RU	13.9	13.6	12.9	11.7
2	ST	16.3	16.2	15.6	14.2
	SU	14.6	14.2	13.6	12.4
	RU	15.5	15.2	14.2	12.9
3	ST	19.6	19.1	18.4	16.8
	SU	17.2	16.7	15.8	14.5
	RU	18.1	17.9	16.7	15.0
4	ST	18.7	18.9	18.9	19.6
	SU	17.0	16.9	16.8	16.2
	RU	18.1	17.9	17.6	17.0
5	ST	20.4	20.0	19.1	17.9
	SU	18.4	18.0	17.4	16.3
	RU	19.4	19.0	18.0	16.8
6	ST	21.1	20.8	20.0	19.0
	SU	19.3	19.1	18.7	17.9
	RU	20.5	20.1	19.4	18.5
7	ST	19.0	18.8	18.5	18.1
	SU	19.0	18.8	18.6	18.2
	RU	19.9	19.6	19.2	18.7

[1] straw scattered conventionally tilled

[2] straw scattered zero tilled

[3] straw removed zero tilled

AVERAGE WEEKLY SOIL TEMPERATURES (°C)
GRAYSVILLE, 1979 (continued)

WEEK	TREATMENT	2.5 cm	5.0 cm	10.0 cm	20.0 cm
8	ST	18.1	17.9	17.5	17.1
	SU	18.4	18.1	17.9	17.5
	RU	19.0	18.6	18.3	18.0
9	ST	16.7	16.7	16.5	16.4
	SU	17.1	17.0	16.9	16.8
	RU	17.3	17.3	17.2	17.0
10	ST	15.8	15.8	15.7	15.7
	SU	16.3	16.3	16.1	16.0
	RU	16.5	16.4	16.3	16.2
11	ST	13.7	13.8	13.8	14.0
	SU	14.5	14.5	14.5	14.5
	RU	14.9	14.9	14.9	14.9

AVERAGE WEEKLY SOIL TEMPERATURES (°C)

SANFORD, 1979

WEEK	TREATMENT	2.5 cm	5.0 cm	10.0 cm	20.0 cm
1	[1]SU	14.0	13.7	12.8	11.3
	[2]RU	15.7	15.2	13.9	12.3
	[3]ST	-	14.8	11.9	-
	[4]BT	15.3	14.4	12.7	10.6
	[5]RT	15.8	13.8	13.2	11.0
	[6]BU	-	15.1	13.8	-
2	SU	16.4	15.9	15.1	13.9
	RU	18.0	17.4	16.2	14.8
	ST	-	17.1	14.7	-
	BT	17.8	16.9	15.3	13.6
	RT	18.1	15.8	15.5	13.9
	BU	-	17.3	16.2	-
3	SU	19.0	18.7	17.8	16.3
	RU	20.7	19.9	18.8	17.2
	ST	-	19.7	17.0	-
	BT	20.4	19.7	18.3	16.4
	RT	20.3	18.3	17.9	16.3
	BU	-	20.1	18.9	-
4	SU	22.0	21.3	20.0	18.1
	RU	23.0	22.4	20.8	18.9
	ST	-	22.7	19.5	-
	BT	23.3	22.3	20.8	18.9
	RT	22.6	21.5	20.6	19.7
	BU	-	22.4	21.1	-

[1] straw scattered zero tilled

[2] straw removed zero tilled

[3] straw scattered tilled

[4] straw burned tilled

[5] straw removed tilled

[6] straw burned zero tilled

AVERAGE WEEKLY SOIL TEMPERATURES (°C)

SANFORD, 1979 (continued)

WEEK	TREATMENT	2.5 cm	5.0 cm	10.0 cm	20.0 cm
5	SU	19.2	19.1	18.4	17.7
	RU	-	19.8	18.8	-
	ST	-	20.3	19.1	-
	BT	20.2	20.0	19.7	18.7
	RT	-	19.9	18.9	-
	BU	-	19.5	18.3	-
6	SU	20.0	19.7	19.2	18.4
	RU	20.5	20.7	19.4	18.4
	ST	-	21.1	19.8	-
	BT	21.7	21.9	20.7	19.2
	RT	22.5	21.0	20.9	19.5
	BU	-	20.5	19.4	-
7	SU	17.5	17.4	17.0	16.5
	RU	18.1	18.4	17.4	17.4
	ST	-	18.3	18.0	-
	BT	18.9	19.2	18.6	17.8
	RT	19.5	18.6	18.7	17.9
	BU	-	17.5	17.2	-
8	SU	15.6	15.3	14.7	14.2
	RU	15.7	15.9	14.9	14.5
	ST	-	15.6	15.3	-
	BT	16.2	16.4	15.7	15.1
	RT	16.6	16.4	16.0	15.5
	BU	-	14.0	14.0	-

Volumetric Water Content (%)[1] of the Zero Tilled Soil at Homewood, 1978[2]

Depth (cm) \ Date	14 Jun	5 Jul	13 Jul	18 Jul	26 Jul	3 Aug	17 Aug
0-15	34.00	36.64	37.04	39.41	32.68	28.19	23.30
15-30	47.13	39.87	41.53	47.00	43.67	42.13	38.33
30-45	43.40	38.33	37.93	43.40	39.87	37.60	34.73
45-60	42.73	40.67	39.00	40.33	38.33	36.87	37.47
60-75	41.73	39.87	40.33	40.20	38.67	37.73	34.00
75-90	39.40	39.00	38.80	39.73	38.07	36.40	32.60
90-105	36.40	46.27	37.60	35.47	35.00	31.87	27.13
105-120	32.13	-	31.87	31.27	29.60	29.40	27.33

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[1] Measured by the neutron moisture meter method.

[2] Clay loam soil

Volumetric Water Content (%)[1] of the Conventionally Tilled Soil at Homewood, 1978.[2]

Depth (cm) / Date	14 Jun	5 Jul	13 Jul	18 Jul	26 Jul	3 Aug	17 Aug
0-15	35.85	33.73	34.13	44.17	27.92	24.49	21.18
15-30	47.73	39.27	38.20	55.20	41.27	39.87	36.40
30-45	43.20	38.80	36.87	40.80	37.00	36.07	33.53
45-60	41.27	38.53	36.40	36.27	34.13	33.07	30.20
60-75	41.53	40.47	39.60	39.00	36.53	35.47	31.53
75-90	43.53	41.53	41.40	42.13	39.87	39.40	35.93
90-105	39.00	38.53	41.27	38.20	36.67	36.67	34.00
105-120	38.33	-	42.47	37.00	35.20	34.13	30.80

[1] Measured by the neutron moisture meter method.

[2] Clay loam soil

Volumetric Water Content (%)[1] of the Zero Tilled Soil at Graysville, 1978[2]

Depth (cm) \ Date	5 Jul	13 Jul	18 Jul	26 Jul	2 Aug	11 Aug	17 Aug	22 Aug	24 Aug	29 Aug
0-15	30.56	20.39	24.88	16.56	14.98	13.65	13.39	13.39	15.64	18.94
15-30	24.87	24.60	33.20	25.47	22.00	18.33	18.07	17.47	17.00	21.07
30-45	23.20	24.40	29.60	25.93	23.67	21.53	20.93	20.33	20.60	21.07
45-60	20.80	20.93	24.27	21.53	19.87	21.87	18.67	18.33	18.33	18.53
60-75	24.87	24.40	24.87	22.27	21.07	20.00	19.87	20.33	19.73	19.73
75-90	33.53	34.00	33.67	29.27	28.80	27.73	26.67	26.53	26.27	26.67
90-105	36.67	36.67	36.27	32.33	30.67	28.30	28.33	27.47	27.13	27.47
105-120	39.40	40.80	39.40	39.40	38.20	35.20	33.80	32.47	32.60	32.47

[1] Measured by the neutron moisture meter method.

[2] Sandy loam texture

[3] Below range of calibration curve.

Volumetric Water Content (%)[1] of the Conventionally Tilled Soil at Graysville, 1978.[2]

Depth (cm) \ Date	5 Jul	13 Jul	18 Jul	26 Jul	2 Aug	11 Aug	17 Aug	22 Aug	24 Aug	29 Aug
0-15	21.84	23.30	29.37	18.01	16.16	14.45	14.58	14.31	14.58	21.05
15-30	21.40	22.00	30.93	23.53	18.07	15.60	13.80	13.07	13.20	16.07
30-45	20.47	21.40	26.27	23.80	20.93	15.80	15.00	14.27	13.80	14.53
45-60	20.33	20.20	21.40	20.80	19.73	17.00	16.67	15.80	15.20	15.47
60-75	22.73	23.07	23.07	23.07	23.53	22.13	20.60	20.33	19.73	20.93
75-90	33.53	33.33	33.20	32.47	32.33	30.47	29.13	28.33	28.33	28.20
90-105	35.20	35.33	34.73	37.00	35.80	34.27	33.80	32.33	31.67	32.13
105-120	41.40	41.27	40.80	42.00	40.47	38.33	37.00	36.53	36.27	35.80

[1] Measured by the neutron moisture meter method.

[2] Sandy loam texture

Soil Temperature[1] down to 150 cm on the Straw Scattered Zero Tilled Treatment, Graysville, 1978

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
14/06	1505	29.4	26.4	21.9	16.0	15.1	12.6	9.6
20/06	1120	16.0	15.1	14.2	13.9	14.5	11.6	9.2
22/06	1300	26.4	23.8	19.2	16.0	15.1	12.5	9.8
27/06	1600	29.2	21.3	23.2	18.0	15.1	12.6	10.1
29/06	1330	30.5	28.8	22.7	18.3	16.1	13.0	10.4
05/07	1130	21.2	-	19.9	19.0	17.1	12.9	10.3
06/07	1050	21.3	-	18.8	19.0	17.1	13.0	10.2
11/07	1100	18.1	-	15.6	15.3	15.0	13.0	10.9
13/07	1230	21.3	-	18.8	19.0	17.0	13.0	10.2
18/07	1115	22.0	-	18.0	19.1	17.6	14.1	11.6
20/07	1020	20.3	19.2	17.7	17.2	16.7	13.8	11.3
26/07	1170	24.1	-	20.5	20.0	18.9	15.7	13.4
27/07	1120	22.9	-	19.7	19.4	18.9	15.6	13.2
02/08	1100	17.2	-	16.9	18.0	18.0	15.1	13.3
03/08	1100	19.6	-	15.4	15.7	16.7	15.0	13.1
08/08	1300	25.5	-	20.7	19.3	18.2	15.3	13.2
11/08	1415	33.4	-	23.3	20.4	18.7	16.1	14.3

[1] Taken by using a portable potentiometer

Soil Temperature [1] down to 150 cm on the Straw Scattered Conventionally Tilled Treatment, Graysville, 1978

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
14/06	1505	27.9	24.6	20.2	16.2	15.4	12.2	9.2
20/06	1120	16.7	14.6	13.2	13.4	14.4	11.3	8.7
22/06	1300	26.4	23.2	18.9	16.0	14.6	11.7	9.4
27/06	1600	29.3	26.6	23.2	18.5	15.3	13.0	10.6
29/06	1330	32.5	28.3	24.3	19.8	17.2	13.6	11.5
05/07	1130	22.7	20.9	20.0	18.9	16.9	12.8	10.5
06/07	1030	21.1	19.9	19.3	18.9	17.3	13.0	10.4
11/07	1050	19.9	17.2	15.6	15.3	15.3	13.0	11.0
13/07	1010	21.1	19.9	19.3	18.9	17.3	13.0	10.4
18/07	1115	22.9	20.7	19.3	19.8	17.3	13.9	11.3
20/07	1020	19.0	17.8	16.4	17.5	17.4	14.5	11.7
26/07	1110	26.0	22.8	20.6	20.0	18.7	15.3	13.0
27/07	1126	24.9	21.1	19.3	19.1	18.7	15.5	13.1
02/07	1100	19.6	18.2	17.6	18.2	18.3	15.5	13.1
03/07	1100	21.0	17.9	15.9	15.9	16.8	15.0	13.1
08/07	1300	27.8	24.2	21.9	20.3	19.2	16.3	14.3
11/07	1415	36.5	30.4	26.3	22.2	19.7	16.8	14.7

[1] Taken by using a portable potentiometer

Soil Temperature[1] down to 150 cm on the Straw Scattered Treatment, Graysville, 1979

ZERO TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1030	19.3	18.2	16.8	16.4	15.6	13.2	10.8
24/07	1140	23.5	22.0	20.0	19.3	17.5	14.3	12.1
31/07	1150	-	18.8	16.5	16.9	16.6	14.3	12.3
09/08	1050	-	19.7	17.6	17.0	15.8	14.2	12.3
14/08	1122	-	16.8	13.8	14.4	15.2	14.4	13.3
21/08	1120	20.0	18.3	17.8	17.8	17.2	15.0	13.9
28/08	1050	-	20.0	17.8	17.2	15.6	14.4	13.3

CONVENTIONALLY TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1030	19.1	18.0	16.9	16.6	15.6	13.2	10.7
24/07	1130	24.6	23.1	21.2	20.2	18.4	15.1	12.7
31/07	1140	23.0	21.4	18.2	17.2	17.0	14.9	12.8
09/08	1100	19.5	18.8	17.6	16.8	15.5	13.8	12.2
14/08	1105	17.2	16.1	15.0	14.4	16.1	14.4	13.3
21/08	1110	21.1	20.0	18.3	18.3	17.8	15.5	13.9
28/08	1030	21.7	20.6	18.3	17.8	16.7	14.4	13.3

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[1] Taken by using a portable potentiometer

Soil Temperature[1] down to 150 cm on the Straw Removed Treatment, Graysville, 1979

ZERO TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1030	21.4	19.5	18.3	17.4	16.9	14.5	12.2
24/07	1130	22.4	21.4	20.2	19.3	17.8	14.8	12.4
31/07	1210	18.8	17.5	16.4	15.8	16.1	14.8	12.7
09/08	1030	12.8	11.4	10.2	09.0	7.8	6.0	4.6
14/08	1130	15.0	14.4	14.4	14.4	16.1	15.0	13.8
21/08	1112	23.3	18.9	17.8	17.2	16.7	13.9	13.3
28/08	1100	20.0	18.3	17.8	17.2	16.1	14.4	13.9

CONVENTIONALLY TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1030	26.2	23.2	19.0	17.2	16.7	14.2	11.8
24/07	1140	23.9	22.2	19.7	18.8	17.7	14.7	12.3
31/07	1205	20.9	19.6	17.4	17.3	17.8	15.8	13.6
09/08	1125	16.3	14.4	11.7	10.5	9.5	7.3	5.8
14/08	1125	17.2	16.7	14.4	14.4	16.1	15.0	13.8
21/08	1115	20.6	20.0	18.3	18.3	17.2	14.4	13.3
28/08	1110	22.8	21.1	17.8	17.2	16.7	15.0	13.9

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[1] Taken by using a portable potentiometer

Soil Temperature [1] down to 150 cm on the Straw Burned Treatment, Graysville, 1979

ZERO TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1030	21.2	19.6	17.2	16.0	14.4	13.4	11.1
24/07	1150	23.8	22.6	-	19.0	17.3	14.0	11.9
31/07	1200	19.0	18.0	-	15.7	16.2	14.4	12.4
09/08	1100	19.9	18.6	-	13.2	11.3	10.1	8.8
14/08	1620	17.8	16.7	-	14.4	15.6	14.4	13.3
21/08	1123	20.0	19.4	-	17.8	17.2	15.0	13.9
28/08	1020	22.2	20.6	-	17.2	16.1	14.4	13.3

CONVENTIONALLY TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1030	21.9	19.6	17.6	16.2	15.3	13.0	10.1
24/07	1140	24.6	22.5	20.8	19.6	17.6	14.3	12.0
31/07	1155	24.4	21.2	18.2	16.6	16.8	15.1	13.0
09/08	1100	22.1	20.3	18.6	18.0	16.3	14.6	12.7
14/08	1615	20.6	18.3	16.1	15.0	16.7	14.4	13.3
21/08	1130	21.1	21.1	20.0	18.9	17.8	15.0	13.9
28/08	1015	25.6	22.2	20.0	17.8	16.7	15.0	13.9

[1] Taken by using a portable potentiometer

Soil Temperature [1] down to 150 cm on the Straw Scattered Treatment, Sanford, 1979

ZERO TILLED

Date	Time	Soil Temperature (^oC)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1345	27.6	25.4	21.6	17.8	15.4	11.3	8.8
24/07	1510	25.7	24.8	22.2	19.3	16.4	12.0	9.2
31/07	1400	23.2	21.4	18.6	16.5	15.3	11.8	9.2
14/08	1410	17.2	16.7	15.0	14.4	14.4	13.3	11.1
21/08	1351	20.6	20.0	18.3	16.7	15.5	13.3	11.7
28/08	1405	24.4	22.2	20.0	17.2	15.0	13.9	12.2

CONVENTIONALLY TILLED

Date	Time	Soil Temperature (^oC)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1335	29.9	27.5	22.7	18.3	15.9	11.3	7.5
24/07	1450	29.5	27.8	24.1	20.1	17.2	12.7	9.4
31/07	1400	28.3	25.6	21.2	17.4	16.2	12.8	9.7
14/08	1410	16.7	16.1	14.4	13.8	14.4	13.3	10.6
21/08	1340	21.1	20.6	–	18.3	16.7	13.9	11.7
28/08	1410	26.1	22.8	20.6	17.2	15.6	13.9	12.2

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[1] Taken by using a portable potentiometer

Soil Temperature [1] down to 150 cm on the Straw Removed Treatment at Sanford, 1979.

ZERO TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1335	29.1	26.4	22.2	18.6	16.4	12.7	9.5
24/07	1515	26.4	25.2	22.9	20.2	-	12.5	9.6
31/07	1400	22.9	20.9	18.1	16.2	15.0	11.8	8.7
09/08	1610	23.2	21.6	19.4	17.7	15.9	13.4	11.0
14/08	1400	20.0	18.3	16.1	15.0	15.6	13.3	11.1
21/08	1357	20.6	19.4	18.3	17.2	16.1	12.7	11.1
28/08	1405	27.8	24.4	21.1	18.3	16.7	14.4	13.3

CONVENTIONALLY TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1345	27.0	24.9	22.0	18.8	16.7	-	9.2
24/07	1440	31.2	27.9	24.4	21.2	18.4	13.8	10.3
31/07	1400	23.9	22.2	20.3	18.2	17.4	-	10.8
9/08	1400	20.0	17.8	16.7	15.0	16.1	20.0	11.7
14/08	1615	22.5	21.4	20.1	18.3	16.6	-	11.0
21/08	1348	22.2	21.1	20.0	18.3	16.7	-	12.2
28/08	1400	28.9	25.6	21.7	18.3	16.7	-	12.8

[1] Taken by using a portable potentiometer

Soil Temperature [1] down to 150 cm on the Straw Burned Treatment at Sanford, 1979.

ZERO TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1345	28.4	26.6	22.2	18.0	15.5	11.0	7.6
24/07	1500	26.6	25.0	22.0	19.3	16.3	11.8	8.5
31/07	1400	22.2	20.9	18.3	16.4	15.4	11.9	9.1
14/08	1415	16.1	15.0	13.8	13.8	14.4	12.8	11.1
21/08	1344	20.6	20.6	19.4	17.8	16.1	13.9	11.7
28/08	1415	25.0	22.8	20.6	17.2	15.5	13.9	11.7

CONVENTIONALLY TILLED

Date	Time	Soil Temperature (°C)						
		2.5 cm	5.0 cm	10.0 cm	20.0 cm	50.0 cm	100 cm	150 cm
17/07	1345	26.9	24.2	-	17.7	15.6	10.6	7.3
24/07	1430	29.0	26.1	-	21.0	18.2	12.9	9.5
31/07	1400	26.2	23.1	-	17.9	16.6	13.2	9.3
9/08	1605	27.0	-	-	24.7	21.5	17.1	13.6
14/08	1350	18.9	17.2	-	15.6	15.6	13.3	11.1
21/08	1350	25.6	22.8	-	18.3	16.7	14.4	12.8
28/08	1354	21.1	20.0	-	17.2	16.1	13.3	11.1

[1] Taken by using a portable potentiometer.

The calculation of the regression equation relating rapeseed emergence time to soil temperature

X = temperature (^{o}C) (maintained as constant for D)

Y = ^{1}/days to emergence

D = days to emergence

T = temperature at a given time

X	Y	$(X - \bar{X})$	$(Y - \bar{Y})$	$(X - \bar{X})^2$	$(Y - \bar{Y})^2$	$(X - \bar{X})\ (Y - \bar{Y})$
4	0.037037	-10.8	-0.149416	116.64	.0223250	1.613693
10	0.142857	- 4.8	-0.043596	23.04	.0019006	.209261
14	0.133333	- 0.8	-0.05312	00.64	.0028217	.042496
20	0.285714	5.2	+0.09926	27.04	.0098525	.516152
26	0.333333	11.2	.14688	125.44	.0215737	1.645056
	Σ Y=.932268			Σ=292.80	Σ =.0584735	Σ =4.026658

$\bar{Y}$=.186453

ΣX=74

$\bar{X}$=14.08

$$\text{Regression coeffient} = b = \frac{(X-\bar{X})\ (Y-\bar{Y})}{(X-\bar{X})^2}$$

$$b = 1.37 \times 10^{-2}$$

$\bar{y} = a + b\bar{x}$

$.186453 = a + (1.37 \times 10^{-2})\ (14.08)$

$a = -.016307$

$^{1}/D = -.016307 + 1.37 \times 10^{-2}\ (T)$

$^{1}/D = 1.37 \times 10^{-2}\ (T - .016307/1.37 \times 10^{-2})$

$^{1}/D = 1.37 \times 10^{-2}\ (T - 1.19)$

When $1_{/D}$ = 1 emergence occurs