THE EFFECTS OF STUBBLE HEIGHT AND CROP RESIDUES ON THE SURVIVAL AND GROWTH OF WINTER WHEAT (TRITICUM AESTIVUM L.) IN MANITOBA

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Robert John Doell

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ABSTRACT

Doell, Robert John, M.Sc., The University of Manitoba, October, 1983. The Effects of Stubble Height and Crop Residues on the Survival and Growth of Winter Wheat (Triticum aestivum) in Manitoba. Major Professor; Dr. F. Schwerdtle, Department of Plant Science.

The greatest barrier to successful winter wheat production in Manitoba is winter-kill. Research has shown that the chance of survival is improved if an adequate snow cover is maintained through the winter. This is due to the insulative properties of the snow. Standing stubble has been shown to be effective in trapping and holding snow.

The stubble height experiment was carried out for two seasons. Winter wheat, C.V. Norstar, was seeded into barley stubble in early September. The crop was seeded into chemical summer fallow, conventionally tilled stubble, and standing stubble that was 7.5, 15, and 30 cm high.

Soil temperatures were monitored daily, and snow depths of the plots were recorded on a weekly basis throughout the winter. There was a significant difference in snow depths between treatments, but this was not reflected in a difference in winter survival. This could be partly attributed to the mild winter in 1980-81, and to increased snow retention on all plots due to deep (5 cm) drill furrows and the presence of volunteer barley in 1981-82. Snow depths had a significant effect on soil temperature.

Snow depths had a significant effect on the depth of ground frost penetration, but had no substantial measured effect on the rate of downward retreat of frost in the ground.

The only marked decrease in survival was due to water ponding in the spring. This caused the death of some plants, primarily on the conventional tillage plots. The chemical fallow treatment showed an increase in dry matter over the other treatments. There were, however, no significant differences in yield between treatments in either year.

Additional experiments were carried out to find out if rates or types of crop residues possible with zero-tillage had adverse effects on the winter wheat. Plots were seeded into 15 cm stubble, and barley straw was applied at rates of 1500, 3000, and 4500 kg/ha. Winter survival was not affected, although plants under the higher rates were smaller and fewer in number. In a separate experiment, rapeseed straw had the least effect on wheat survival and growth, when compared to barley or winter wheat straw. In all three cases, adverse effects were more noticeable at higher rates of straw mulch.

INTRODUCTION

Winter wheat has been successfully produced on the Canadian prairies for over 70 years, but has been limited to southwestern Alberta and the extreme southwestern part of Saskatchewan, due to moderating influences on the climate in these areas. In other areas of the Canadian prairies, winter wheat has proven to be unreliable due to the frequency of winterkill (Grant et al., 1976).

With the introduction of zero-tillage as an alternate management system, there has been an increased potential for the expansion of winter wheat production into areas previously unsuited. With the use of zero-tillage, an insulating blanket of snow is trapped by the standing stubble, which protects the crop against lethal temperatures (Aase and Siddoway, 1980). In addition to this, the insulation provided by the snow reduces the depth of frost penetration. This reduction results in a greater retention of the latent heat of crystalization of water within the soil, with a corresponding lack of need to replace it from the ambient energy supply during the early part of the growing season (Sawatzky, 1983). These factors are very important in the introduction of winter wheat to areas in which it was previously impractical to grow it. This is true, both for reasons of moisture retention, and for modification of temperatures in winter and spring.

The production of winter wheat presents the grower with the prospect of a number of benefits. Winter wheat has demonstrated a higher yield potential than spring wheat, in part at least, because of its greater utilization of fall and spring moisture. It is a superior competitor vis-a-vis annual weeds, due to its early spring growth. Fall seeding and early maturity and harvest spread the workload for the farmer. Winter wheat also minimizes the effects of insect problems due to its advanced growth in spring (Grant et al., 1976). It also provides some measure of erosion control throughout winter and early spring, especially when grown under conditions of minimal soil disturbance.

Zero-tillage production of winter wheat has produced results superior to those generally obtained with conventional tillage practices in Montana (Aase and Siddoway, 1979, 1980; Black and Siddoway, 1977). The objective of this study is to help determine the optimum stubble management system for winter wheat production in southern Manitoba.

LITERATURE REVIEW

Zero-Tillage

Plowing or similar deep tillage operations have been a part of the more advanced cropping systems for centuries. Recently, both researchers and farmers have been questioning this practice, because of the expenses involved, both in fuel costs and, most importantly, in the erosion of soils. These factors have led to the introduction of a cropping practice known as "zero-tillage". The term "zero-tillage" is used to designate a tillage system in which the mechanical soil manipulation is reduced to that caused by incidental traffic and seedbed preparation only (Baeumer and Bakermans, 1973), or a system in which a crop is seeded into a non-disturbed seedbed with a minimum of soil disturbance, and chemical weed control, if necessary (Donaghy, 1973).

There are several advantages to this method of cropping. There may be a reduction in labour and energy. More importantly, an improved soil structure, such as that found under sod, where organic matter accumulates at the surface, stimulates aggregate stability (Baeumer and Bakermans, 1973), and reduces the risk of soil erosion (Aase and Siddoway, 1980). This soil structure should eventually provide optimum conditions both for plant growth and the necessary traffic on the fields (Baeumer and Bakermans, 1973).

Soil Structure

Zero-tillage results in a changed soil structure. In England, Finney and Knight (1973) noted that a plowed soil had a lower bulk density, more pores of a size suitable for root extension, and that the soil was more malleable. Conversely, Bauemer and Bakermans (1973), cite Czeratszki and Ruhm (1971) who found that zero-tillage caused a decrease of large air filled pores (diameter >30 μm) which reduced aeration of the soil. However, cultivations decreased the continuity of the soil pores, and the increase in porosity was often only temporary (Finney and Knight, 1973). The undisturbed soil may be more dense and firm, at the same time having a more stable crumb structure than cultivated soil. This friable crumb structure in the upper horizons prevents slaking and crust formation during rainfall (Baeumer and Bakermans, 1973). It has also been noted in West Germany that zero-tilled soils harbour a greater population of earthworms (Schwerdtle, 1969). Zero-tillage also helps to eliminate a compacted plow pan in the soil, although Wilhelm et al., (1982), in studies near Lincoln, Nebraska, stated that root function may not be seriously impaired by a plow layer, due to an excessive number of roots. The greater density of zero-tilled soils increased the resistance to root elongation resulting in more lateral branching (Finney and Knight, 1973).

Soil Moisture

One of the benefits of zero-tillage is the increase in available soil moisture, especially at the surface. In Kentucky, Blevens et al., (1972) found no tillage treatments had higher volumetric water contents to a depth of 60 cm during most of the growing season with the greatest difference occurring in the upper 8 cm. Zero-tilled soils, when compared to conventionally tilled soils of the same water content, generally had a lower soil water tension, due to an increase in organic matter. This resulted in a smaller resistance to water uptake by plants, as well as higher conductivity (Baeumer and Bakermans, 1973). The zero-tilled soils also tend toward a more uniform distribution of water in the soil profile, being wetter at the surface, (Blevens et al., 1972) and drier at a depth than plowed soil (Finney and Knight, 1973). The reason for this may be due to the stubble mulch. In Manitoba, Gauer et al., (1982) found the largest moisture savings in zero-tillage early in the season, when the bulk of moisture loss was evaporative. The greatest differences occurred in the surface horizons, indicating that more moisture would be available for germination and seedling establishment. At the same time, there is less danger of waterlogging the soil. Decomposing roots and improved structure provide channels for rapid infiltration (Baeumer and Bakermans, 1973). These factors help prevent extremes of dryness and moisture in the rooting zone. Aase and Siddoway

(1980), in Montana, found that most soil water recharge and extraction took place in the top 75 cm of the soil profile.

Snow retention by the standing stubble is a means of increasing the available water in zero-tilled soils. This is important in areas of dryland farming on the northern great plains (Willis et al., 1969). In studies near Swift Current, moisture was retained by stubble land due to faster thawing of the ground (Staple and Lehane, 1952), possibly due to decreased frost penetration, as well as a decrease in evaporative cooling (Sawatzky, 1983). Willis et al. (1969), found that as standing stubble height increased, the snow melt began at an earlier date and proceeded at a faster rate. The reasons given were that the standing straw conducts heat into the snowpack, intercepts and absorbs more solar radiation, reflects solar energy onto the soil surface, and decreases convective and evaporative cooling. Willis et al. (1960) found that spring runoff tends to be less from a dry soil, because frozen moisture is not present to an extent which inhibits infiltration. In Montana, Black and Siddoway (1977) found that 38 cm stubble trapped a water equivalent, in the form of snow, four times as great as that retained by bare soil. Aase and Siddoway (1980) found that 35 cm stubble trapped water equivalent 2.5 times that achieved by bare soil. In both cases this resulted in significantly higher soil-moisture levels in spring.

Soil Temperature

The temperature of the soil depends upon numerous factors, both internal and external. Internal factors include thermal conductivity, water content and related heat capacity, and gaseous content of the various horizons (Baeumer and Bakermans, 1973; Crawford and Legget, 1957; Willis et al., 1960). External factors include ground cover, precipitation, radiation, and general air exchanges (Crawford and Legget, 1957). The amplitude of diurnal and yearly fluctuations decreases with increasing amounts of ground cover. The lag in temperature also becomes greater with depth.

Gauer et al. (1982), found zero-tilled soils were 0.5°C to 2.0°C lower in temperature than conventionally tilled soils and zero-tilled soils from which the straw had been removed. This resulted in fewer degree days above 5°C and 10°C at the 5 cm depth level during the period from May 4th to August 7th. Smika and Greb (1973) found similar results, and attributed this to the insulating effect of the straw mulch on the surface. Similarly in Oregon, Russelle and Bolton (1980), found temperatures during the fall at 5 cm were 1-2°C warmer under bare fallow than under stubble mulch. Soil temperatures are depressed as the rate of mulch increases (Anderson and Russel, 1964), because of the insulation and also because the bright straw reflects sunlight. Increases in reflection were found by Anderson and Russel (1964), to occur up to about 4,000 kg/ha, at which point full ground cover was achieved. When straw is removed, the temperature on zero-tilled soils may be higher than conventionally tilled soils, due to improved heat flow with the greater bulk density (Gauer et al., 1982). Aase and Siddoway (1980), found wind passage at 9 cm height to be 5.5 times greater over bare soil than over 30 cm stubble. The 5 cm air temperature in these treatments was 2-3°C higher in the 30 cm stubble when compared to bare soil, suggesting that the reduction in turbulence conserved heat.

During the winter, the temperatures of zero-tilled soils are most often warmer than those fields that have been tilled. This is due to two factors, namely the surface trash and the trapped snow. During the fall, in Montana, Aase and Siddoway (1979) found temperatures at the 5 cm depths to be 4-5°C warmer under standing stubble than under bare soil. The stubble also reduced diurnal fluctuations, with 35 cm stubble having a greater effect than 19 cm stubble (Aase and Siddoway, 1980). The mulch also helps prevent evaporative water loss, and this extra moisture could act as a heat reservoir, enhancing the insulation of the straw (Hay, 1977). During the summer of 1975, in Montana, Black and Siddoway (1977) found the average soil temperatures at 5 cm depth to be significantly lower for 28 and 38 cm stubble heights when compared to 15 cm stubble and to bare soil. This was for the 24 day period from May 14th to June 10th.

The insulating value of snow is important in determining winter soil temperatures in zero-tilled soils. Many researchers have found increased soil temperatures under snow cover (Crawford and Legget, 1957; Gauer et al., 1982; Willis et al., 1960; Willis et al., 1969; Worzella and Cutler, 1941). As soil depth increases temperatures increase (Kimball and Salisbury, 1971; Crawford and Legget, 1957), especially during the cooling phase. Snow cover also moderates the diurnal temperature fluctuation. Aase and Siddoway (1980), found fluctuations of 15°C under bare soil, while nearby plots under 10 cm snow fluctuated by only 2°C at the 5 cm depth. Snow depths of 10 cm or greater effectively block diurnal variation in temperature. Moisture levels also affect freezing patterns within the soil. Soil which was dry in fall froze faster and deeper than a wet soil (Willis et al., 1960), due to a smaller reservoir of latent heat in the soil (Sawatzky, 1983). Dry soil thawed from the lower depths, while wet soil thawed both from the top and the bottom (Willis et al., 1960). The reduction in heat loss also lessens ice formation, which is the cause of soil heaving (Aase and Siddoway, 1980).

Surface Residues

In zero-tilled soils, the crop residues are not turned under, but remain on the soil surface for a longer period of time. This changes the effect of the residues on the soil and the subsequent crop. Surface mulches increased water infiltration and decreased evaporation (Rickman and Klepper, 1980). The residues also prevent soil slaking and sealing during rainfall as well as subsequent crust formation (Bauemer and Bakermans, 1973). The greatest potential for reduced evaporation by vegetative mulches is during the constant stage rate of evaporation, when the soil surface is wet (Bond and Willis, 1969). Reduction in evaporation during greenhouse studies was linear at about .1 cm per day per 560 kg/ha residue, up to 2240 kg/ha, or complete ground cover. This contradicts Anderson and Russel (1964), although the variation may be accounted for by different definitions of complete ground cover or a variation in mulch density. Bright straw also reflects radiation. After 35 to 40 days, cumulative evaporation was only slightly higher for the low mulch rates, and rate of evaporation was equal for rates of 0 to 6720 kg/ha residues. Implications are that residues are mose useful in conserving moisture when precipitation is frequent and heavy enough to penetrate the mulch (Bond and Willis, 1969). A heavy mulch of plant residues may also have a detrimental effect on cropping. Aside from the obvious difficulty of seeding through the trash, or controlling weeds (Bauemer and Bakermans, 1973), the residues may also smother emerging seedlings (Anderson and Russel, 1964), and decrease yields (Ferguson, 1967). Not all effects are this obvious. Kimber (1973) during greenhouse studies, noted a marked depression in germination where wheat straw was rotted on the soil surface. The effect was reduced where straw was incorporated, but could not be eliminated by addition of nitrogen. He attributed this effect to toxins leaching from the straw and becoming absorbed in a band in the soil. Incorporating the straw diluted the toxins. These toxins, which present a problem in the Pacific Northwest, may have come from fresh residues, or may have been produced by microorganisms during straw decomposition (Cochran et al., 1977). The decomposition of green weeds and volunteer crops may also pose a problem. Toussoun et al. (1968) reported that in greenhouse studies the decay of green barley produced phytotoxic substances when moisture of the soil was greater than 30%. These were most toxic 3 weeks after incorporation and toxicity persisted for 7-8 weeks.

The rate of straw decomposition is speeded up as contact between soil and biomass increases. Low temperature retarded decomposition (Brown and Dickey, 1970). Plants with a higher nitrogen content in the crop residue decompose at a faster rate (Bauemer and Bakermans, 1973).

Soil Fertility

The changes in soil structure, temperature, moisture and fertility, as well as the increased amounts of surface residue, all have an effect on the location and availability of plant nutrients. Bauemer and Bakermans (1973) state that generally, one could expect an increased concentration of nutrients at the surface of zero-tilled soils and a reduction at greater depths. Moschler et al. (1969) found an increase in available Ca., Mg., and P. in the top 5 cm of an orchardgrass-clover stand following zero-tilled corn, compared to the orchardgrass-clover following conventionally tilled corn. In Montana, Brown and Dickey (1970) in studies with wheat straw, showed that buried straw immobilized more phosphorus than did straw on the soil surface or straw above the soil surface, but also that it decomposed at a faster rate, making the phosphorus more available to plants. Smika and Ellis (1971) found no significant differences in P. concentration in winter wheat plants during the tillering or heading stage, regardless of rate of soil warming, presence of mulch or addition of fertilizer nitrogen. The plants were grown both in the greenhouse, and in Nebraska fields where stubble mulch tillage practices had been used. Mulch was present at about 5000 kg/ha at time of seeding.

Moschler et al. (1972) also found P and K to be higher in the top 30 cm of 2 soils tested after 9 and 6 years of continuous zero-tilled corn. Higher moisture in the surface layers may lead to a greater solubility and increased uptake of the nutrients which accumulate there, either through fertilization or through decomposition of plant residues.

The practice of zero-tillage also alters the available nitrogen in the soil. Harapiak (1980) mentions several reasons for this. Mineralization of nitrogen from organic matter is hastened by tillage and therefore slows down under zero tillage. Nitrification is also slowed down because of a combination of less available nitrogen and wet cool compacted soils. Immobilization, the process of combining plant available N with organic residues, also increases because of the more protracted decomposition time of residues (Brown and Dickey, 1970). Denitrification by oxygen-starved microorganisms may also be a problem in soils that are saturated for prolonged periods (Harapiak, 1980; Rickman and Klepper, 1980). This could be a problem in poorly drained soils because of the increased infiltration and decreased evaporation caused by a straw mulch (Rickman & Klepper, 1980). Moschler et al. (1972) found higher levels of organic matter in Virginia soils after 6 years of continuous zero-till corn. Plant analyses showed adequate levels of nutrients, and zero-till plants consistently out-yielded plants grown under conventional tillage, indicating more efficient use of nutrients. Nutrients applied during these studies were the same on both conventional and zero-tillage fields. Blevins et al. (1972) found higher moisture in zero-tilled Kentucky soils down to 60 cm when compared to conventionally tilled soils. The greater differences occurred in the top 8 cm during spring and summer. The two soils were nearly equal by September. This higher moisture content has certain implications for movement of fertilizers, especially water soluble ones like N. Higher fertilizer rates of nitrogen were needed on the zero-tilled corn for a yield equal to the conventionally tilled corn. Analysis of nitrate nitrogen at the end of July showed a much lower concentration of nitrate at the 0-20 cm level for the zero-tilled soil. Below 20 cm the zero-tilled soil had a higher level of NO_3-N. The authors postulated that due to the increased moisture in the upper regions of the soil, leaching may have removed the NO_3-N from the upper root zone.

Winter Wheat

Bread wheat, Triticum aestivum is grown on 26.8 million acres on the Canadian prairies. Of this acreage, only 0.3 million acres or 1.2% is winter wheat (Can. Coop. Wheat Prod. Ltd., 1972). Winter wheat differs from spring wheat in that it requires a longer period of vernalization, as well as being able to survive at lower temperatures once hardened. Vernalization is a low temperature promotion of flowering (Salisbury and Ross, 1978). Without this, the wheat will remain in vegetative stage. In order for the wheat to survive the winter which follows the vernalization period, especially in areas with a continental climate, the plants must become hardened.

Fall Hardening

Time of seeding is an important factor in the proper establishment, growth, and hardening of winter wheat. The recommendations for western Canada are to seed during the first 2 weeks of September (Grant et al., 1976). This has been shown to give the best survival, highest yield, and best grade. There are several reasons for this. The optimum temperature for wheat germination is 20° to 25°C although wheat will germinate at a temperature as low as 4°C (Evans et al., 1978). Earlier seeding could then hasten germination because of warmer soil temperatures as soil temperatures at the 5 cm depth can sink to 4°C or lower by mid-October as shown by Fowler and Gusta (1977) at Saskatoon. This seeding date also allows the plants to reach the 4-6 leaf stage before freeze-up. Seven to nine weeks of growth are needed so that they will attain a maximum level of hardiness (Roberts and Grant, 1968). This agrees with work by Worzella and Cutler (1941) who stated that winter wheat was most hardy from the 5 to 15 leaf stage. The larger range may be explained by the milder winters at Lafayette, Indiana. Later plantings also show more fluctuation in hardiness (Kimball & Salisbury, 1971).

The formation of a crown by the wheat plants is essential as this is the organ that regrows in the spring. It is also the origin for all adventitious roots. The stage of development is largely a function of seeding date (Fowler and Gusta, 1977), while the location of the crown in relation to the seed as well as the soil surface is influenced mostly by environment (Ferguson and Boatwright, 1968). The location of the crown is important for two reasons. First of all, the deeper the crown is, the more likely it is that it will be protected from lethal soil temperatures, and secondly, the crown node is the site of adventitious root development which is stunted if the crown forms in dry soil. Ferguson and Boatwright (1968) found adventitious roots formed but did not elongate in dry soil. This was detrimental to survival, since general field observations indicated that plants with a well developed root system were better able to withstand the stresses of winter.

The presence of a straw mulch also influences the location of the crown node. In greenhouse experiments, Ferguson and Boatwright (1968) found that in general, as the rate of straw increased, the crown formed farther from the seed, in some cases even above the soil. At straw rates less than 4500 kg/ha, winter hardy varieties formed their nodes closer to the seed than did the non-hardy varieties. The authors also found that as the light intensity increased, the node formed closer to the seed, and as temperature decreased, the node formed closer to the seed. This would support the conclusion that the influence of the mulch is due primarily to a light response, since one would expect the soil to be cooler under a mulch. However, Gauer et al. (1982) found that the straw mulch on zero-tilled Manitoba soils insulated the soil, with the result that fall temperatures were higher under the mulched soils. Temperature could also be a factor influencing crown node location.

Date of seeding has a significant effect on crown characteristics. Fowler and Gusta (1977) found that winter wheat plants seeded September 15th had a higher crown water content, smaller crowns and crowns formed at a greater depth than plants seeded August 21st.

The process of hardening in cereals, has been reviewed (Single, 1971) and investigated (Andrews and Pomeroy, 1974; Chen and Gusta, 1978; Fowler and Carles, 1979; Fowler and Gusta, 1977; Gusta and Fowler, 1976; Roberts and Grant, 1968; Tumanov et al., 1974; Worzella and Cutler, 1941) by many researchers. It is the process by which a plant, or plant organ by undergoing a period of cool temperatures, usually below 10°C (Chen and Gusta, 1978), is able to withstand much more intense cold without injury. Winter wheat plants do not have a true dormancy period but slowly respire through the winter months, depleting energy reserves (Gusta and Fowler, 1976). The variety or cultivar of winter wheat also plays a large role in the extent of hardening (Andrews, Pomeroy and Grant, 1974; Fowler and Carles, 1979; Roberts and Grant, 1968; Worzella and Cutler, 1941). Environmental factors, by influencing physiological adjustments, play an important role in the plant's ability to harden.

Fertility is a factor in determining the eventual cold hardiness of the winter wheat plants. Worzella and Cutler (1941) found that wheat seedlings grown on high levels of fertility showed the greatest injury. They attributed this to the influence on plant development. Rich soils develop large succulent plants, and result in stages of plant development that are susceptible to cold. Plants grown under conditions of moderate fertility were less advanced, having 5 to 15 leaves, and were more resistant to cold. Grant (1982) found no correlation between plant tissue nutrient content and winter hardiness of winter wheat plants grown in central Manitoba. High rates of nitrogen fertilizers applied in the fall resulted in a decrease in winter survival. Fall phosphorus fertilization resulted in an increase in winter survival, even when applied at low rates. Grant (1982) also found an interaction between nitrogen and phosphorus, in that when phosphorus was applied, addition of nitrogen had very little effect on survival.

Soil moisture affects both the growth of the wheat plant, (Ferguson and Boatwright, 1968) and the ability to withstand freezing and ice crusting (Rakitina, 1976). Ferguson and Boatwright (1968) have reported that winter wheat plants fail to develop adventitious roots when the crown is surrounded by dry soil. These plants may die during the winter, whereas adjacent plants in the field with adventitious roots will survive. In the U.S.S.R., Rakitina (1977) subjected several varieties of winter wheat plants to three degrees of flooding, after which they were frozen to three depths in ice. This was done for varying time periods at different temperatures. Flooding increased the sensitivity of plants to cold temperatures, affecting not only survival but also regrowth when compared to plants that were not flooded. Total flooding had a greater effect than partial flooding. These effects were magnified when plants were frozen into an ice crust. Again, plants were damaged more when they were entirely in ice than when they were only partially in ice. The effects were more pronounced for the less hardy varieties like TAH-186 than for hardier varieties like Ul'yanovka or Bezostaya.

The effects of temperatures on the hardening of winter wheat plants has been studied on seedlings grown in the greenhouse or growth chamber (Andrews et al., 1974; Gusta and Fowler, 1976; Pomeroy et al., 1974) and in the field (Fowler and Carles, 1979; Gusta and Fowler, 1976; and Worzella and Cutler, 1941). Worzella and Cutler (1941) found a high correlation between the results of field trials and artificial freezing tests for cold resistance in winter wheat. Their data indicated that the air temperatures which prevailed several days before the freezing test, affected the plant's ability to resist low temperatures. When the air temperatures increased, the ability of the plants to withstand cold declined. This was true for the plants in the fall as well as through the winter, resulting in periods of greater hardiness in response to cold weather. Similar results were reported by Gusta and Fowler (1976).

Andrews et al. (1974) found that a temperature regime of 2°C for two to three weeks, followed by diurnal exposure to -2°C was excellent for hardening the seedlings of Rideau and Cappelle Desprez. However, the seedlings of Rideau, the more hardy cultivar, hardened to a greater extent as determined by the LT_{50}. Pomeroy et al. (1978) established this for the cultivar Kharkov, noting that the LT_{50} decreased from -8.5°C at one week to -21.0°C at six weeks' exposure. The hardening process was speeded up by growth at 15°C/10°C for four to six days before being transferred to the 2°C/-2°C regime. This would more closely approximate normal ground temperatures in fall when the winter wheat germinates and begins growth. Fowler and Carles (1979), at Saskatoon agree with this information. During studies conducted in 1972, 1975 and 1977, the ground temperature at 5 cm was 12-15°C at the beginning of September and slowly decreased to 0-2°C by November. Hardy and non-hardy varieties can grow and develop during near freezing temperatures (Kimball and Salisbury (1971), however the non-hardy variety showed more growth which may reflect an inability to acclimatize in late fall.

Light is necessary for the complete hardening of winter wheat. In the U.S.S.R., Tumanov et al. (1975) found that prolonged residence of winter wheat plants in the dark lowers their ability to be hardened by frost. They kept wheat plants in the growth chamber on a 12% sucrose solution at 2°C for eight days. Plants in the light survived at -26°C but those kept in the dark all died at -13°C. At higher temperatures, the plants kept in the dark were even more sensitive to frost, although raising the sucrose concentration in the nutrient solution increased their hardiness slightly. Frost resistant varieties like Ul'yanovka are more able to tolerate darkness without decreasing in hardiness than are less frost resistent varieties like Mironovska 808.

Andrews et al. (1974) found similar results when working with Rideau and Cappelle Desprez wheat. Seedlings grown in petri-plates in the dark at low temperatures increased in cold hardiness as measured by LT_{50}. After five weeks, Rideau attained an LT_{50} of -12°C and Cappelle Desprez an LT_{50} of -6°C. Exposure to light delayed maximum hardiness by two weeks and increased it by 6°C in both cultivars. The authors attributed this to the depletion of endosperm reserves in the dark, which lowered the carbohydrate content of the plants, making them more susceptible to damage. Gusta and Fowler (1976) stored hardened winter wheat seedlings at -2.5°C for 120 days under continuous light and noticed no decrease in hardiness during this time.

A situation where wheat seedlings may be subject to darkness during hardening may occur in the field (Tumanov et al, 1975). This happens when snow falls on insufficiently frozen ground and remains for a long time. Plants may then enter the winter in an unfrozen state; with the result that they may die with the advent of frosty weather.

One of the first manifestations of cold hardiness in winter cereals is a reduction in crown moisture content (Chen and Gusta, 1978). This is not the result of a reduction of crown water, but rather an increase in the rate of dry matter accumulation (Fowler and Carles, 1979). Researchers have found a positive correlation between crown water content and cold hardiness as determined by LT_{50} (Chen and Gusta, 1978; Fowler and Carles, 1979; Fowler and Gusta, 1977). This relationship is especially evident within species (Fowler and Carles, 1979). When exposed to conditions conducive to hardening, the hardiest cultivars will have the lowest crown water content, the cultivars of limited hardiness will have a higher crown water content, and cultivars having a spring growth habit will have the highest crown water content. This principle does not hold true between species (Fowler and Carles, 1979). For example, the hardy winter wheat Kharkov may have the same crown water content as the winter rye, Frontier, but there is a 10°C difference in cold hardiness (Chen and Gusta, 1978). The converse relationship between crown water content and cold hardiness is also true. As a hardened cereal plant is exposed to warmer temperatures the water content rises and the cold hardiness decreases.

Winter Survival. The period of time most crucial in determining the viability of winter wheat as a commercial success is between freezeup and spring. Unfavourable conditions result in an average loss of 10% (Worzella and Cutler, 1941) or winterkilling 1 year in 10 (Grant et al., 1976) in areas where winter wheat is normally grown. Losses may be much higher in areas not normally suited for the production of winter wheat. Survival of plants during the harsh winter months depends largely on 2 factors; the physical environment, and the condition of the plants.

Physical Environment. The physical environment of the wheat plant during the winter consists of the temperature, both of the air and the soil, the depth and degree of frost in the soil, snow and ice cover, soil moisture, and exposure to light. Winter injury may be caused by cold temperatures, heaving of the soil and smothering (Worzella and Cutler, 1941). The same authors noted that soil temperatures under an ice layer closely followed the air temperature while there was little fluctuation in temperature under a blanket of snow. Snow is a much better insulator than ice. The hardiness levels of plants frozen into ice were reduced (Andrews et al., 1974), perhaps due to a worsening of gas exchange (Rakitina, 1977). This is considered more damaging than fall flooding (Rakitina, 1977).

Water may be limiting during the winter. The soil may freeze to the extent that the dormant plants are no longer able to absorb sufficient water to replace that lost by transpiration (Alessi and Power, 1971). Brief thaws may thus be beneficial due to melting of snow around plants, improving the water status of the crown.

Snow cover is the most important factor in ensuring winter survial, since a layer of snow insulates the soil, preventing killing temperatures at the crown depths (Aase and Siddoway, 1979, Aase and Siddoway, 1980; Alessi and Power, 1971; Worzella and Cutler, 1941). Snow cover of 6-7 cm would keep the ground temperature at a 3 cm depth above -16°C at air temperatures as low as -35°C. With a snow cover of 15-17 cm, the soil temperature would only reach -11°C at a -35°C air temperature (Aase and Siddoway, 1979). Standing stubble provided only slight protection. Aase and Siddoway (1979) stated that 7 cm of snow should provide protection to wheat even through the air temperatures might occasionally approach -40°C. Prolonged exposure of plants to near lethal temperatures may weaken them and reduce their cold hardiness (Fowler and Gusta, 1977b).

Plant Condition. The level of hardiness of the wheat plants, determines their reaction to the environment. The hardiness corresponds to the air temperature on preceding days. When the weather becomes warmer, the wheat plants lose their hardiness to some degree, but usually regain it with the advent of colder weather (Worzella & Cutler, 1941). Generally speaking, hardiness decreases from fall to spring (Fowler & Gusta, 1977b), possibly due to depleted energy reserves as a result of slow transpiration through the winter (Gusta and Fowler, 1976b). Gusta and Fowler (1976b) noted that hardened Kharkov winter wheat was able to survive temperatures of -19°C in the fall but only -11°C in the spring. The same trend was true for rye, which dropped to a survival temperature of -17°C from -24°C in fall. Plants with a greater energy reserve as reflected in percent dry matter, may be more able to harden or reharden, regardless of season.

Kimball and Salisbury (1977), in Utah, noted that a hardy variety Brevor had a higher % dry matter all winter than a less hardy variety Lehmi. As plants approach spring in the less hardy state they become increasingly susceptible to periods of low temperatures, especially because the snow cover melts as well. Once plants are dehardened past a certain point, they will not reharden and are unable to maintain their hardiness (Gusta and Fowler, 1976b).

Regrowth and Maturity

The wheat plants, having survived the winter, deharden, and begin regrowth with the advent of warm weather in spring. This will be the reproductive phase of growth, because their requirement for vernalization has been met during the previous fall.

Spring Growth.

Available moisture is important in determining the rate and type of growth of the wheat plants. There is little or no penetration of roots into dry ground (Evans, 1978) or through dry straw mulch (Cochran et al. 1977; Ferguson and Boatwright, 1968). Excess moisture is just as damaging to the plants. Belford (1981) noted that waterlogging of the soil restricted seminal root growth and increased nodal root production. The overall effect was a decrease in the size of the root system. This would result in a lower capacity to absorb mobile nutrients like N and K, and is manifested in chlorotic leaves which senesce prematurely. Symptoms dissapear when waterlogging is over and new leaves appear. The stage of growth is not crucial in determining waterlogging resistance (Belford, 1981).

Soil structure influences rooting patterns. There is a slower extension of seminal roots into undisturbed soils, resulting in a shallow intensive root system (Finney and Knight, 1973). The authors noted an increased tendency for lateral branching when elongation is inhibited. Wilhelm (1982) also found that root density of winter wheat was greatest in a no tillage situation when compared to plowed or subtilled areas. However, he did not notice any influence on root length.

The surface environment, as determined by crop residues, has an effect on winter wheat growth and development. Aase and Siddoway (1980) found that winter wheat grew taller and had a greater dry weight on stubble plots than on bare seeded plots. This was only true until mid-June, when the bare seeded plots grew taller than the stubble seeded plots (Aase & Siddoway, 1980; Black and Siddoway, 1977). Anderson and Russel at Lethbridge (1964), found maturity was delayed up to 6 days with the application of 8000 lb/acre of wheat straw. Plant height was also depressed. Baeumer and Bakermans, (1973) also noted a decrease in N uptake over that of conventionally tilled wheat, possibly due to immobilization of fertilizer by surface residues. Toxins leached from straw may also inhibit the growth of secondary roots (Cochran et al., 1977), as well as reducing tillering. This setback could result in increased weed competition and damage by frost, chemicals or drought. In Nebraska, Smika and Ellis (1971) noted a reduction in tillering under straw mulch conditions, but they attributed this to cooler soil temperatures, because no differences were noted when soil temperatures of mulched and unmulched soils were the same. Black and Siddoway (1977) saw reduced growth on plots of winter wheat seeded into 38 cm stubble when compared to wheat seeded into 15 or 28 cm stubble. They attributed this in part, to cooler soil temperatures caused by shading.

Winter wheat responds well to the addition of fertilizers, especially nitrogen. Addition of nitrogen increased the number of adventitious roots (Black and Siddoway, 1977). The number of adventitious roots per plant is positively correlated with final grain yield. The addition of N fertilizers also helped to overcome any growth differences due to stubble heights (Black and Siddoway, 1977; Smika and Ellis, 1971).

Yield and Protein. The factors determining yield and grain protein content in a crop of winter wheat are a complex mixture of N fertility and available moisture. The time of availability and the amount of both nitrogen and soil moisture affect the final outcome (Smika & Greb 1973).

Yield. Waterlogging may cause a yield decrease of 2-19% during 80 days of waterlogging (Belford, 1981). Usually, however, the losses in yield on the northern Great Plains are due to limiting water (Smika and Greb, 1973; Terman et al., 1960). Available nitrogen is the other factor affecting yield. Increasing the nitrogen through fertilization increased yield if other requirements were not limiting (Black and Siddoway, 1977; Smika and Greb, 1973; Terman, 1969). Grain yields increased as the amount of nitrogen applied increased from 0 to 67 kg/ha and were greater at an early application on May 1st than on a late application on May 23rd (Black and Siddoway, 1977). All nitrogen was topdressed. They found ammonium nitrate to be more effective than urea, presumably because the hydrolysis and mineralization needed for urea to become available to the plants was slowed down by the cooler zero-tilled soils. For both dates of nitrogen application, the yield was higher for 15 and 28 cm stubble heights than for the bare seeded or 38 cm stubble height, possibly due to a more favourable soil temperature and microclimate. Anderson and Russel (1969) also noted decreased yield for winter wheat at rates of straw mulch over 5000 lb/acre. Part of this decrease could be due to nitrogen immobilization. Kimber (1973) showed increased numbers of tillers, heads and final yield when 300 kg/ha nitrogen was applied to pots in which straw had either been spread or incorporated. Higher and lower rates of nitrogen generally did not give the same positive response.

Protein. The date and rate of nitrogen fertilization is also important in determining protein content of wheat grain. Hucklesby et al. (1971) found grain protein and yield of winter wheat in Illinois were increased most by late spring applications, and that this did not present an environmental problem. Only the 224 kg/ha rate provided the soil with a gain of N after crop removal. Black and Siddoway (1971) increased grain protein from 11.5 to 12.5% with 67 kg/ha ammonium nitrate regardless of early or late spring application. Soil nitrate at time of seeding was positively correlated with grain protein (Smika and Greb, 1973). Available moisture determines wheat grain protein. Smika and Greb (1973) found that precipitation 40-55 days before maturity and available soil water at seeding were both negatively correlated with grain protein. In summary, the chief effect of applied nitrogen with adequate water was to increase yields, while the chief or entire effect with severe water deficits was to increase protein content. In intermediate situations, nitrogen increased both yield and protein content (Terman et al., 1969).

Temperature of the air and soil environment also plays a role in determining grain protein. During the 5 days, 15-20 days before maturity, maximum air temperature has a large effect on grain protein (Smika and Greb 1973). The protein content was highest at a mean maximum air temperature of

32°C, decreasing as the mean maximum temperature rose or fell from this point. They also found the average soil temperature at crown depth during the period from regrowth to the soft dough stage to be positively correlated with grain protein.

MATERIALS AND METHODS

Field experiments were conducted on the University of Manitoba Plant Science Research Station at Portage la Prairie, Manitoba, in 1980-81 and 1981-82. In 1980-81 trials were situated on a Dugas silty clay. In 1981-82 trials were shifted to a Fortier silty clay (Michalyna & Smith, 1972). All experiments were laid out as a randomized complete black design with four replicates.

In both years, winter wheat was sown into barley stubble. A Noble 2000 hoe drill was used for all seeding operations and set to sow to a depth of approximately 5 cm. All trials were seeded to Norstar winter wheat. Harvest methods varied and are described under individual experiments. All the samples were cleaned, weighed and tested for actual moisture content. Yield was determined at 14.0 percent grain moisture as weight per unit area harvested and expressed in kg/ha.

Protein determination of the grain was conducted by the protein analysis laboratory at the University of Manitoba using the Kjeldahl method.

All the data was statistically analyzed and treatment means were compared using Duncans Multiple Range Test at the .05 level.

Trials conducted in 1980-81

Barley from the previous crop was harvested on August 13 after it had been dessicated. The straw was chopped and spread uniformly. The rate of seeding was 70 kg/ha for Norstar winter wheat which was seeded on September 14th, and 109 kg/ha for Neepawa spring wheat which was seeded on May 13th. The spring wheat was seeded only as a yield comparison. All experiments were seeded in a north-south direction. Phosphate fertilizer was applied as 11-51-0 with the seed at a rate of 43 kg/ha P_2O_5. Nitrogen fertilizer was broadcast on 5-6 cm of snow on November 13th as 46-0-0 at the rate of 125 kg/ha N.

Experiment 1 The Effects of Stubble Height on the Winter Survival and Growth of Winter Wheat

This experiment consisted of seven treatments. Five of these were winter wheat, seeded into 21 x 30 m ($630m^2$) plots consisting of chemical summerfallow, conventionally tilled barley stubble 7.5 cm high barley stubble, 15 cm barley stubble and 30 cm barley stubble. Two other wheat treatments consisted of spring wheat seeded into 15 cm barley stubble and wheat seeded into a conventionally tilled seedbed. These plots were side-by-side and 10.5 x 30 m ($315m^2$) in size.

The chemical summerfallow was treated with two applications of paraquat at .56 kg/ha during the 1980 growing season

The conventionally tilled plots were deep tilled twice and harrowed before seeding. The coventionally tilled spring wheat was cultivated and harrowed once more before seeding. Standing stubble was cut to the appropriate height at the time of harvest. In place of cultivation, the zero-tilled spring wheat plots received an application of glyphosate at 1.7 kg/ha, prior to seeding. The whole experiment was treated with .56 kg/ha bromoxynil on May 21st and with .71 kg/ha dichlofop methyl on May 26th. In addition to this, dichlofop methyl and bromoxynil were applied to the spring wheat on June 8th and 9th respectively to control a second flush of weeds.

Plant counts were taken on four random .25m^2 areas in each plot on November 4th. Plants were at the three leaf stage at the time of freeze-up.

Snow depths in the plots was measured after every snowfall or after drifting had occurred. Temperature was recorded at one location per plot, on one plot of each of the conventionally tilled seedbed, chemical summerfallow, 15 cm stubble and 30 cm stubble. The temperatures were taken at depths of 2.5, 5, 10, and 20 cm below ground level with copper constantan thermocouples. These were connected to a Campbell Scientific CR5 digital recorder which was programmed to record temperatures once daily, during the early morning, when soil temperatures were at their lowest.

Spring plant counts were taken on May 1st on four .25m^2 random samples. These counts were compared to those taken in the fall, and percent winter survival was calculated. The number of leaves and tillers per plant were noted, after removal from the soil, and then the plants from each plot were bulked and the dry matter determined after drying. Plant counts and dry matter determinations were done again from June 29th to July 1st in the same fashion.

The plots of winter wheat were harvested August 10th to 13th with a Gleaner E straight cut combine. The spring wheat plots were harvested with a Hege plot combine on August 21st. Volumetric soil moisture was determined on April 24th to detect differences in moisture due to variable snow cover. This was done by means of soil samples using a ring of 23.89 cm^3 volume down to 25 cm and by means of a neutron moisture meter from 25 to 100 cm depth. Access tubes for the neutron moisture meter had been installed on the first two replicates the previous fall.

Experiment 2 The Effects of Four Rates of Barley Straw Mulch on the Growth of Winter Wheat

This experiment consisted of six treatments with a plot size of 3 x 6 meters (18m^2). On one plot the stubble was mowed to ground level and all straw raked off. The other five treatments were all in 15 cm stubble. Of these, one was raked to remove all straw except standing stubble and the second was left with normal crop residue. The other three plots were raked, and then chopped barley straw was added at the rate of 1500 kg/ha, 3000 kg/ha and 4500 kg/ha and spread uniformly. The mulch was applied October 14th, 1980.

Spring plant counts were done on May 12th, 1981, on three random $.25m^2$ samples per plot. Samples were treated as in Experiment 1. The stage of growth, according to the Feekes scale (Large, 1954), was assessed on the same date. Weed control consisted of an application of bromoxynil at .56 kg/ha on May 21st and an application of dichlofop methyl at .71 kg/ha on May 26th. Plots were harvested on August 10th with a Hege plot combine.

Trials Conducted in 1981-82

Barley from the previous crop was harvested on August 19th. Norstar winter wheat was sown on September 4th at 70 kg/ha and Benito spring wheat was sown on May 24th at 97 kg/ha. Phosphate was applied as 11-51-0 with the seed at the rate of 20 kg/ha P_2O_5 as per soil test recommendations. Nitrogen fertilizer was broadcast on May 3rd as 34-0-0 at the rate of 155 kg/ha N. Because of the cool spring, weed germination and growth were slow. The winter wheat grew rapidly and held a competitive advantage over the grassy and broadleaf weeds, except in areas where the stand was poor or nonexistent. Therefore herbicide application in 1981-82 was omitted.

Experiment 3 The Effects of Stubble Height on the Winter Survival and Growth of Winter Wheat.

Experimental treatments and plot size were the same as Experiment 1, with the exception of the conventionally tilled seedbed. It was prepared by deep tilling once, double discing twice to reduce the size of clods and harrowing before seeding. In addition, the conventionally tilled seedbed for spring wheat was disced before seeding and harrowed immediately after seeding.

The zero-tilled spring wheat plots were sprayed with glyphosate at 1.68 kg/ha before seeding. Both spring wheat treatments received an application of .56 kg/ha bromoxynil on June 28th and an application of .71 kg/ha dichlofop methyl on July 6th.

Fall plant counts were taken October 10th on four 1.5-meter rows in the central portion of each of the winter wheat plots. This was changed from previous methods to improve the accuracy.

Snow depths were taken at 6 locations per plot on a weekly basis throughout the winter. Soil temperatures were monitored by means of thermocouples placed at 2.5 and 5 cm depths at each of 2 locations in every winter wheat plot in the first replicate. These temperatures were recorded once daily in the early morning about 8:00 am, with a Campbell Scientific CR5 digital recorder. Unfortunately, wires leading to the 30 cm stubble plot were torn by a snowmobile near the end of December, so readings were unavailable for this plot from this time. In addition to this, thermocouple temperatures at 10 and 20 cm depths were recorded on a weekly basis with a hand-held Westcor digital thermometer. As well, soil temperatures at 2.5 cm, 5 cm, 10 cm, and 20 cm depths were measured at 1 location per plot from May 15th until the winter wheat canopy closed the rows on about June 8th. This was done by means of thermocouples at those depths and measured with the Westcor thermometer.

Volumetric soil moisture content at 0-25 cm was determined at 1 location per plot on October 7th and at 2 locations per plot on April 26th to determine moisture gain over winter, and on May 22th, June 21st and July 20th to monitor changes through the summer. Methods were the same as those previously described. In addition to this, soil moisture at 25-100 cm was determined on October 6th and May 4th using a portable neutron moisture meter.

The depth of frost penetration and degree of soil thawing in spring were determined on April 27th using a portable, motorized soil auger. Presence of the frost was determined by the increased resistance to drilling. The difference in the depth of the holes between first encountering resistance and lack of resistance was taken to be the depth of the frost layer.

The winter wheat resumed growth during the last week of April, and spring plant counts were done on May 14th on the same four 1.5-meter rows per plot as in the fall. Winter survival was determined from these counts. In addition, the number of tillers and growth stage were also recorded, after which the plants were clipped off at ground level, and the tops dried and weighed. Plants, number of tillers, and dry weight were recorded again after a second sampling June 22th.

The winter wheat lodged very badly because of heavy rainstorms in late July. As a result, since mechanical harvest was difficult, harvest samples were taken by hand from four $1m^2$ areas in each of the plots. The samples were taken on August 13th for the winter wheat and on August 30th for the spring wheat. Samples were tied in bundles and allowed to dry several days before threshing with a Vogel stationary thresher.

<u>Experiment 4</u> The Effects of Four Rates of Barley Straw Mulch on the Growth of Winter Wheat

This experiment consisted of eight treatments, with a plot size of 3m x 12 m ($36m^2$). After the experiment was seeded into 15 cm barley stubble, 4 treatments were mowed to ground level. Of these 4 treatments, one was raked bare, the second had chopped barley straw added to bring the total crop residue up to 1500 kg/ha, the third and fourth mowed treatments had 3000 and 4500 kg/ha respectively. The plots with standing stubble were treated in a similar manner so that they had one plot each of 0 mulch (raked), 1500, 3000, and 4500 kg/ha mulch. The mulch was applied after seeding, but before the crop was fully emerged. The added straw had been run through a combine straw chopper to simulate actual field crop residues.

Fall plant counts were taken on October 15th on four 1.5 m rows in each plot.

Soil temperature measurements during the winter were conducted as described in Experiment 3. Snow depths were measured at 2 locations per plot on a weekly basis.

Spring plant counts were done on May 13th on the same four 1.5 m rows in each plot, and survival calculated. Plants were dug up, clipped at ground level, and shoot dry matter determined after counting tillers and noting growth stage.

Plots were harvested on August 17th with a Hege small plot combine.

Experiment 5 A Comparison of the Effects of Three Types of Straw Mulch on the Growth of Winter Wheat.

This experiment consisted of seven treatments. Plot size was 3 m x 12 m ($36m^2$). It was seeded into 15 cm barley stubble, and all treatments were raked, leaving only standing stubble. One plot was left bare, and the other six covered with winter wheat straw, or barley straw or rapeseed straw, each at rates of 1500 and 3000 kg/ha. All straw had previously been run through a combine with straw chopper to simulate field crop residues.

Fall plant counts were taken on October 16th on four 1.5m rows in each plot.

Spring plant counts on May 28th and harvest on August 13th was as outlined for Experiment 4.

RESULTS AND DISCUSSION

Experiment 1 The Effects of Stubble Height on the Winter Survival and Growth of Winter Wheat in 1980-81

Snow Depths

The stubble height had an effect on snow retention in the plots (Figure 1), despite the atypical climatic conditions for the winter of 1980-81. Precipitation for the five months, November through March, was only 60% of normal (Appendix Table 1). As well, the precipitation fell in the form of rain before November 23rd, and after February 15th, as well as on the 14th and 27th of December. Thaws reduced snow cover to near zero on December 28th and January 18th, dividing the winter into three periods of snow accumulation.

During these periods, the levels of snow accumulation corresponded to stubble heights (Figure 1). The snow accumulations on the chemical fallow were lower than all other treatments, averaging about 2 cm in depth. The conventional tillage trapped more snow, about 3 to 4 cm, except during mid-January when all treatments had 2 to 4 cm of snow on the soil surface. The 7.5 cm stubble trapped 4 to 6 cm snow. The 15 cm and 30 cm stubble heights trapped similar amounts of snow, up to a maximum of 6 to 9 cm. The similarity in snow retention between the 15 and 30 cm stubble heights can be attributed to the lack of snow. Presumably, if more snow had fallen, the 30 cm stubble would have held

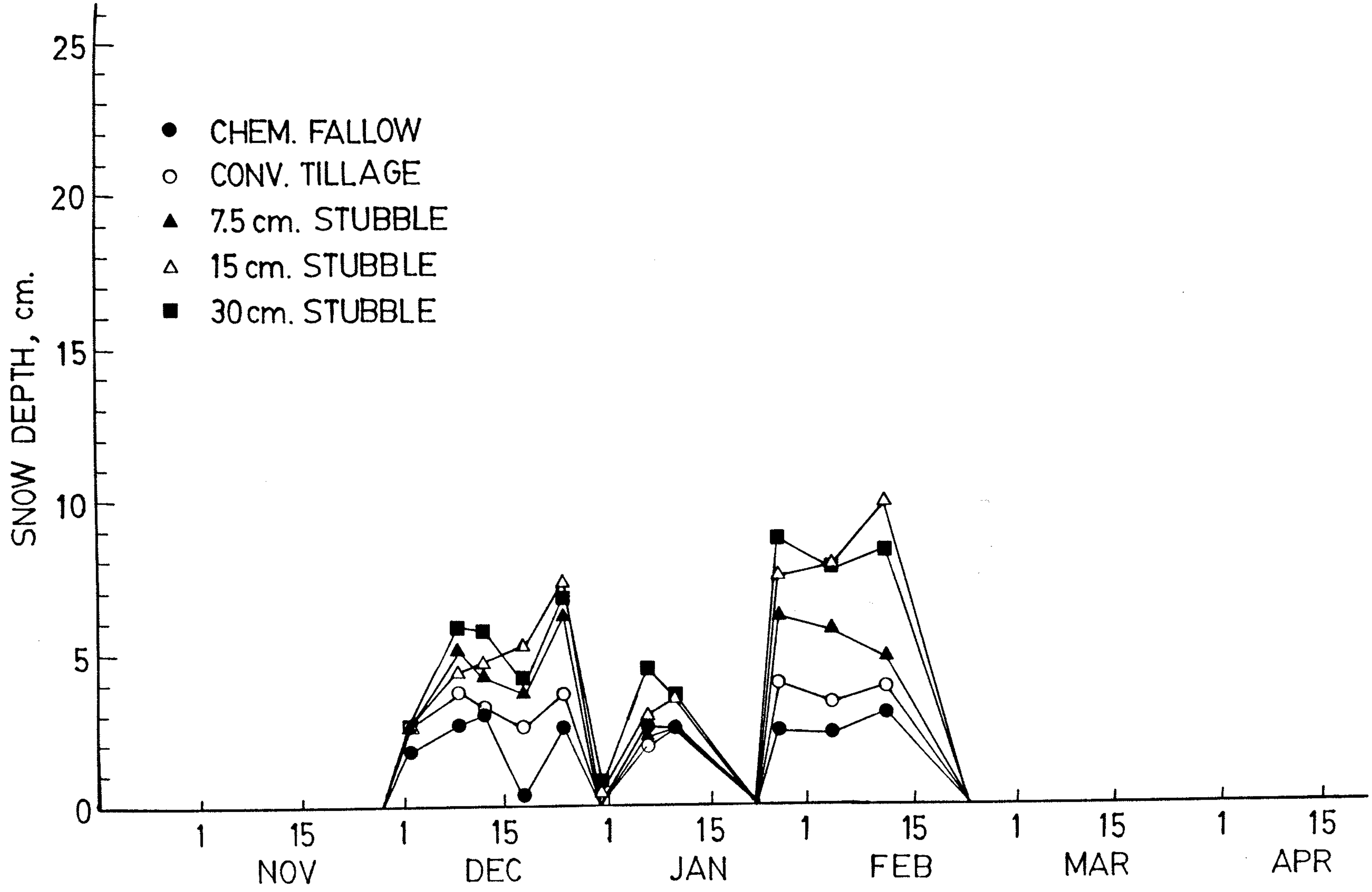

Figure 1. The effects of stubble height on snow retention during the winter of 1980-81.

more snow after wind drifting than any of the other treatments.

Soil Temperatures in Winter

The winter of 1980-81 was exceptionally mild (Appendix Table 1). Temperatures for December were 1.9°C below normal but they were 2.9, 5.5, 6.1 and 6.8°C above normal for November, January, February and March respectively.

Snow depths had an influence on soil temperatures. There were periods of the winter when snow cover was nonexistent, namely up to November 30th, near December 28th, January 18th to 23rd, and February 15th to March 22nd (Figure 1). The soil temperature at 2.5 cm depth closely paralleled air temperatures (Figure 2) during this time. When a snow cover was present, air temperature and soil temperature were more widely separated. The degree of separation was dependent upon the amount of snow as well as the speed and magnitude of temperature fluctuation. The lowest temperatures were recorded in the chemical fallow plots. Three exceptions occurred on December 12th, January 4th, and February 8th, when the temperature of the soil in the 15 cm stubble was identical to that of the chemical fallow, despite differences in plot snow cover. The reason for this was not clear, but possibly the drifting snow created a hollow around the stake to which the thermocouples were attached, so that the actual snow depth at the recording location was less than that of the plot as a whole.

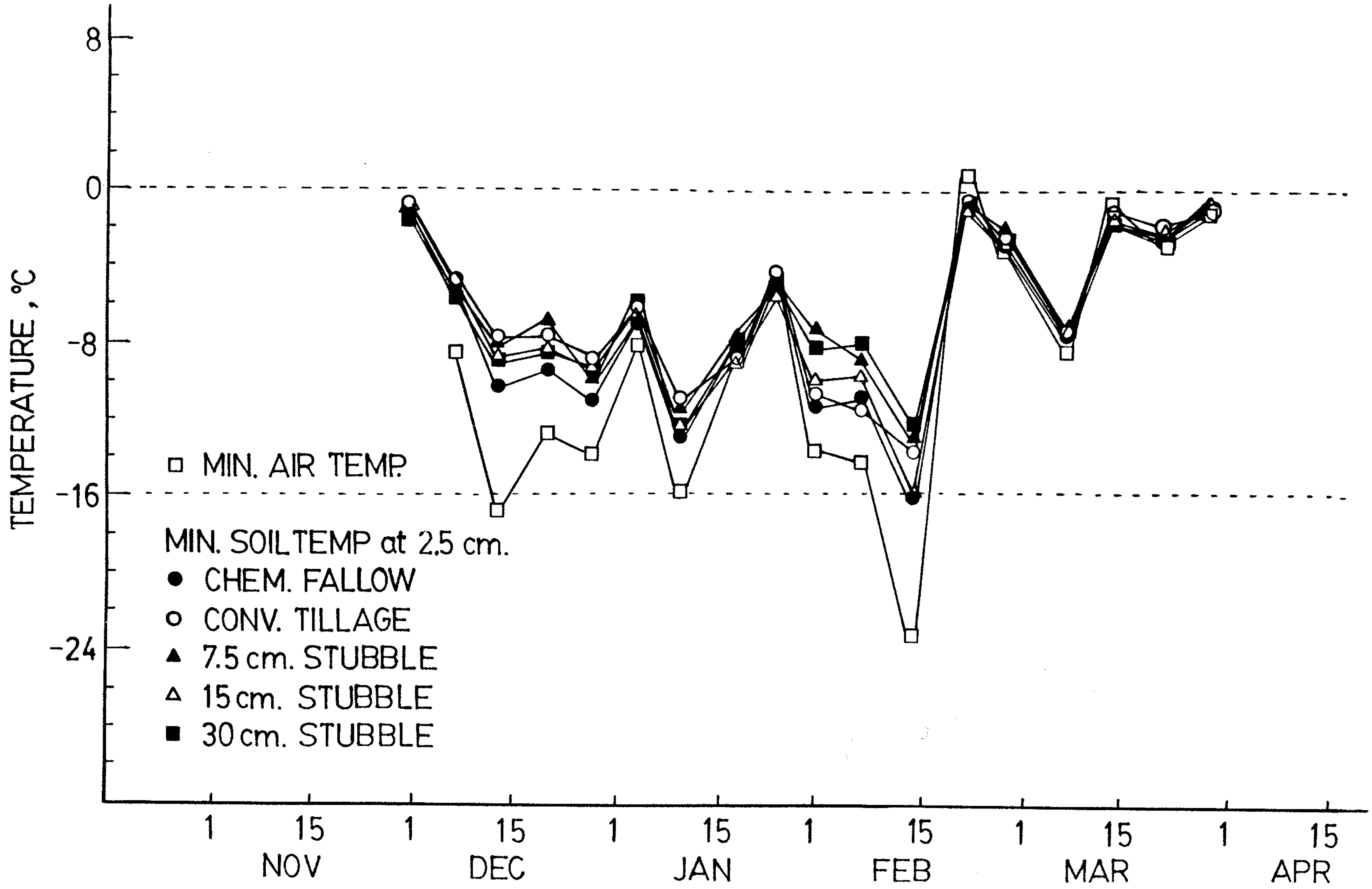

Figure 2. Minimum soil temperatures at the 2.5 cm. depth during the winter of 1980-81, expressed as weekly means.

Soil Temperatures in Spring

Temperatures of the soil at the 5 cm depth seldom varied more than 1°C between treatments during the period from May 26th to June 26th (Table 1). Slight variations occurred on May 26th when the conventional tillage plots were 1-1.5°C higher than all the others, and on the 5th, 8th, and 10th of June when the 15 cm stubble plots were 1.5-2.0°C higher than all other treatments. The reasons for this are not clear, since by June 8th, the wheat was 30 cm tall and providing nearly complete ground cover. The wheat plants would have provided an effect on microclimate far greater than the remaining stubble.

Soil Moisture

Volumetric soil moisture measurements were taken in April to determine if there were any differences in soil moisture due to differential snow rentention (Appendix Table 2). There were no significant differences in the volumetric soil moisture content in the 0 to 25 cm layer of soil or in the 25 to 100 cm layer. Apparently, the below average precipitation and warm temperature during March and April, erased any differences that may have occurred due to the mid-February snow accumulations. Snow melt from the 2-9 cm depths of snow on the plots would not have been of any real significance.

TABLE 1

Mid-day Soil Temperatures at the 5 cm Depth Recorded During the Spring of 1981 in Five Stubble Heights

Treatment	Date								
	May 25	May 29	June 1	June 5	June 8	June 10	June 17	June 23	June 26
	Growth Stage (Feekes)								
	4	5	5.5	6	6.5	7	8.5	10	-
Chemical Fallow	15.1 ab[1]	14.6 a	15.0 a	17.2 ab	16.1 a	15.4 ab	15.4 a	16.2 a	18.7 a
Conventional Tillage	16.1 a	14.6 a	14.5 a	17.2 ab	16.1 a	15.6 ab	15.3 a	16.1 a	18.6 a
7.5 cm Stubble	14.8 ab	14.2 a	14.4 a	16.9 b	15.8 a	14.9 b	15.2 a	15.7 a	18.0 a
15 cm Stubble	14.6 b	15.1 a	14.7 a	18.5 a	17.4 a	16.7 a	15.4 a	16.3 a	18.4 a
30 cm Stubble	15.1 ab	14.5 a	14.3 a	16.7 b	15.8 a	15.1 b	15.3 a	16.0 a	18.1 a

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[1] Means in columns followed by the same letter do not differ significantly at the .05 level.

Winter Survival

There were no significant differences in fall plant stand between treatments (Table 2). The wheat seeded on the chemical fallow had a larger recorded number of plants per square meter than any of the other treatments.

In the spring, wheat seeded in 15 cm stubble had a significantly higher plant density than wheat seeded in conventionally tilled soil. All other treatments were intermediate and did not differ significantly from these two. Plant stand in all stubble treatments increased over that of the previous fall, whereas plant stand on the chemical fallow and conventionally tilled plots decreased over winter. This loss can be attributed to a weakening of plants by cold temperature as a result of reduced snow cover, as well as damage by soil drifting during the spring.

In spite of the changes in plant population over winter, there were no significant differences in winter survival between treatments (Table 2).

Vegetative Growth

The dry matter per square meter on May 1st is significantly higher for wheat sown in 15 cm stubble than for wheat sown in conventionally tilled soil (Table 3). All other treatments do not differ from either of these. There are no significant differences in dry weight between treatments on a per-plant basis, so the differences in dry matter per square meter are a reflection of plant stand, not plant size.

TABLE 2

Winter Survival and Growth of Winter Wheat in 1981 When Grown in Five Stubble Heights

Treatment	Plant Counts/m^2		% Survival	Plant Counts	Tillers per Plant		Heads/m^2
	Nov. 4	May 1		July 1	May 1	July 1	July 1
Chemical Fallow	155 a[1]	140 ab	92 a	139 a	2.3 a	5.7 a	725 ab
Conventional Tillage	135 a	119 b	91 a	135 a	2.5 a	5.1 a	673 b
7.5 cm Stubble	136 a	150 ab	111 a	151 a	2.4 a	5.4 a	800 a
15 cm Stubble	131 a	162 a	119 a	146 a	3.2 a	5.3 a	753 ab
30 cm Stubble	131 a	144 ab	111 a	139 a	2.5 a	5.7 a	769 ab
C. V.	15.3	14.9	19.6	9.8	21.2	15.5	9.4

[1] Means within columns followed by the same letter are not significantly different at the .05 level.

There were no significant differences in tiller number between treatments on May 1st. They ranged from a high of 3.2 tillers per plant in the 15 cm stubble to a low of 2.3 tillers per plant in the chemical fallow.

On July 1st, wheat seeded into 7.5 cm stubble had significantly greater dry matter than wheat seeded into conventionally tilled soil (Table 3). All other treatments did not differ from these two. For the zero-tilled treatments, dry matter decreases as stubble height increases, but all stubble treatments had a greater dry matter than chemical fallow which, in turn, was greater than conventional tillage. There were no significant differences in dry matter per plant on July 1st.

The number of fertile tillers per plant ranged from 5.7 for the 30 cm stubble, down to 5.1 for the conventional tillage but did not vary significantly. The number of heads/m^2 was significantly higher for the wheat seeded in 7.5 cm stubble than for wheat seeded in conventionally tilled soil, but this was not reflected in final grain yield.

Yield and Protein

There were no significant differences in the yields of winter wheat. Yields ranged from a high of 3820.3 kg/ha on wheat planted in 30 cm stubble, to a low of 3203.8 kg/ha for wheat planted in chemical fallow. The zero-till stubble treatments had the highest yield followed by conventionally tilled plots and by chemical fallow plots.

The grain protein at 14% grain moisture ranged from a high of 12.3% for wheat grown on chemical fallow, to a low of 10.4% for wheat grown in 30 cm stubble (Table 3). The wheat

TABLE 3

Dry Matter and Yield of Winter Wheat in 1981
When Grown in Five Stubble Heights

Treatment	Dry Matter/m^2(g)		Dry Matter/Plant (g)		Yield kg/ha	% Protein
	May 1	July 1	May 1	July 1		
Chemical Fallow	7.7 a[1]	849.5 ab	0.05 a	6.34 a	3204 a	12.3 b
Conventional Tillage	5.8 b	763.8 b	0.05 a	5.75 a	3648 a	11.1 c
7.5 cm Stubble	7.2 ab	954.0 a	0.05 a	6.34 a	3749 a	10.9 c
15 cm Stubble	9.0 a	906.3 ab	0.06 a	6.27 a	3743 a	10.6 c
30 cm Stubble	7.7 ab	878.0 ab	0.05 a	6.35 a	3820 a	10.4 c
Spring Wheat, Zero-Tillage					3419 a	13.5 a
Spring Wheat, Conventionally Tilled					3221 a	14.3 a
C. V.	21.9	11.3	15.9	11.7	12.3	6.4

[1] Means within columns followed by the same letter are not significantly different at the .05 level.

grown on chemical fallow had a significantly higher protein content than all other treatments. It was followed by wheat grown on conventionally tilled soil and by wheat sown into standing stubble. Protein content decreased as stubble height increased, but the differences were not significant. There was a highly significant negative correlation (r = -.586) between yield and protein.

Comparison of Spring Wheat and Winter Wheat

There were no significant differences between yields of spring wheat and yields of winter wheat (Table 3). The yields of the spring wheat were at the lower end of the range, and compared favorably with the winter wheat grown on chemical fallow and conventional tillage. Zero-tilled spring wheat had a slightly higher yield than conventionally tilled spring wheat.

The protein content for spring wheat was significantly higher than that of winter wheat. The % grain protein was 14.3% for conventionally tilled wheat and 13.5% for zero-tilled wheat.

Experiment 3 The Effects of Stubble Height on the Survival and Growth of Winter Wheat in 1981-82

Snow Depths

There were marked differences in snow retention during the winter of 1981-82 (Figure 3), despite the fact that precipitation was below normal. After receiving 200% of normal precipitation in October, only 44% of normal precipitation was received from November to March (Appendix Table 2).

The first snowfall, resulting in the accumulations of 2 cm occurred on October 21st, but melted after 2 to 3 days (Figure 3). Permanent snow cover started December 20th, when a light snowfall filled the furrows to a depth of 1 cm. Subsequent snowfall on December 22nd provided a cover of 5-12 cm over the entire experiment, with the higher amounts trapped in the stubble treatments. Additional snowfall during the first week of January increased the snow cover to 9 cm on chemical fallow, 14 cm on conventional tillage, 15 cm on the 7.5 cm stubble, 17 cm on 15 cm stubble, and 23 cm on the 30 cm stubble. The exact amounts of snow cover varied with additional snowfall and drifting, but the relative order of accumulations remained the same throughout the winter.

The reason for the substantial accumulations of snow on the chemical fallow plots is that the hoe-drill used to seed the plots left furrows of 4-5 cm depth. These furrows remained throughout the winter, holding 3-4 cm of snow during

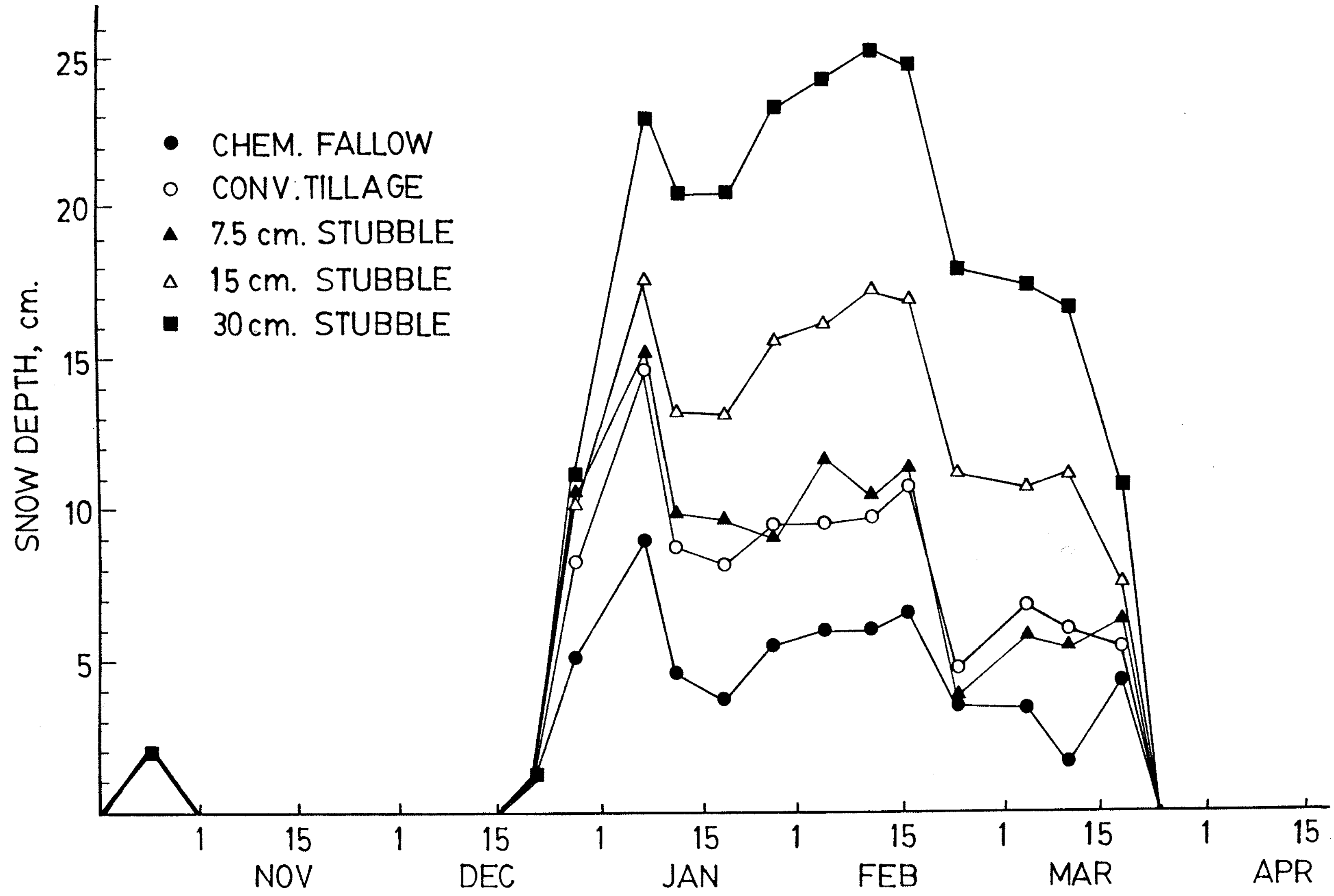

Figure 3. The effects of stubble height on snow retention during the winter of 1981-82.

this time. Nearby plots which had been fallow, and which were not seeded with the furrow drill, were bare for a large part of the winter.

The height of the stubble on the conventionally tilled plots and the 7.5 cm plots did not differ, because the stubble on the conventionally tilled plots, which was originally about 15 cm in height, had been flattened by the tillage operations. Mean stubble heights for the conventionally tilled plots and 7.5 cm stubble plots were 9 cm and 9.6 cm respectively. Stubble density was 42 standing straws per square meter for the conventionally tilled plots, and 194 standing straws per square meter for the 7.5 cm stubble plots. When combined with the effect of the furrows caused by seeding, the stubble density did not have any effect on snow retention.

The actual measured stubble heights were 26.8 cm for the 30 cm measured stubble plots and 15.2 cm for the 15 cm stubble plots. Snow cover was closely related to stubble height for these two treatments.

All treatments were bare by March 23rd, except for the 30 cm stubble plots where 1 to 2 cm of slush remained in the bottom of the furrows. This would imply that the snow melted at a faster rate on the higher stubble treatments (Figure 3), (Willis et al., 1969).

Soil Temperatures in Winter

The air temperatures and the resultant soil temperatures were very different during the winter of 1981-82 (Appendix Table 2), when compared to the winter of 1980-81 (Appendix Table 1). Temperatures for November were 5°C above normal; December, February and March were near normal; and January was 6.5°C below normal. Temperatures did not fluctuate as much as they did the previous year, remaining below freezing from the end of November to the middle of March, with the exception of two brief thaws. The thaws, which occurred on December 20th and February 17th, were not warm enough to melt the snow, although the warm spell on February 17th caused a reduction in snow depths.

Snow cover had an effect on soil temperatures (Figure 4). The soil temperatures at the 2.5 cm depth paralleled air temperature until substantial snow accumulated at the end of December. Soil temperatures did not drop as rapidly as the previous year, due to above normal temperatures in November and early December. The soil was also very wet as a result of October precipitation, and this will have increased the ability of the soil to retain heat (Hay, 1977). There was very little difference in temperature between treatments, with the chemical fallow and the 7.5 cm stubble generally being about 1 to 2°C higher than the other treatments.

Differences in temperature between treatments became noticeable with the first substantial snowfall, at the end of

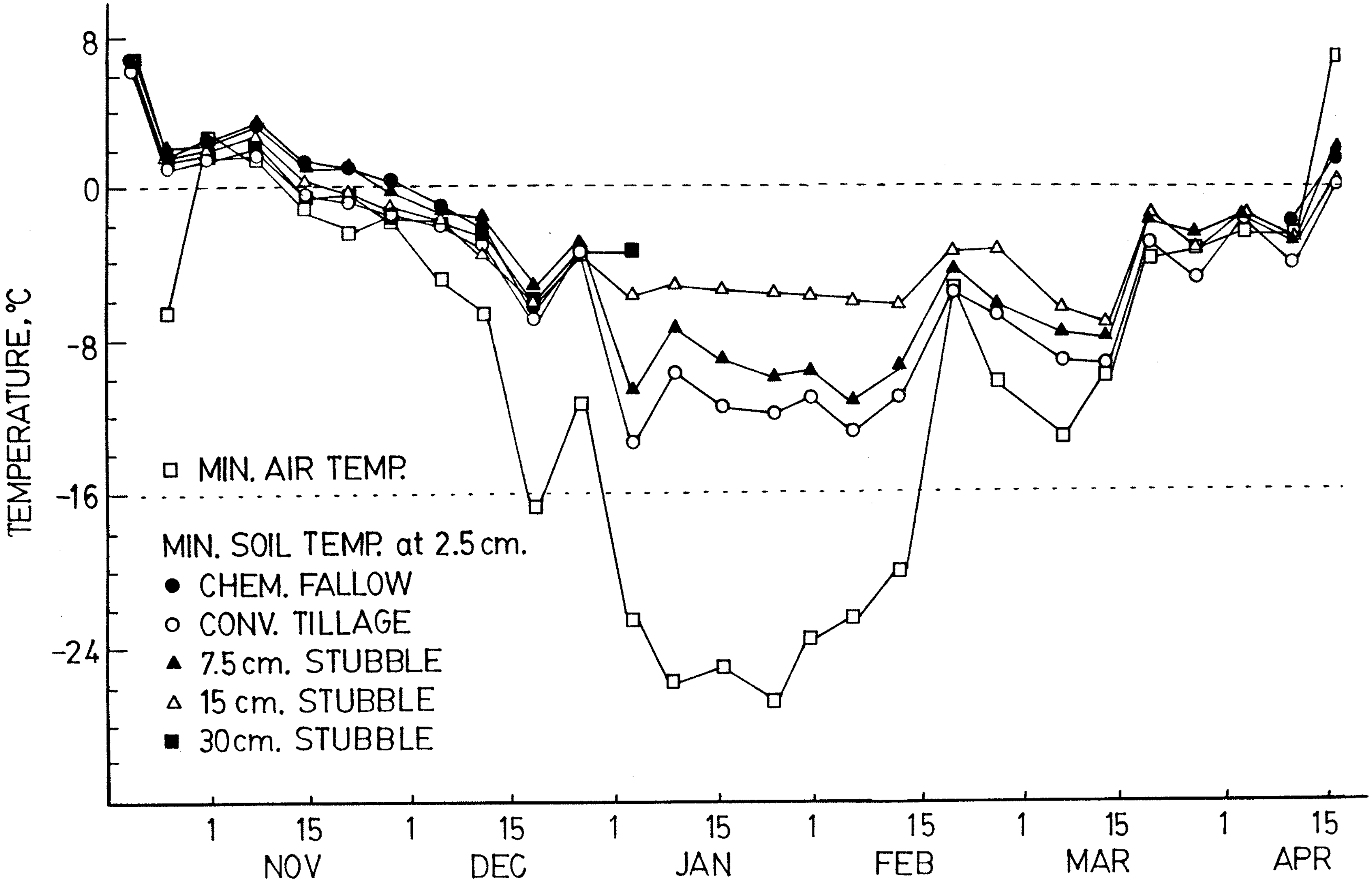

Figure 4. Minimum soil temperatures at the 2.5 cm. depth during the winter of 1981-82, expressed as the mean weekly temperature.

December, and lasted until early March, with the exception of a thaw on February 17th. The temperatures of the 30 cm stubble plots were warmer than those of the 15 cm stubble plots. The 7.5 cm stubble plots had lower temperatures with the lowest temperatures recorded on the conventional tillage plots. The soil temperature at the 2.5 cm depth in the 30 cm stubble treatment remained at -3°C until readings stopped in January due to equipment malfunction. The temperatures in the 15 cm stubble plots remained between -5°C and -7°C. The 7.5 cm stubble and the conventional tillage, aside from an increase in temperatures in early January, averaged about -10°C and -12°C respectively.

The brief increase in temperature observed in the 7.5 cm stubble and conventionally tilled plots is due to the insulation of the snow. This slowed the rate of cooling, allowing the warmer soil at greater depths to influence surface temperatures. The soil cooled again following drifting and removal of snow from these plots. Even after drifting, enough snow was retained on the 15 cm and 30 cm stubble plots to protect against a sudden lowering of the temperature.

The soil temperatures at 2.5 cm corresponds with the amount of snow trapped on each plot. Due to unexplained equipment malfunction, soil temperatures were not obtained for the chemical fallow plot from December 20th to March 28th. Some idea of the temperature in the chemical fallow plots relative to other treatments can be obtained by comparing temperatures at the 10 cm depth (Appendix Tables 7, 8, 9, 10). Also, although survival was good (Table 9), some thinning of the stand occurred in exposed locations, so temperatures were probably very near the lethal temperature at times.

The snow accumulations of the 7.5 cm stubble and the conventional tillage treatments are very similar. The warmer soil temperatures in the 7.5 cm stubble could be attributed to increased rates of straw mulch on the soil surface.

Frost Penetration

Measurements were taken on April 27, 1982, to determine the depth of the receding frost, as well as the thickness of the frozen soil layer. There were no significant differences between treatments in the amount of ground-frost retreat that had occurred (Table 4). When the energy requirements of melting the various snow depths are considered, it appears that any prospective albedo related energy absorbtion advantage in bare soil is offset by energy loss by evaporation brought about by increased windspeed (Sawatzky, 1983). There was a highly significant treatment effect on the depth of frost penetration, and therefore also on the total depth of frozen soil. There was significantly less frost penetration of the soil under the 30 cm stubble plots (Table 4). The residual layer of frozen soil on April 27th ranged from 64.3 cm for the chemical fallow, down to 19.3 cm for the 30 cm

TABLE 4

The Effects of Stubble Height on Snow Retention
and Subsequent Ground Frost Penetration
on April 27, 1982

Treatment	Depth at Which Frost Starts (cm)	Depth at Which Frost Stops (cm)	Total Depth of Frozen Soil (cm)	Mean Plot Snow Depth Dec. 29 to March 18
Chemical Fallow	44.0 a[1]	108.3 a	64.3 a	4.9 d
Conventional Tillage	43.0 a	99.3 a	56.3 a	7.8 c
7.5 cm Stubble	44.7 a	95.7 a	51.0 a	8.4 c
15 cm Stubble	43.3 a	88.7 a	45.3 a	13.4 b
30 cm Stubble	46.3 a	66.0 b	19.3 b	19.8 a

[1] Means in columns followed by the same letter do not differ significantly at the .05 level.

stubble plots. Less energy would then be needed to thaw the frozen soil, primarily in the replacement of latent heat of crystallization, which may be available to influence crop growth in spring or early summer (Sawatzky, 1983).

The mean treatment snow depths for the time December 30th to March 18th, 1982 were calculated for each treatment (Table 4). All treatments differed significantly in the amount of snow retention except for the 7.5 cm stubble, and the conventional tillage, which did not differ.

There was a highly significant negative correlation (r = -.795 between plot snow depth, January 6th to March 18th, and the total depth of the frost layer.

Soil Moisture

Volumetric soil moisture was determined to a depth of 25 cm on October 7th (Appendix Table 2). There were no significant differences between treatments. This is to be expected due to the above average precipitation at this time of year. Also, the evaporation from the soil, as well as the transpiration from the plants, would be low due to decreased temperatures and low levels of insolation.

The following spring, on April 26th, there were significant differences in volumetric soil moisture in the top 25 cm of soil (Appendix Table 2). The 30 cm stubble plots had significantly more moisture than any other treatment. The chemical fallow plots had significantly less moisture than all other treatments except for the 7.5 cm stubble plots.

All other treatments did not differ. The snow retention resulted in increases in soil moisture content after melting. As expected (Black & Siddoway, 1977), the increases in moisture were greater where more snow was retained.

Soil moisture measurement throughout the summer showed considerable variation. On May 22nd, soil moisture levels in the plots were much different than on April 26th. The conventionally tilled plots had the highest volumetric water content, significantly greater than the chemical fallow or the 30 cm stubble plots. The 30 cm stubble plots had a significantly lower soil moisture than any of the other plots. There may be several reasons for this. A rainfall of 18.3 mm occurred within one week of sampling. Also, it was noted that the conventionally tilled plots were less permeable to water. Water ponded more quickly on these plots, and the puddles lasted longer after a rain. This may be the result of a compacted layer caused by cultivation. One of the reasons for the significantly lower moisture levels in the 30 cm stubble plots may be the increased permeability of zero-tilled soils (Baeumer & Bakermans, 1973). The smaller amounts of frozen soil in these plots would also have thawed faster (Staple and Lehane, 1952), allowing the water to percolate through the soil. The thicker frozen layers on the other treatments would have prevented downward movement of the water until the soil thawed at a later date, so the surface would have remained wet longer.

On June 21st, the chemical fallow plots had significantly lower soil moisture levels than did the 30 cm stubble plots. Increased surface evaporation during the last month, as well as increased water usage by the crop, may account for this difference. The wheat seeded on chemical fallow had a significantly higher dry matter per square meter than any of the other treatments on June 22nd (Table 10), indicating a greater potential for transpiration. All treatments had a lower soil moisture content than they did on May 22nd.

On July 20th, the 30 cm stubble plots had significantly more moisture than the 7.5 cm stubble plots. All other treatments did not differ significantly from either of these two.

Spring Soil Temperatures

Temperatures at the 2.5 cm depths did not usually vary more than 3°C between plots (Table 5). On May 15th, the chemical fallow plots had significantly higher temperatures than the 30 cm stubble plots. Temperature decreased as stubble height increased. The conventionally tilled plots were cooler than the chemical fallow but warmer than the stubble plots. As the summer progressed this trend gradually reversed itself, although differences were not significant until June 8th. At this time the 30 cm stubble plots had the highest temperatures, significantly higher than all other treatments. The chemical fallow treatment was significantly lower than all other treatments except the conventionally tilled plots.

The soil temperatures at the 5 cm depth followed the same trend as those at the 2.5 cm depth (Table 6). On May 15th, the chemical fallow plots had significantly higher temperatures than the stubble plots. This continued to the end of May. On June 1st, the 30 cm stubble plots had significantly higher temperatures than the conventionally tilled plots. On June 8th, 30 cm stubble plots were significantly higher in temperature than all other plots. Temperature on this date increased as stubble height increased. Temperature on May 18th, 28th and June 4th did not differ significantly between treatments.

Temperatures at the 10 and 20 cm depths (Tables 7 - 8) followed the same trends, that is during mid-May the chemical fallow plots had significantly higher temperatures, and by early June the 30 cm stubble plots had the highest temperatures. This change seemed to come sooner as the depth increased.

Initially, when temperature readings were started, the soil was shaded mostly by the stubble in those plots with standing stubble. These plots registered the coolest temperatures at this time, cooler than the chemical fallow or tilled plots, which had a darker surface. Zero-tilled soils are slower to warm up in spring, due to trash cover (Gauer, 1982). As time progressed, the plants grew, and by the end

TABLE 5

Mid-day Soil Temperatures at 2.5 cm During the Spring of 1982 in Five Stubble Heights

Treatment	Date							
	May 15	May 18	May 22	May 25	May 28	June 1	June 4	June 8
Chemical Fallow	18.6 a[1]	13.7 a	20.8 a	22.0 a	22.7 a	13.6 a	18.1 a	9.4 c
Conventional Tillage	16.9 ab	13.8 a	20.0 a	21.4 a	21.4 a	12.8 a	18.5 a	9.8 bc
7.5 cm Stubble	18.0 ab	13.4 a	19.6 a	21.1 a	22.3 a	13.1 a	19.0 a	10.2 b
15 cm Stubble	16.8 ab	13.1 a	18.7 a	20.9 a	22.1 a	13.6 a	19.8 a	10.3 b
30 cm Stubble	16.5 b	13.1 a	20.3 a	23.4 a	22.3 a	13.6 a	20.5 a	11.0 a

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[1] Means in columns followed by the same letter do not differ significantly at the .05 level.

TABLE 6

Mid-day Soil Temperatures at 5 cm During the Spring of 1982 in Five Stubble Heights

Treatment	Date							
	May 15	May 18	May 22	May 25	May 28	June 1	June 4	June 8
Chemical Fallow	16.3 a[1]	12.3 a	18.5 a	18.7 a	20.3 a	11.3 ab	15.3 a	9.0 c
Conventional Tillage	14.7 ab	11.9 a	16.7 ab	17.4 ab	18.5 a	10.1 b	15.3 a	9.1 bc
7.5 cm Stubble	14.4 b	11.4 a	16.5 ab	17.5 ab	19.8 a	10.8 ab	15.6 a	9.5 bc
15 cm Stubble	13.5 b	10.6 a	15.3 b	16.4 b	17.6 a	10.6 ab	16.0 a	9.7 b
30 cm Stubble	13.6 b	10.5 a	16.1 b	18.5 ab	20.2 a	11.7 a	17.3 a	10.8 a

[1] Means in columns followed by the same letter do not differ significantly at the .05 level.

TABLE 7

Mid-day Soil Temperatures at 10 cm During the Spring of 1982 in Five Stubble Heights

Treatment	Date							
	May 15	May 18	May 22	May 25	May 28	June 1	June 4	June 8
Chemical Fallow	11.7 a[1]	9.5 a	13.8 a	14.0 a	16.0 a	8.7 b	12.3 ab	8.3 d
Conventional Tillage	10.7 ab	9.5 a	12.5 ab	13.1 a	15.2 a	8.1 b	12.1 b	8.6 cd
7.5 cm Stubble	10.7 ab	8.8 a	12.4 b	13.0 a	15.8 a	8.5 b	12.6 ab	9.0 bc
15 cm Stubble	10.4 b	8.8 a	11.9 b	12.5 a	15.5 a	8.9 ab	13.1 ab	9.3 b
30 cm Stubble	9.7 b	8.4 a	11.8 b	13.5 a	16.4 a	9.6 a	14.1 a	10.2 a

[1] Means in columns followed by the same letter do not differ significantly at the .05 level.

TABLE 8

Mid-day Soil Temperatures at 20 cm During the Spring of 1982 in Five Stubble Heights

Treatment	Date							
	May 15	May 18	May 22	May 25	May 28	June 1	June 4	June 8
Chemical Fallow	7.4 a[1]	7.2 a	8.9 a	9.9 b	12.3 b	7.6 b	8.9 b	7.7 d
Conventional Tillage	6.8 ab	6.6 a	8.6 a	9.6 b	12.0 b	7.2 b	8.8 b	8.0 cd
7.5 cm Stubble	6.6 b	7.0 a	8.1 a	9.3 b	11.9 b	7.7 b	9.2 b	8.3 c
15 cm Stubble	6.4 b	6.9 a	8.1 a	9.2 b	11.8 b	7.7 ab	9.3 b	9.2 b
30 cm Stubble	6.3 b	6.8 a	9.2 a	11.0 a	13.4 a	9.2 a	11.1 a	9.9 a

[1] Means in columns followed by the same letter do not differ significantly at the .05 level.

of May, most of the shading was due to the winter wheat plants. The plants completely covered the interrow spaces by June 8th, when sampling was stopped. Once the variation in plots due to surface cover was overshadowed by plant growth, the zero-tilled soils warmed faster, possibly due to the higher thermal conductivity in the surface layers (Gauer, 1982) and the lack of heat requirements for the melting of residual ice at greater depths (Sawatzky, 1983). The chemical fallow plots also had a greater vegetative growth, so they would shade the ground and increase the boundary layer, thus making the conduction of heat into the soil more difficult.

Winter Survival

The fall plant counts were done on October 14th, about 40 days after seeding. All plants should have emerged by this time. The counting was complicated by the presence of volunteer barley. The 30 cm stubble plots and the 15 cm stubble plots had significantly higher plant populations than the conventional tillage plots (Table 9). The 30 cm stubble plots were also significantly higher than all others, except for the 15 cm stubble plots. There was a highly significant correlation (r = .638) between stubble height and plant population in the fall. Zero-tilled soils have been shown to be warmer in the fall, both because of the insulation of the straw mulch, and because the standing stubble lowers windspeed, decreasing convective cooling (Aase & Siddoway, 1980).

TABLE 9

Winter Survival and Growth of Winter Wheat in 1982 When Grown in Five Stubble Heights

Treatment	Plant Counts/m^2		% Survival	Plant Counts	Tillers per Plant		Heads/m^2
	Oct. 10	May 14		June 22	May 14	June 22	June 22
Chemical Fallow	141 bc[1]	149 a	106 a	133 a	5.3 a	6.1 ab	973 a
Conventional Tillage	129 c	108 a	84 a	113 a	3.6 b	6.1 ab	791 b
7.5 cm Stubble	139 bc	131 a	94 a	129 a	3.3 b	5.6 b	867 ab
15 cm Stubble	154 ab	135 a	87 a	128 a	3.4 b	6.1 ab	926 ab
30 cm Stubble	164 a	133 a	81 a	108 a	3.8 b	7.0 a	899 ab
C. V.	9.1	19.0	18.4	13.9	16.6	11.1	11.5

[1] Means within columns followed by the same letter are not significantly different at the .05 level.

Increased soil temperatures should hasten the germination and growth of winter wheat (Evans et al., 1978).

There were no significant differences in plant population in spring. On May 13th, the chemical fallow plots had the highest number of plants per square meter, and the conventional tillage had the lowest. The reason for the low plant populations in the conventional tillage may be water ponding. It was noted that water ponded in low lying areas on the conventionally tilled plots but not in the adjacent zero-tilled plots. In some plots, areas were present where all winter wheat plants were killed. This probably occurred during March and April when the water ponded and then froze. Rakitina (1977) has shown this to be lethal to winter wheat.

There were no significant differences in winter survival, even though it ranged from 106% for the chemical fallow plots, down to 81% for the 30 cm stubble plots (Table 9). The 106% survival for the chemical fallow plots may be due to the more accurate destructive sampling carried out in spring. The chemical fallow plots also warmed up faster in the spring, so any seeds that had germinated, but not emerged in the fall will have resumed growth sooner than in other plots.

The reductions in plant population, especially in the 30 cm stubble plots and the conventionally tilled plots, may be due in part to waterlogging in the spring. Three of the 30 cm stubble plots were situated in low-lying areas.

Vegetative Growth

On May 13th, the wheat grown on chemical fallow produced significantly more dry matter per square meter than wheat grown on any other treatment (Table 10). Wheat grown on all other treatments did not differ from each other. This difference in dry matter was due to the significantly larger plants growing on the chemical fallow plots.

The wheat growing on chemical fallow also had significantly more tillers than wheat growing on any of the other treatments (Table 9).

The increased vegetative growth of wheat seeded on chemical fallow as seen by plant dry weights (Table 10) could be due to a number of factors. The soil temperature was warmer on the chemical fallow plots early in the growing season (Figure 4). This would lead to more rapid root growth, which in turn, would increase the nutrients and moisture available to the plants (Smika and Greb, 1973). The wheat growing in the chemical fallow plots would also benefit more from solar radiation, as there would be no straw or standing stubble to shade it. During the 1981-82 growing season, the chemical fallow plots also had a greater amount of available nitrogen at the time of seeding. The plants would have benefited from this, both in fall and during spring regrowth, before the broadcast nitrogen application on May 3rd.

There were no significant differences in plant population on July 1st, and populations were not very different from May 13th (Table 9).

TABLE 10

Dry Matter and Yield of Winter Wheat in 1982
When Grown in Five Stubble Heights

Treatment	Dry Matter/m^2(g)		Dry Matter/Plant (g)		Yield kg/ha	% Protein
	May 14	June 22	May 14	June 22		
Chemical Fallow	61.2 a[1]	894.7 a	0.41 a	6.73 a	3985 a	13.0 b
Conventional Tillage	31.2 b	632.3 b	0.30 b	5.73 bc	3805 a	10.7 d
7.5 cm Stubble	33.5 b	656.0 b	0.24 b	5.04 c	4428 a	11.4 cd
15 cm Stubble	27.0 b	677.0 b	0.20 b	5.33 bc	3692 a	11.8 cd
30 cm Stubble	29.6 b	663.0 b	0.22 b	6.14 ab	3771 a	10.5 d
Spring Wheat, Zero-Tillage					2233 b	14.4 a
Spring Wheat, Conventionally Tilled					2241 b	14.9 a
C. V.	34.1	13.9	24.6	9.32	16.0	5.7

[1] Means within columns followed by the same letter are not significantly different at the .05 level.

The wheat seeded on chemical fallow had a significantly greater dry matter per square meter than did any other treatment (Table 10). The wheat seeded on the conventionally tilled plots had the lowest dry matter per square meter, but it was not significantly different from any of the zero-tilled stubble plots.

The number of tillers per plant increased in all cases, even though at the later date only fertile tillers were counted. The highest average number of tillers per plant, 7.0, was in the 30 cm stubble, but this was significantly different only from the 7.5 cm stubble plots, which at 5.6 had the lowest number of tillers per plant. All other treatments did not differ from these two in regards to tillers per plant (Table 9).

The average dry matter of individual plants showed much greater variation in July than they did in May (Table 10). The wheat seeded on chemical fallow had a significantly greater plant dry weight than all other treatments except for the wheat seeded into 30 cm stubble. The wheat seeded in 7.5 cm stubble had the lowest dry weight per plant, but did not differ significantly from the wheat seeded in conventionally tilled soil, or into 15 cm stubble.

The greater number of heads/m^2 in the chemical fallow did not result in a significantly greater yield.

Yield and Protein

There were no significant differences in yield between treatments in 1981-82 (Table 10). Yield ranged from a high of 4428 kg/ha for wheat seeded into a 7.5 cm stubble, to a low of 3691.5 kg/ha for wheat seeded into 15 cm stubble. The highest yield was obtained on plots with the lowest number of tillers per plant. Under the stress due to the lodging, these plants may have been able to fill the grain to a larger degree.

Several factors may have minimized the yield differences between treatments. The first was an infestation of volunteer barley in the fall of 1981, which emerged shortly after the wheat crop. It grew to a height of 10-12 cm before being killed by frost, so it would have competed with the wheat for space, light and nutrients. The barley cover also minimized the effects of the straw mulch and stubble in effects on microclimate. The barley was practically non-existent on the chemical fallow plots, perhaps giving them an unfair advantage in this regard. The wheat was smothered in spots due to the mat of dead plants in the spring. Since the infestation which occurred on all plots was very spotty, it was hard to determine the effect this had on the plot yields. Yields were determined for small areas of comparable infestation (Appendix Table 12). Only very heavy infestations had a significant effect on wheat yield.

The second factor which may have served to minimize yield differences was the lodging of the wheat. This first occurred about July 12th, after a heavy rain storm. Only the wheat growing on chemical fallow was badly lodged, due to its lush growth and greater height. All other plots were bent slightly. A later storm about July 18th flattened all the plots. The plants were at the milk stage, so with the bent and twisted stems, a decreased supply of water and nutrients will have hindered grain filling, and decreased yield.

The wheat seeded on chemical fallow had a significantly higher protein content than any of the other treatments (Table 10). There were no statistically significant differences between any of the other treatments. Since high protein content is correlated with high levels of nitrogen in the soil, the wheat grown on chemical fallow had a double advantage in this regard. First, the chemical fallow plots had a much larger amount of available nitrogen, because it was not depleted by the previous crop. Secondly, there were no crop residues present to immobilize the nitrogen that was broadcast in spring.

There was a highly significant correlation (r = .665) between protein content of the grain and plant dry matter on July 1st, probably because the wheat seeded on chemical fallow also showed the most vegetative growth, again due to the large amount of available nitrogen.

Comparison of the Yield and Protein of Spring Wheat and Winter Wheat

The yields of zero-tilled and conventionally tilled spring wheat were significantly lower than yields of winter wheat (Table 10), differing by 1400 to 2200 kg/ha. There were some fungal diseases in the spring wheat which probably reduced yield to slightly below average. The late seeding on

May 25th may have been detrimental to producing optimum yields.

The spring wheat had significantly higher protein content than did the winter wheat. There were no significant differences in protein between spring wheat sown in conventionally tilled soil and zero-tilled spring wheat.

Regression Studies of Air Temperature and Soil Temperatures Under 4 Depths of Snow Cover

The influence of snow depth on soil temperatures during the winter is illustrated in Figures 5, 6, 7, and 8. Snow depth had a marked influence on the effect of air temperature on soil temperature.

With snow depths of only 0-1 cm, there was a direct relationship between air temperature and soil temperature (Figure 5). The correlation between air and soil temperature was highly significant ($r = .975$). The slope of this relationship was less than 1 due to the insulative value of the snow, as well as the latent heat in the soil. The line does not pass through the origin because when air temperatures near zero were recorded, soil temperatures during the thaws were still below zero. With these minimal amounts of snow cover, a soil temperature of -16°C could be expected at the 2.5 cm depth when air temperatures drop below -23°C. Crown temperatures of -16°C are considered dangerous or lethal for winter wheat. In light of the recorded air temperatures

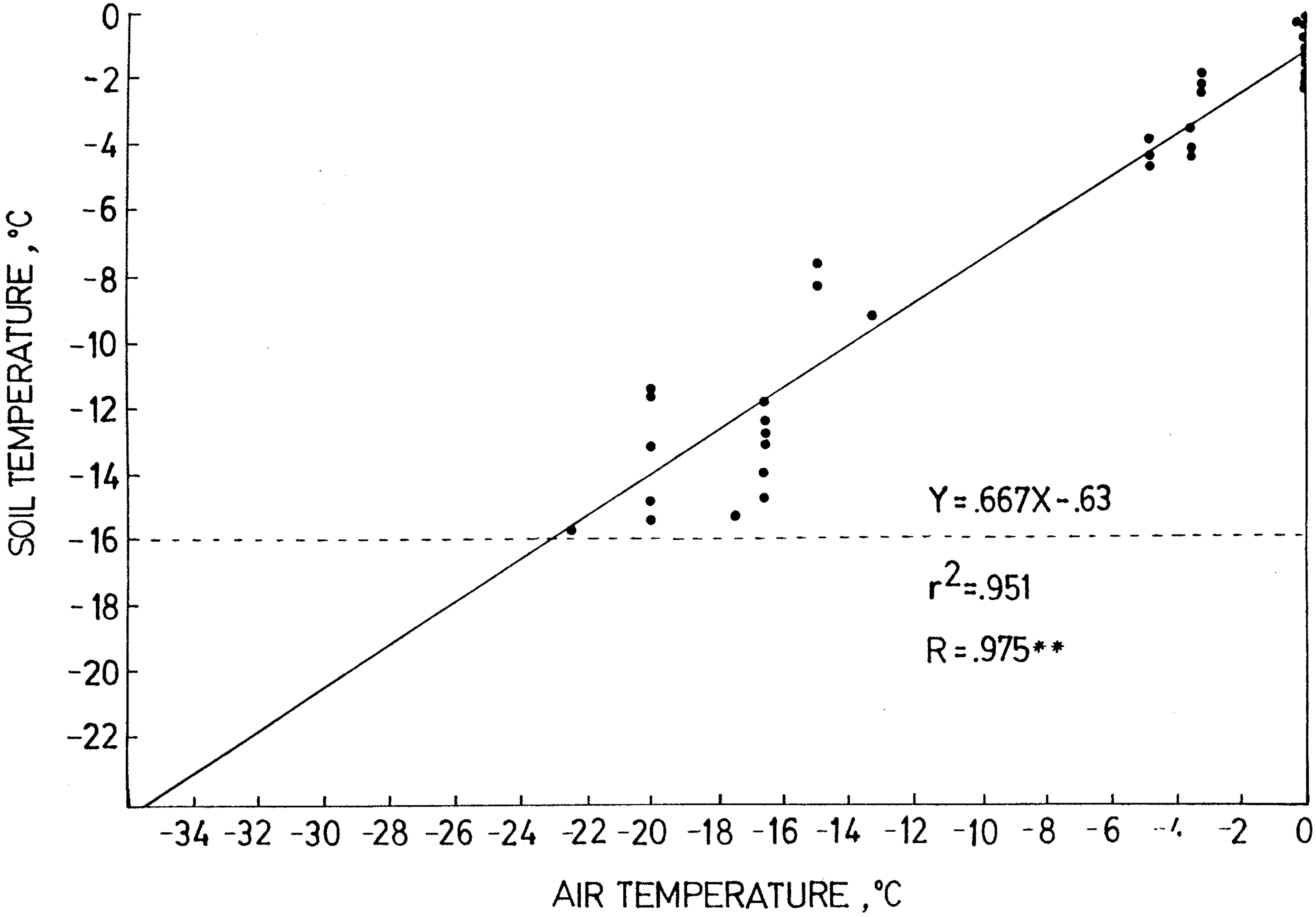

Figure 5. The influence of air temperature on soil temperature at the 2.5 cm. depth, with a snow cover of less than 1 cm.

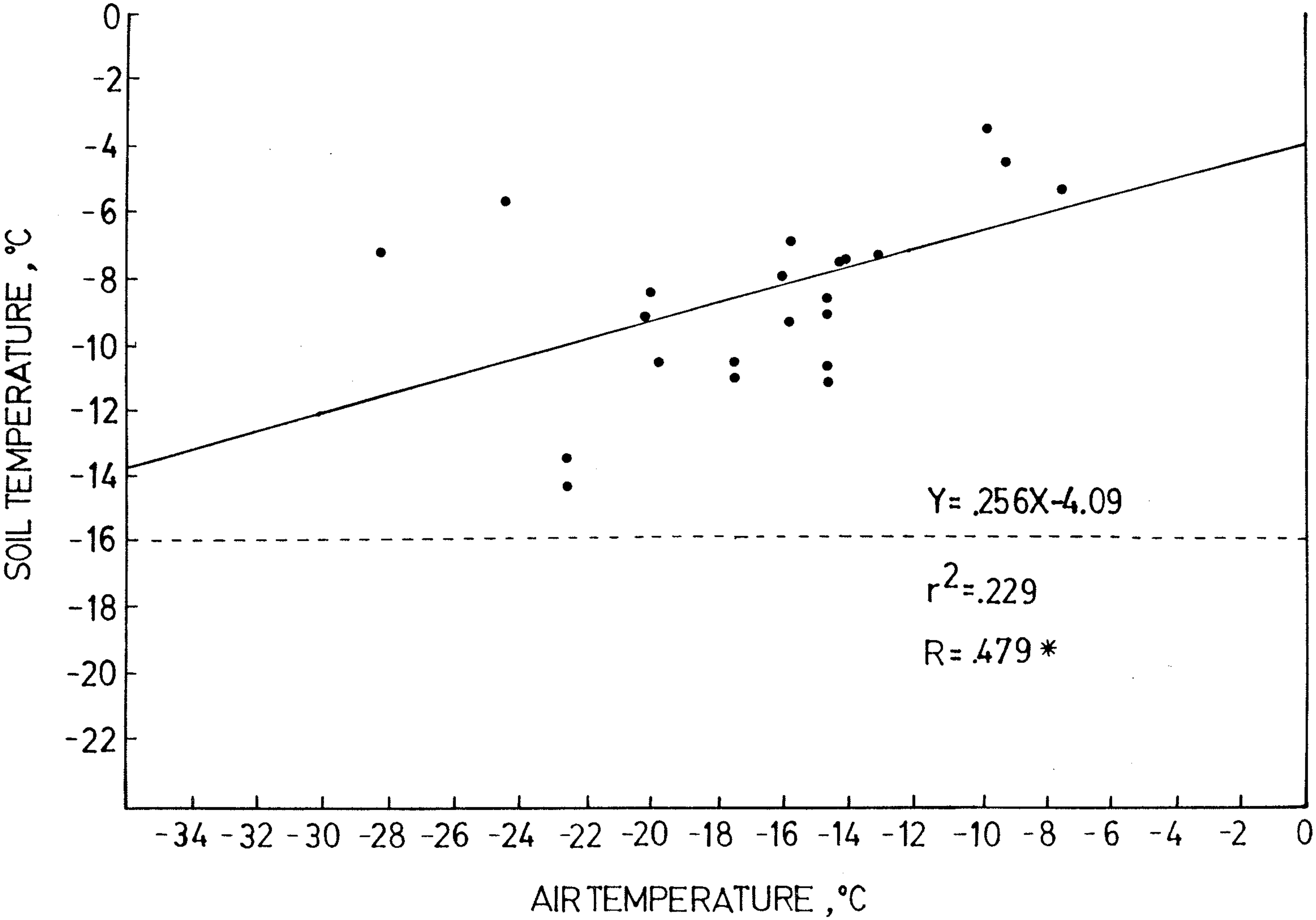

Figure 6. The influence of air temperature on soil temperature at the 2.5 cm. depth, with a snow cover of 4 to 7 cm.

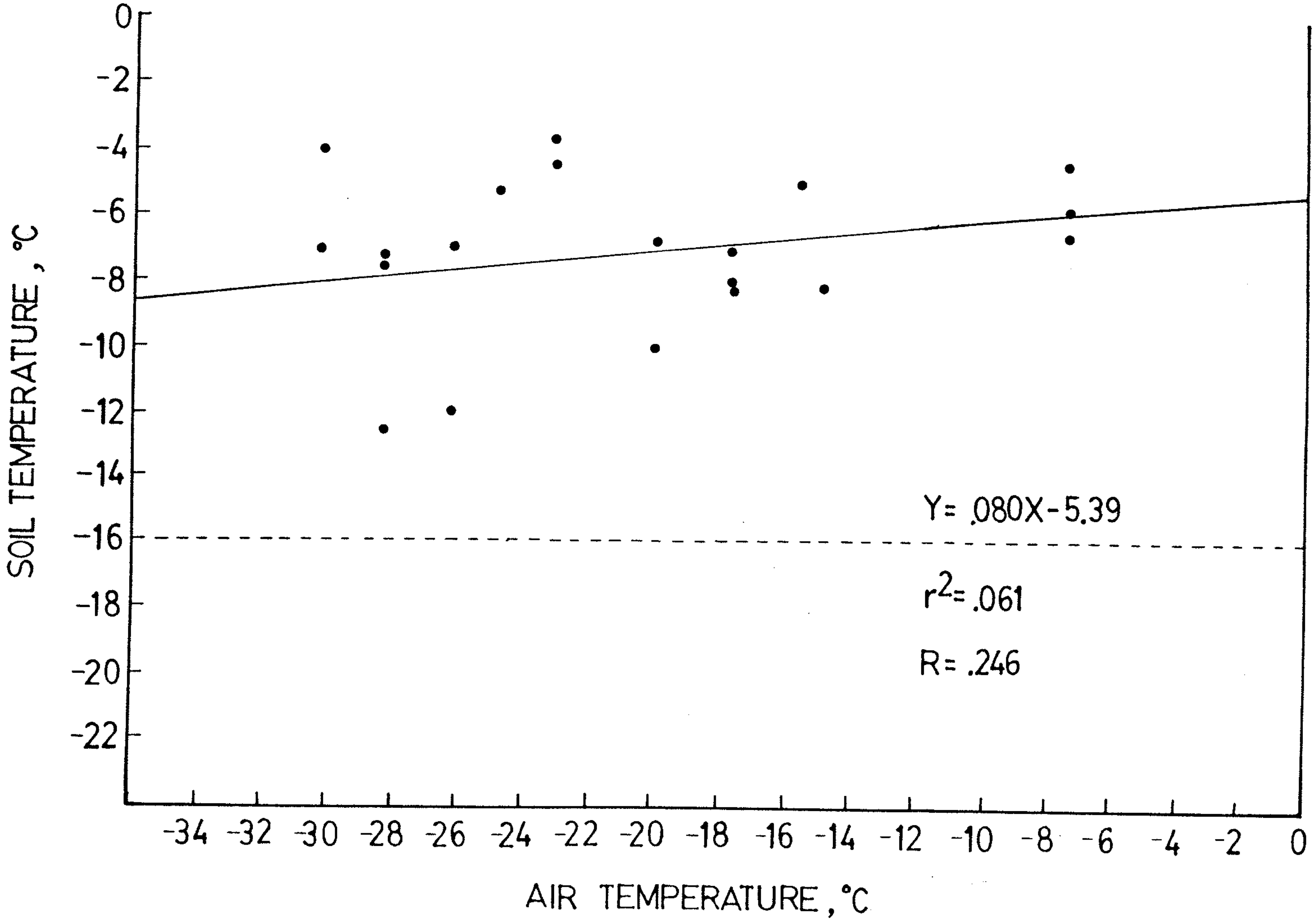

Figure 7. The influence of air temperature on soil temperature at the 2.5 cm. depth, with a snow cover of 10 to 13 cm.

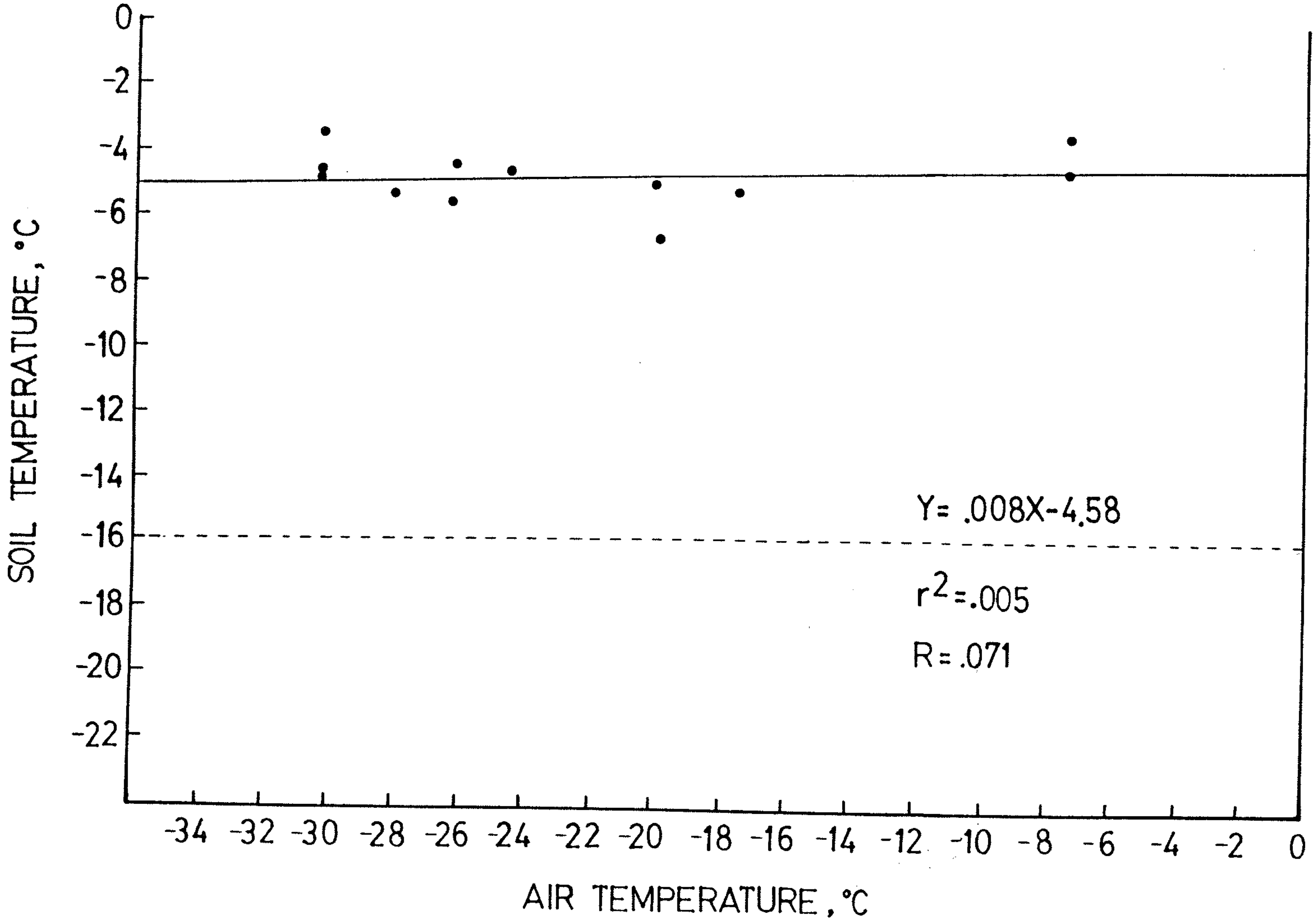

Figure 8. The influence of air temperature on soil temperature at the 2.5 cm. depth, with a snow cover of 16 to 20 cm.

during the winters of 1980-81 and 1981-82, winter wheat would be in danger of winterkill with these minimal amounts of snow cover.

At a snow depth of 4 to 7 cm, the relationship between air temperature and soil temperature is not as strong (Figure 6). There is still a significant correlation (r = .479) between the two. At these snow depths, air temperatures could drop to about -44°C before the soil temperature would drop below -16°C at a 2.5 cm depth. At these snow depths, as well as greater depths, soil temperatures do not reach 0°C when air temperatures do. When air temperatures occur that are above freezing, the snow insulates the soil from the warmer air. The soil temperature at 2.5° cm is also affected by the frozen soil at greater depths. When soil temperatures do warm up to near 0°C, the snow melts, or shrinks in size, so that it is no longer possible to consider the relationship at the original depth.

This is especially evident in Figure 7 and 8, which show the soil temperature versus air temperature relationship at 10-13 cm snow and 16-20 cm snow respectively. Snow accumulations of these depths were much harder to come by, especially on those days when the depths were measured, so the sample size is limited. Also, most of the temperatures for the 10-13 cm depth, and all of the temperatures for the 16-20 cm depth were from the winter of 1981-82. Snow did not accumulate to these depths in 1980-81. In 1981-82, snow fell on ground that was frozen but not very cold, and remained all winter. In those plots where snow accumulations were substantial, the insulation provided by the snow kept the soil temperatures from dropping to near lethal temperatures. The snow also insulated the soil from increases in air temperature, until the snow melted. These factors account for the low correlation (r = .246 and r = .071) between air temperature and soil temperature under 10-13 cm snow and 16-20 cm snow respectively.

In all cases, no distinction was made between temperature readings during rising or falling temperatures, because of a shortage of data points. A hysteresis effect would be present (Crawford and Legget, 1957), although this would be minimal at a 2.5 cm depth.

Experiment 2 The Effects of Four Rates of Barley Straw Mulch on the Survival and Growth of Winter Wheat 1980-81

Snow Cover

The snow cover was fairly consistent over all the plots due to the 15 cm stubble. The mowed treatment plots were too small for the wind to blow them clear of snow. The snow depths throughout the winter were very similar to those of the 15 cm stubble height in Figure 1.

Soil Temperature

As a rule, soil temperatures paralleled air temperatures, but did not show as much fluctuation (Appendix Table

13). The soil temperatures of the plots having 3000 kg/ha mulch did not correspond to the other mulch rates or to the air temperature until mid-February. Presumably this is the result of a malfunction in the temperature recording equipment rather than a reflection of the actual temperature. The rate of mulch did not exert a strong influence on soil temperature. The mowed treatment with no mulch generally had the lowest temperature, but it did not differ from the highest temperature by more than one or two degrees (Appendix Table 13).

Survival

It is not possible to present data for the survival in this experiment because fall plant counts were not taken. There were no significant differences in plant stand between treatments in spring. Rate of mulch was not correlated to plant stand in the spring.

Vegetative Growth

The amount of vegetative growth in spring was measured on May 12th. At this time there were no significant differences in the number of tillers per plant, dry weight per m^2 or stage of growth as measured by Feekes scale (Table 11). The plots with the 3000 kg/ha mulch were lowest in all three measurements, although the difference was not significant. This may be because the straw on this treatment was not chopped as finely and interfered with plant growth to a greater extent.

TABLE 11

Plant Population, Dry Matter, and Yield of Winter Wheat in 1982 When Grown in Four Rates of Barley Crop Residues

Treatment	Plant Counts/m^2	Tillers/Plant	Dry Matter/m^2	Growth Stage (Feekes)	Yield kg/ha	% Protein
	May 12					
Normal	132 a[1]	3.3 a	12.2 a	2.7 a	3761 a	10.8 a
Raked	120 a	3.6 a	10.1 a	2.8 a	3678 a	11.3 a
1500 hg/ha Mulch	117 a	3.4 a	10.5 a	2.9 a	3940 a	11.5 a
3000 kg/ha Mulch	111 a	2.7 a	8.2 a	2.7 a	3735 a	10.9 a
4500 kg/ha Mulch	135 a	3.3 a	13.0 a	2.9 a	4082 a	10.8 a
Mowed and Raked	127 a	2.9 a	10.6 a	2.8 a	3838 a	11.2 a
C. V.	12.9	17.5	43.0	9.5	11.2	8.7

[1] Means within columns followed by the same letter are not significantly different at the .05 level.

Yield and Protein

There were no significant differences in yield (Table 11). It ranged from a high of 4081.5 kg/ha for the treatment having 4500 kg/ha of straw mulch to a low of 3678.3 kg/ha for the treatment without mulch. Protein content of the grain ranged from 11.5% to 10.8%. There were no significant differences between treatments. There was a significant negative correlation between protein and dry matter (r = -.419).

Experiment 4 The Effects of Four Rates of Barley Straw Mulch on the Survival and Growth of Winter Wheat 1981-82

Snow Depths

There was a continual snow cover on the plots from December 21st to March 21st. The snow depths on the mowed plots were less than on the stubble plots, especially where there were two or more adjoining mowed plots. Also, plot size was larger than the previous year, so the wind was able to clear snow from the plots. Average snow depths from December 29th to March 21st over the entire experiment were 12.4 cm and 8.2 cm for stubble and mowed treatments respectively. Snow depths on the replicate where temperatures were monitored, averaged 14.1 cm and 8.6 cm for stubble and mowed plots respectively.

Soil Temperatures

The effects of straw mulch on soil temperatures was minimal (Appendix Table 14). This can be attributed in part to the complicating effect of the snow cover on the plots for most of the winter. At no time did the soil temperatures at a 2.5 cm depth come close to lethal temperatures in any of the plots. Average mean temperatures from November 22nd to March 28th were -4.4, -4.4, -4.6 and -3.6°C for plots with 0, 1500, 3000, and 4500 kg/ha barley straw mulch respectively (Appendix Table 14). This includes both mowed and stubble treatments, and shows the mulch may have an insulating effect. During the same time, the mean temperatures for all mowed and stubble treatments were -4.7°C and -3.9°C respectively. This difference in temperature could be accounted for by the difference in snow depths.

During the period from October 4th to November 22nd, the average temperatures increased as the rate of mulch increased from 3.5°C for the treatments having no mulch, to 4.2°C for treatments having 4500 kg/ha mulch. The mulch could be expected to insulate the soil, thus raising the average temperature during this period of falling temperature.

In spring, from March 28th to May 8th, the average temperatures were lower as rates of mulch increased (Appendix Table 14). Temperatures ranged from 3.8°C for plots having no mulch, to 2.4°C for plots having 4500 kg/ha mulch.

It would appear that the straw mulch had very little effect on the winter wheat during the winter, as soil temperatures are all below freezing, but well above lethal temperatures.

Increased fall temperatures under a surface mulch may give opportunity for more growth in the fall. Lower spring temperatures may also slow dehardening during spring thaws. These effects would be beneficial, but in light of the small differences in temperature, the differences seem negligible.

Winter Survival

There were significant differences in the plant stand before winter (Table 12). The treatments with no straw mulch had significantly higher stands than those treatments with 4500 kg/ha mulch. The inhibition may be due to smothering (Anderson and Russel, 1964) or to the leaching of toxins from both the fresh and decomposing straw (Cochran et al., 1977; Kimber, 1973). There was a highly significant negative correlation (r = -.672) between rate of mulch and fall plant counts.

The same trend was apparent in the spring (Table 12). Both of the 0 mulch treatments, as well as the 1500 kg/ha mowed treatment had a significantly higher plant population than did the stubble treatment with 4500 kg/ha mulch. All other treatments did not differ significantly from either the 0 rates of mulch or the 4500 kg/ha stubble treatment. There

TABLE 12

Winter Survival and Growth of Winter Wheat in 1982 When Grown Under Four Rates of Barley Crop Residues

Treatment	Plant Counts/m^2		Survival, %	Tillers/ Plant
	Oct. 15	May 13		
Stubble 0 Mulch	159 ab[1]	154 a	98 a	3.7 ab
Stubble 1500 kg/ha Mulch	152 abc	130 ab	86 a	2.8 bc
Stubble 3000 kg/ha Mulch	150 abcd	139 ab	93 a	2.6 c
Stubble 4500 kg/ha Mulch	140 cd	118 b	88 a	2.6 c
Mowed 0 Mulch	167 a	149 a	91 a	3.8 a
Mowed 1500 kg/ha Mulch	144 bcd	153 a	107 a	3.7 ab
Mowed 3000 kg/ha Mulch	136 cd	128 ab	95 a	3.3 abc
Mowed 4500 kg/ha Mulch	131 d	130 ab	101 a	3.2 abc
C.V.	8.3	13.0	16.1	18.7

[1] Means in each column followed by the same letter are not significantly different at the .05 level.

was a significant negative correlation (r = -.440 between mulch rate and spring plant counts.

When these two sampling dates were compared, there was no significant differences in winter survival between treatments.

Vegetative Growth

There were significant differences in the extent of tillering between the various treatments (Table 12). Both of the 0 mulch treatments, as well as the 1600 kg/ha mowed treatment, had significantly more tillers per plant than did the 3000 and 4500 kg/ha mulch stubble treatments. This may be the result of toxins leached from the straw (Cochran et al., 1977) or cooler soil temperatures (Smika and Ellis, 1971). The actual physical smothering may also have a detrimental effect (Anderson and Russell, 1964).

The mowed treatment with no mulch had a significantly higher dry matter per square meter than both 4500 kg/ha treatments as well as the 1500 and 3000 kg/ha stubble treatments. (Table 13)

Generally, the trend was for the mowed treatments to have a higher dry matter per square meter. Mean dry matter for mowed treatments, 28.46 g/m^2 is significantly higher than that of stubble, 19.56 g/m^2. The stubble influences the characteristics of the straw mulch. On the mowed treatments, the mulch is packed into a fairly dense mat, whereas on the stubble, the mulch is held off the ground to some extent, forming a deeper layer, which prevents the soil from warming as fast in spring due to its greater insulative properties. This could reduce tillering and growth (Smika and Ellis, 1971). The loose layer will also shade the plants for a longer period of time, thus weakening them.

There are significant negative correlations between the amount of mulch applied and the number of tillers per plant (r = -.430), and between the amount of mulch applied and plant dry matter per square meter (r = -.435).

The dry matter of individual plants showed similar trends (Table 13). The mowed treatment with no mulch had plants of a significantly higher dry weight than the plants of the stubble treatments with mulch at the rate of 3000 or 4500 kg/ha. The mean plant weight for mowed treatments and stubble treatments were 0.19 g and 0.14 g respectively. There was a significant negative correlation (r = -.404) between mulch rate and plant dry matter.

The plants growing in the higher rates of mulch set crowns within the straw layer or on top of the soil surface where they were more susceptible to frost damage and drought. Formation of tillers and adventitious roots is stunted in plants growing in a dry environment (Ferguson and Boatwright, 1968). These factors may influence dry weight and vigor of the plants.

TABLE 13

Dry Matter and Yield of Winter Wheat in 1982
When Grown Under Four Rates of Barley Crop Residues

Treatment	Dry Matter/m^2 (g)	Dry Matter/ Plant (g)	Feekes Growth Stage	Yield kg/ha	% Protein
	May 13		June 14		
Stubble 0 kg/ha Mulch	29.9 ab[1]	0.19 ab	8.6 a	3702 ab	11.8 a
Stubble 1500 kg/ha Mulch	18.4 b	0.14 ab	8.4 ab	3629 abc	12.0 a
Stubble 3000 kg/ha Mulch	15.0 b	0.10 b	8.3 ab	3269 bc	11.6 a
Stubble 4500 kg/ha Mulch	14.9 b	0.12 b	7.8 c	2723 d	11.1 a
Mowed 0 kg/ha Mulch	36.4 a	0.23 a	8.6 a	3833 a	11.8 a
Mowed 1500 kg/ha Mulch	32.8 ab	0.21 ab	8.3 ab	3342 abc	11.0 a
Mowed 3000 kg/ha Mulch	26.0 ab	0.19 ab	8.0 bc	3427 abc	11.4 a
Mowed 4500 kg/ha Mulch	18.6 b	0.14 ab	7.8 c	3150 cd	12.0 a
C.V.	45.1	36.5	3.0	8.8	6.2

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[1] Means in each column followed by the same letter are not significantly different at the .05 level.

The plants in those plots with a lower rate of mulch grew and matured at a faster rate than did those plants growing in heavily mulched plots (Table 13). On June 14th, those plants growing on the mulch plots were significantly more advanced than those on both 4500 kg/ha mulch treatments, as well as the 3000 kg/ha mowed treatment, as determined by Feekes growth scale. The two 4500 kg/ha treatments were significantly less advanced than all other treatments except for the mowed 3000 kg/ha treatment. This trend was evident until the time of maturity and harvest.

Yield and Protein

There is a highly significant negative correlation (r = -.673) between yield and rate of mulch. The two treatments with 0 mulch differ significantly from the treatments with 4500 kg/ha mulch (Table 13). As the rate of mulch increases, the yield decreases. With the exception of the 1500 kg/ha rate, the yield for treatments with the standing stubble is lower than the mowed treatments (Figure 9), although the differences are not significant at the .05 level. Mean yield for mowed treatments is 3438 kg/ha and for stubble treatments it is 3331 kg/ha. Increasing rates of mulch affect plant yield by decreasing the capacity for vegetative growth. High rates of mulch may also immobilize nitrogen, especially when the nitrogen is broadcast, making it less available to the plants and thereby decreasing yield.

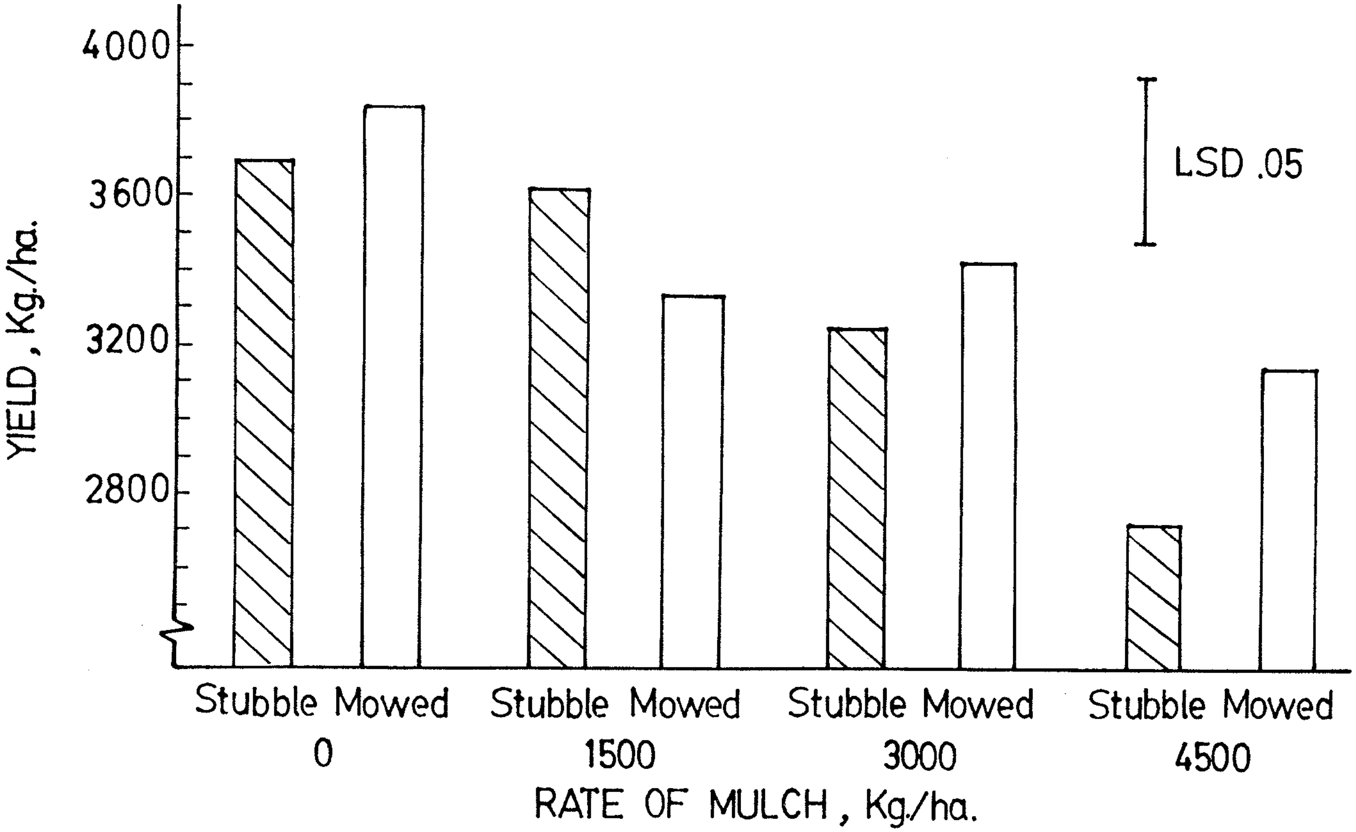

Figure 9. The effects of barley straw on the yield of winter wheat, when applied at four rates on mowed and standing stubble.

Experiment 5 A Comparison of the Effects of Rapeseed, Winter Wheat, and Barley Straw on the Survival and Growth of Winter Wheat

Winter Survival

There were no significant differences in the fall plant counts (Table 14). The plots with the higher rates of barley and winter wheat straw had the lowest plant populations. This may have been due to physical smothering (Anderson and Russel, 1964) or toxins from the straw (Kimber, 1973) and from microbial decomposition (Cochran et al., 1977).

The spring plant population showed no significant difference between treatments (Table 14), although the high rates of barley and winter wheat straw had the lowest number of plants per square meter.

The winter survival of the wheat was over 100% in all treatments, indicating an increase in observed plant population. This can probably be accounted for by the greater precision in the spring plant counts, in which plants were removed from the soil for counting. The high survival would also imply that none of the treatments suffered winterkill from cold temperatures.

Vegetative Growth

The rate and type of straw applied had a significant effect on tiller production when compared to the control (Table 14). All treatments with 1500 kg/ha straw as well as

TABLE 14

Winter Survival and Growth of Winter Wheat in 1982
When Grown Under Three Different Types
of Crop Residues Each Applied at Two Different Rates

Treatment	Plant Counts/m^2		% Survival	Tillers/ Plant
	Oct. 16	May 28		May 28
No Mulch (Control)	191 a[1]	197 a	103 a	3.9 a
1500 kg/ha Barley Straw	191 a	209 a	109 a	3.6 ab
3000 kg/ha Barley Straw	172 a	174 a	101 a	3.2 b
1500 kg/ha Winter Wheat Straw	192 a	203 a	106 a	3.3 ab
3000 kg/ha Winter Wheat Straw	172 a	191 a	111 a	3.1 b
1500 kg/ha Rapeseed Straw	197 a	205 a	105 a	3.5 ab
3000 kg/ha Rapeseed Straw	189 a	196 a	104 a	3.5 ab
C.V.	8.8	12.1	9.8	11.36

[1] Means in each column followed by the same letter are not significantly different at the .05 level.

the treatment with 3000 kg/ha rates of winter wheat or barley straw. The high rate of winter wheat or barley residue did differ significantly from the treatment receiving no straw residues. The rapeseed straw forms a less dense mat than the cereal residues, shading the ground less. Under cereal residues, this could result in reduced light and lowered soil temperatures causing a reduction in tillering (Smika and Ellis, 1971). Toxins leached from the crop residue may also reduce tillering (Cochran et al., 1977). The negative correlation between tiller production and rate of mulch ($r = -.508$) was highly significant. Also, plots with the winter wheat straw mulch were infected by tan spot *Pyrenophora trichostoma*, the infection being more severe on plots with 3000 kg/ha residue than plots with 1500 kg/ha residue. In both treatments, nearly all the plants were infected. The lower 2-3 leaves were almost completely infected, while the later leaves had occasional lesions. Plots with barley or rapeseed straw mulches were not infected to nearly the same level, as these crops are immune to the disease and do not have the spores on their crop residues. The disease disappeared with the onset of dry warm weather towards the end of May.

Dry weight samples were taken on May 27th, approximately one month after regrowth began in spring. The treatment with no mulch had a significantly higher dry weight than all other treatments except the low rate of barley residues (Table 15).

TABLE 15

Dry Matter and Yield of Winter Wheat in 1982
When Grown Under Three Different Types of Crop Residues
Each Applied at Two Different Rates

Treatment	Dry Matter /m^2 (g)	Dry Matter Plant (g)	Yield kg/ha	% Protein
	May 28			
0 Mulch (Control)	185.4 a[1]	0.95 a	3677 a	10.3 a
1500 kg/ha Barley Straw	153.9 ab	0.74 b	3198 bc	10.2 a
3000 kg/ha Barley Straw	101.8 cd	0.63 bc	2789 cd	10.7 a
1500 kg/ha Winter Wheat Straw	139.9 bc	0.66 bc	3198 bc	10.5 a
3000 kg/ha Winter Wheat Straw	90.5 d	0.50 c	2547 d	10.9 a
1500 kg/ha Rapeseed Straw	126.1 bcd	0.61 bc	3291 ab	10.5 a
3000 kg/ha Rapeseed Straw	128.3 bc	0.66 bc	3041 bc	10.4 a
C.V.	17.7	14.6	9.0	4.6

[1] Means in each column followed by the same letter are not significantly different at the .05 level.

The treatment having the high rate of winter wheat residues again had the lowest dry weight production. A heavy straw mulch causes the crown node to form farther from the seed, in some cases even above ground level, within the straw layer (Ferguson and Boatwright, 1968). This was observed in some of the plots having higher rates of mulch. The formation of adventitious roots is also stunted in a dry environment (Ferguson and Boatwright, 1968). The plant crown would also be less protected against cold temperatures. These factors, together with a lack of physical support for the plant, could lead to decreased vigor and dry weight. When compared to the no mulch treatment which had a dry weight of 185.4 g/m^2, the averages for the 1500 and 3000 kg/ha straw mulch rates were 138.2 g/m^2 and 106.9 g/m^{2}respectively. These comparisons showed highly significant differences. The weight per plant follows the same trend as well, with the control (0 mulch) having a significantly higher weight per plant than any of the other treatments (Table 15). The 3000 kg/ha winter wheat straw plots again had the lowest dry weight per plant, although it did not differ significantly from any treatments except the control and the light rate of barley mulch. There is a significant negative correlation (-.443) between mulch rate and dry weight/m^2 but not between mulch rate and dry weight per plant, indicating that the mulch had more effect on the number of plants than on the size of plants.

Yield and Protein Content

The highest yield, 3677.2 kg/ha, was obtained with the control treatment (Table 15). It was significantly higher than all others except the treatment with the low rate of rapeseed straw. The lowest yield, 2547.2 kg/ha was obtained on the plots having a high rate of winter wheat mulch. This was significantly lower than all other treatments except the high rate of barley mulch. The three plots with the low rate of mulch had yields lower than the control, but higher than the plots with the heavy rates of mulch. The plot with 3000 kg/ha rapeseed mulch outyielded the plots with barley and winter wheat by about 250 and 500 kg/ha respectively. There was a highly significant negative correlation between the rate of mulch and yield (r = -.655); as well as highly significant positive correlations between dry matter and yield (r = 772), and between plant dry weight and yield (r = .692). This suggests that a healthy vigorous stand in the spring plays an important role in determining yield.

There were no significant differences in protein content between treatments (Table 15). The grain protein at 14% moisture ranged from 10.9% to 10.3%. There was a highly significant negative correlation betwen protein and spring plant counts (r = -.683) and a highly significant positive correlation between protein and plant dry matter (r = .556). There was no correlation between rate of mulch and protein.

CONCLUSIONS

Zero-tillage is conducive to providing an environment suitable for the production of winter wheat in Manitoba. The standing stubble can trap enough snow to insure against damage by lethal temperatures. A snow cover of 4 to 7 cm is sufficient to provide insulation throughout the winter. This has been accomplished by the use of stubble as low as 7.5 cm in height. Higher levels of snow retention are advantageous, because a level of protection is maintained even after partial snow melting occurs. In addition, the increased amounts of snow retained in taller stubble provide the crop with more available moisture in the spring. This moisture would be the more available to the plants, because decreased incidence of ground frost would encourage greater infiltration of melt-water. Runoff and losses due to field ponding are greatly diminished.

In the two years of this study, there were no statistically significant differences in winter survival or in the grain yield between the zero-tilled winter wheat and that sown on chemical fallow or conventionally tilled soil. Other studies in Manitoba (Rourke et al., 1982; Stobbe et al., 1981) show differences in this regard. Two factors may account for this variation. Firstly, the furrows created at the time of seeding held enough snow over winter to protect the wheat on the chemical fallow and conventionally tilled seedbed against prolonged lethal temperatures. Secondly, there was enough precipitation during the growing seasons for the crop to mature satisfactorily, so the moisture gain from retained snow did not, in these cases, appear to have an appreciable influence on yield.

The zero-tilled plots were also more permeable to water than conventionally tilled plots. This characteristic is of special importance in the spring, when ponded water may freeze, with resultant high plant mortality.

The quantity of mulch or crop residue on the surface has a significant effect on plant population and also on yield. As the rate of application of mulch increased, plant population and yield decreased. For this reason, it would be inadvisable to cut the stubble very low, as most of the straw would then be lying on the ground. If possible, straight combining would provide an ideal environment in this respect.

The effect of mulch on soil temperature was negligible throughout the winter, and is not believed to have affected the wheat. Temperatures during the fall and spring showed more variation, but the influence on growth is not known, because plots with high quantities of mulch were slower to cool in fall and also slower to warm up in spring.

It would also be inadvisable to recrop winter wheat for several reasons. Firstly, the possibility of disease infection is increased by recropping into standing stubble. Secondly, the crop residues left after harvesting winter wheat may make seeding difficult. They would also hinder growth and development of the succeeding crop.

Although there were no differences in yield or survival during these two seasons, it would seem, that in the light of the evidence presented, zero-tillage would provide a consistantly favorable environment for winter wheat production.

RECOMMENDATIONS FOR RESEARCH

1) More work is required to determine the optimum fertilization requirements for winter wheat when large amounts of crop residues remain on the soil surface. The effects of timing and placement of N fertilizer on the grain protein is of importance. This may also have some effect on the susceptibility of winter wheat to lodging. Control of lodging through growth regulators is also possible.

2) Studies are required in which the effect of the straw residues is examined with regard to the individual effects of toxicity to the seedlings, physical smothering, and effect on the nutrient availability.

3) Further studies are needed to examine the effects of ground frost penetration on water infiltration and on the rate of soil warming in the spring, and the implications of these in terms of crop growth and environmental protection.

4) It is recommended the effects of the previous crop on the winter wheat be studied with regard to the transmission of diseases, and that a suitable rotation or control methods be established.

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APPENDIX

Appendix - Table 1

Climatic Data for the 1980-81 Growing Season at Portage la Prairie

	Temperature °C											
	September 1980				October 1980				November 1980			
Date	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	21.1	9.1	15.1		17.2	4.8	11.0	2.3	2.5	-5.1	-1.3	•
2	22.0	9.2	15.6	T	6.4	1.6	4.0	2.3	14.3	-2.5	5.9	2.5
3	23.7	12.1	17.9	5.6	12.3	2.7	7.5		10.8	-0.8	5.0	T
4	19.7	9.5	14.6	1.3	12.3	-0.4	6.0		6.5	-2.5	2.0	
5	24.3	8.8	16.6		18.9	2.3	10.6		14.8	-1.1	6.9	8.4
6	29.4	7.7	18.6		21.3	2.5	11.9		7.6	-1.7	3.6	
7	35.1	10.1	22.6	9.7	25.3	8.9	17.1		0.0	-3.8	-1.9	12.7
8	27.1	9.9	18.5	2.5	17.8	3.3	10.6		1.8	-3.1	-0.7	3.3
9	19.8	6.3	13.1		17.1	3.2	10.2	1.1	-2.1	-12.6	-7.4	1.5
10	25.9	10.3	18.1		10.6	1.3	6.0	3.3	-1.7	-14.9	-8.3	
11	21.2	8.1	14.7	0.8	4.8	-3.4	2.2		4.7	-3.3	0.7	
12	14.1	9.2	11.7	14.7	5.8	-2.6	1.6		2.1	-0.3	0.9	
13	19.0	8.3	13.7		7.3	-3.7	1.6		1.9	2.6	-0.4	
14	19.7	3.8	11.8		6.3	0.1	3.2		4.0	-5.8	-0.9	
15	16.9	6.2	11.6		6.8	2.4	4.6		4.1	5.9	-0.9	
16	11.6	4.0	7.8	1.0	5.6	0.4	3.0	21.1	1.3	7.7	-3.2	
17	5.2	1.5	3.4	1.8	2.6	0.3	1.5	2.3	2.2	-7.7	-2.8	
18	10.9	-3.4	3.3	4.3	5.8	0.2	3.0		7.0	-4.5	1.3	
19	7.0	2.1	4.6	7.6	5.4	1.7	3.6	0.5	5.2	-0.8	2.2	
20	10.9	4.3	7.6	T	9.8	-1.4	4.2		2.6	-14.4	-0.9	
21	14.0	8.0	11.0	5.6	6.6	-3.5	1.6		6.9	-2.8	2.1	
22	9.9	0.8	5.4		5.4	-4.6	0.4	3.8*	7.1	-3.2	2.0	
23	8.7	0.7	4.7	1.3	3.4	--0.6	1.4	T	-2.3	-12.1	-7.2	
24	8.6	3.8	6.2	0.3	2.7	-1.2	0.8	1.8*	4.7	-10.4	-2.9	
25	8.8	0.2	4.5		3.2	--4.0	-0.4		-2.6	-6.6	-4.6	T
26	14.4	-0.9	6.8		5.3	-6.3	-0.5		3.1	-4.5	-0.8	
27	14.2	-1.9	6.2		2.4	-6.1	-1.9		0.9	-8.1	-3.6	1.8
28	23.3	4.4	13.9	0.3	3.5	-7.6	-2.1		2.5	-3.5	-0.5	0.5*
29	17.6	7.3	12.5		7.6	-3.8	1.9		2.9	-1.9	0.5	
30	25.7	6.9	16.3	1.5	11.1	-3.8	7.5		-0.7	-19.8	-10.3	
31					4.3	-5.5	-0.6					
A	17.1	5.5	11.6	58.3	8.9	-0.4	4.3	38.5	3.7	-5.5	-0.9	30.7
B	-0.6	-0.9	-0.8	116%	-3.5	-1.9	-2.7	126%	3.5	2.5	2.9	98%

A = Monthly
B = Departure from Normal
* = Snowfall

Appendix - Table 1

Climatic Data for the 1980-81 Growing Season at Portage la Prairie

Date	Temperature °C											
	December 1980				January 1981				February 1981			
	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	-19.1	-22.5	-20.8		-9.3	-18.0	-13.7	2.0*	-16.6	-22.6	-19.1	0.4*
2	-15.4	-24.6	-20.0		-17.3	-25.7	-21.5		-15.5	-19.8	-17.7	
3	-7.8	-18.1	-19.0	0.5*	-19.8	-27.9	-23.9	0.2*	-11.9	-18.0	-15.0	
4	-1.9	-8.1	-5.0	0.3*	-15.5	-26.1	-20.3	4.2*	-5.1	-21.3	-13.2	T*
5	-2.6	-13.4	-8.0	0.8*	-2.4	-15.8	-9.1	T*	-3.7	-8.1	-5.9	0.5*
6	-12.7	-19.9	-16.3		-8.2	-21.9	-15.1		-3.9	-9.7	-6.8	4.9*
7	-15.8	-20.4	-18.1		-15.2	-23.4	-19.3	0.7*	-6.2	-22.6	-15.4	0.3*
8	-10.8	-18.5	-14.7	0.8*	-10.7	-21.2	-16.0		-17.8	-24.3	-21.1	0.3*
9	-11.3	-23.7	-17.5	1.0*	-18.4	-24.8	-21.6		-19.7	-27.7	-23.7	
10	-20.9	-27.4	-24.2		-13.8	-25.8	-19.8	T*	-24.3	-33.2	-28.8	
11	-11.0	-22.1	-16.6	0.8*	-3.4	-22.6	-13.0		-21.4	-31.7	-26.6	
12	0.4	-21.7	-10.7		0.4	-10.0	-4.3	2.0*	-15.6	-29.0	-22.3	
13	-4.2	-21.3	-12.8		1.4	-7.2	-2.9	T*	-8.7	-19.5	-14.1	
14	-9.5	-19.1	-14.3	1.5*	-3.5	-15.1	-9.3	1.0*	4.8	-16.8	-6.0	
15	-4.2	-10.0	-7.1		-12.0	-18.2	-15.1		8.0	-3.0	2.5	
16	3.5	-10.2	-3.4	2.0	-4.0	-19.9	-12.0		9.3	0.8	5.1	T
17	5.1	-14.2	-4.6		2.3	-5.9	-1.8		11.2	0.5	5.9	T
18	-12.8	-22.1	-17.5		3.5	-10.7	-3.6	0.4*	4.4	-0.6	1.9	T
19	-21.3	-24.6	-23.0		-4.3	-11.4	-7.9		6.1	-1.4	2.4	T
20	-17.3	-26.1	-21.7		0.9	-13.1	-8.1	T*	3.8	-0.8	1.5	1.0
21	-13.5	-24.5	-19.0	1.8*	4.4	-5.7	-0.7	1.8*	6.3	-0.6	2.9	
22	-14.0	-19.6	-16.8	1.3*	5.8	-8.0	-1.1	1.4*	5.3	-4.2	0.6	
23	-15.4	-27.6	-21.5		6.1	-5.0	0.6		10.0	-4.5	2.8	
24	-21.6	-32.1	-26.9	0.2*	1.7	-5.9	-2.1	2.8*	-0.2	-6.0	-3.1	T*
25	-14.2	-25.9	-20.1	T*	-3.1	-7.7	-5.4	T*	-2.0	-8.7	-5.4	
26	-14.1	-27.2	-20.7		-7.0	-21.7	-14.4		3.8	-8.6	-2.4	
27	9.5	-14.3	-2.4		-9.9	-22.5	-16.2	0.6*	1.3	-6.1	-2.4	
28	-1.3	-4.0	-6.5		-11.7	-24.9	-18.3		2.1	-9.6	-3.7	
29	-4.0	-12.4	-8.2	T*	-11.3	-26.6	-19.0					
30	2.0	-4.8	-1.4	T*	-7.6	-22.6	-15.1					
31	1.9	-9.5	-3.8	0.2	-6.4	-17.5	-12.0					
A	-8.8	-19.3	-14.1	11.3	-6.1	-17.2	-11.7	12.7	-3.5	-12.8	-8.2	7.9
B	-1.1	-2.6	-1.9	56.5%	6.4	4.7	5.5	48.5%	5.4	6.9	6.1	35.6%

A = Monthly
B = Departure from Normal
* = Snowfall

Appendix - Table 1

Climatic Data for the 1980-81 Growing Season
at Portage la Prairie

	Temperature °C											
	March 1981				April 1981				May 1981			
Date	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	0.8	-11.5	-5.4	•	9.4	-2.5	3.5	•	15.7	-2.4	6.7	0.3
2	-0.6	-17.6	-9.1	1.0*	14.0	-0.4	6.8		19.2	3.9	14.1	
3	0.0	-8.5	-4.3	0.3*	5.6	-2.2	1.7		11.8	3.6	7.7	
4	-2.3	-9.7	-6.0		2.9	-5.7	-1.4		11.2	0.6	5.9	
5	-3.9	-15.0	-9.5		12.4	-6.6	2.9		13.7	-3.8	5.0	
6	-2.8	-14.8	-8.8		13.8	-2.9	8.4		16.4	-2.2	8.1	
7	2.2	-12.1	-5.0		10.4	2.1	6.3		20.6	3.0	11.8	
8	3.8	-9.2	-2.7		11.4	-2.3	4.6		15.1	-1.2	7.0	
9	3.8	-7.1	-1.7	T*	17.2	-2.2	7.5		8.7	-4.2	2.3	
10	6.1	-5.3	0.4		11.3	-5.5	2.9		12.1	-0.5	5.8	
11	14.3	-1.2	6.6		5.9	- 6.4	-0.3		17.2	4.1	10.7	
12	4.6	-5.3	-0.4	T*	13.6	-3.9	4.9	1.0	20.3	0.3	10.3	
13	7.4	-7.5	-0.1		6.1	-8.6	-1.3		21.8	-0.8	10.5	
14	12.9	0.1	6.5		7.2	-11.8	-2.3		22.9	1.8	12.4	
15	2.0	-5.6	-1.8		22.8	0.4	11.5		16.3	5.1	10.7	
16	14.3	-4.3	5.0		24.7	3.6	14.2	T	17.5	2.2	9.9	
17	-2.2	-10.6	-6.4		14.5	-3.2	5.7		22.2	3.5	12.9	
18	0.7	-10.8	-5.1		13.3	-2.9	5.2		24.8	2.6	13.8	
19	3.2	-7.1	-2.0		5.3	-3.9	0.7		26.8	10.8	18.8	
20	8.1	-8.4	-0.2		13.5	-8.0	2.8	T	28.9	9.5	19.2	
21	7.6	-6.4	0.3		12.7	2.5	7.6	2.2	30.3	10.3	20.3	3.0
22	1.1	-8.6	-3.8		4.4	1.4	2.9		22.0	5.8	13.9	4.4
23	7.7	-6.2	0.8		5.4	-1.9	1.8		7.3	5.3	6.3	26.2
24	15.0	-5.4	4.8	4.4	12.3	-2.1	5.1	2.0	8.9	6.8	7.9	
25	7.9	-0.7	3.6	9.0	9.9	1.7	5.8		14.2	8.2	11.2	
26	2.0	-1.8	0.1		20.3	-1.6	9.4		20.7	4.9	12.8	
27	8.7	0.8	4.8	3.4	12.9	4.6	8.8		20.2	7.2	13.7	
28	11.3	1.1	6.2		16.9	-0.4	8.3	0.2	23.3	12.2	17.8	6.8
29	13.2	-0.2	6.5		17.8	5.0	11.4	0.2	17.4	3.2	10.3	2.6
30	11.2	0.0	5.6		10.3	2.4	6.4		18.8	0.8	9.8	
31	8.8	-1.1	3.9	0.3					22.3	6.6	14.5	
A	5.4	-6.5	-0.6	18.4	11.9	-1.9	5.0	5.6	18.4	3.6	11.0	43.3
B	7.7	8.2	6.8	58%	3.6	0.3	1.9	13.6%	1.8	-0.6	-0.5	68%

A = Monthly
B = Departure from Normal
* = Snowfall

Appendix - Table 1

Climatic Data for the 1980-81 Growing Season at Portage la Prairie

	Temperature °C											
	June 1981				July 1981				August 1981			
Date	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	20.9	10.5	15.7		29.9	17.7	23.8		24.8	11.5	18.2	
2	22.8	4.8	13.8		26.0	16.1	21.1	1.2	26.3	14.5	20.4	
3	27.0	4.3	15.7	2.5	28.6	13.5	21.1		24.4	14.4	19.4	7.9
4	21.7	12.1	16.9	9.0	31.4	16.4	23.9		29.0	13.6	21.3	23.7
5	23.7	12.0	17.9		30.6	18.9	24.8		21.6	16.8	19.2	57.2
6	23.7	9.1	16.4		37.2	15.3	26.3		25.4	16.9	21.2	0.4
7	22.8	12.3	17.6	0.2	35.0	22.6	28.8	0.2	29.0	15.2	22.1	
8	19.3	9.2	14.3	5.2	27.6	14.6	21.1		21.5	11.9	16.7	
9	18.9	7.6	13.3	6.0	30.3	11.8	21.1		23.0	10.6	16.8	1.0
10	19.2	7.3	13.3		29.1	13.4	21.3	5.1	27.1	13.5	20.3	
11	21.3	6.9	14.1		27.5	14.7	21.1	0.8	32.7	16.0	24.4	
12	25.6	7.1	16.4	8.8	29.8	16.2	23.0		26.1	13.3	19.7	
13	20.5	13.9	17.2	8.0	30.4	16.5	23.5		33.3	14.0	23.7	
14	17.2	12.9	15.1	11.6	22.9	16.0	19.5	0.4	23.1	12.0	17.6	
15	13.9	7.5	10.7		23.3	15.9	19.6	37.6	21.9	9.0	15.5	
16	25.2	6.6	15.9	6.2	22.4	13.1	17.8	0.4	24.2	6.3	15.3	
17	19.5	11.5	15.5	2.3	24.8	13.4	19.1		29.2	14.6	21.9	
18	17.7	8.4	13.1		27.1	13.8	20.5		30.3	14.2	22.3	
19	21.2	7.0	14.1		27.8	15.0	21.4		31.2	14.4	22.8	
20	22.8	9.0	15.9	2.0	20.9	11.0	16.0		28.7	13.9	21.3	
21	20.0	9.0	14.5		23.9	8.2	16.1		27.2	16.9	22.1	
22	20.4	11.7	16.1		24.0	9.7	16.9		27.6	14.6	21.1	
23	21.0	9.5	15.3	6.4	29.7	13.5	21.6		27.0	18.4	22.7	11.0
24	23.4	12.0	17.7		19.8	12.9	16.4		27.6	18.4	23.0	
25	22.8	12.0	17.4	1.3	21.1	7.5	14.3		27.2	16.8	22.0	
26	26.9	10.0	18.5		25.0	6.8	15.9		27.8	16.9	22.4	
27	28.5	15.5	22.0	11.4	26.2	10.7	18.5		26.8	12.1	19.5	
28	22.3	12.8	17.6	16.6	26.3	13.3	19.8		27.3	12.4	19.9	
29	24.6	10.9	17.8		26.1	14.6	20.4	T	30.1	12.3	21.2	
30	27.6	13.4	20.5		28.3	15.6	22.0	25.0	31.3	13.6	22.5	6.6
31					24.0	13.2	18.6		23.6	8.9	16.3	50.0
A	22.1	9.9	16.0	97.5	27.0	13.9	20.5	70.7	27.0	13.8	20.4	157.7
B	-0.5	-0.6	-0.6	119%	1.1	0.3	0.7	88%	2.1	1.5	1.8	194%

A = Monthly
B = Departure from Normal

Appendix - Table 2

Climatic Data for the 1981-82 Growing Season at Portage la Prairie

	Temperature °C											
	September 1981				October 1981				November 1981			
Date	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	20.0	5.0	12.5		11.8	3.1	7.5		15.0	2.0	8.5	
2	24.4	9.6	17.0		13.7	4.3	9.0		11.7	-2.9	4.4	T
3	15.0	3.8	9.4		9.8	4.2	7.0	24.0	17.4	1.0	9.2	
4	20.5	2.3	11.4		9.8	7.1	8.5		16.7	2.9	9.8	
5	23.6	12.3	18.0	C	11.2	2.3	6.8	0.6	8.2	-1.9	3.2	
6	18.4	10.9	14.7	34.9	14.4	-0.4	7.0		16.9	-0.3	8.3	
7	22.7	8.9	15.8		13.7	3.7	8.7		15.6	-1.7	7.0	
8	26.1	8.3	17.2		15.9	6.2	11.1	1.0	1.0	-7.9	-3.5	
9	27.8	12.9	20.4		17.8	5.8	11.8	1.5	10.2	-7.4	1.4	
10	34.0	11.4	22.7		19.2	1.6	10.4		6.7	-3.7	1.5	
11	25.3	11.6	18.5		19.2	7.1	13.2	1.8	11.8	-3.8	4.0	
12	24.2	9.9	17.1		14.1	7.9	11.0	12.0	19.0	-3.6	7.7	
13	21.2	7.9	14.6		10.9	4.8	7.9		16.1	2.8	9.5	
14	17.6	6.5	12.1		8.7	2.3	5.5		11.6	-3.6	4.0	T
15	13.3	6.3	9.8		11.1	3.5	7.3		12.4	1.9	7.2	T
16	13.0	6.1	9.6		19.6	4.5	12.1	1.0	5.8	0.0	2.9	T
17	19.8	3.5	11.7		12.6	2.2	7.4	2.0	1.5	-2.0	-0.3	
18	23.6	7.4	15.5		3.9	-1.3	1.3	T	-1.1	-4.9	-3.0	
19	19.9	5.0	12.5		13.0	2.9	8.0	0.4	-3.1	-5.9	-4.5	T
20	19.8	1.6	10.7	2.0	4.0	-5.4	-0.7	T*	-3.2	-11.9	-7.6	
21	17.1	7.6	12.4		-1.4	-9.6	-5.5	4.0*	-1.6	-8.9	-5.3	
22	15.4	3.1	9.3		-2.3	-6.9	-4.6	T*	1.6	-3.7	-1.1	T
23	20.9	6.5	13.7		-1.9	-10.4	-6.2	2.1*	6.9	-3.3	1.8	T
24	20.9	4.1	12.5		0.6	-6.8	-3.1	T	0.5	-2.3	-0.9	
25	19.4	3.7	11.6	39.8	-2.8	-13.4	-8.1		0.0	-2.4	-1.2	T
26	16.3	3.9	10.1		12.6	-4.7	4.0		-0.8	-4.8	-2.8	
27	9.4	-1.5	4.0	2.8	0.3	-2.8	-1.3	3.4	0.7	-7.9	-3.6	
28	2.9	-1.7	0.6	3.8	11.7	-0.4	5.7	0.8	-2.8	-5.1	-4.0	
29	12.6	0.8	6.7	0.4	14.2	4.0	9.1	0.4	1.0	-7.3	-3.2	
30	7.8	2.8	5.3	7.9	11.3	3.5	7.4	5.4	0.2	-8.5	-4.2	
31					13.8	3.5	8.7					
A	19.1	6.0	12.6	91.6	10.0	0.7	5.4	55.8	6.5	-3.5	1.5	T
B	0.8	-0.4	0.2	184%	-2.4	-0.6	-1.3	183%	6.3	4.3	5.3	-

A = Monthly
B = Departure from Normal
* = Snowfall

Appendix - Table 2

Climatic Data for the 1981-82 Growing Season at Portage la Prairie

Date	Temperature °C											
	December 1981				January 1982				February 1982			
	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	-0.8	-6.2	-3.5		-20.1	-32.0	-26.1	2.0*	-14.3	-25.2	-19.8	0.8*
2	-1.7	-7.7	-4.7		-18.6	-26.7	-22.7		-20.2	-30.4	-25.3	
3	-0.1	-6.8	-3.5		-23.9	-29.4	-26.7	0.2*	-19.8	-32.3	-26.1	T*
4	0.3	-10.3	-5.0		-18.6	-24.9	-21.8	4.2*	-20.6	-29.7	-25.2	
5	-1.8	-13.7	-7.8		-18.0	-29.4	-23.7	T*	-19.5	-32.3	-25.9	0.5*
6	1.1	-8.7	-3.8		-24.7	-32.1	-28.4		-10.6	-26.4	18.5	1.0*
7	-0.3	-4.6	-2.5		-19.1	-31.0	-25.1	0.7*	-12.4	-23.2	-17.8	T*
8	-4.0	-14.3	-9.2		-23.2	-32.8	-28.0		-19.2	-27.6	-23.4	0.2*
9	-5.4	-14.5	-10.0		-26.9	-34.1	-30.5		-18.7	-30.7	-24.7	
10	-3.9	-10.9	-7.4	1.8*	-17.8	-32.9	-25.4	T*	-11.8	-21.8	-16.8	
11	1.5	-7.1	-2.8		-22.3	-27.3	-24.8		-13.9	-20.5	-17.2	
12	-4.3	-11.4	-7.9		-20.1	-30.4	-25.3	2.0*	-12.4	-26.8	-19.6	
13	-6.9	-12.9	-9.9		-20.5	-28.0	-24.3	T*	-13.6	-22.9	-18.3	T*
14	-11.5	-19.7	-15.6		-11.6	-26.4	-19.0	1.0*	-2.6	-16.8	-9.7	
15	-11.0	-20.0	-15.5	T*	-17.6	-30.6	-24.1		-9.4	-18.8	-14.1	T*
16	-14.2	-20.6	-17.4		-27.2	-34.5	-30.9		0.2	-11.4	-5.6	T*
17	-14.6	-23.0	-18.8		-23.1	-33.5	-28.3		5.8	-1.2	2.3	
18	-11.4	-23.8	-17.6		-19.8	-32.6	-26.2	0.4*	1.9	-4.3	-1.2	T*
19	-9.4	-20.6	-15.0	T	-19.7	-35.7	-27.7		6.7	-6.7	0.0	
20	0.9	-12.9	-6.0	T	-24.9	-36.6	-30.8	T*	3.8	-4.0	-0.1	
21	1.6	-8.7	-3.6	0.8*	-23.6	-31.9	-27.8	1.8*	10.1	-4.7	2.7	
22	-7.4	-14.4	-10.9	2.3*	-20.4	-26.0	-23.2	1.4*	0.5	-15.3	-7.4	T*
23	-12.3	-18.9	-15.6	T*	-22.6	-31.2	-26.9		-8.7	-17.0	-12.9	
24	-7.8	-14.3	-11.1		-26.7	-34.7	-30.7	2.8*	-7.3	-15.9	-11.6	
25	-10.8	-26.0	-18.4		-20.4	-33.3	-26.9	T*	-3.3	-16.1	-9.7	T*
26	-7.5	-21.4	-14.5		-7.0	-28.7	-17.9		-10.4	-18.0	-14.2	3.0
27	-8.2	-25.0	-16.6		2.5	-21.6	-9.6	0.6*	-6.7	-20.1	-13.4	
28	-19.6	-26.2	-22.9		-15.5	-22.6	-19.1		-2.6	-12.4	-7.5	
29	-20.0	-26.2	-23.1		-13.1	-23.0	-18.1					
30	-22.2	-31.0	-26.6		-21.6	-29.6	-25.6					
31	-21.6	-31.8	-26.7		-12.7	-29.1	-20.9					
A	-7.5	-16.6	-12.1	4.9	-19.3	-30.1	-24.7	17.1	-8.2	-19.0	-13.6	5.5
B	0.2	0.1	0.1	25%	-5.8	-7.0	-6.4	60%	1.0	0.9	1.0	25%

A = Monthly
B = Departure from Normal
* = Snowfall

Appendix - Table 2

Climatic Data for the 1981-82 Growing Season at Portage la Prairie

Date	Temperature °C											
	March 1982				April 1982				May 1982			
	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	-11.3	-17.2	-14.3		-2.2	-10.6	-6.4	0.8*	23.7	0.3	12.0	
2	-15.3	-23.6	-19.5	T*	-2.5	-14.1	-8.3	6.6*	28.3	6.1	17.2	
3	-7.8	-23.8	-15.8	0.2*	-9.9	-15.9	-12.9		28.3	15.7	22.0	
4	-7.3	-19.6	-13.5	T*	-7.6	-19.0	-13.3		21.8	7.8	14.8	
5	-5.1	-17.4	-11.3		-6.5	-16.2	-11.4		17.8	4.1	11.0	
6	-6.6	-22.0	-14.3		-2.0	-15.9	-9.0		10.3	0.3	5.6	1.3
7	-11.4	-22.8	-17.1		2.2	-9.9	-3.9		8.0	0.6	4.3	
8	-11.0	-23.8	-17.4		3.2	-4.1	-0.5		7.6	-0.4	3.6	1.3
9	-7.3	-19.8	-13.6	0.2*	2.9	-5.3	-1.2		13.5	2.4	8.0	
10	-5.8	-15.2	-10.5		0.0	-7.0	-3.5		8.1	5.7	6.9	11.2
11	2.6	-14.9	-6.2		12.1	-5.0	3.6		16.4	5.0	10.7	
12	3.6	-3.7	-0.1	1.0	8.8	0.4	4.6		17.6	1.7	9.7	
13	1.0	-7.2	-3.1		6.6	-5.1	0.8	T	19.9	5.9	12.9	
14	3.6	-10.1	-3.3		20.9	1.6	11.3		21.9	8.3	15.1	
15	3.7	0.4	2.1	T*	15.6	6.2	10.9		13.1	8.8	11.0	10.7
16	3.5	-0.4	1.6	2.5*	8.9	-1.0	4.0		14.0	9.9	12.0	
17	0.7	-9.4	-4.4	1.2*	11.1	-6.3	2.4	1.7	12.5	9.4	11.0	7.6
18	-8.4	-14.7	-11.6		10.1	0.7	5.4		14.9	8.8	11.9	
19	-2.4	-18.3	-10.4		8.1	-2.7	2.7		13.9	7.5	10.7	
20	-0.4	-12.9	-6.7		11.5	-6.1	2.7		19.6	6.0	12.8	
21	4.2	-9.1	-2.5		12.8	-0.7	6.1		22.3	4.2	13.3	
22	4.4	-5.2	-0.4		23.8	4.0	13.9		24.7	6.1	15.4	
23	1.8	-3.3	-0.8	0.6*	26.6	10.5	18.6		25.5	6.3	15.9	
24	-1.4	-9.8	-5.6		28.1	7.0	17.6		21.5	11.5	16.5	
25	-1.8	-13.3	-7.6		8.6	-3.5	2.6		26.3	8.8	17.6	
26	-1.7	-14.6	-8.2		11.9	-3.7	4.1		27.8	13.1	20.5	
27	2.6	-8.6	-3.0		17.9	1.0	9.5		28.1	12.0	20.1	
28	8.6	-3.2	2.7		20.1	3.8	12.0		22.9	11.5	17.2	
29	5.3	0.5	2.9	4.2	13.3	3.6	8.5		19.3	8.2	13.8	2.3
30	4.5	0.1	2.3	6.8	19.5	4.5	12.0		16.2	6.9	11.6	
31	3.4	-7.8	-2.2						11.3	3.4	7.4	0.3
A	-1.7	-12.0	-6.9	16.7	9.1	-3.6	2.8	9.1	18.6	6.7	12.7	34.7
B	0.4	0.7	0.5	67%	0.5	-1.3	-0.4	20%	2.0	2.5	2.2	54%

A = Monthly
B = Departure from Normal
* = Snowfall

Appendix - Table 2

Climatic Data for the 1981-82 Growing Season at Portage la Prairie

	Temperature °C											
	June 1982				July 1982				August 1982			
Date	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)	Max.	Min.	Mean	Precip. (mm)
1	13.2	4.4	8.8		27.6	8.5	18.1		21.3	11.3	16.3	
2	17.6	-0.2	8.7		24.3	17.1	20.7		22.3	16.0	19.2	
3	24.9	4.4	14.7		30.0	16.8	23.4	10.4	30.4	14.0	22.2	
4	24.1	10.7	17.4		31.6	14.0	22.8		25.5	15.3	20.4	
5	25.7	14.3	20.0	21.6	27.6	17.4	22.5	5.3	27.5	11.9	19.7	
6	16.4	12.1	14.3		24.0	12.4	18.2		28.2	18.1	23.2	
7	14.2	3.2	8.7	3.8	22.9	9.0	16.0		25.8	15.0	20.4	3.8
8	11.2	0.4	5.8		23.8	9.8	16.8	0.3	20.2	11.8	16.0	
9	17.0	6.8	11.9		25.3	14.5	19.9		17.8	9.0	13.4	
10	24.2	4.4	14.3		26.2	14.4	20.3	3.8	21.5	5.6	13.6	
11	17.2	7.9	12.6		27.5	12.5	20.0		25.2	8.4	16.8	
12	24.3	4.1	14.2	0.8	28.2	15.2	21.7	6.1	20.3	14.1	17.2	1.3
13	24.7	9.6	17.2		20.8	14.6	17.7	0.3	27.7	14.1	20.9	
14	21.2	8.7	15.0		24.9	9.4	17.2		31.0	15.1	22.6	23.4
15	20.4	6.3	13.4		29.8	18.2	24.0	20.3	24.4	14.2	19.3	
16	22.9	10.3	16.6		25.3	16.4	20.9		26.0	14.4	18.7	
17	13.7	6.4	10.1		22.1	12.6	17.4		29.9	12.8	20.4	2.0
18	18.9	8.5	13.7		23.7	9.4	16.6	25.7	28.7	16.9	22.8	0.8
19	15.8	10.3	13.1	6.9	26.8	12.5	19.7		26.1	13.6	19.9	
20	19.8	8.9	14.4		25.3	16.0	20.1		25.6	11.9	18.8	
21	20.2	7.5	13.9		22.8	12.8	17.8		23.8	13.7	18.8	17.3
22	19.5	7.8	13.7	0.8	23.2	11.7	17.5	4.6	21.8	12.3	17.2	
23	28.7	11.5	20.1		26.8	16.8	21.8		22.1	9.1	15.6	
24	18.0	6.9	12.5		27.7	17.5	22.6		18.3	11.0	14.7	0.3
25	23.2	4.2	13.7		24.6	14.5	19.6		13.0	4.2	8.8	
26	25.2	12.7	19.0	0.5	27.5	12.6	20.1	34.5	16.0	3.2	8.4	
27	23.4	10.8	17.1		25.3	15.7	20.5		14.9	1.4	8.2	
28	21.0	10.5	15.8		26.9	12.8	19.9	43.2	20.7	4.9	12.8	
29	19.6	6.4	13.0		23.2	12.2	17.7		19.7	5.6	12.7	
30	24.0	4.2	14.1		26.3	12.9	19.6		17.1	4.5	10.8	
31					30.0	15.9	23.0		24.5	8.3	16.4	
A	21.0	7.5	13.9	35.2	25.9	13.7	19.8	154.5	23.1	10.9	17.0	48.9
B	-1.6	-3.0	-2.7	43%	0.0	-0.1	0.0	192%	-1.8	-1.4	-1.6	60%

A = Monthly
B = Departure from Normal

Appendix - Table 3

Mean Weekly Soil Temperatures at the 2.5 cm Depth for the 1980-81 Stubble Height Experiment

Week Ending	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Nov. 29	- 1.5	- 1.3	- 1.3	- 1.3	- 1.8
Dec. 6	- 5.7	- 5.0	- 4.8	- 5.8	- 5.9
Dec. 13	-10.7	- 7.8	- 7.8	- 8.7	- 8.9
Dec. 20	- 9.7	- 7.8	- 6.8	- 8.6	- 8.2
Dec. 27	-11.6	- 9.5	- 9.9	- 9.8	- 9.5
Jan. 3	- 6.9	- 6.4	- 6.2	- 6.6	- 5.1
Jan. 10	-12.7	-11.1	-11.4	-12.6	-12.1
Jan. 17	- 8.0	- 8.2	- 7.7	- 8.5	- 7.7
Jan. 24	- 4.9	- 4.4	- 4.8	- 5.2	- 5.0
Jan. 31	-11.4	- 9.2	- 7.7	-10.1	- 8.0
Feb. 7	-11.2	- 8.6	- 8.5	-10.0	- 8.0
Feb. 14	-16.0	-13.2	-12.8	-16.0	-13.1
Feb. 21	- 9.8	- 0.6	- 0.6	- 0.6	- 0.4
Feb. 28	- 3.1	- 2.7	- 2.1	- 3.1	- 2.7
Mar. 7	- 7.5	- 7.1	- 6.8	- 7.5	- 7.7
Mar. 14	- 1.8	- 1.7	- 2.0	- 1.8	- 1.9
Mar. 21	- 2.9	- 2.1	- 2.5	- 2.6	- 3.4
Mar. 28	- 0.6	- 0.6	- 0.5	- 0.5	- 1.0

Appendix - Table 4

Mean Weekly Soil Temperatures at the 5 cm Depth for the 1980-81 Stubble Height Experiment

Week Ending	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Nov. 29	- 1.0	- 0.8	- 0.9	- 0.7	- 1.0
Dec. 6	- 5.2	- 3.7	- 4.0	- 4.9	- 4.5
Dec. 13	- 8.8	- 6.3	- 6.5	- 7.3	- 6.7
Dec. 20	- 8.5	- 6.5	- 6.2	- 7.7	- 6.8
Dec. 27	-11.8	- 9.2	- 9.2	- 8.8	- 8.8
Jan. 3	- 6.5	- 6.1	- 5.9	- 5.5	- 4.8
Jan. 10	-11.4	-10.4	-10.6	-11.3	-10.8
Jan. 17	- 7.8	- 7.8	- 7.5	- 7.2	- 7.5
Jan. 24	- 4.5	- 4.0	- 4.5	- 3.5	- 4.5
Jan. 31	- 9.9	- 8.2	- 7.1	- 8.9	- 6.3
Feb. 7	-10.8	- 9.0	- 8.0	- 8.9	- 7.2
Feb. 14	-14.9	-13.0	-12.0	-15.0	-11.8
Feb. 21	- 1.4	- 0.8	- 0.9	- 0.8	- 0.6
Feb. 28	- 2.4	- 2.0	- 1.7	- 2.0	- 2.0
Mar. 7	- 6.0	- 5.8	- 6.1	- 5.8	- 6.6
Mar. 14	- 1.8	- 1.5	- 1.9	- 0.4	- 2.0
Mar. 21	- 2.0	- 1.3	- 1.9	- 1.4	- 2.4
Mar. 28	- 0.5	- 0.3	- 0.5	- 0.3	- 0.6

Appendix - Table 5

Mean Weekly Soil Temperatures at the 10 cm Depth for the 1980-81 Stubble Height Experiment

Week Ending	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Nov. 29	- 0.8	- 0.5	- 0.6	- 0.5	- 0.7
Dec. 6	- 3.9	- 2.8	- 2.8	- 2.7	- 3.3
Dec. 13	- 6.8	- 4.9	- 4.9	- 3.5	- 5.3
Dec. 20	- 7.4	- 5.8	- 5.2	- 5.7	- 5.8
Dec. 27	-11.1	- 8.9	- 8.5	- 8.4	- 8.2
Jan. 3	- 6.0	- 5.5	- 5.4	- 5.3	- 4.5
Jan. 10	-10.2	- 9.7	- 9.6	- 9.8	- 9.8
Jan. 17	- 7.4	- 7.4	- 7.0	- 7.4	- 7.1
Jan. 24	- 4.1	- 3.7	- 4.0	- 4.2	- 4.1
Jan. 31	- 8.2	- 6.9	- 6.1	- 7.2	- 5.5
Feb. 7	- 9.4	- 8.2	- 7.3	- 8.0	- 6.6
Feb. 14	-14.0	-12.8	-11.0	-12.8	-11.2
Feb. 21	- 2.1	- 1.6	- 1.3	- 1.7	- 1.0
Feb. 28	- 1.8	- 1.5	- 1.1	- 1.8	- 1.4
Mar. 7	- 4.4	- 4.5	- 4.9	- 4.8	- 5.3
Mar. 14	- 1.6	- 1.5	- 1.7	- 1.9	- 1.8
Mar. 21	- 0.8	- 0.6	- 1.1	- 1.4	- 1.4
Mar. 28	- 0.3	- 0.2	- 0.3	- 0.7	- 0.5

Appendix - Table 6

Mean Weekly Soil Temperatures at the 20 cm Depth for the 1980-81 Stubble Height Experiment

Week Ending	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Nov. 29	- 0.1	+ 0.1	+ 0.0	+ 0.0	- 0.1
Dec. 6	- 1.8	- 0.9	- 1.1	- 0.9	- 1.4
Dec. 13	- 3.8	- 2.9	- 3.0	- 2.3	- 3.1
Dec. 20	- 5.2	- 4.5	- 4.4	- 3.5	- 4.2
Dec. 27	- 9.7	- 7.5	- 7.2	- 6.9	- 6.6
Jan. 3	- 5.3	- 4.6	- 4.6	- 4.3	- 3.9
Jan. 10	- 8.9	- 8.3	- 8.3	- 8.2	- 8.4
Jan. 17	- 6.8	- 6.3	- 6.3	- 5.8	- 6.4
Jan. 24	- 3.8	- 3.5	- 3.6	- 3.7	- 3.7
Jan. 31	- 6.5	- 5.4	- 4.8	- 5.5	- 4.3
Feb. 7	- 8.0	- 7.1	- 6.3	- 6.8	- 5.6
Feb. 14	-12.1	-10.6	- 9.0	-10.4	- 8.5
Feb. 21	- 2.7	- 2.4	- 2.1	- 2.4	- 1.7
Feb. 28	- 1.3	- 1.1	- 0.7	- 1.3	- 0.9
Mar. 7	- 3.0	- 3.0	- 3.1	- 3.2	- 3.5
Mar. 14	- 1.5	- 1.5	- 1.5	- 1.8	- 1.5
Mar. 21	- 0.7	- 0.6	- 0.8	- 1.0	- 0.9
Mar. 28	- 0.5	- 0.5	- 0.5	- 0.5	- 0.6

Appendix - Table 7

Mean Weekly Soil Temperatures at the 2.5 cm Depth for the 1981-82 Stubble Height Experiment

Week Ending	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Oct. 10	6.1	5.3	6.3	5.8	5.8
Oct. 17	7.0	6.5	7.2	6.9	6.7
Oct. 24	1.8	1.2	2.2	1.6	1.5
Oct. 31	2.5	1.8	2.4	1.8	2.0
Nov. 7	3.3	1.9	3.5	2.2	2.1
Nov. 14	1.4	- 0.4	1.4	0.1	- 0.3
Nov. 21	1.1	- 0.7	1.0	- 0.2	- 0.2
Nov. 28	0.2	- 1.7	- 0.2	- 1.4	- 1.8
Dec. 5	- 1.4	- 2.4	- 1.1	- 2.1	- 2.1
Dec. 12	- 2.2	- 3.3	- 1.8	- 2.9	- 3.0
Dec. 19	- 6.4	- 6.6	- 5.3	- 6.2	- 6.0
Dec. 26	-	- 3.9	- 3.3	- 3.7	- 3.6
Jan. 2	-	-13.2	-10.4	- 5.5	- 3.6
Jan. 9	-	- 9.8	- 7.6	- 4.9	-
Jan. 16	-	-11.7	- 9.5	- 5.5	-
Jan. 23	-	-11.9	-10.1	- 5.7	-
Jan. 30	-	-10.8	- 9.9	- 5.8	-
Feb. 6	-	-12.9	-11.2	- 6.2	-
Feb. 13	-	-11.2	- 9.4	- 6.2	-
Feb. 20	-	- 5.3	- 4.5	- 3.9	-
Feb. 27	-	- 6.3	- 6.2	- 3.8	-
Mar. 6	-	- 9.3	- 7.4	- 6.2	-
Mar. 13	-	- 9.6	- 7.7	- 6.8	-
Mar. 20	-	- 2.9	- 1.9	- 1.9	-
Mar. 27	-	- 5.0	- 2.5	- 3.8	-
Apr. 3	-	- 2.2	- 1.7	- 1.5	-
Apr. 10	-	- 4.4	- 3.0	- 3.4	-
Apr. 17	1.6	0.2	2.3	0.2	-
Apr. 24	3.9	2.0	4.9	2.2	-
May 1	5.6	3.0	6.6	3.3	-
May 8	10.3	7.9	11.7	8.9	-

Appendix - Table 8

Mean Weekly Soil Temperatures at the 5 cm Depth for the 1981-82 Stubble Height Experiment

Week Ending	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Oct. 10	7.0	6.1	7.4	6.6	6.6
Oct. 17	7.5	6.9	7.8	6.9	7.2
Oct. 24	2.8	2.0	3.2	2.3	2.5
Oct. 31	2.6	2.0	2.7	1.9	2.3
Nov. 7	3.8	2.7	4.2	2.9	3.1
Nov. 14	1.9	0.4	2.5	0.5	0.9
Nov. 21	1.6	0.1	2.1	0.4	0.9
Nov. 28	0.0	- 1.2	0.5	- 1.3	- 0.8
Dec. 5	- 0.5	- 1.7	- 0.0	- 1.5	- 1.1
Dec. 12	- 1.2	- 2.5	- 0.8	- 2.3	- 1.8
Dec. 19	- 4.4	- 5.2	- 3.8	- 5.0	- 4.2
Dec. 26	-	- 3.5	- 2.4	- 3.5	- 2.7
Jan. 2	-	- 5.6	- 9.1	- 5.1	- 2.7
Jan. 9	-	- 5.0	- 7.6	- 4.7	-
Jan. 16	-	- 6.8	- 9.4	- 5.1	-
Jan. 23	-	- 8.0	- 9.8	- 5.5	-
Jan. 30	-	- 8.0	- 9.5	- 5.5	-
Feb. 6	-	- 9.1	-10.3	- 5.8	-
Feb. 13	-	- 8.0	- 8.9	- 5.9	-
Feb. 20	-	- 4.7	- 4.1	- 4.0	-
Feb. 27	-	- 5.6	- 5.4	- 4.0	-
Mar. 6	-	- 7.3	- 6.5	- 6.0	-
Mar. 13	-	- 8.1	- 7.4	- 6.6	-
Mar. 20	-	- 2.3	- 1.2	- 2.1	-
Mar. 27	-	- 3.5	- 2.0	- 3.5	-
Apr. 3	-	- 1.7	- 0.7	- 1.7	-
Apr. 10	-	- 3.9	- 2.2	- 3.3	-
Apr. 17	0.6	0.1	1.6	- 0.5	-
Apr. 24	2.2	1.9	3.1	0.9	-
May 1	3.5	2.8	4.3	1.6	-
May 8	7.7	7.6	8.6	6.2	-

Appendix - Table 9

Weekly Soil Temperatures at the 10 cm Depth for the 1981-82 Stubble Height Experiment

Date	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Oct. 19	7.6	6.9	6.9	7.0	6.9
Oct. 21	2.6	3.8	2.8	3.8	4.0
Oct. 30	6.6	6.4	6.2	6.2	6.4
Nov. 6	3.4	3.4	3.9	3.8	3.9
Nov. 12	2.6	2.3	2.8	2.8	2.5
Nov. 20	1.0	1.9	0.7	2.1	1.0
Nov. 27	0.6	0.6	0.6	0.8	0.6
Dec. 2	- 0.1	0.1	0.0	0.2	0.0
Dec. 9	- 1.2	- 0.6	- 0.4	- 0.2	- 0.7
Dec. 15	- 3.1	- 1.3	- 1.6	- 1.3	- 1.8
Dec. 21	- 1.8	- 1.8	- 2.2	- 1.7	- 1.8
Dec. 29	- 7.8	- 3.7	- 5.5	- 3.0	- 2.8
Jan. 6	- 6.1	- 2.4	- 4.0	- 0.8	- 1.4
Jan. 11	- 9.4	- 4.3	- 4.6	- 3.7	- 1.4
Jan. 18	-12.6	- 6.5	- 6.3	- 4.5	- 3.0
Jan. 26	-11.9	- 7.7	- 7.1	- 4.9	- 3.5
Feb. 3	-12.1	- 8.3	- 8.3	- 6.1	- 4.0
Feb. 10	-11.0	- 7.5	- 8.4	- 5.5	- 4.0
Feb. 16	- 6.4	- 4.5	- 4.6	- 3.2	- 1.7
Feb. 22	- 1.6	- 1.7	- 1.9	- 0.7	- 1.0
Mar. 3	- 6.2	- 4.4	- 5.3	- 3.2	- 1.8
Mar. 9	- 8.3	- 7.4	- 7.3	- 6.4	- 4.1
Mar. 23	- 1.0	- 0.0	- 0.4	- 0.6	0.1
Apr. 6	- 4.3	- 3.6	-	- 3.0	- 2.6
Apr. 15	2.2	2.5	-	2.3	2.6
Apr. 21	5.1	5.5	2.2	4.3	5.0
Apr. 28	5.7	4.0	4.4	3.1	4.1
May 5	11.9	9.8	9.4	9.4	10.0
May 11	5.9	6.8	3.7	4.2	9.8

Appendix - Table 10

Weekly Soil Temperatures at the 20 cm Depth for the 1981-82 Stubble Height Experiment

Date	Treatment				
	Chem. Fallow	Conv. Tillage	7.5 cm Stubble	15 cm Stubble	30 cm Stubble
Oct. 19	7.0	7.0	6.9	7.0	7.0
Oct. 21	4.6	5.1	4.4	5.1	5.4
Oct. 30	5.9	5.7	5.8	5.5	5.7
Nov. 6	5.2	4.7	4.8	5.2	4.5
Nov. 12	2.7	3.8	3.1	2.9	3.1
Nov. 20	1.8	2.4	1.6	2.1	2.6
Nov. 27	1.2	1.1	1.1	1.2	1.3
Dec. 2	0.7	0.6	0.9	0.8	0.5
Dec. 9	0.0	0.3	0.3	0.3	0.1
Dec. 15	- 1.2	- 0.7	0.3	0.6	0.1
Dec. 21	- 2.4	- 1.1	- 1.8	- 1.1	- 1.1
Dec. 29	- 6.2	- 2.5	- 3.8	- 1.4	- 1.4
Jan. 6	- 4.5	- 1.8	- 3.4	- 1.5	- 1.4
Jan. 11	- 7.6	- 2.9	- 3.8	- 2.6	- 1.1
Jan. 18	-10.1	- 4.0	- 5.0	- 3.1	- 2.5
Jan. 26	-10.97	- 6.4	- 6.0	- 4.3	- 2.7
Feb. 3	- 8.1	- 7.8	- 6.7	- 4.8	- 3.0
Feb. 10	- 8.8	- 6.4	- 6.8	- 4.2	- 3.1
Feb. 16	- 6.4	- 4.5	- 4.0	- 2.9	- 1.4
Feb. 22	- 2.1	- 1.4	- 1.4	- 1.1	- 0.7
Mar. 3	- 6.1	- 4.7	- 4.6	- 2.8	- 1.2
Mar. 9	- 7.9	- 6.4	- 5.8	- 5.0	- 3.6
Mar. 23	- 2.2	- 0.4	- 0.6	0.0	0.0
Apr. 6	- 3.0	- 1.6	-	- 1.0	- 0.9
Apr. 15	0.2	1.0	-	0.1	1.3
Apr. 21	1.2	1.6	- 1.0	0.8	1.4
Apr. 28	2.7	2.0	2.1	2.2	2.2
May 5	10.9	6.7	7.0	7.5	6.0
May 11	3.2	4.6	2.7	3.9	-

Appendix - Table 11

Volumetric Soil Moisture for the 1980-81, and 1981-82 Stubble Height Experiments, Expressed as a Percent

Treatment	1980-81		1981-82			
	Apr. 24[1]	Oct. 7[1]	Apr. 26	May 22	June 21	July 20
0-25 cm:						
Chemical Fallow	34.56 ab	40.68 a[2]	41.03 c	43.19 b	31.16 b	32.85 ab
Conventional Tillage	37.54 a	41.72 a	44.41 b	45.61 a	33.86 ab	33.57 ab
7.5 cm Stubble	36.50 a	41.65 a	42.91 bc	43.43 ab	31.38 ab	31.08 b
15 cm Stubble	36.60 a	41.50 a	45.71 b	45.17 ab	32.18 ab	32.21 ab
30 cm Stubble	35.57 a	43.08 a	48.46 a	41.05 c	34.95 a	34.48 a
25-100 cm:[1]						
Chemical Fallow	51.60 a		55.29 a			
Conventional Tillage	51.02 a		54.14 a			
7.5 cm Stubble	50.17 a		49.07 a			
15 cm Stubble	49.24 a		52.64 a			
30 cm Stubble	51.61 a		52.75 a			

[1] - Two replicates only

[2] - Means in the same column followed by the same letter do not differ significantly at the 0.5 level.

Appendix - Table 12

Effects of Volunteer Barley on the Yield of Winter Wheat

Level of Infestation	Yield (kg/ha)
0	5039 a[1]
Light	5184 a
Moderate	4712 a
Heavy	2735 b

[1] Means in the same column followed by the same letter do not differ significantly at the .05 level.

Appendix - Table 13

Weekly Mean Minimum Soil Temperatures at the 2.5 cm Depth
for the 1980-81 Mulch Rate Experiment

Week Ending	Treatment					
	Normal	0 Mulch	1500 kg/ha Mulch	3000 kg/ha Mulch	4500 kg/ha Mulch	Mowed and Raked
Nov. 29	- 1.4	- 0.9	- 1.3	- 4.4	- 1.3	- 1.5
Dec. 6	- 5.8	- 6.1	- 5.4	- 4.1	- 5.6	- 6.5
Dec. 13	- 8.2	- 8.3	- 8.3	- 1.1	- 9.2	-10.5
Dec. 20	- 8.6	- 9.0	- 8.2	- 3.7	- 8.4	- 9.3
Dec. 27	- 9.8	-10.7	-10.5	- 1.8	-10.3	-11.5
Jan. 3	- 6.6	- 6.1	- 6.3	- 2.6	- 6.4	- 6.6
Jan. 10	-12.6	-12.6	-11.2	- 3.5	-11.7	-12.5
Jan. 17	- 8.5	- 8.1	- 8.1	- 5.5	- 8.1	- 8.6
Jan. 24	- 5.2	- 4.2	- 4.7	- 6.4	- 4.7	- 4.7
Jan. 31	-10.1	- 9.1	- 9.1	- 3.0	- 9.2	-10.8
Feb. 7	-10.0	-11.0	-10.1	- 4.3	-11.2	-11.4
Feb. 14	-16.1	-16.0	-16.2	-10.3	-16.2	-17.4
Feb. 21	- 0.6	- 0.2	- 0.9	- 1.3	- 0.7	- 0.9
Feb. 28	- 3.1	- 2.4	- 2.8	- 0.6	- 2.8	- 3.1
Mar. 7	- 7.5	- 7.0	- 6.6	- 6.0	- 7.1	- 7.6
Mar. 14	- 1.8	- 1.4	- 1.9	- 0.5	- 1.8	- 1.9
Mar. 21	- 2.6	- 2.1	- 2.7	- 0.3	- 2.7	- 2.6
Mar. 28	- 0.6	- 0.3	- 0.7	- 0.5	- 0.8	- 0.6
Treatment Mean	- 6.6	- 6.4	- 6.4	- 3.3	- 6.6	- 7.1

Appendix - Table 14

Weekly Mean Minimum Soil Temperatures at the 2.5 cm Depth for the 1981-82 Mulch Rate Experiment

Week Ending	Treatment							
	Stubble				Mowed			
	0 Mulch	1500 kg/ha Mulch	3000 kg/ha Mulch	4500 kg/ha Mulch	0 Mulch	1500 kg/ha Mulch	3000 kg/ha Mulch	4500 kg/ha Mulch
Oct. 10	6.7	6.4	6.9	7.0	6.4	7.2	6.7	7.6
Oct. 17	7.7	7.1	7.7	7.8	6.5	7.8	7.5	8.0
Oct. 24	2.6	2.1	2.9	3.2	1.9	2.9	2.5	3.5
Oct. 31	2.5	2.1	2.7	2.7	2.3	2.8	2.5	3.0
Nov. 7	3.8	2.9	4.0	4.0	3.2	4.4	3.6	4.2
Nov. 14	1.9	0.6	2.0	2.0	1.2	2.4	1.5	2.2
Nov. 21	1.6	0.7	1.7	1.7	0.9	2.1	1.3	1.8
Nov. 28	0.4	-0.9	0.4	0.3	-0.3	0.7	0.0	0.4
Dec. 5	-0.6	-1.3	-0.4	-0.3	-1.0	0.1	-0.6	-0.1
Dec. 12	-1.4	-2.3	-1.2	-0.8	-1.9	-0.8	-1.4	-0.7
Dec. 19	-5.0	-5.7	-4.3	-3.5	-5.5	-4.0	-4.5	-2.9
Dec. 26	-2.5	-3.4	-2.5	-1.9	-3.2	-2.3	-2.6	-2.1
Jan. 2	-4.7	-8.3	-6.4	-3.3	-9.4	-4.6	-7.5	-6.4
Jan. 9	-4.1	-6.3	-5.3	-3.1	-7.5	-4.4	-5.8	-5.4
Jan. 16	-5.3	-7.4	-7.1	-4.4	-9.5	-5.8	-7.6	-7.4
Jan. 23	-6.0	-7.7	-7.8	-4.9	-9.7	-6.9	-7.8	-8.2
Jan. 30	-6.1	-6.8	-7.5	-5.1	-9.6	-6.5	-7.3	-7.9
Feb. 6	-5.5	-7.8	-7.5	-4.8	-10.2	-6.3	-8.1	-8.3
Feb. 13	-5.7	-7.4	-6.8	-4.8	-6.5	-6.3	-7.8	-7.8
Feb. 20	-2.8	-4.0	-3.3	-2.7	-4.2	-2.8	-3.7	-3.9
Feb. 27	-3.3	-4.0	-3.9	-2.4	-5.2	-3.6	-4.1	-4.1
Mar. 6	-4.9	-5.8	-5.7	-4.0	-7.0	-5.0	-6.2	-6.3
Mar. 13	-5.6	-6.7	-6.5	-4.7	-7.4	-5.6	-6.5	-7.0
Mar. 20	-0.8	-1.3	-1.1	-0.4	-1.7	-1.0	-1.4	-1.5
Mar. 27	-2.1	-3.4	-2.0	-1.7	-2.7	-1.7	-2.8	-2.3
Apr. 3	-0.1	-0.9	-0.5	-0.3	-0.2	0.1	-0.3	-0.9
Apr. 10	-2.1	-3.2	-2.7	-2.1	-2.6	-2.2	-2.7	-3.5
Apr. 17	2.0	1.0	-2.4	1.0	3.1	2.0	1.6	1.6
Apr. 24	4.3	2.8	-4.5	3.1	5.8	4.1	3.9	3.6
May 1	5.7	4.9	-5.9	4.4	6.9	5.4	5.7	4.6
May 8	10.7	10.2	10.3	8.4	12.5	9.1	10.2	8.8
Mean								
Oct.4-Nov.22	3.8	3.1	4.0	4.1	3.2	4.2	3.7	4.3
Nov.23-Mar.27	-3.7	-5.0	-4.4	-2.7	-5.7	-3.7	-4.8	-4.6
Mar.28-May 8	3.4	2.5	3.3	2.4	4.3	3.0	3.0	2.4