Weed populations and crop yield as influenced by the temperature and soil moisture characteristics of no-till cropping practices
by Steven Arlen Dewey

A thesis submitted in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE in Agronomy
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Abstract:
No-till and conventional tillage methods of small grain production were compared in a dryland annual cropping situation. Yield data were collected and the weed population in each cropping system was characterized.

Tillage and no-till yields differed significantly in winter wheat, hut not in spring wheat or barley, No-till winter wheat plots produced 875 kg/ha more grain and 1277 kg/ha more vegetative dry matter.

After one growing season, broadleaf weeds were generally more abundant in tillage plots. Some shifts in the predominent weed species were also evident. Meadow salsify and prickly lettuce were more common in no-till plots, while common lambsquarters was the predominent weed in tillage treatments. Volunteer wheat was a weed problem in winter wheat, being more abundant in the tillage plots.

Moisture and temperature characteristics of the two cropping systems were studied to evaluate their potential influence on weed populations and crop yield. Results indicate that no-till cropping is capable of greater soil water accumulation and conservation. In the spring, no-till winter wheat plots contained 5.44 cm more available soil moisture than tillage plots in the surface 1.2 meters of soil. Tilled plots actually lost moisture overwinter, due to evaporative loss from the soil surface, Temperatures measured above and below the soil surface demonstrated significant differences between the two cropping systems.

During the winter, no-till air and soil temperature fluctuations were less extreme than those in tillage plots. In the spring and summer soil temperatures in tillage plots were warmer than in the no-till treatments. This difference was as great as 4,1° C at a 2 cm depth.

Air temperatures in tillage plots were cooler in the spring and summer by as much as 4.5°C at a height of 2 cm.

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Date June 26, 1978

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BY THE TEMPERATURE AND SOIL MOISTURE CHARACTERISTICS
OF NO-TILL CROPPING PRACTICES

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ABSTRACT

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Temperatures measured above and below the soil surface demonstrated significant differences between the two cropping systems. During the winter, no-till air and soil temperature fluctuations were less extreme than those in tillage plots. In the spring and summer soil temperatures in tillage plots were warmer than in the no-till treatments. This difference was as great as 4.1° C at a 2 cm depth. Air temperatures in tillage plots were cooler in the spring and summer by as much as 4.5° C at a height of 2 cm.

INTRODUCTION

No-till farming is rapidly gaining acceptance among farmers in many areas of the United States. It is presently being practiced successfully in corn, soybeans, cotton, rice, peanuts, wheat, barley, oats, tobacco, grain sorghum, sunflowers, forage crops, and some vegetables. In 1976 no-till methods of crop production were used on 7.3 million acres in the U.S.; a value which represents 2.6% of the total cropland that year. An additional 52.5 million acres, or 28.9% of the total, were cropped using a form of minimum tillage. By the year 2010 it is estimated by the USDA that 90% of all U.S. cropland will be in some form of minimum tillage production; and that no-till will represent over 50% of our total cropping acreage (Triplett and Van Doren 1977).

If the anticipated success of no-till is to be realized, a better understanding must be gained as to its influence on the plant growth environment. The ability of a plant to grow and reproduce is dependent upon external or environmental conditions. Soil moisture, soil temperature, and air temperature are major variables in determining the success of a crop.

The standing stubble environment created by no-till dryland wheat production methods modifies temperature and moisture conditions from those common to conventional practices. The nature and intensity of these changes will affect crops, weeds, and their competitive interaction.

In this study no-till and conventionally cropped small grain plots were established under dryland conditions. The objectives were to determine 1) weed population and crop yield characteristics of no-till and conventional methods in an annual cropping situation, 2) soil moisture, soil temperature, and air temperature conditions created in each system, and 3) whether differences in moisture and/or temperature are of sufficient magnitude to contribute significantly to crop and weed growth differences between the two systems.

LITERATURE REVIEW

Moisture

Small grain production under dryland conditions is dependent upon the available soil moisture present at planting, and the amount and distribution of precipitation received during the growing season. In the Northern Great Plains no other single factor is more critical in limiting dryland small grain yields than is moisture (Bauer 1972).

Because of their role in determining crop success, soil moisture and precipitation data are often used to project grain yields. Based on 871 trials between 1909 and 1962 (Bauer 1972), more than 9.4 cm of available soil moisture was required to obtain any yield of spring wheat in the Northern Great Plains. Each 2.5 cm of moisture in excess of that amount increased grain yields by 161 kg/ha. These data represent moisture use efficiency under conditions of generally inadequate soil fertility and weed control. More recent studies indicate that higher soil fertility levels improve water use efficiency. Bauer et al. (1965, 1966) reported an average yield increase of 403 kg/ha with each additional 2.5 cm of available soil moisture. Their work involved 31 adequately fertilized locations in North Dakota.

Seasonal distribution is often more crucial than the total amount of precipitation received during the growing season. Water stress on a cereal plant at a critical stage of development can result in significant and irreversible yield reduction (Dubetz 1973).

It appears that all stages of plant growth--from germination to maturity--are sensitive to moisture stress. The degree of yield reduction depends upon intensity and duration of the stress, in addition to the stage of plant growth. According to Aspinall (1965), the plant organ growing most rapidly at the time of water stress will be the one most affected. Aspinall et al. (1964) conducted both long and short duration stress experiments with barley at various growth stages. Pre-flowering moisture stress resulted in 8% yield reduction while stress at flowering reduced yields by 37%. Multiple (5-7) short-term stress periods prior to flowering reduced yields as much as 70%. The greater yield reduction observed when moisture stress occurs between heading and flowering is probably due to the water stress vulnerability of pollen formation and fertilization processes (Bauers 1972). Robins and Domingo (1962) produced moisture stress on spring wheat by omitting one scheduled irrigation during various plant growth stages. Stress while plants were in the boot to heading stage resulted in 28% yield reduction. Water stress at boot to late heading, and soft dough to maturity, resulted in yield reductions of 38% and 30%, respectively.

There are several ways, depending upon the plant development stage, in which water stress can reduce grain yields. Chinoy (1962) allowed wheat plants to wilt at one of three developmental stages and then kept them well watered to maturity. The number of kernels per spike was reduced when moisture stress occurred at jointing or at flowering. The number of spikelets per spike was also reduced when wilting occurred at jointing, but not at flowering. The number of spikes and spike length were significantly reduced only when stress occurred during the jointing stage. Of the three stages studied, tillering was the least sensitive to moisture stress. Wardlaw (1966) observed a significant reduction in seed set and larger kernels in wheat plants which were stressed for six days, beginning at anthesis. Langer and Ampong (1970) noticed a reduction in kernel weight when wheat plants were stressed at anthesis. Wells and Dubetz (1966) imposed a water stress situation under greenhouse conditions. A loam soil was allowed to dry to 8 bars atmospheric pressure at one of four plant developmental stages. The number of spikes was reduced by 14% when wheat plants were stressed at early boot stage or at the soft dough stage. Number of kernels per spike was reduced by 15% when soil moisture stress occurred at early boot stage.

No-till and tillage systems differ significantly in terms of soil moisture accumulation and moisture conservation (Jones et al. 1969, Wilson 1976). The moisture advantages offered by no-till make it especially attractive in areas where moisture is sometimes limited.

Standing stubble and surface mulch in no-till cropped cereals cause increased soil moisture accumulation. Smika and Whitfield (1966) measured the amount of total soil moisture accumulated overwinter in tillage and no-till plots. No-till plots consisted of standing stubble (46 cm), while stubble in tillage plots had been incorporated. Results demonstrate an overwinter gain of 5 cm moisture in the top 1.8 m of soil on no-till plots. Tillage plots actually showed a net overwinter loss of water. Staple et al. (1960) determined from a 20 year study the average overwinter soil moisture accumulation in tilled and undisturbed stubble fallow in Saskatchewan. They reported soil water increases of 5.1 cm in stubble and 1.1 cm in tilled fallow.

Krall (1969) and others have questioned the need for summer fallow in some areas. According to Black and Siddoway (1976), often as much soil moisture can be stored overwinter with no-till as during an entire summer fallow period using tillage. Increased soil moisture accumulation in no-till is due, in part, to snow retention differences. The standing stubble acts as a snow trap to prevent loss of snow from blowing and drifting. In many areas of the Northern Great Plains the removal of snow by wind from cropland represents a significant loss of potential moisture. Black and Siddoway (1977) recorded a four fold snow depth difference between no-till and tillage plots after just one wind-accompanied snow storm. Snow depth on tillage plots averaged 6 cm while no-till plots (38 cm stubble) accumulated 26 cm. Aase and Siddoway (1978) used stubble heights of 0, 19, and 35 cm to study snow accumulation. The tall stubble collected 3.6

times more snow and 2.5 times more water equivalent than the bare plots during one snow storm.

Snow moisture accumulation in no-till is also enhanced by increased water infiltration. Early work done by Barnes et al. (1955) compared infiltration rates on bare and straw mulch covered soils. In the first hour the water infiltration rate on mulch covered soil was 3.82 cm/hr while that for bare soil was 2.49 cm/hr. Some researchers attribute increased infiltration rates in no-till to improved soil macrostructure (Black 1973, Blevins et al. 1977). Russel et al. (1975) observed an increase in soil surface aggregates, extensive root channel networks created by previous crops, vertical planes of weakness remaining from drying or shrinking soil, and an increase in earthworm channels in the soil of no-till plots. He considered the changes in macrostructure to be responsible for the increased infiltration rates.

No-till cropping practices not only accumulate more soil moisture, but are also more efficient at conserving existing levels of water in the soil. The surface mulch serves to greatly reduce evaporative loss from the soil surface. Russel (1940) compared evaporative water loss on bare soil and soils covered with various amounts of straw mulch, and found that bare soil lost the greatest amount of moisture. Evaporative water loss was reduced 55% by 2250 kg/ha of mulch, and 4500 kg/ha of straw reduced the loss from bare soil in the first 24 hours following irrigation by 62%. Bond and Sillis (1969) noted that, because of decreased evaporation, mulch covered soils remained moist much longer in no-till plots following precipitation.

Standing stubble, grass barriers, or any other form of windbreak also serve to reduce evaporation from the soil surface. Aase and Siddoway (1976) showed bare soils exposed to reduced wind movement remained wet three days longer than check plots.

Temperature

Temperature is important in determining cereal growth and grain yield. However, it is difficult to quantify its individual contribution to yield in relation to that of moisture. Hopkins (1935), in Canada, concluded that ambient temperature conditions during the growing season were secondary to precipitation in determining grain yield. Blair (1918) found that in South Dakota ambient temperatures during May and June were often of greater importance than precipitation in determining wheat yields. Army and Hanson (1960) found that spring wheat yields in Montana were more closely correlated to temperature than to precipitation after heading.

The effect of temperature stress on plant growth depends on the stage of plant growth. Above average temperatures may be detrimental at some stages and beneficial at others. Hopkins (1935) reported above average air temperatures in western Canada to be detrimental during mid-season, and beneficial at emergence and prior to ripening.

Walster and Nystuen (1948) compiled spring wheat yield and air temperature data from 1911 to 1945 in North Dakota. They demonstrate significant negative correlations between yield and temperature during June and July. Thompson (1962), using data from the Dakotas from 1935 to 1961, determined that air temperatures one degree (^{o}C) above average during April and May increased yields from 12.1 to 22.9 kg/ha. The same temperature increase in June reduced yields by 61.9 to 63.2 kg/ha. In July the warmer temperature resulted in yield reductions of 15.5 to 57.8 kg/ha. Brengle and Whitfield (1969) noted significant positive correlations between increasing soil temperature and grain yield when temperature treatments were applied at the three-leaf stage. Treatment at heading resulted in a significant negative correlation.

Wardlaw (1970), in determining the effect of air temperature on wheat yield, established three temperature regimes. Day/night temperatures were 27/22, 21/16, and 15/10^{o} C during the first ten days after anthesis. Air temperatures before and after the ten day treatment period were 21^{o} during the day and 16^{o} during the night. The highest temperature treatment resulted in larger kernels but fewer kernels per spike. Total grain yield was highest and vegetative yield lowest at 27/22. Asana (1964), using somewhat higher temperatures, found total grain weight per spike to decrease as air temperatures increased from 20^{o} to 31^{o} C. By exposing 23-day-old wheat plants to an air temperature of 42° C for 36 hours, Sojka et al. (1972) were able to significantly reduce tillering. Total dry weight at maturity had also been significantly reduced.

Fischer (1976) modified air temperatures in the field by covering plants with a transparent ventilated chamber that could be heated or cooled to differ by as much as 10° C from the ambient temperature. He noted the greatest temperature effect between the time from jointing to anthesis. A grain yield reduction of 4% was associated with each 1° C increase above ambient temperature during that period.

Warrington et al. (1977) demonstrated direct effects of air temperature on cereals. Spring wheat plants were grown in liquid growth medium in chambers of controlled vapor pressure deficit. Plants were subjected to day/night temperatures of 25/20, 20/15, or 15/10 during one of three growth stages for approximately a 30-day period. The plants were grown at 20/15 during the other two growth stages. Growth stages were: 1) germination to pre-boot; 2) boot to anthesis; and 3) anthesis to maturity. Total grain weight per spike was most affected in stage 2, but was also influenced in stages 1 and 3. Grain weight per spike was largest at the lowest temperature treatment. Only the most distal kernels on the spike were affected in stages 1 and 2 while all were influenced by temperature in period 3. The number of kernels per spike was least affected by temperature in stage 1, but at stage 2 there were 3.5 more kernels per head at 15/10 than at 25/20. More fertile tillers per plant resulted from high temperatures in stage 1 and low temperatures in stage 2. Total vegetative dry matter yields followed this same pattern. Plant height was only affected in stage 2, where low temperatures gave the shortest plants. The authors feel that temperature can influence yield at any stage of plant development and that this influence upon yield is growth stage dependent. Total yield was greatest when air temperatures were high in stage 1 and low in stages 2 and 3.

Peters et al. (1971) found that night air temperatures of 8.9, 15.3, and 26.5^{o} C corresponded to wheat yields of 2556, 2421, and 1345 kg/ha, respectively. High night temperatures reduced yields by 47.4%. Kerby (1973) observed spike deformation from high air temperatures to be very similar to that caused by 2,4-D.

Many other researchers have done work to determine the influence of air temperature on cereals; all showed significant responses. Contradictions in response trends may be due to varietal differences (as demonstrated by Varade et al. 1970), plant growth stage, or from inability to separate influence of temperature interactions with the water balance of the plant.

Soil temperature has been studied by researchers in an effort to determine its effect upon wheat and barley. Sojka et al. (1975), in studying a semi-dwarf spring wheat variety, observed the effect of three soil temperatures. Treatments of 9, 15, or 21^{o} C were initiated at the three leaf stage and continued for 25 days. Plants were then harvested, and vegetative yields determined. Fifteen degrees was the optimum temperature for shoot dry weight, root dry weight, tillers per plant, and leaves per plant. Brengle and Whitfield (1969) found decreasing soil temperatures from 18° to 12° at this growth stage to cause reduced tillering of spring wheat. Labanauskas et al. (1975) recorded nearly a 50% reduction in total grain yield when soil temperatures during grain filling were increased from 15° to 25° C. Individual kernel weight was much reduced. Luxmoore et al. (1973), using soil temperature treatments of 5, 15, and 25° C during grain filling, observed similar trends in grain yields. The lowest soil temperature during the 30-day treatment resulted in the highest total dry weight per plant, largest spike size, most kernels per spike, and the largest total grain yield. Individual grain weight was greatest at 15° C. Of the soil temperatures 8, 12, 19, and 26° C compared in a study by Boatwright et al. (1976), the greatest total dry weight per plant was obtained at 19°. Plants in this study were treated for 11 days, beginning seven days after emergence, and soil temperatures were varied only in the top 2.5 cm of soil. Soil below that point was held constant at 18° C.

Whitfield and Smika (1971) in Colorado noted extreme variability in varietal response to soil temperature. Wheat plants were subjected to soil temperatures of 7, 13, and 18° C from seeding until plants were 3/4 headed. Of the four varieties tested, two were winter wheats (Witchita and Lancer), and two were spring wheats (Lee and Crim). Winter wheat varieties produced more spikes per plant at 13° (after vernalization) than at 7° or 18°. Spring wheats, on the other hand, produced most spikes at 18° and fewest at 7°. Root weight increased with increasing soil temperature for all varieties, but response of top growth to temperature was again dependent on variety. Both winter wheat top growth yields were highest at 13°. Lee and Crim vegetative yields were lowest at that temperature, and yielded best at 18°. Tillering was greatest at 18° for all varieties. Spikelets per spike increased with increasing temperature in the winter wheats and Crim spring wheat. Lee wheat produced most spikelets per spike at 7°. The number of tillers producing spikes was also temperature dependent. The number decreased with increasing temperature in Lancer and Witchita, remained unchanged in Crim, and increased in Lee. Wall and Cartwright (1974) observed similar varietal differences in response to air temperature.

The crown node was tested by Boatwright et al. (1976) for its role in plant response to soil temperature. It was concluded that the crown node is the seedling part most sensitive to temperature; and therefore, temperatures in the top 3 cm are the most critical in determining plant growth response. Smika (1974) attempted to determine the optimum crown depth temperatures from planting to heading.

For winter wheat varieties the greatest number of spikelets per spike were formed at 15° C, and the most spikes per plant resulted from the 13° treatment. For spring wheat varieties, spikes per plant and spikelets per spike were greatest at 18° and 13.5° C, respectively.

The effect of a mulch on the soil surface, such as occurs in no-till, is to lower temperatures of the soil, especially near the surface. Being a poor conductor, a straw mulch absorbs radiant energy from the sun but transmits little to the soil in the form of heat. It also acts as an insulator to reduce transfer of heat from warmer air to cooler soil.

Work done in corn (Lemon 1956, Moch and Erbach 1977) shows that a straw mulch on the soil surface results in reduced soil temperatures. Van Wijk (1959) recorded average weekly soil temperatures to be as much as 5.6° C lower under mulch in corn. Early vegetative growth was significantly reduced by this temperature depression in Minnesota and Ohio; but not in South Carolina where normal soil temperatures are significantly higher. The same trend appears true for wheat and barley.

Black and Siddoway (1977) in Montana measured soil temperature in spring wheat at the 5 cm depth from the middle of May to June 10. Maximum soil temperatures in no-till plots (stubble heights of 28 and 38 cm) averaged 18.3 and 17.1° C, respectively, while those in tillage plots averaged 20.2° C. Black (1970) planted winter wheat by conventional methods and then covered the plots with straw. Residue rates of 0, 1680, and 3360 kg/ha produced average midday May temperatures of 17.1, 12.0, and 8.1° C at the 5 cm depth.

Aase and Siddoway (1978) planted winter wheat using no-till methods into stubble heights of 0 (burned), 17, and 33 cm. Much of the loose straw was removed. Readings taken every half hour from late September to early April showed soil temperatures at the surface to differ significantly. During the fall and spring, stubble-plot daytime soil surface temperatures were as much as 5° C cooler. Winter temperature data showed the daily range of temperatures in stubble plots to be less extreme than those in bare plots. That is, the highest and lowest soil temperatures recorded overwinter were in bare plots. Under certain conditions bare-soil winter temperatures fluctuated as much as 15° C daily while temperatures under tall stubble varied only 1°. This pattern is principally due to snow insulation. Stubble plots in this example had approximately 11 cm of snow while bare plots had snow only in the drill furrows.

Aase and Siddoway et al. (1977) suggested that under extreme cold conditions the added snow in no-till plots could insulate sufficiently to prevent or reduce winter kill. Their studies showed the minimum winter soil temperature at a 5 cm depth that year to be -19° in stubble-free tillage plots. The minimum temperature at that depth in no-till plots (35 cm stubble) was -15° C. If the threshold for winter kill of winter wheat is -16° C at the crown depth (Ulanova 1975), no-till would have been beneficial in reducing wheat loss.

Air temperatures are also affected by no-till. In the absence of snow, daytime temperatures in the stubble are higher and night temperatures lower than those over bare soil. Aase and Siddoway (1978) observed higher fall and spring midday temperatures in stubble. At a 5 cm height these differences were as great as 3° C.

Weeds

Weed population changes have always accompanied changes in agricultural practices (Thurston 1971). The interaction between weeds and their environment is delicate; and even a slight change in the timing of events or conditions of the environment may have a great effect on weed growth. Weed responses to environmental changes include changes in 1) the size, vigor, or competitiveness of a weed, 2) the number of individual weed plants, and 3) the number of weed species.

The moisture characteristics of a soil are influencial in determining the weed population density and species composition. This is demonstrated by an experiment conducted under greenhouse conditions by Weise and Vandiver (1970). Corn, sorghum and eight weeds were subjected to three levels of soil moisture. Common cocklebur (<u>Xanthium</u>

strumarium), common crabgrass (Digitaria sanguinalis), and barnyardgrass (Echinochloa crusgalli) grew best and were most competitive under moist soil conditions. Kochia and Russian thistle plants were comparatively large and competitive at very low soil moisture levels. Palmer amaranth was most suited to a moderate soil moisture content. The authors suggest that the moisture characteristics of an area determine, in part, the weeds which will be present in agronomic crops. They also demonstrated that the soil moisture level affects the ability of a weed to compete with a crop.

Weeds respond to temperature much as do crop plants (McWhorter and Jordon 1976). Weed species differ in their temperature requirements; and thus temperature change could be expected to produce some change in the weed population (Hallgren 1976, Harris 1972, Potter 1976).

Weeds are a major variable in determining the success of no-till yields. This is especially true in areas where the soil moisture advantage of no-till is of primary importance. It has been shown that weed populations can be changed by variations in temperature and soil moisture, and that temperature and moisture conditions in no-till can differ significantly from those of tillage methods. On the basis of those facts alone, it might be expected that weed populations in no-till will differ from those in tilled systems. However, there are other, and possible more important, reasons why no-till weed problems should be different.

Tillage in itself significantly affects weeds. Stobbe (1977) categorized weeds under major headings according to germination response to tillage. Arable response weeds exhibit increased germination in response to increased tillage. Germination of inverse response weeds decreases with increasing tillage. He found a shift from tillage to no-till resulted in a shift towards less arable response weeds and more inverse response weeds.

The increased dependence upon herbicides in no-till allows for additional weed population changes. Weed population shifts in response to herbicides are often rapid and dramatic (Fryer and Chacelle 1970, Shuck 1975). Weeds controlled by a herbicide decline in number while resistant weeds become more numerous. Weeds not presently controlled by available herbicides should become more prevalent in non-tilled crops if they are suited to the no-till environment. Further restrictions are made on "available" herbicides because, without tillage, only those herbicides requiring no incorporation can be used.

Interception of herbicide spray by straw residue results in less herbicide reaching the smaller weeds, thus, less effective weed control (Erbach 1975).

Actual reports of weed population changes in no-till are common, and follow a general pattern. Bachthaler (1975) compared weed infestations in wheat for six years. Broadleaf weeds decreased in no-till plots while perennial grasses (especially _Agropyron repens_) increased.

The perennial grasses became such a problem that plots at some locations were discontinued after five years. From his own work and that of others in Great Britain and Europe, Cussans (1975) concluded that, in general, annual broadleaf weeds are greatly reduced in no-till systems. Annual grasses as a group follow no pattern. Some such as Setaria sp., Avena fatua, and Bromus sp. have been reported to increase significantly. Volunteer grain, often considered an annual grassy weed, is usually less of a problem in no-till. Perennials, especially grasses, increase in no-till cereals. Researchers in the U.S. and Canada generally agree with the pattern outlined by Cussans (Stobbe and Taylor 1977, Triplett and Lytle 1972, Kapastra and Strieka 1976, Larson 1970).

Additional research is needed to determine effective means of no-till weed control if the projected success of this cropping method is to be achieved. Proper timing of herbicides and use of crop rotations will be of primary importance in adequately controlling weeds in no-till systems.

MATERIALS & METHODS

Two small grain cropping methods were initiated on a Manhattan very fine sandy loam soil September 7, 1976 in a dryland agricultural area of southwestern Montana. A description of these two methods is presented in Table 1. This study was designed to compare yield and weed population characteristics of no-till and conventional small grain cropping practices. Temperature and moisture conditions throughout the year were recorded in an effort to determine their relationship to the weed problem and crop yield of each cropping system.

Plots were established 15 km north of Belgrade, Montana in the Horseshoe Hills. This area receives an average annual precipitation of 35.3 cm (Appendix, Table 1). The study site is an area 91.4 x 100.6 meters, located on a northeast facing slope. Plots were arranged in a randomized complete block design with nine replications. Individual plot dimensions were 6.1 x 9.1 meters. The entire plot area had been cropped to winter wheat during the previous season (1975-76). Straw residue remaining after that harvest averaged 4770 kg/ha with an average stubble height of 31.9 cm.

The two cropping methods (treatments) were designated tillage and no-till (Table 1). Both treatments were established for winter wheat, spring wheat, and barley. Cheyenne winter wheat was seeded at a rate of 87 seeds per meter Sept. 28, 1976. Newana spring wheat (87 seeds per meter) and Shabet barley (54 kernels per meter) were

Table 1: Treatment description for tillage and no-till on winter wheat, spring wheat, and barley plots from Sept. 1976 to Aug. 1977.

Crop & Date	Tillage treatment	No-till treatment
Winter Wheat		
Sept. 25	Seedbed preparation	-------
Sept. 27	Fertilizer application	Fertilizer application
Sept. 28	Seeding	Seeding
Oct. 6	-------	.56 kg glyphosate
May 12	.28 kg/ha 2,4-D .02 kg/ha picloram	.28 kg/ha 2,4-D .02 kg/ha picloram
Aug. 4	Harvest	Harvest
Spring Wheat and Barley		
April 19	Seedbed preparation	-------
April 20	Fertilizer application	Fertilizer application
April 21	Seeding	Seeding
April 28	-------	.56 kg glyphosate
Aug. 12	Harvest	Harvest

seeded April 23, 1977. Seeding depth was approximately 5 cm, and row spacing was 35.6 cm in all plots. Both no-till and tillage plots were seeded with a no-till press drill with double-disc openers.

The tillage treatment consisted of planting into a prepared seedbed. Seedbed preparation was accomplished by discing each tillage plot twice prior to seeding. Seed in no-till plots were sown directly into undisturbed stubble. A post-plant pre-emergence application of glyphosate (N-phosphonomethyl glycine) at a rate of .56 kg/ha followed. Fertilizer (11-55-0) at a rate of 225 kg/ha (25 kg/ha nitrogen) was surface broadcast to all tillage and no-till plots immediately prior to planting. Tillage plots were disced before the application.

Post-emergence weed control was accomplished in both treatments by the use of herbicides. A late spring tank mix application of .28 kg/ha 2,4-D (2,4-dichlorophenoxy acetic acid) and .02 kg/ha picloram (4-amino-3,5,6-trichloropicolinic acid) was made on no-till and tillage winter wheat plots, but was not considered necessary on spring wheat or barley. All herbicides were applied in water at a rate of 190 L/ha. All herbicides were applied with a CO_2 pressurized backpack sprayer.

Moisture

Soil moisture measurements were taken in the fall of 1976, spring of 1977, and again in the fall of 1977. A "King Tube" was used to collect soil samples in 30.5 cm increments to a depth of 1.83 meters. Due to possible horizontal subsurface water movement below 1.2 meters, only soil moisture data to that depth are reported. Soil samples were weighed, dried at 60° C for 48 hours, and weighed again to determine moisture content on a percentage basis. Water content was then calculated by volume. Soil bulk density was estimated to be 1.4 g/cm^3 (Ferguson 1978).

Three permanently fixed meter sticks in each of six plots were used to measure snow accumulation throughout the winter in the winter wheat plots.

Temperature

Temperatures were recorded with YSI #44005 thermistors. Five thermistors were positioned on a partially buried, white, wooden dowel in such a manner that temperatures could be measured at depths of 2 and 8 cm below, and heights of 2, 8, and 16 cm above the soil surface. The thermistors were positioned on the north side of the dowel in an effort to reduce the effect of solar radiation on the thermistors. Because of the expense involved, only enough thermistors were acquired to monitor temperatures in six plots. Three no-till and three tillage winter wheat plots were selected randomly, and the thermistors were placed in them December 16, 1976. An equilibrating period of 21 days was allowed before the first readings were taken.

Air and soil temperatures were recorded in tillage and no-till winter wheat plots from January 1 to August 20, 1977. Readings were taken near midday at approximately weekly intervals throughout the eight month time period. Weekly temperature readings were then classified into one of three seasonal categories, according to reading date. Winter temperatures were designated as those taken between January 1 and April 1. Spring temperatures were those recorded between April 1 and June 15, while the summer category included temperatures recorded between June 15 and Aug. 20. Temperature data from each season were then used to compute average seasonal midday temperatures.

Only temperatures on clear, non-stormy days were used in calculating summer and spring average temperatures. Data from both clear and stormy days were used to determine average midday winter temperatures. However, to compensate for the extreme weather variability, three sub-classifications of winter temperature conditions were created. Average temperatures were computed for each sub-category. Daily maximum air temperatures were the basis for categorizing temperature reading dates into these three sub-classifications. Maximum air temperatures recorded at Belgrade were used to represent the approximate maximum temperature at the plot location on each recording date (Appendix, Table 3). Winter-subzero was the designation given to days with a maximum air temperature below 0° C. Maximum air temperatures between 0 and 5° C were considered winter-moderate conditions; and winter-melt was the term applied to winter days with a maximum temperature above 5° C. Snow was present in at least some of the plots during all temperature readings classified in winter categories.

Weeds

Weed stand densities in both winter wheat and spring grains were determined by actual counts at planting and at harvest. Weeds were also counted on four additional dates between planting and harvest in winter wheat plots, but not in spring wheat or barley. Weeds were counted at harvest over the entire 55.5 m^2 area of each plot in all nine replications of each treatment. Counts prior to that date were made on two .5 m^2 subplots in three replications of each treatment.

Yield

Plant heights were measured, and vegetative samples were collected throughout the growing season in order to estimate vegetative yield in winter and spring wheat. Sixteen representative plants in each of three tillage and no-till plots were marked and their height measured weekly. Marking was accomplished by placing a flagged nail in the ground near each plant. Plants in a 2.44 meter length of row were harvested from each of these plots every two weeks, by clipping to ground level. Vegetative matter was then oven dried at 60° C for

48 hours and weighed to calculate vegetative yields. The final height and vegetative yield measurements at harvest were recorded from all nine replications of each treatment.

Grain yield was obtained by hand harvesting plants from a 1.73 m^2 area in each plot. Bundles were tied and placed in bags to prevent grain loss in handling. Samples were threshed with a gravity "Vogel" thresher. Spikes in a representative 2.44 meter length of row in each plot were counted prior to harvest. The number of seeds per spike was determined by harvesting 20 average mature spikes in each plot on Aug. 3.

When an effort was made to differentiate between volunteer and non-volunteer wheat plants, an arbitrary decision was made to classify as volunteer plants any which did not appear to originate near the bottom of the seed furrow. This included plants between rows and those growing on or near the crest of a seed furrow.

Treatment means were statistically compared by means of a simple analysis of variance.

RESULTS & DISCUSSION

Moisture

A base-line value representing the fall soil moisture levels in both no-till and tillage plots was obtained on Oct. 15, 1976 by sampling four non-tilled plots in the study area. The average amount of stored moisture in the surface 1.2 meters of soil was determined to be 18.74 cm on that date. Six months later, on April 15, a noticeable moisture difference had developed between treatments in the winter wheat plots. No-till plots had gained 3.69 cm of moisture, while tillage plots had lost 1.75 cm. This constitutes a difference of 5.44 cm (Table 2). The total precipitation received at the nearest weather station (16 km south) over the six month time period was 7.32 cm.

Table 2: The effect of cropping method on overwinter soil moisture storage in winter wheat to a depth of 1.2 meters.

	Soil moisture in cm 1/		
	Oct. 15, 1976	Apr. 15, 1977	Accumulated
No-till	18.74	22.43	3.69
Tillage	18.74	16.99	-1.75
Difference			5.44*

1/ Average from one 1.2 meter soil sample in each of 3 plots
* Significant at the P=.06 level

The overwinter moisture accumulation capabilities of tillage and no-till cropping methods can be attributed to differences in snow retention and evaporative water loss. No-till plots accumulated more snow over the winter than did tillage plots, due to the ability of standing stubble to retain or even accumulate snow under windy conditions. The first two major snow storms during the 1976-77 winter (January 3 and January 15) were both followed by strong northerly winds. Snow depth measurements on January 18 demonstrate the effect of stubble on wind blown snow (Table 3). On that date 5.9 and 16.8 cm of snow were recorded in tillage and no-till plots, respectively. Greater snow depth was recorded in no-till plots following each wind-accompanied snow storm during the remainder of the year.

The significant over-winter loss of soil moisture from tilled plots was probably due to evaporation rather than percolation. The only significant loss of soil moisture in tillage plots occurred in the first sampling depth (shaded area on Figure 1) with no significant overwinter change in moisture below that depth, indicating no movement of moisture down through the soil profile. Although some evaporative loss appeared to have occurred on the surface of no-till plots, there was a six-fold greater loss in tillage plots. Soil moisture values in tillage plots were significantly different from those of no-till in all but the last depth increment (.9-1.2 m) (Figure 1).

Table 3: The effect of cropping method on snow depth in winter wheat from Jan. 1 to April 7, 1977.

Date	Cropping method and snow depth[1/]		
	No-till cm	Tillage cm	Difference cm
Jan. 6	19.8	15.8	4.0**
Jan. 11	15.8	5.7	10.1*
Jan. 18	16.8	5.9	10.9**
Feb. 1	11.6	.3	11.3**
Feb. 7	12.5	.3	12.2**
Feb. 15	8.7	0	8.7**
Feb. 17	7.2	0	7.2**
Feb. 19	4.8	0	4.8*
Feb. 22	1.7	.7	1.0
Mar. 1	.2	0	.2
Mar. 31	8.0	1.8	6.2*
Apr. 4	1.1	0	1.1
Apr. 7	0	0	0

1/ Average of 3 measurements in each of 3 plots
* Significant at the P=.05 level
** Significant at the P=.01 level

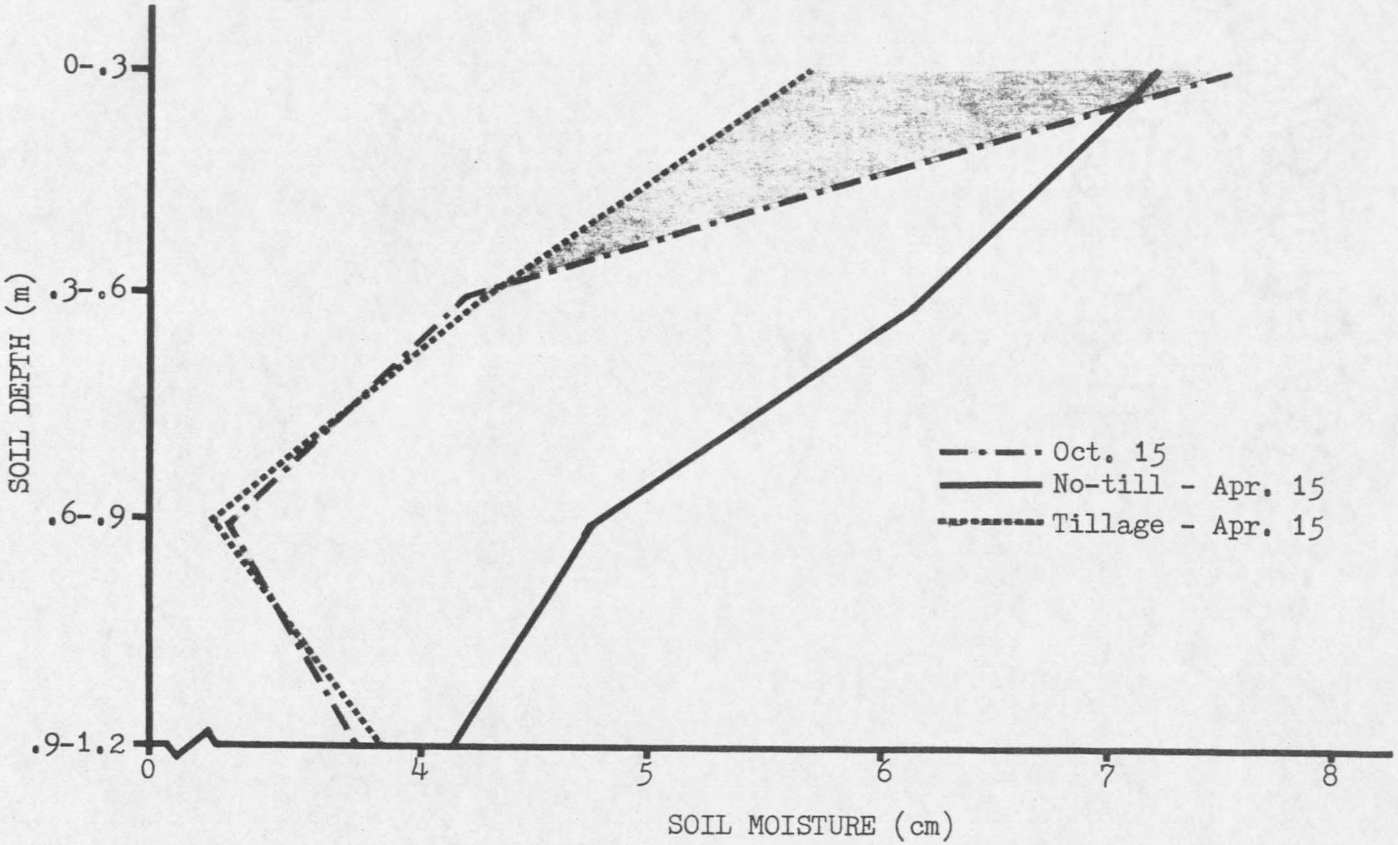

Figure 1: The effect of cropping method on overwinter soil moisture storage in winter wheat to a depth of 1.2 meters. (Each point on a line is an average moisture measurement from one 30-cm sample increment in each of 3 plots.)

Evaporation of soil moisture is reduced by straw. When both tillage and no-till plots were free of snow (Sept. thru Dec.), the straw mulch in no-till plots would contribute to evaporation differences. However, the length of time the soil is covered with snow also contributed to overwinter evaporation loss differences. No-till plots were covered with snow during a greater portion of the winter (Figure 2). This situation was most noticeable in February when a warm period caused a spring-like snow melt. Tillage plots were completely free of snow by Feb. 15. No-till plots on that date were covered with 8.7 cm of snow. Three days later the surface 5 cm of soil in tillage plots was dust dry. No-till plots were still under 4.8 cm of snow. This warming trend continued until March 1 when no-till plots were muddy with some scattered snow cover remaining (Figure 2). Tillage plots had been bare of snow for two weeks, and were dry on the surface.

A series of snow storms during March and the first of April replenished soil moisture in both treatments. However, they were not of sufficient magnitude to reverse the net overwinter evaporative loss of moisture in tillage plots.

Although it was not the purpose of this experiment to study water usage of crop plants during the growing season, some comparisons of the two cropping methods and their effect on water use are possible. On April 15, 1977 no-till winter wheat plots contained 5.42 cm (Table 4). Those data indicate that plants in no-till plots used

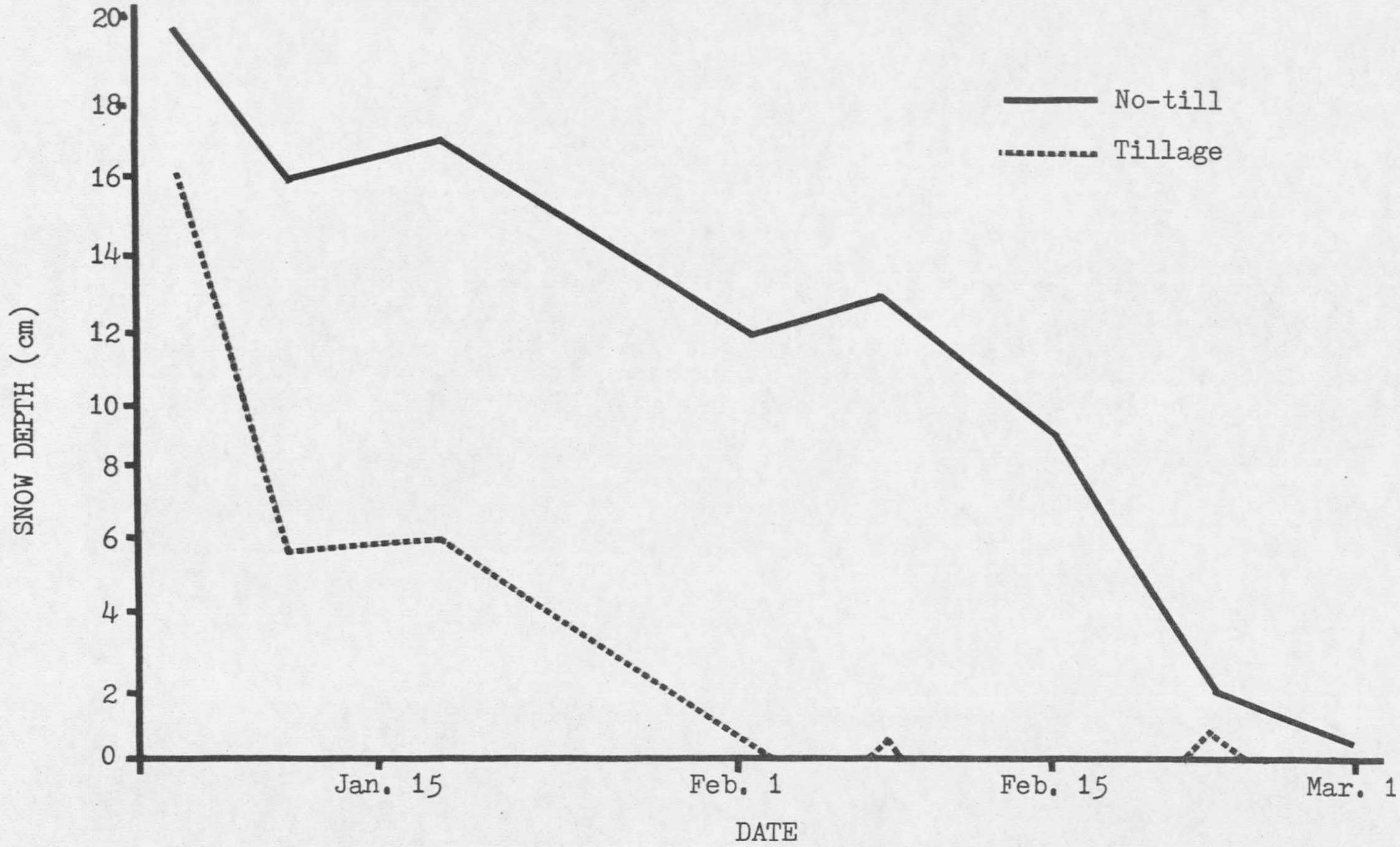

Figure 2: The effect of cropping method on snow depth in winter wheat from Jan. 1 to March 1, 1977. (Each point on a line is an average snow depth measurement from 3 locations in each of 3 plots.)

Table 4: The effect of cropping method and kind of crop on amount of soil moisture to a depth of 1.2 m on Oct. 12, 1977.

Cropping method	Kind of crop and soil moisture[1/]		
	Winter wheat cm	Spring wheat cm	Barley cm
No-till	22.32	21.99	22.86
Tillage	20.79	20.61	20.42
Difference	1.53	1.38	2.44*

1/ Average moisture measurements from one 1.2 meter core sample in each of 9 plots
* Statistically significant at the P=.05 level

more water over the summer than did plants in tillage plots. Yield data presented later support this conclusion. It is not suggested that water is used any more efficiently, only that plants growing under the no-till system used more water.

Both tillage and no-till spring grain plots were left as standing stubble over the winter and therefore showed no overwinter moisture accumulation differences. By Oct. 12, 1977 slight treatment differences existed, with no-till plots having more moisture in the surface 1.2 meters of soil (Table 4). Barley and spring wheat no-till plots contained 2.44 and 1.38 cm more water, respectively. Greater evaporative loss and/or greater usage of water by plants in tillage plots may account for this difference.

Temperature

Average midday temperatures in tillage and no-till plots were compared under winter, spring, and summer conditions. Significant treatment differences were observed for both air and soil temperature during each of the three seasons. Generally, treatment differences were greater near the soil surface and diminished with increasing height or soil depth.

Under winter-subzero conditions (daily maximum air temperature below 0°), there were no significant temperature differences between treatments above the soil surface. However, soil temperatures were significantly warmer in no-till plots (Table 5 and Figure 3). The average midday no-till temperature for the winter-subzero category was -4.1° C at a depth of 8 cm. The average temperature in tillage plots at this depth was -6.0°; or 1.9° C colder. At a depth of 2 cm tillage plots were 1.8° C cooler. The insulation effect of snow is probably responsible for the temperature difference between treatments; no-till plots were covered by 7 cm more snow. As pointed out by other researchers (Aase and Siddoway 1977, 1978a), the milder subzero soil temperatures of no-till cropping may significantly reduce winter-kill of wheat in cold areas of the U.S.

Temperatures in tillage and no-till plots differed very little on winter-moderate days (daily maximum temperatures between 0° and 5° C). Where differences existed, tillage plots were warmer (Table 5,

Table 5: The effect of cropping method on average midday air and soil temperatures (°C) in winter wheat during winter, spring, and summer.

Temperature	Treatment	Location of thermistor in relation to the soil surface				
		Height			Soil depth	
		16 cm	8 cm	2 cm	-2 cm	-8 cm
Winter-subzero	NT	-8.2	-6.5	-5.2	-4.6 1/	-4.1 1/
	T	-7.3	-6.2	-5.7	-6.4	-6.0
Winter-moderate	NT	1.4	1.4	.6	-.6	-.7
	T	1.5	1.7	2.0	-.3	-.7
Winter-melt	NT	6.0*	2.8*	.3**	-.7	-1.1
	T	8.6	9.0	10.1	1.2	.9
Spring	NT	22.7	24.8	28.2*	20.3**	14.0*
	T	21.6	22.8	25.9	22.5	15.1
Summer	NT	32.7*	34.9**	38.5**	27.5**	21.9**
	T	31.4	32.7	34.0	31.6	23.9

1/ Significantly different (P=.10) from the corresponding tillage treatment mean

* Significantly different (P=.05) from the corresponding tillage treatment mean

** Significantly different (P=.01) from the corresponding tillage treatment mean

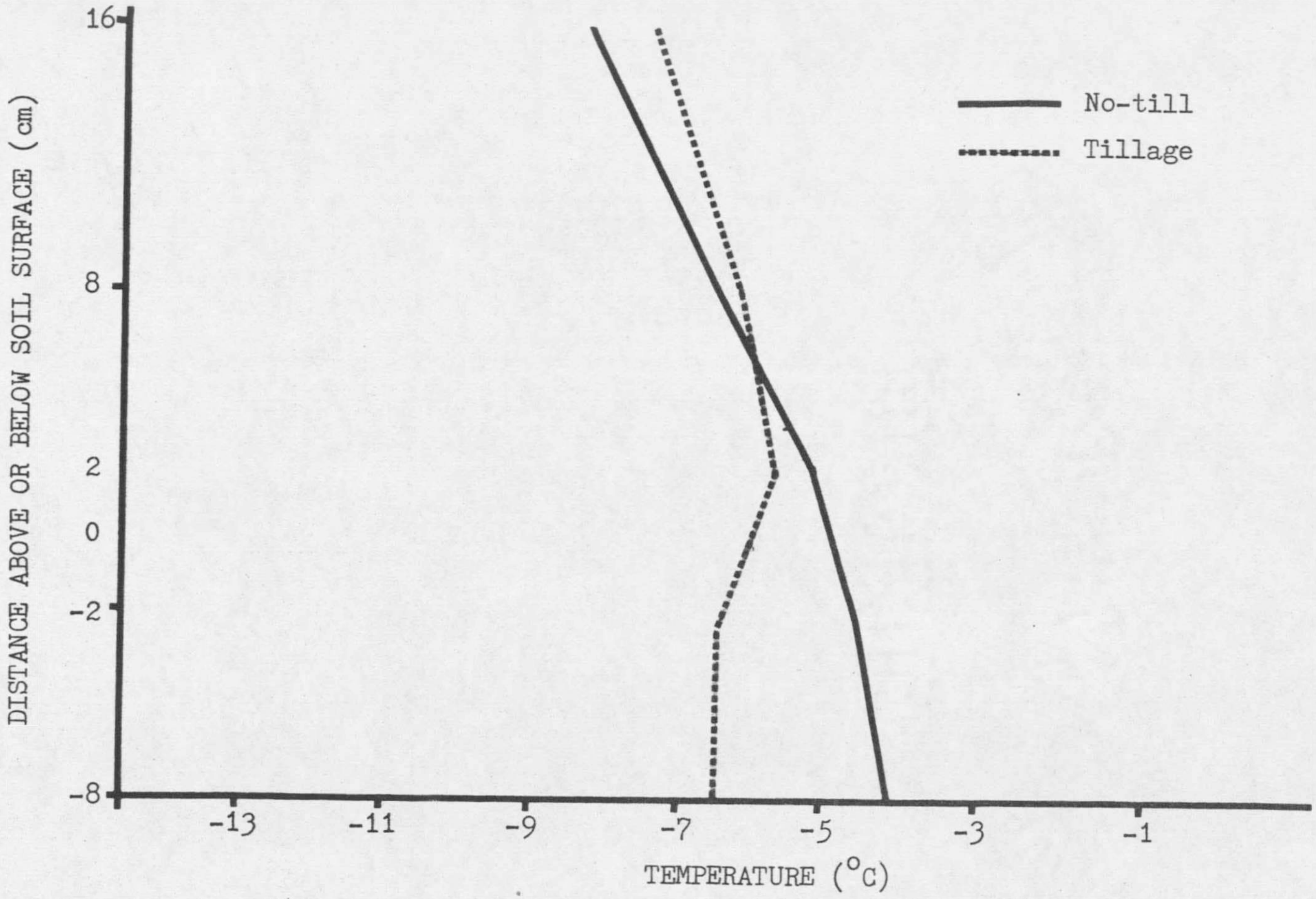

Figure 3: The effect of cropping method on average midday soil and air temperatures in winter wheat under winter-subzero conditions.

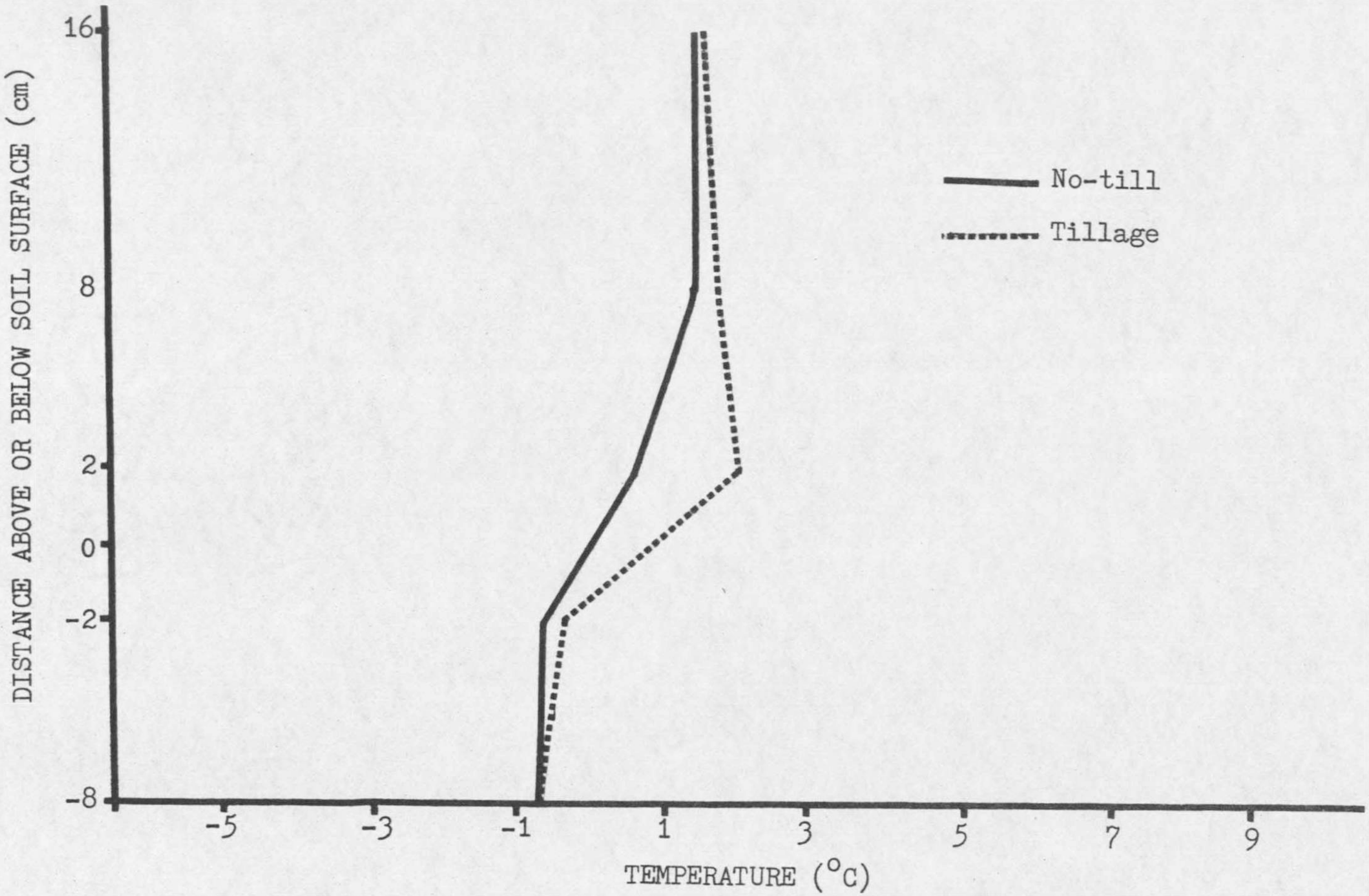

Figure 4: The effect of cropping method on average midday soil and air temperatures in winter wheat under winter-moderate conditions.

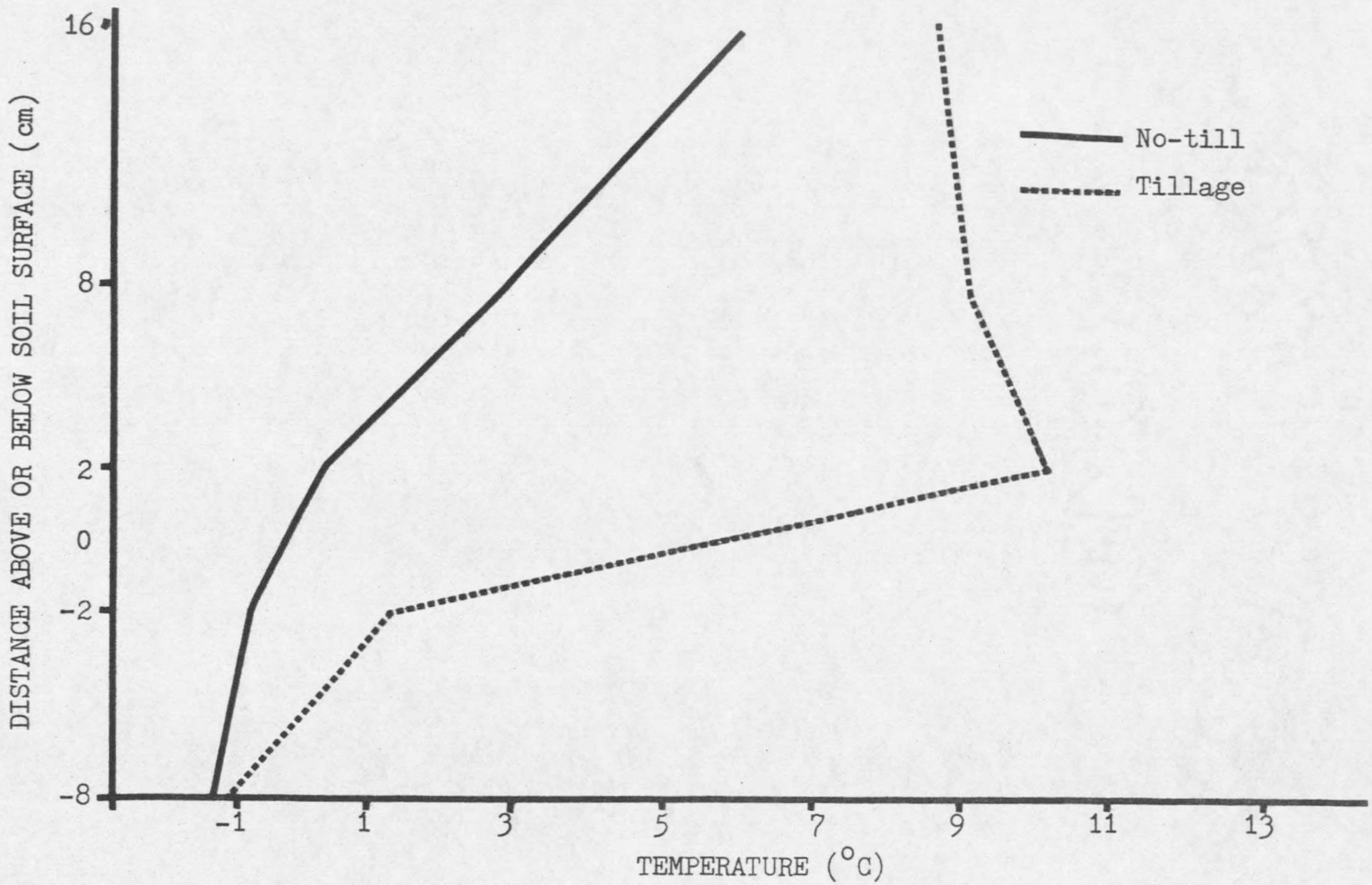

Figure 5: The effect of cropping method on average midday soil and air temperatures in winter wheat under winter-melt conditions.

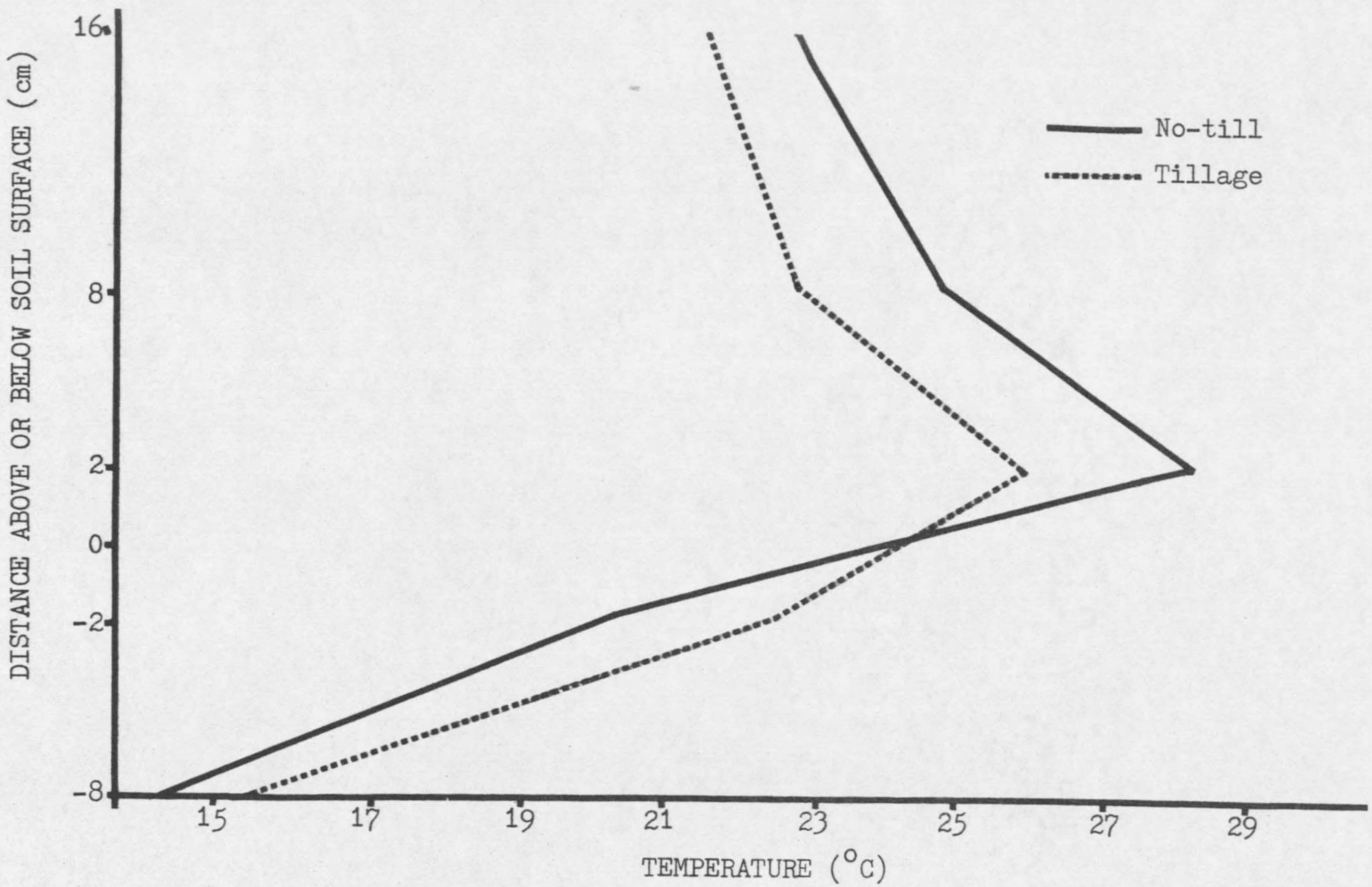

Figure 6: The effect of cropping method on average midday soil and air temperatures in winter wheat on non-stormy spring days.

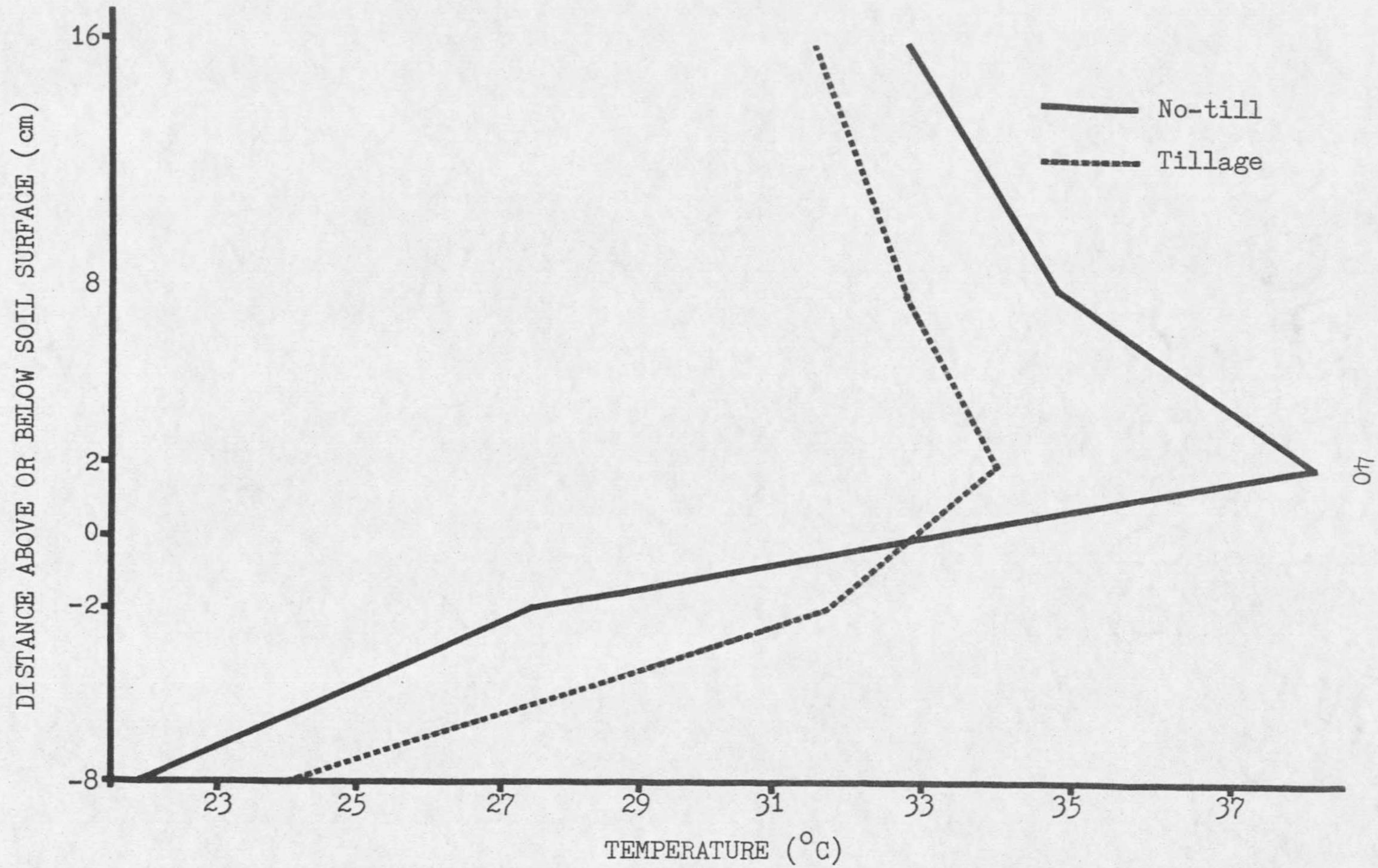

Figure 7: The effect of cropping method on average midday soil and air temperatures in winter wheat on non-stormy summer days.

Figure 4). Temperature differences were greatest at the +2 cm position where tillage thermistors were above the snow line and no-till thermistors were snow-covered. The average tillage plot temperature at this height was 1.4° C warmer than that of no-till plots.

The third category of winter temperatures is that of winter-melt (daily maximum temperatures between 5° and 15° C). Temperatures in this category were recorded in February and represent warm winter days when considerable snow melt occurred. No-till plots had an average snow depth of 8.1 cm on the temperature reading dates placed in this category. Tillage plots were essentially snow free. This condition caused extremely large midday temperature differences between the two treatments (Table 5, Figure 5). Temperatures were higher in tillage plots at all five positions, but the greatest difference occurred above the soil surface, especially at the 2 cm height. Average midday temperatures at this position were 10.1° C in tillage plots, and .3° C in the snow covered no-till plots. Treatment differences decreased with increasing height, but even at the 16 cm position no-till was 2.6° C cooler. Soil temperatures during this February warming period remained near zero in both treatments. Several snow storms occurred in March, following the February warming period. Winter-melt conditions followed each of these storms.

In spite of warmer air temperatures and earlier snow removal under winter-melt conditions, growth of winter wheat in tillage plots did not appear to be favored over that in no-till plots. Soil temperatures near 0° C in both treatments during the winter-melt periods may account for the lack of earlier spring plant growth in tillage plots.

Soil temperatures were cooler and air temperatures warmer in no-till plots during the spring (April 5 to June 15) (Table 5, Figure 6). Temperature differences between treatments were greatest near the soil surface. No-till soils were 2.2° C cooler than tillage plots at a depth of 2 cm. Air temperatures 2 cm above the soil surface in no-till plots were 2.3° C warmer, with an average temperature of 28.2° C. The tillage plot temperature at this height was 25.9° C.

Summer temperature profiles (June 15 to Aug. 20) were similar to those in the spring; however, treatment differences were generally greater (Table 5, Figure 7). No-till treatment temperatures below the soil surface were cooler than those of tillage treatments by an average of 4.1° C at the 2 cm depth. An even greater temperature difference was noted 2 cm above the soil surface where the average tillage and no-till summer midday air temperatures were 34.0 and 38.5° C, respectively. At this position no-till plots were 4.5° C warmer.

Cooler spring and summer soil temperatures in no-till plots are probably due to the shading and insulating effect of the straw mulch. Straw insulation reduced heat exchange between the soil and atmosphere.

It also intercepts solar energy which would normally contribute to heating of the soil surface. Because of the poor conductive ability of straw, little of the radiant energy that it absorbs will be transferred to the soil as heat.

Spring and summer air temperature differences between tillage and no-till treatments is believed to be caused, in part, by the reduction of horizontal air flow near the soil surface in no-till plots. Aase and Siddoway (1978), in measuring wind flow at a height of 9 cm, reported 5.5 times less horizontal wind passage in 33 cm stubble than over bare soil. Skidmore (1976) states that the reduction of horizontal air movement and subsequent increase in mixing of the air in stubble is expected to result in higher daytime and lower nighttime temperatures.

The heat conserving properties of stubble may also play a role in air temperature differences. Aase and Siddoway (1978) attributed higher no-till air temperatures to the "heat trapping" characteristics of stubble. They suggest that stubble acts to conserve heat derived from long wave radiation emanating from the soil surface.

Average temperatures in spring wheat were determined from four sample dates during the period of time from July 14 to Aug. 19 (Table 6). In order to make a valid comparison, average temperatures in winter wheat plots were computed using data from the same dates. Temperature differences between tillage and no-till plots were similar

Table 6: The effect of cropping method on average midday soil and air temperatures (°C) in winter and spring wheat on non-stormy summer days.

Crop	Treatment	Location of thermistor in relation to the soil surface				
		Height			Soil Depth	
		16 cm	8 cm	2 cm	-2 cm	-8 cm
Spring wheat	NT	31.9	34.3**	35.4**	25.9 1/	21.3 1/
	T	30.9	31.6	32.6	27.4	21.7
Winter wheat	NT	33.1**	34.6	36.9 1/	28.1**	22.2 1/
	T	31.7	34.1	34.3	29.6	22.8

1/ Significantly different (P=.10) from the corresponding tillage treatment mean

* Significantly different (P=.05) from the corresponding tillage treatment mean

** Significantly different (P=.01) from the corresponding tillage treatment mean

for both spring and winter wheat. No-till air temperatures were warmer and soil temperatures were cooler than those of tillage plots. The reason for somewhat higher temperatures in winter wheat plots is uncertain.

Weeds

Significant weed population differences developed between tillage and no-till treatment during this first year of study. A list of weeds observed at the study site is presented in Table 4 (Appendix). They will be discussed under categories of volunteer wheat, broadleaf weeds, and grassy weeds.

Volunteer wheat was a significant weed problem only in winter wheat, and was much more serious in the tillage treatment (Table 7). The average number of volunteer plants/m^2 was determined to be 43.1 immediately prior to plot establishment in September, 1976. Counts conducted the following April found 18.3 and 55.0 volunteer plants/m^2 in no-till and tillage plots, respectively. The three-fold difference could be a result of the fall precipitation pattern and planting procedure differences. Because of dry soil conditions, only a portion of the volunteer wheat had emerged by Sept. 25, when the tillage plots were disced. Receipt of 2.9 cm precipitation shortly after seedbed preparation, and warm temperatures well into October allowed germination and establishment of additional volunteer plants after Sept. 25 and before the Oct. 6 application of glyphosate in no-till plots.

Table 7: The effect of cropping method on the number of volunteer wheat and broadleaf weed plants in winter wheat.

Date	Number of plants per square meter 2/			
	Broadleaf weeds		Volunteer wheat	
	No-till	Tillage	No-till	Tillage
Pre-planting 2/	.60	.60	43.05	43.05
Nov. 4	.37	0	---	---
Apr. 23	1.00 1/	7.00	14.00	42.33
Apr. 30	1.67 1/	8.33	18.33 1/	55.00
June 13	1.00	2.00	15.00 1/	43.33
Harvest 3/	.02	.02	---	---

1/ Significantly different (P=.10) from the corresponding tillage treatment mean

2/ Average from counts made September 24, 1976 to August 13, 1977 (see page 25 for number and size of plots counted)

3/ Weed counts were taken Oct. 6 on untilled, unplanted check plots but represent approximate weed stands in both tillage and no-till plots on Sept. 24

4/ Weed counts were taken Aug. 13, but represent weed stands at harvest on Aug. 4.

Both seedbed preparation in the tillage plots and the glyphosate application in no-till plots were probably effective in controlling volunteer plants emerged at the time of these weed control operations. However, a greater percentage of the total volunteer seed supply had germinated before the glyphosate application, resulting in better volunteer control.

A second possible factor contributing to volunteer stand differences is the ability of wheat seeds on the soil surface to germinate, become established seedlings, and survive winter temperatures. No-till planting causes little soil disturbance and leaves most volunteer seeds exposed on the soil surface. Seedbed preparation in tillage plots resulted in the shallow burial of almost all of the wheat seed left from the previous crop. Low germination and poor overwinter survival may account for reduced no-till volunteer stands in the spring.

Volunteer stands in the spring grain plots immediately prior to seedbed preparation were found to average 39.0 plants/m^2 (Table 8). Seedbed preparation in tillage plots and the no-till glyphosate application were both effective in controlling these volunteer plants. Counts at harvest in both spring wheat and barley found only an occasional volunteer wheat plant.

The broadleaf weed stands were thin and variable during the entire year at the study location. Broadleaf weed stands in winter

Table 8: The effect of cropping method on the number of volunteer wheat and broadleaf weed plants in spring wheat and barley.

Crop	Date	Number of plants per square meter[1/]			
		Broadleaf weeds		Volunteer wheat	
		No-till	Tilled	No-till	Tilled
Spring wheat	Pre-planting[2/]	2.33	2.33	39.00	39.00
	Harvest[3/]	.11	.18	.01	.01
Barley	Pre-planting[2/]	2.33	2.33	39.00	39.00
	Harvest[3/]	.04	.06	.01	.01

1/ Average from counts made April 19 to August 13, 1977

2/ Weed counts were taken April 23 on untilled, unplanted check plots, but represent approximate weed stands in both tillage and no-till plots on April 19

3/ Weed counts were taken Aug. 13 but represent weed stands at harvest on Aug. 12

wheat plots at the beginning of the study were limited to meadow salsify (*Tragopogon pratensis* L.) and skeletonweed (*Lygodesmia juncea* (pursh) D. Don), and averaged .6 plants/m^2 (Table 7). Both of these weeds were sporadically distributed throughout the study area. By April 30 there had been some increase in the number of broadleaf weeds in both tillage and no-till winter wheat plots; the most dramatic increase occurring in the tillage treatment. Tillage plots averaged 8.3 weeds/m^2; while there were 1.7 weeds/m^2 in no-till treatments. On this date there were 21 times more waterpod plants (*Ellisia nyctelea*) in tillage plots.

An analysis of broadleaf weed populations in winter wheat immediately after harvest (Aug. 13) revealed a sharp reduction in total broadleaf weed numbers, as well as a disappearance of treatment differences observed in the spring. This is attributed to the effectiveness of the post-emergence broadleaf herbicide treatment of May 12 (Table 7).

Broadleaf weeds in spring grains were only counted in the spring before planting, and in the late summer after harvest (Table 8). Preplant counts revealed broadleaf weed stands to average 2.3 plants/m^2. The subsequent seedbed preparation in tillage plots, and the glyphosate application in no-till plots, were effective in controlling the weeds emerged at the time of treatment. This is evident in the post harvest weed counts of Aug. 13 where there were less than .2 weeds/m^2

in all plots. No herbicides were applied to spring grains after emergence.

After-harvest broadleaf weed stands in both barley and spring wheat were slightly higher in tillage plots. No-till and tillage weed counts in barley averaged .04 and .06 plants/m^2, respectively. Those in spring wheat were .11 and .18, respectively. Where these differences were not significant, they appear to reflect certain trends when the species composition is studied (Table 9). Meadow salsify and prickly lettuce were more common on non-tilled plots while common lambsquarters and Russian thistle were more prevalent on the tilled plots. The differences observed for skeletonweed are believed due to a distribution pattern on the field, rather than from the influence of treatment.

From the Aug. 13 data it is evident that it is not sufficient to report the net effect of no-till on the broadleaf weed population. Some broadleaf weed species may become more abundant in no-till plots even though the total broadleaf weed population declines. After several years of no-till, it is conceivable that these species could become a major problem. It is believed that of all the weeds observed, salsify is the most likely to increase in numbers on no-till plots. This biennial, normally controlled easily with tillage, shows considerable resistance to glyphosate.

Table 9: The effect of cropping method on the species composition of winter wheat, spring wheat, and barley broadleaf weed populations after one year.

Weed	Crop, cropping system and number of weeds/ha[2/]					
	Winter wheat		Spring wheat		Barley	
	NT	T	NT	T	NT	T
Prickly lettuce	0	0	120[1/]	20	139*	0
Lambsquarters	0	0	80*	1116	20	60
Meadow salsify	60	0	618**	0	239[1/]	0
Skeletonweed	139	179	199	498	0[1/]	438
Russian thistle	0	0	0	120	0	140
Misc. broadleaves	0	0	40	40	20	0
TOTAL broadleaves	199	179	1057	1794	418	638

1/ Significantly different (P=.10) from the corresponding tillage treatment mean

2/ Average of one 55 m^2 count on each of 9 replications on August 13, 1977

* Significantly different (P=.05) from the corresponding tillage treatment mean

** Significantly different (P=.01) from the corresponding tillage treatment mean

Downy brome was the only grassy weed present in the plots. However, because of its pattern of distribution at the study site, it was impossible to evaluate its response to tillage and no-till. Plots containing appreciable stands of this weed were individually treated with paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) or metribuzin (4-amino-6-tert-butyl-3-(methylthio)-as-triazin 5(4H) one) to minimize its influence on yield results. These herbicide treatments were very effective in their control and did not appear to adversely affect yields. In addition it was observed that downy brome grass was somewhat more susceptible to paraquat than to glyphosate, while the reverse was true for volunteer wheat.

Downy brome is believed to pose a serious threat to the success of no-till small grain production in many areas. Though it is not reported on in this study, its importance should not be overlooked.

It has been demonstrated in this study that no-till weed populations can differ significantly from those of tillage systems, even during the first cropping season. According to Weise and Vandiver (1970) and Hallgren (1976), a difference or change in weed populations could be partially attributed to moisture and temperature. However, when considering the magnitude of the moisture and temperature differences observed in this study, their data suggest that the contribution would be minor. The response of a weed to soil disturbance, and/or its susceptibility to glyphosate were seen as the major factors influencing weed population differences.

Yield

Plants were taller and vegetative yields higher in no-till winter wheat plots during the entire growing season (Figure 8). At harvest wheat plants averaged 22.7 cm taller in no-till plots (Table 10). Winter wheat vegetative yield differences were apparent on the first sampling date (May 7) and increased over the summer (Figure 9). At harvest, total aboveground vegetative dry matter yields were 2848 and 4125 kg/ha in tillage and no-till plots, respectively (Table 11).

Winter wheat grain yields were significantly higher in no-till plots. An average of 954 kg/ha of grain was produced on tillage plots while no-till plots yielded 1829 kg/ha (Table 12). Volunteer plants contributed 25 percent of the production on the tillage plots, and seven percent on the no-till plots. In spring grains volunteer made no significant contribution to yield.

In winter wheat, an interesting relationship existed between total grain yield (volunteer plus non-volunteer) and the number of volunteer plants per square meter. The correlation coefficient for these two variables was $r=-.83$ (Table 13), indicating that as volunteer stands increase, total grain yield decreases. In the spring, soil moisture levels at the study site were apparently only marginal

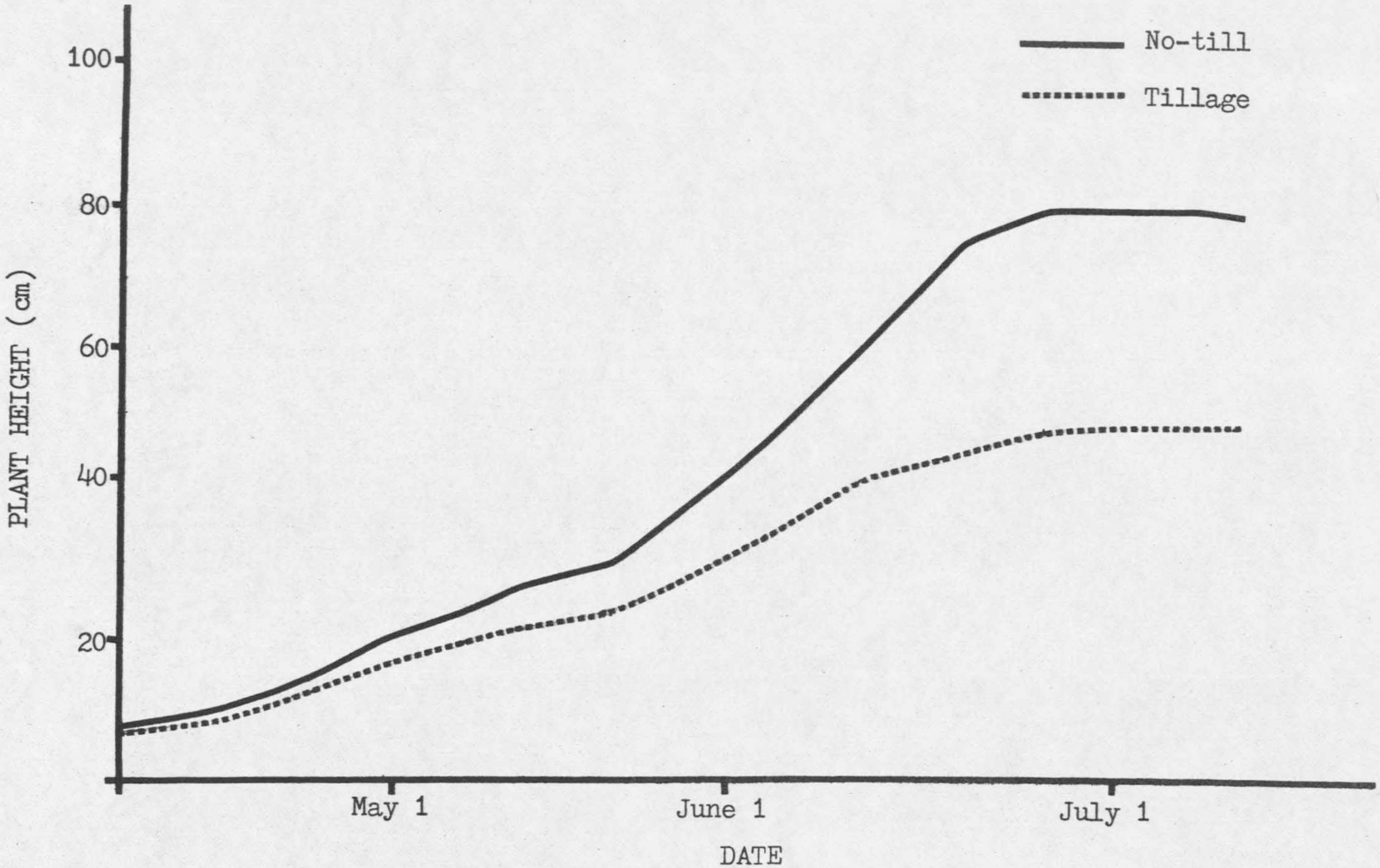

Figure 8: The effect of cropping method on the height of winter wheat plants. (Each point on a line is an average height measurement from 16 plants in each of 3 plots.)

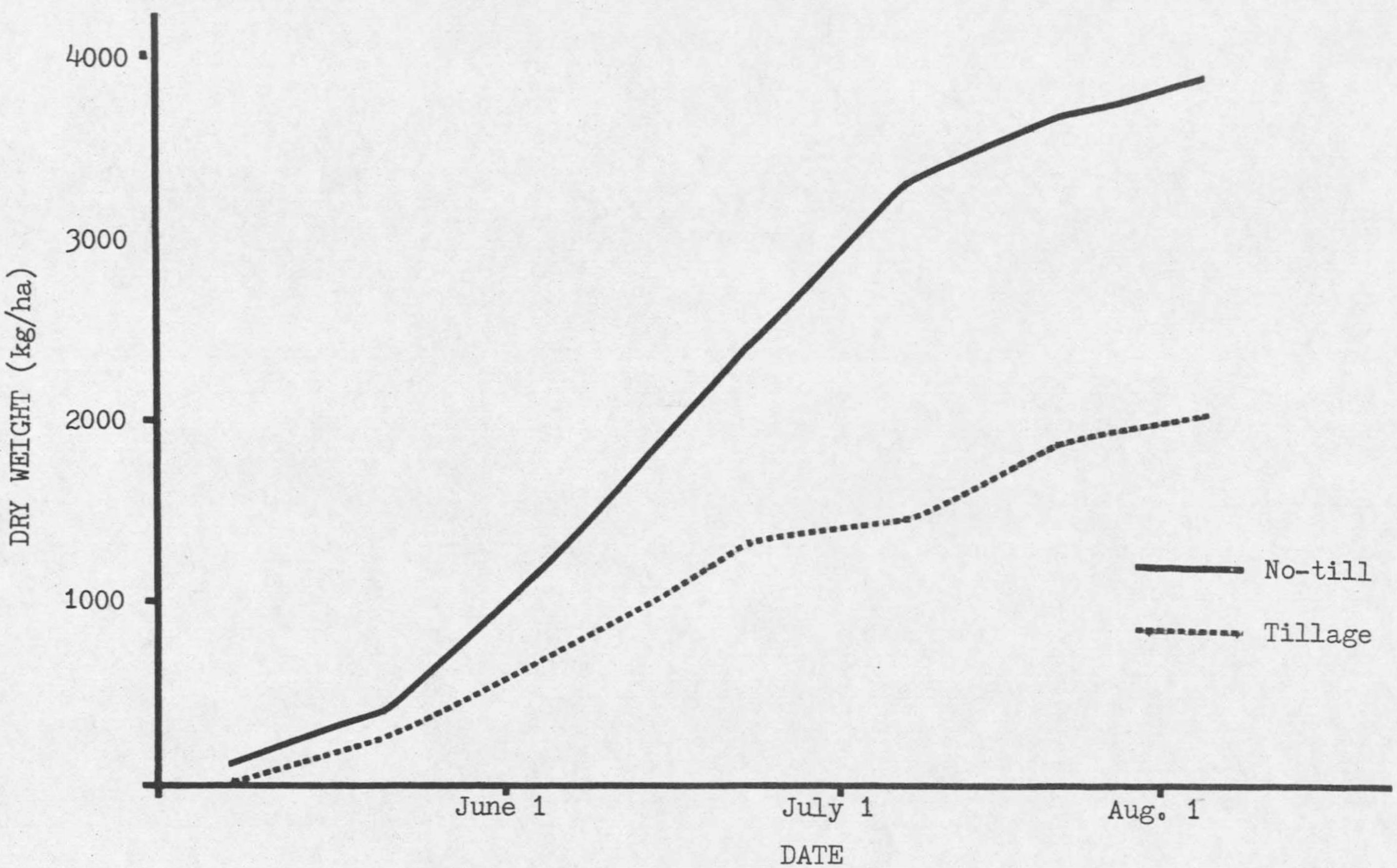

Figure 9: The effect of cropping method on aboveground vegetative dry matter yield of non-volunteer winter wheat from May 7 to harvest. Data used to construct graph are a mean of six values. (Each point on a line is an average yield measurement from 1.73 square meters each of 3 plots.)

Table 10: The effect of cropping method on winter and spring wheat plant height at maturity.

Crop	Cropping method and plant height[1]		
	No-till cm	Tillage cm	Difference cm
Winter wheat[2]	91.1	68.4	22.7**
Spring wheat[3]	70.8	68.8	2.0

1/ Sixteen plants measured in each plot

2/ Average plant height measurements from each of 9 plots

3/ Average plant height measurements from each of 3 plots

** Corresponding tillage and no-till treatment means are significantly different at the P=.01 level

Table 11: The effect of cropping method on aboveground vegetative dry matter yields of wheat and barley at time of grain harvest.

Crop	Treatment	Vegetative yield[1/]		
		Volunteer kg/ha	Non-volunteer kg/ha	Total kg/ha
Winter wheat	NT	284**	3841**	4125**
	T	824	2024	2848
Spring wheat	NT	---	---	3816
	T	---	---	3690
Barley	NT	---	---	4102
	T	---	---	4160

1/ Average yield measurements from 1.73 m^2 in each of 9 plots.
** Significantly different (P=.01) from the corresponding tillage treatment mean

Table 12: The effect of cropping method on grain yield of winter wheat, spring wheat, and barley.

Crop	Treatment	Grain yield (kg/ha)1/ Volunteer	Non-volunteer	Total
Winter wheat	NT	121*	1708**	1829**
	T	242	712	954
Spring wheat	NT	23	1589	1612
	T	5	1624	1630
Barley	NT	---	---	2055
	T	---	---	2131

1/ Average yield measurements from 1.73 m^2 in each of 9 plots
* Significantly different (P=.05) from the corresponding tillage treatment mean
** Significantly different (P=.01) from the corresponding tillage treatment mean

Table 13: Correlation coefficients for six selected variables compared to winter wheat grain yields.

Variable	r-value[1/]
Volunteer culms/m^2	-.83*
Spring soil moisture[2/]	.89*
Spring air temperature[3/]	.74
Summer air temperature[4/]	.64
Spring soil temperature[5/]	-.74
Summer soil temperature[6/]	-.92*

1/ Each correlation coefficient is for 6 X-Y pairs
2/ April 15, 1977 soil moisture to a depth of 1.2 m
3/ Average air temperature at 2 cm height for spring period
4/ Average air temperature at 2 cm height for summer period
5/ Average soil temperature at 2 cm depth for spring period
6/ Average soil temperature at 2 cm depth for summer period
* Significant at the P=.05 level

for annual cropping winter wheat production. An increased number of volunteer wheat plants/m^2 provided additional competition for the limited available water. The fact that moisture was a critical factor in determining yield is also demonstrated by a positive correlation of r=.89.

Winter wheat yield was further broken down into yield components of kernel weight, kernels per spike, and spikes per square meter (Table 14). Plants in no-till plots had more kernels per spike, and kernels were heavier than in tillage treatment plants. There were also more non-volunteer spikes/m^2 in no-till plots. Either soil moisture or temperature could have been responsible for these differences.

Spring wheat plants were slightly taller and the aboveground vegetative dry matter yield was slightly heavier in no-till plots during the year. However, treatment differences were not statistically significant (Table 10 and 11). Grain yields averaged somewhat higher from tillage plots, but the treatment difference was not significant (Table 12). In spite of the fact that yields were not significantly different, there were significant treatment differences noted in kernel weight (Table 14).

Barley vegetative and grain yields were determined to be slightly higher in tillage plots (Table 12). A statistical analysis did not show either tillage yield advantage to be significant.

Table 14: The effect of cropping method on three grain yield components of winter and spring wheat.

Crop	Treatment	Yield component		
		Kernel weight 1/ (mg/seed)	Kernels per spike 2/	Spikes per m^2 3/
Winter wheat	NT	36.2**	15.6**	273.8*
	T	31.7	7.5	224.6
Spring wheat	NT	27.1*	11.1	300.5
	T	28.5	13.5	297.3

1/ Average weights from kernels of 20 spikes in each of 9 plots

2/ Average numbers from 20 spikes in each of 9 plots

3/ Average numbers from .87 m^2 in each of 9 plots

* Significantly different (P=.05) from the corresponding tillage treatment mean

** Significantly different (P=.01) from the corresponding tillage treatment mean

The final objective of this study was to determine whether temperature and moisture conditions in no-till plots were sufficiently different from those of tillage plots to have made a significant contribution to the observed crop yield differences.

The only significant soil moisture difference was in winter wheat. No-till plots had accumulated 5.44 cm more available moisture over the winter period. According to Bauer et al. (1972) this additional amount of water could account for a yield increase of as much as 860 kg/ha in annually cropped spring wheat, and slightly more in winter wheat. Even under conditions of poor weed control and low soil fertility, they estimate that this amount of additional moisture should increase grain yields by 345 kg/ha. From these data it is concluded that soil moisture differences created in winter wheat plots were of sufficient magnitude during this year of below normal precipitation to contribute significantly to observed yield differences. The correlation coefficient between winter wheat grain yield and spring soil moisture is $r=.89$ (Table 13).

Midday spring and summer temperatures characteristic to tillage plots were significantly different from those of no-till in all three crops. These temperature differences were large enough to cause yield differences. For example, estimates by Thompson (1962) suggest that spring air temperature differences alone could have accounted for a 20 kg/ha yield increase in no-till plots. The cooler soil temperatures in no-till plots at this time of year are considered detrimental, however, and may have negated any yield benefit derived from warmer air temperatures. As much as a 70 kg/ha grain yield difference could have resulted from summer air temperature differences, the greater yield occurring in the tillage treatment. However, the less favorable summer soil temperatures in tillage plots may have diminished this yield advantage, or even overcome it entirely.

The air or soil temperature differences in either spring or summer were large enough to cause grain yield differences when considered individually. But, the net effect over the entire growing season may be small due to "cancellation effects".

Correlations between air temperature and winter wheat grain yield were not significant ($P=.05$) during either spring or summer. Correlations between soil temperatures and grain yield were significant during the summer, but not spring.

Tillage and no-till yields differed significantly only for that crop in which no-till had a significant moisture advantage (winter wheat). This is in spite of the fact that growing season temperatures differed significantly between the two treatments in all three crops. From this observation it was concluded that under the climatic conditions of the 1976-77 cropping season treatment temperature differences had little net effect on yield; or the effect was masked by other opposing influences. It was also concluded that the moisture variable was the primary factor involved in determining yield differences between treatments in this study.

SUMMARY

Temperature and moisture characteristics of tilled and non-tilled annually cropped small grains were studied in an effort to determine their influence on weed population and crop yield differences. The major findings and conclusions are:

A. Temperature

1) Minimum soil temperatures during the winter were as much as 1.9° C milder in no-till plots.

2) Air temperatures during the spring and summer were significantly warmer in no-till plots, the treatment differences diminishing with increasing height. At a height of 2 cm no-till plots averaged 2.2 and 4.1° C warmer than tillage plots during the spring and summer, respectively.

3) Soil temperatures during the spring and summer were significantly cooler in no-till plots; the greatest differences observed were near the soil surface. At a depth of 2 cm no-till plots averaged 2.3 and 4.5° C cooler than tillage plots during the spring and summer, respectively.

B. Moisture

1) More snow accumulated and snow remained in the plots over a larger portion of the winter in the no-till treatment.

2) No-till plots accumulated 5.44 cm more soil moisture to a depth of 1.2 meters during the winter period. The tillage treatment showed a net loss of soil moisture, primarily due to evaporation.

C. Weeds

1) Volunteer wheat was a serious problem in winter wheat, being more abundant in tillage plots.

2) After one growing season meadow salsify and prickly lettuce were more common in the no-till treatment. Common lambsquarters was more abundant in tillage plots.

3) Temperature and moisture differences between the two cropping systems apparently had little influence on weed populations.

4) The absence of tillage and use of glyphosate in no-till plots were seen as the major factors contributing to weed population differences between the two cropping systems.

D. Crop

1) Grain and vegetative winter wheat yields were significantly higher in the no-till treatment.

2) No significant yield differences were observed in spring wheat or barley.

3) Temperature differences were believed to have a minor influence on crop yield; or, the influence was hidden by other variables.

4) The moisture advantages of no-till cropping systems is credited as the major cause of significant yield differences in this study.

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APPENDIX

Appendix table 1: Precipitation recorded at Belgrade FAA Airport from Sept. 1, 1976 to Oct. 31, 1977.

Month	Precipitation in centimeters		
	1976-77	Normal*	Departure from normal
Sept.	4.17	3.53	.64
Oct.	2.72	2.54	.18
Nov.	.42	2.06	-1.60
Dec.	.28	1.50	-1.22
Jan.	1.70	1.68	.02
Feb.	.23	1.04	-.81
Mar.	3.94	2.21	1.73
Apr.	.89	2.95	-2.06
May	6.50	5.33	1.17
June	5.89	6.78	-.89
July	2.16	2.79	-.63
Aug.	3.51	2.92	.59
Sept.	7.62	3.53	4.09
Oct.	2.59	2.54	.05

* Climatological Data Montana average for the period 1941 - 1970

Appendix table 2: Soil analysis taken to a depth of 1.2 meters on Sept. 15, 1976 at Horseshoe Hills location.

Block	Organic Matter %	Phosphorous ppm	Potassium ppm	Nitrogen ppm	pH
1	2.1	15	290	2.37	8.2
2	1.8	11	280	1.77	8.2
3	1.6	9	250	1.12	8.2
Average	1.8	11.7	273.3	1.75	8.2

Appendix table 3: Maximum and minimum air temperatures (°C) recorded at Belgrade FAA Airport on dates corresponding to winter wheat plot temperature readings. Dates are grouped according to temperature categories.

Category	Date	Daily maximum	Daily minimum
Winter-subzero	Jan. 6	-8.9	-20.0
	Jan. 11	-8.3	-23.9
Winter-moderate	Feb. 1	1.7	-13.3
	Feb. 22	3.9	-1.1
	Mar. 1	.6	-5.6
	Mar. 25	3.9	-3.3
	Mar. 31	3.9	-8.3
Winter-melt	Feb. 7	2.8	-15.0
	Feb. 15	7.2	-6.7
	Feb. 17	10.0	-3.9
	Feb. 19	11.7	-5.0
Spring	Apr. 6	23.9	-2.8
	Apr. 15	16.7	-3.9
	Apr. 30	21.1	4.4
	May 12	23.9	1.1
	June 14	21.1	9.4
Summer	June 23	27.2	11.7
	July 1	31.1	5.6
	July 5	25.0	6.7
	July 8	27.8	8.3
	July 28	33.3	8.9

Climatological Data Montana

Appendix table 4: Ten most common weeds identified between Sept. 1976 and Aug. 31, 1977 at the study site in Horseshoe Hills.

WSSA Common name	Scientific name
Common lambsquarters	*Chenopodium album* L.
Downy brome	*Bromus tectorum* L.
Flixweed	*Descurainia sophia* (L.) Webb
Meadow salsify	*Tragopogon pratensis* L.
Prickly lettuce	*Lactuca serriola* L.
Russian thistle	*Salsola kali* L.
Skeletonweed	*Lygodesmia juncea* (Pursh) D. Don
Sticktight	*Lappula redowskii* (Hornem.) Greene
Waterpod	*Ellisia nyctelea* L.
Winter wheat (volunteer)	*Triticum aestivum*

Dewey, S. A.
Weed populations and crop yield as influenced by the temperature ...

DATE	ISSUED TO
JUL 2 1 1979	103 [illegible]
[illegible]	Terry Anvik [illegible] 4??A Lanford 994 4678
MAY 7 1986	[illegible] Maxwell [illegible]
[illegible]	Jamshid Golzy Box 165 6
MAY [illegible]	K J Dean [illegible] E Olive 6
[illegible]	J Palmer 405 N John Palmer
NOV 26 [illegible]	[illegible] Schm N. Hed

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