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REDUCED TILLAGE AND SOIL PHYSICAL PROPERTIES IN CONTINUOUS WHEAT

by

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INTRODUCTION

Conservation tillage has proved to be a useful technology in both crop production and natural resources conservation. The scope has been broadened over the years from the original stubble-mulch farming to no-till systems. Increasing need for economy of production and for pollution control has spurred study and acceptance of conservation tillage in recent years.

Reduced and no-tillage systems on wheat under dryland conditions have been investigated with varying results (Anderson, 1971; Lindwall and Anderson, 1977; Unger, 1977; Russ, 1978; Raines, 1978; Hobbs, 1978; Fenster and Peterson, 1979). Wheat yields have been measured and the effects on soil physical, chemical, and biological properties have been determined also.

The effect of plant residues on crop yields has received particular attention. Wheat yields have been both increased and decreased by the presence of crop residues on the soil surface. Increased yields have been credited to a higher fallow efficiency (Fenster and Peterson, 1979). Decreased yields are blamed on phytotoxin production (Cochran et al, 1977) and on difficulties of seeding with conventional drilling equipment (Lindwall and Anderson, 1977).

The effects of soil temperature, as influenced by straw mulches, on wheat growth and nutrient uptake were evaluated in order to explain lower yields under stubble-mulching practices (Brengle and Whitfield, 1969; Smika and Ellis, 1971; Whitfield and Smika, 1971). Greater water storage was obtained under no-till systems in Texas, but this did not cause higher yields compared with disk or sweep cultivation (Unger, 1977). A system of alternating tillage with disk or sweep cultivation was proposed to overcome the residue buildup with continuous no-till wheat. On tropical soils, the soil infiltration rate was found to be higher on no-till plots (Lal, 1977) but again yields were not significantly different on the different tillage systems. Changes in soil bulk density and soil strength under reduced or no-till systems have been studied (Lindwall and Anderson, 1977; Hobbs, 1978).

Knowledge of physical, chemical, and biological changes in the soil-plant environment under reduced tillage systems could lead not only to greater production, but also to be useful models for crop production systems (Unger and McCalla, 1980).

The objectives of this study were to:

a) assess the effect of crop residue on continuous wheat growth and yield under three tillage systems: conventional (tandem disk and chisel), reduced, and no-till;

b) evaluate the soil physical properties soil bulk density, soil strength, soil temperature, soil water, and soil infiltration rate under the three tillage systems and relate their changes to wheat yields;

c) develop a better method of seed placement through surface trash and into firm soil.

LITERATURE REVIEW

Conservation tillage, as a part of the crop production system, has crop residues on the soil surface or partially incorporated to reduce soil erosion and pollution (Unger and McCalla, 1980). The dominant factor governing the effectiveness of conservation tillage is the amount and distribution of crop residues left on the surface, but the amount of residues mixed into the upper part of the soil profile by tillage, the detachability of soil particles by rainfall, runoff, or wind, the presence or absence of residue strips and ridges on the contour, surface roughness, and canopy cover also influence the erosion process (Wischmeier, 1973).

Stubble-mulching and minimum tillage are major methods of conservation tillage. Stubble-mulching involves cultivation with non-inverting implements such as chisels, blade and sweep tools, and the rod weeder. Its success depends upon its effect on moisture storage, weed control, and erosion reduction (Fenster, 1973). Minimum tillage incorporates a purposeful reduction in the number of tillage operations employed in producing a crop. There are several ways to apply minimum tillage: wheel-track planting, plow planting, strip processing, chisel plowing, and zero tillage.

Growing a crop with a minimum of soil stirring has been attempted periodically, but satisfactory yields were seldom obtained until the development of herbicides like dalapon, amitrole, and atrazine which controlled weeds without undue damage to the crop (Baeumer and Bakermans, 1973). Bipyridilium herbicides are non-selective herbicides with no residual effects due to adsorption on soil colloids. The use of these broadened even more the scope of reduced tillage. Goals of reduced tillage systems for continuous wheat production are conservation of natural resources, control of pollution, and reduction of energy requirements.

Biological and chemical processes that occur in the soil or on its surface change when reduced tillage systems are applied (Unger and McCalla, 1980). Such changes have been extensively studied in order to delineate and understand the new environment created with this technology and to understand the role played by each in this mechanism. Good understanding has been acquired in some topics; others need further investigation.

Residue Management

The management of the crop residues after harvest is one of the key factors when reduced tillage systems are practiced. The main function performed by crop residues left on the ground is to protect the soil against erosive forces (wind and water). The residues absorb a great part of the kinetic forces involved in these processes (Wischmeier, 1973; Unger and McCalla, 1980). The amount of water erosion is inversely related to the amount of surface residues (Wischmeier, 1973). Residues also reduce wind erosion with the degree of reduction depending on the quantity, kind, and orientation of residues (Woodruff and Siddoway, 1973).

Straw cover not only affects the velocity of the wind near the ground (height of zero displacement) and the severity of raindrop splash, it also impacts on soil properties (soil erodibility). Smika and Greb (1975) reported a 5% increase in the nonerodible aggregate fraction when straw mulch was increased from 1680 to 3360 kg/ha. The amounts of fats, waxes, and oils in the soil were increased also.

There are four main systems of residue management: left on the surface (standing or flat), mixed with the surface soil, turned under, and removed from the field (burned or harvested). The method of residue management affects soil environment and crop growth (van Doren and Allmaras, 1978). Soil environment changes are reflected in different temperature patterns, moisture profiles, and soil strength values. Crop growth reflects chemical and physical changes.

Fenster and Peterson (1979), on a wheat-fallow rotation, showed that residues decompose only slowly under a chemical fallow regime. During a 14-month chemical fallow period losses were about 20-25%. Douglas et al (1980) reported losses of wheat straw over a 26-month wheat fallow period of 25, 31, and 85% from standing stubble, matted surface straw, and incorporated straw, respectively. Even though residues provide outstanding protection against erosive forces, residue buildup over several years of minimum or no-tillage systems may cause serious problems.

Smika et al (1969) found a positive correlation between mulches and soil water stored at seeding time but not in all cases and years. Mulched soils accumulated more water than did bare soils, but straw mulch rates higher than 3360 kg/ha significantly reduced soil NO_3-N during fallow. Under no-tillage conditions in a wheat-fallow sequence in Nebraska Fenster and Peterson (1979) found a moisture storage efficiency of 40 to 50%. This was reflected in higher no-till wheat yields.

One common problem, faced when reduced tillage systems are conducted, is the difficulty of getting good crop stands. Reduced wheat stands, associated with surface residues of minimum or no-till practices, have been blamed on phytotoxic effects and on poor seed placement. Phytotoxic effects seem to be caused by leaching substances liberated by surface straw mulches. Cochran et al (1977) presented data suggesting that plant inhibitors "may be present in wheat, barley, and blue grass straw during the spring, when most secondary roots are formed". Their data also show a link between toxicity periods and wheat emergence in the fall. Plants which had grown through heavy residues had fewer tillers, higher crown nodes, and in general reduced vigor, but "wheat seedlings having good soil contact by the primary roots were not always noticeably abnormal in the early growth stage, even under heavy surface straw." They considered management of the residues the clue to solving this problem. In order to get deeper crown development the residues should be moved away from the seeded row. Elliot et al (1978), suggested that although phytotoxicity and poor wheat growth under straw cover are related, further studies of the management of residues are needed to develop techniques that will insure good emergence and good stands.

Seeding

Reduced stands and reduced wheat yields are often associated with minimum or no-tillage systems. These reductions may be caused by seeding machinery that does not work through the residues and place the seed into firm contact with the soil. Lindwall and Anderson (1979) found that double and triple disc press drills were unable to penetrate no-till lands under heavy residue conditions (> 3700 kg/ha). They reported poor stands, retarded emergence, and slow growth on fields seeded with these drills. Drills equipped with hoe openers penetrated the soil better, but with heavy residue seeding was still difficult. Semi-deep-furrow drills performed best. These authors recommended moving residues from the seed row whenever possible under minimum tillage practices.

Raines (1978), in Kansas, noted a year-by-year decrease of yields of continuous wheat under no-till (chemical weed control) management. He blamed this reduction on the failure of seed drills "to place the seeds in the soil firmly and cover it adequately". He concluded that some tillage should be included in seedbed preparation for continuous wheat production.

Weed control

Baeumer and Bakermans (1973) considered weed infestation a main cause of reduced yields on untilled surfaces. Anderson (1971), working with chemical fallow in a wheat-fallow rotation, found foxtail barley (*Hordeum jubatum* L.)

difficult to control under complete chemical treatment. He used 2,4-D ester to control annual weeds. He also reported some difficulties in controlling volunteer wheat. A combination of 2,4-D ester, MCPA, and paraquat was required to control volunteer wheat and annual grassy weeds completely. According to Unger and McCalla (1980) some sort of change in weed population should be expected in no-till systems because of the change from mechanical to chemical weed control.

Recently, Gadhiri et al (1981), reported that the use of combinations of selective herbicides, like metribuzin and oryzalin and others, on tillering wheat not only provided longer weed control after harvest but also caused less winter wheat injury.

Soil Environment

Four soil physical properties that are affected by minimum or no-till systems will be considered in this review: soil bulk density, soil strength, soil temperature, and soil water.

Soil Bulk Density and Soil Strength:

Baeumer and Bakermans (1973), reviewing zero tillage results, presented data showing lower total porosity on untilled plots. The main change occurred in the large pore fraction (> 30 μm). These differences were greater in surface layers.

Lindwall and Anderson (1977) reported seeding problems on untilled surfaces when soil bulk density was greater than 1.2 g/cm^3. Traffic areas with bulk density greater than 1.2 g/cm^3 decreased wheat yields by as much as 50% because of improper seed placement. Increased soil bulk density could cause a decrease in saturated hydraulic conductivity (Unger and McCalla, 1980) and higher impedance to root penetration, but high bulk density alone does not explain poor root penetration totally; other factors are involved. Taylor and Gardner (1963), working with cotton plants grown in cylinders at different bulk densities and moisture contents, found that root penetration correlates inversely with bulk density, but this relationship was affected by water content. A better correlation was obtained between soil strength values and root penetration percentages ($r = 0.96$).

Higher soil strength values might be expected under no-till conditions. Hobbs (1978) showed significant increases in soil strength in chemically treated no-till plots for both wheat and row crops at Manhattan and Belleville (Kansas), but the increases did not seem to affect seed placement during the seeding operation.

Soil Temperature:

Unger and McCalla (1980) considered soil temperature an important parameter that influences "chemical and biological components of the soil plant environment." Smika and Ellis (1971) studied the effect of soil temperature with or without straw mulch on wheat growth and nutrient concentration. They found reduced tillering of wheat plants grown in a growth chamber at soil temperatures less than $10^{\circ}C$ for 50 days, but numbers of tillers and heads per plant were not significantly different on mulched and bare plots when soil temperature was the same. However, fewer tillers were produced on mulched plots when mulching caused lower spring soil temperatures. Concentration of nitrogen was lower in plants grown on mulched soils without nitrogen fertilization. Potassium and iron uptake appeared to be decreased by cooler temperatures.

Whitfield and Smika (1971) in a greenhouse study found that straw affected spring wheat growth but had very little effect on winter wheat varieties. Boatwright _et al_ (1976) studied the effect of mulch on soil temperature and on nutrient uptake by spring wheat. He believed the crown node was the most low-surface-temperature sensitive part of the plant. He linked high crown node development with phytotoxicity, low soil temperature, and seeding problems.

Soil Water:

Unger and McCalla (1980) expressed the need to develop a model applicable to conservation tillage in order to understand the system better and to extrapolate results. They believed that tillage variables influence soil temperature, soil air, and water content which in turn influence crop growth and yield. Anderson (1971), in a summer fallow-wheat study in Saskatchewan (Canada), found that the use of herbicides instead of tillage did not affect soil moisture conservation, soil temperature, or wheat yields.

Unger (1977) found in a Texas study that water content at harvest near the surface of no-till plots was higher than in tilled plots. He suggested that this was because residues "increased infiltration and decreased evaporation after precipitation, which occurred as wheat approached maturity." He associated higher water storage in no-till plots during relatively dry years with residue effects.

Hobbs (1978) recorded higher water content to a depth of 160 cm in chemically treated continuous wheat plots than in conventionally treated ones at all times during crop growing season.

MATERIALS AND METHODS

The experimental site was on the Kansas State University Agronomy Farm, located 2 km north of Manhattan, Kansas. The soil is described as Smolan silty clay loam (Pachic Argiustoll; fine, montmorillonitic, mesic), derived from loess with a B_2t silty clay horizon at 37-107 cm (Bidwell, 1981). Average annual precipitation is 800 mm with 75% falling between April 1, and September 30. Summers are warm to hot and winters cold (Jantz et al, 1975).

The experimental design selected was split plot with three replications. Three residue treatments were used as main blocks with combinations of three tillage treatments and two seed drills as sub-blocks (a total of eighteen different combinations per replication). Plot dimensions were 7.5 by 15 m.

Residue variables consisted of: a) no residue treatment after harvest, untreated (U); b) residues chopped with a rotary mower, mowed (M); and c) residues removed by burning, burned (B).

Three tillage treatments were evaluated: a) conventional with chisel plow and tandem disk, (C); b) reduced tillage with major weed control obtained by the use of herbicides; 2,4-D (2,4-Dichlorophenoxiacetic acid) at 1.1 kg/ha and glyphosate (N-[phosphonomethyl] glycine) at 2 kg/ka and if necessary for weed control or seedbed preparation one tillage operation with chisel or disk just before planting (R); and c) no-till system using the same kind and doses of herbicides for weed control as in b) (Z).

Two drills were used in this experiment: a conventional John Deere single disk planter (D) and an experimental machine (E) designed by Prof. C. Swallow and constructed at the North Agronomy Farm. It was built from an FMC Side-Winder (rotary tiller) with sixteen 1.25 cm-thick straight disks replacing the tillage tines. "Teeth", 1.9 cm wide, were welded at 30-cm intervals around the circumference. The disks are set 20 cm apart on the main shaft and are turned by a power takeoff. Grain planter tubes convey seed from the supply boxes to shoes immediately behind each disk. Press wheels are used as covering devices. The drill is equipped with a fertilizer attachment which places liquid fertilizer 7.5 cm beside and 5 cm below the seed.

Nitrogen and phosphorous dressing was added to all plots at the rate of 77 and 22 kg/ha respectively. On conventional plots, the fertilizer was applied as a liquid during the chisel operation to a depth of 15 cm. On reduced and no-till plots, fertilization was performed at seeding time with the experimental drill. On disk-seeder plots, granulated starter fertilizer was fed from the fertilizer attachment down the grain tubes; additional nitrogenous fertilizer was broadcast in the spring.

Winter wheat (Triticum aestivum var. Newton) was seeded at a rate of 66 kg/ha on October 1, 1980. Spring application of 2,4-D was necessary to control tansy mustard (Descurainia pinnata (Walt.) Britt.) and field bindweed (Convolvulus arvensis L.).

Straw cover was evaluated immediately after planting using a string with 100 beads attached 15 cm apart (Sloneker and Moldenhauer, 1977). The string was placed diagonally across the plot and each significant piece of straw which was directly below a bead was taken as one count (1% of cover). This procedure was repeated four times in each plot. Emergence counts were taken 21 days after planting on a 2-m row basis; four counts were taken and averaged for each plot. At heading stage (4/21/1981), different visual determinations were made on each plot: stand (uniformity), heading stage (percentage), plant height, color, weeds, and drill failures.

A Proctor needle penetrometer fitted to a proving ring and dial gauge was used to determine soil strength in the conventional and no-till treatments at three different depth intervals: 0-0.8; 0.8-3.0; and 3.0-8.5 cm. Six measurements were averaged and converted to kg/cm^2 to obtain values for each plot. Soil bulk density values were obtained by sampling all plots at two different sites with a double-cylinder, hammer-driven core sampler from a depth of 2.5 to 10.0 cm. Soil cores were oven dried at 105°C for 48 hrs. Results are expressed in g/cm^3,

Minimum and maximum soil temperatures at a depth of 5 cm were recorded in °C with a thermocouple thermometer[1/] during November, April, May, and June.

Total water by depth in the soil profile was obtained gravimetrically for the top 7.6 cm and using a neutron probe[2/] from 7.6-160 cm at intervals of 15.24 cm. Standard aluminum access tubes were driven into the ground to accommodate the neutron probe. Moisture values were recorded at different times during the growing season from November through June.

Water infiltration rate was determined using double ring infiltrometers (Bertrand, 1965) on all the residue variables from conventional and from untilled treatments. Each infiltration run lasted 6 hours with the following reading sequence: 0, 20, 40, 60, and 120 minutes, and 3, 4, 5, and 6 hours. A total of six days was needed to complete the study. It was possible to handle only six infiltration determinations per day (all the variables included in one replication), obtaining two sets of data for each plot.

Statistical analyses were performed using computing facilities at Kansas State University, the level chosen for significance was 5%.

[1/] Wescor, Inc. TH60TC thermometer

[2/] Troxler model 2601

RESULTS AND DISCUSSION

Results and discussion are presented in two parts: wheat production and soil environment. The first contains information concerning emergence and stem counts, residue cover, wheat yields, and drill performance. The second section is devoted to soil bulk density, soil strength, soil temperature, and soil water results.

Wheat Production

Seedling emergence and stand development, general crop condition, and yield were influenced to some degree by the method of crop residue management, tillage, and drill types.

Crop Stand:

Wheat stand in the different plots was measured on two occasions: 21 days after planting (emergence count) and 5 days after harvest (stem count). Stands were relatively different at the two times. Emergence-count averages for main treatments are presented in Table 1. Emergence count analysis of variance revealed significant interactions ($P = 0.05$) in all two-way combinations: residue-tillage, tillage-drill, and residue-drill. (See Fig. 1, 2, and 3.) After-harvest stem-count results showed a different situation with higher counts on no-till plots than on reduced and conventional tilled plots. In addition, plots seeded with the experimental drill had more stems than the ones seeded with the single disk drill, the reverse of the situation in the fall (Table 2). Wheat yields were significantly correlated with stem counts ($r = 0.49$) but not with emergence counts. Average straw cover percentages are presented along with the emergence count averages for the different treatment combinations in Table 3.

As emergence counts were significantly lower on mowed plots, a possible

Table 1. Emergence count averages on wheat plots expressed as number of plants/2-m row.

Residue	Mean	Tillage	Mean	Drill	Mean
Untreated	50[a]	Conventional	48[a]	Disk	51[a]
Burned	48[a]	Reduced	48[a]	Experimental	43[b]
Mowed	44[b]	Zero	46[a]		

Note: Means followed by the same letter are not significantly different.

Table 2. Stem counts on wheat plots after harvest expressed as number of plants/2-m row.

Residue	Mean	Tillage	Mean	Drill	Mean
Untreated	193[a]	Zero	202[a]	Experimental	196[a]
Mowed	181[a]	Reduced	189[b]	Disk	168[b]
Burned	167[a]	Conventional	154[c]		

Note: Means followed by the same letter are not significantly different.

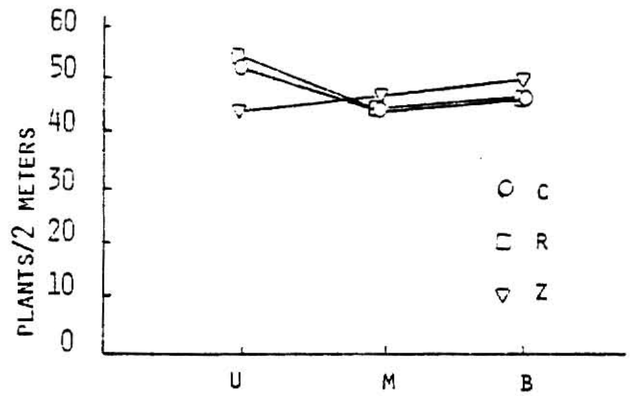

Fig. 1. Residue-tillage effect on wheat emergence.

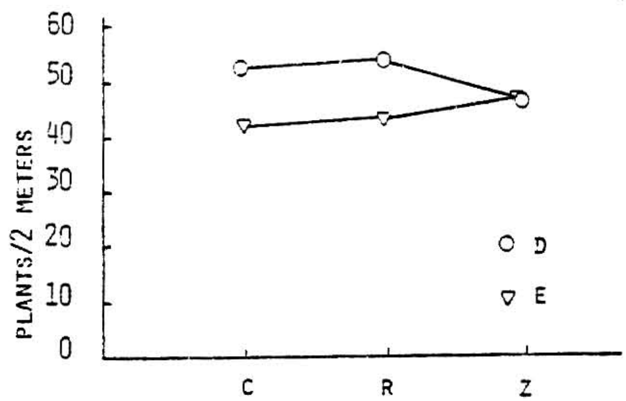

Fig. 2. Tillage-drill effect on wheat emergence.

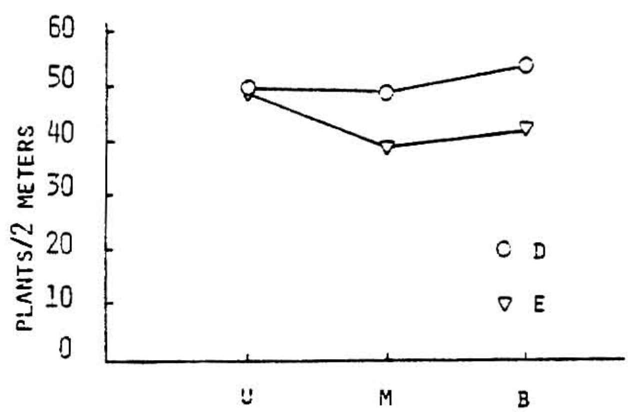

Fig. 3. Residue-drill effect on wheat emergence.

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Table 3. Emergence Counts (plants/2-m row) and straw cover (percent) for the different treatment combinations.

Treatments		Untreated		Mowed		Burned	
		Emerge count	Straw cover	Emerge count	Straw cover	Emerge count	Straw cover
Conventional	Disk	58	34	48	11	54	1
	Experimental	46	41	39	20	40	0
Reduced	Disk	57	81	50	68	54	2
	Experimental	51	79	38	68	40	1
Zero	Disk	35	98	49	94	55	2
	Experimental	50	89	42	85	45	1

relationship between emergence and straw cover was tested but no significant correlation was determined. The emergence count on untreated, disk-seeded plots (Table 3) was similar for conventional and reduced tillage systems (58 and 57, respectively) but lower on no-till plots (35). These latter plots had an average of 98% straw cover. Although emergence counts were lower on plots seeded with the experimental drill, surface residues did not likely affect emergence. On mowed plots seeded with the disk drill, counts were similar on all tillage treatments regardless of straw cover amount. Without residues, both drills performed equally over the different tillage treatmennts, but again, the experimental planter had lower emergence. A possible closer contact between seed and residues may explain the overall effect of lower emergence counts on mowed plots, but evidence is elusive.

Field Observations:

Visual observations on April 29 showed a higher heading percentage for the burned treatments. Considering tillage treatment alone, conventional-tilled plots headed sooner than reduced or no-till plots. In general, wheat plants growing on reduced and no-till plots, whether with untreated or mowed residues, displayed darker green leaves and more vegetative growth.

Yields:

Wheat yields are presented in Fig. 4. Table 4 presents wheat yield means arranged according to the three main effects studied: residue management, tillage systems, and drills. Differences in yield among crop residue treatments were not significant. Zero tillage yield was significantly higher than those obtained under reduced and conventional tillage treatments. The experimental drill produced significantly better yields than the single disk drill. Combining the main effects in this crop production model the best two combinations for growing wheat were provided by seeding with the experimental

Table 4. Average wheat yields for residue, tillage, and drill treatments.

Treatment	Yield q/ha
Residue	
Untreated (U)	22.0[a]
Mowed (M)	21.5[a]
Burned (B)	21.2[a]
Tillage	
Zero (Z)	23.7[a]
Reduced (R)	21.2[b]
Conventional (C)	20.1[b]
Drill	
Experimental (E)	22.8[a]
Disk (D)	20.5[b]

Note: Means followed by the same letter are not significantly different.

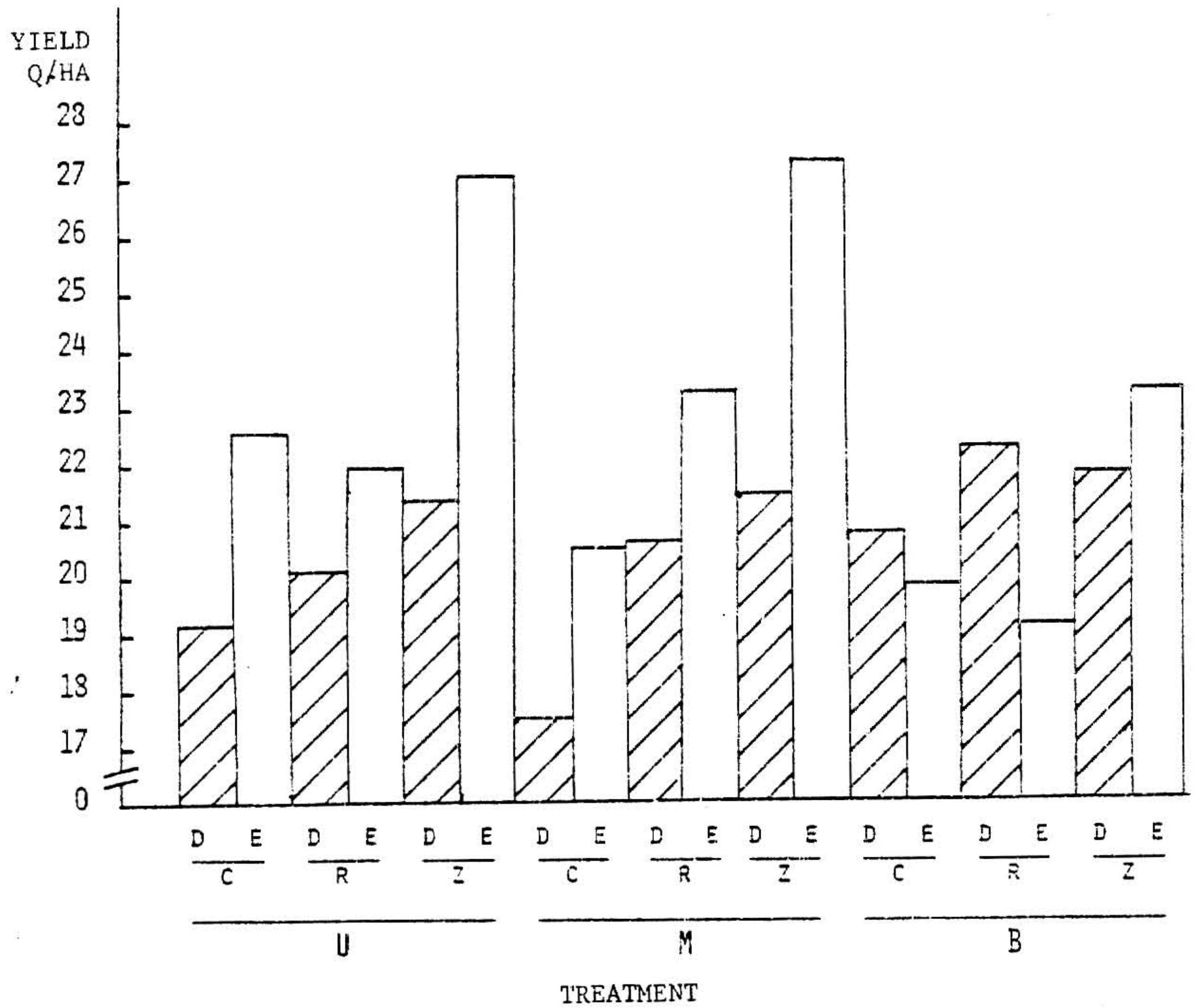

Fig. 4. 1980-81 wheat yields expressed in q/ha. $LSD_{0.05}$ (within each residue treatment) = 6 q/ha.

drill in no-till surfaces either on untreated or mowed residues (Fig. 4). It should be mentioned here that the summer period of 1980 was hot and dry. In general, wheat production during 1980-1981 season was affected by water deficiencies. Average wheat yields for the State of Kansas was 16.8 q/ha (Walter and Fjell, 1981) while the average yield for the experimental site was 21.6 g/ha.

Wheat weight by measured volume averages, expressed in kg/hectoliter, did not differ significantly among treatments except for tillage effects. Zero-till (Z) and conventional (C) wheat weights were significantly higher than reduced-tilled wheat weights, 72.3, 72.1 and 71.4, respectively.

Differences in nutrient uptake by wheat plants, reflected as differences in nitrogen and phosphorous grain contents, are presented and grouped according to main treatments in Tables 5 and 6.

The information presented above indicates that the presence of wheat surface residues on the plots did not reduce yield based on 1980-1981 data; rather, surface residues had an indirect positive effect on wheat yields. Higher production was obtained using the experimental drill on untreated or mowed, zero-till plots, but these results cannot be reasonably explained on a single cause basis. The crop was seeded under dry conditions. During October 14-17 it rained 6.5 cm helping to ensure germination. During October 27-28, the crop received 2 more cm of water. Conditions during January through March were dry and with little snow. In the spring, the plots started to look different from the fall. Fig. 5, 6, 7, and 8 show pictures taken at the end of March. Fig. 5 contrasts two untreated plots seeded with the experimental drill on reduced (right) and conventional tillage (left). Fig. 6 presents two untreated disk seeded plots under zero-till (left) and conventional tillage (right). Fig. 7 and 8 match two mowed, zero-till plots seeded with the single disk drill (7) and the experimental model (8).

Table 5. Nitrogen content (%) in wheat grain.

Residue	N (%)	Tillage	N (%)	Drill	N (%)
Burned	2.64^{a}	Reduced	2.56^{a}	Experimental	2.56^{a}
Untreated	2.48^{b}	Zero	2.49^{a}	Disk	2.42^{b}
Mowed	2.33^{c}	Conventional	2.42^{a}		

Note: Means followed by the same letter are not significantly different.

Table 6. Phosphorous content (%) in wheat grain.

Residue	P (%)	Tillage	P (%)	Drill	P (%)
Mowed	0.34^{a}	Zero	0.33^{a}	Experimental	0.33^{a}
Untreated	0.33^{a}	Reduced	0.33^{a}	Disk	0.32^{a}
Burned	0.30^{b}	Conventional	0.31^{a}		

Note: Means followed by the same letter are not significantly different.

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Fig. 5. View of growing wheat March 27 showing crop condition on untreated residue plots seeded with the experimental drill. The left area is conventional drill; the right reduced till. The stake for thermocouple support and the access tube for moisture determination are shown in teh center of the photograph.

Fig. 6. View of growing wheat March 27 on untreated residue plots seeded with single disk drill. The left area is zero till; the right- conventional till.

Fig. 7. View of growing wheat March 27 showing crop condition on mowed residue, zero-till plot, seeded with the single disk drill.
(Compare with Fig. 8-seeded with experimental drill.)

Fig. 8. View of growing wheat March 27 showing crop condition on mowed residue, zero-till plot, seeded with the experimental drill.
(Compare with Fig. 7-seeded with single disk drill.)

Different and interrelated reasons are proposed to explain final yield results. The disk drill placed the seed at a shallower depth than the experimental model and while emergence was good on the disk drill plots, more winter killing occurred because the drier conditions and lower temperatures near the surface likely affected the crown node development (Boatwright et al, 1976). Drier surface soil under conventional tillage system affected tillering and contributed to water stress experienced by the crop at heading time. Further discussion about soil water is provided in the next section.

Nitrogen and phosphorous content in wheat grain agrees in general with yield results, except for the nitrogen outcome with the different residue treatments. Biederbeck et al (1980), found a higher amount of exchangeable NH_4-N for single burns of wheat straw in a study carried out in Saskatchewan (Canada). This result may help to explain why wheat from plots with burned residues contained more nitrogen, or it may be that decomposition of straw on the unburned plots tied up available nitrogen.

According to these results and the conditions in which the study was conducted, surface residues did not have a negative influence on wheat production. When proper seed placement was achieved, surface residues contributed to a higher wheat yield. The experimental drill was capable of penetrating untilled surfaces either with or without residues. Observations after planting showed that the experimental model incorporates part of the residues or scatters it over the surface during the seeding operation.

Soil Environment

Results of four soil physical properties are presented and discussed in this section: soil bulk density, soil strength, soil temperature, and soil water.

Soil Bulk Density:

Results of treatment effects on bulk density are presented in Table 7. Soil bulk densities for zero-tillage treatment were significantly higher than for reduced and conventional treatments. Disk-seeded plots also had higher bulk densities than experimental drill plots. Although zero tillage was associated with significantly higher bulk densities, these did not reduce emergence or crop yields. Accordingly, these results do not agree with those obtained by Lindwall and Anderson (1977). A direct variation related to the change in soil bulk density is the value of total porosity which was lower in no-till plots. Also, fraction of large pores should be expected to decrease under no-till practices (Baeumer and Bakermans, 1973). Differences in soil bulk density observed between drills may be due to the fact that the experimental model produces some lateral cracking. General soil bulk density results agree with those obtained by Hobbs (1978) with no-till row crops and by Gantzer and Blake (1978) in a no-till corn study.

Soil Strength:

Values of soil strength at the three depths studied are presented in Table 8. Zero tillage values were significantly higher than conventional tillage at all three depths studied. There was a significant difference in soil strength for the 0.0 to 0.8 cm depth between drills. There was a significant interaction ($P = 0.05$) between drill used and kind of tillage performed for the 0.0 to 0.8 cm depth (Fig. 9). Fig. 10 presents another significant interaction effect between tillage and residue treatments in the 3.0 to 8.5 cm depth.

Emergence counts did not correlate with soil strength values at any of the three depths studied. Correlation coefficients were slightly negative but not significant. The interaction effect observed in 0.0 to 0.8 cm depth

Table 7. Soil bulk density means expressed in g/cm^3.

Residue	Mean	Tillage	Mean	Drill	Mean
Mowed	1.22[a]	Zero	1.24[a]	Disk	1.23[a]
Untreated	1.19[a]	Reduced	1.18[b]	Experimental	1.16[b]
Burned	1.17[a]	Conventional	1.16[b]		

Note: Means followed by the same letter are not significantly different.

Table 8. Soil strength means expressed in kg/cm^2.

Treatment	Depth (cm) 0-0.8	0.8-3.0	3.0-8.5
Residue			
Untreated	1.99[a]	8.41[a]	15.79[a]
Mowed	1.95[a]	7.35[a]	13.67[a]
Burned	1.90[a]	7.38[a]	19.98[a]
Tillage			
Conventional	0.00[a]	0.10[a]	2.53[a]
Zero	3.89[b]	15.32[b]	30.43[b]
Drill			
Disk	2.65[a]	7.70[a]	16.76[a]
Experimental	1.24[b]	7.72[a]	16.19[a]

Note: Means followed by the same letter are not significantly different.

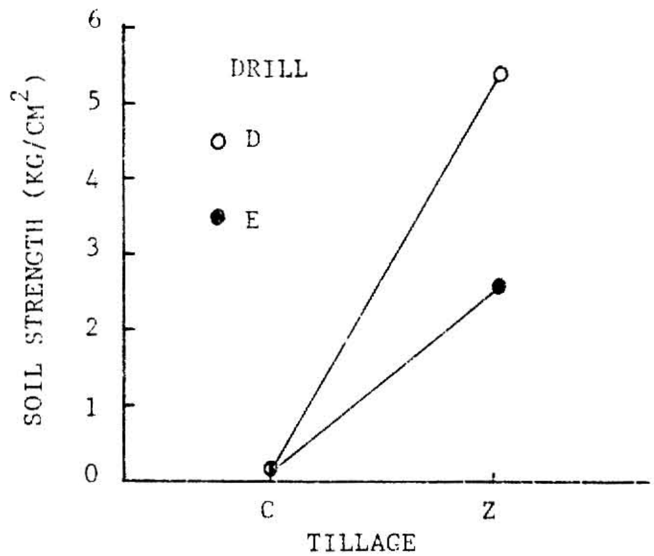

Fig. 9. Tillage-drill effect on soil strength in 0.0-0.8 cm depth.

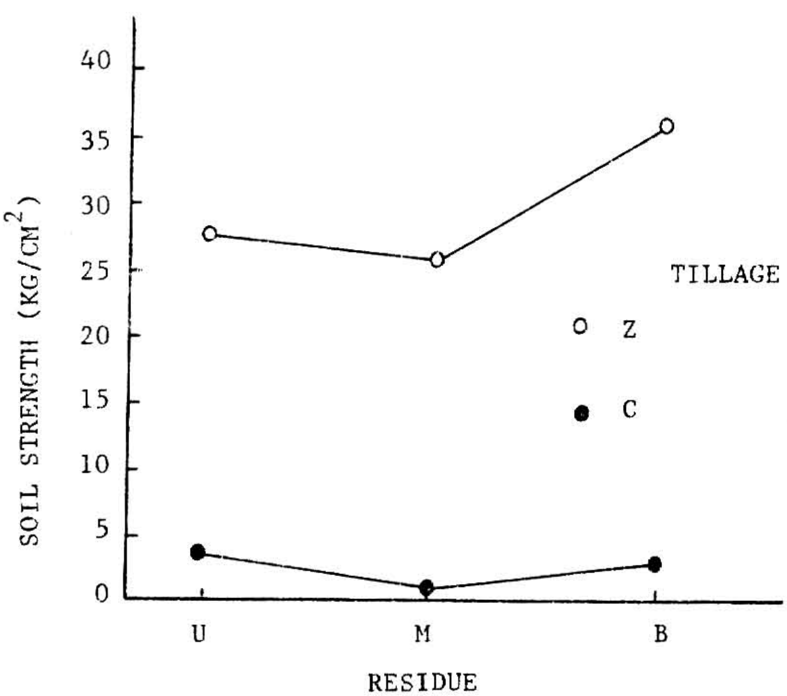

Fig. 10. Residue-tillage effect on soil strength in 3.0-8.5 cm depth.

between tillage and drills (Fig. 9) may be explained by the degree of loosening caused by the two drills the previous year. In Fig. 10 it is possible to appreciate that the difference in soil strength in the third depth between conventional and zero-till plots was larger when residues were burned. At this time, no reasonable explanation is provided but additional results may help to explain this fact.

Soil Temperature:

Soil temperatures at a depth of 5 cm were recorded during different periods from November through June (morning temperatures were taken at dawn and afternoon readings at approximately 3:30 hours). November and the first set of April results consisted of the average temperatures during 6-day periods. The second April period was calculated from readings taken during 3 days and May-June data were taken from 2 days. In the case of morning temperatures, neither principal treatments nor interaction effects were significantly different. Differences in average afternoon temperatures due to tillage and residue treatments were significant at different times during the period of study (Table 9).

Differences in afternoon soil temperatures between conventional and no-till systems whether with untreated or mowed residues varied within 1.2°C and 2.8°C through the different periods. The depressing effect of surface residues on afternoon soil temperatures lessened as the wheat canopy covered the ground. Differences of 1.8°C for the November period between residue and no-residue conditions on zero-till plots narrowed to 1.0°C during the May-June period.

Untilled plots presented lower afternoon soil temperatures than conventional tilled treatments (differences of 1.0 to 2.2°C) due to higher volumetric heat capacity, greater water content in the surface layer, and greater

Table 9. Soil temperature at 5 cm depth expressed in ^{o}C

Treatment	November		April (I)		April (II)		May-June	
	am	pm	am	pm	am	pm	am	pm
Residue								
Untreated	9.3^{a}	12.7^{a}	11.5^{a}	19.0^{a}	13.6^{a}	23.6^{a}	18.0^{a}	27.4^{a}
Mowed	9.4^{a}	12.9^{ab}	11.5^{a}	19.2^{a}	13.4^{a}	23.5^{a}	17.9^{a}	27.3^{a}
Burned	9.3^{a}	13.8^{b}	11.7^{a}	20.2^{a}	13.2^{a}	24.3^{a}	18.0^{a}	27.7^{a}
Tillage								
Conventional	9.3^{a}	13.6^{a}	11.7^{a}	20.2^{a}	13.3^{a}	24.9^{a}	18.0^{a}	28.2^{a}
Zero	9.4^{a}	12.6^{a}	11.4^{a}	18.6^{b}	13.5^{a}	22.7^{b}	17.9^{a}	26.7^{b}
Residue-Tillage								
Untreated Conventional	9.3	13.5	11.8	19.9	13.4	25.0	18.1	28.3
Untreated Zero	9.3	11.8	11.1	18.0	13.7	22.2	17.8	26.5
Mowed Conventional	9.4	13.5	11.6	20.4	13.4	24.8	18.0	28.4
Mowed Zero	9.3	12.3	11.3	18.0	13.3	22.2	17.8	26.3
Burned Conventional	9.0	13.9	11.8	20.4	13.2	25.0	18.0	28.0
Burned Zero	9.6	13.8	11.7	19.9	13.3	23.7	18.0	27.4

Note: Means followed by the same letter are not significantly different.

amounts of solid materials. These conditions, however, did not have a great effect on the temperature responsiveness of no-till soils early in the spring.

Soil Water:

Analysis of variance on total soil water content to a depth of 160 cm was performed individually for each sampling date. Soil water contents by date for residue and tillage treatments are presented in Table 10. There was no significant variation among residue treatments. Greater water contents were available through the growing season in untreated or mowed plots but tillage treatments hardly differed in total soil water content.

A soil infiltration study was carried out during the summer of 1981. Cumulative infiltration curves were drawn from average data for each treatment and, from these, infiltration rate curves were derived (Fig. 11). Conventional tilled plots had higher final infiltration rate regardless of residue treatment applied. Infiltration on mowed plots was consistently lower although not significantly different from burned or untreated ones (Table 11).

Because no major differences of total soil water content among treatments were obtained, soil water distribution by depth on different dates was analyzed. Fig. 12, 13, and 14 show the distribution of soil moisture expressed on volumetric basis by depth and for different treatment combinations of residue and tillage on three dates. Zero-till plot profiles with surface residues exhibit greater water content than conventional tilled ones to a depth of 84 cm (arbitrarily taken for the purposes of this analysis). Below that depth the situation changes in favor of the conventional tillage treatments. Total soil water content to a depth of 84 cm was analyzed statistically by date and results are presented in Table 12. Differences in soil water were significant in the fall between no-till and conventional-tilled surfaces. Early in the spring the presence of surface residues produced significant

Table 10. Total soil water to 160 cm expressed in cm

Treatment	Date										
	11/5	11/12	11/19	12/5	3/27	4/10	4/24	5/6	5/21	6/4	6/16
Residue											
Untreated	51.9	52.2	52.8	52.3	54.5	51.3	50.7	50.1	54.4	53.0	53.7
Mowed	52.8	53.0	53.6	53.2	54.0	50.4	50.0	49.2	54.7	52.9	53.9
Burned	50.9	51.2	51.5	51.3	51.4	48.7	48.6	49.1	52.7	51.6	52.6
Tillage											
Conventional	51.8	51.9	52.5	52.0	52.9	50.0	50.0	49.7	54.3	53.0	54.1
Zero	52.0	52.5	52.7	52.5	53.6	50.2	49.5	49.3	53.5	51.9	52.8
Residue vs Tillage											
Untreated Conven.	52.6	52.6	53.2	52.7	54.0	50.9	50.7	50.0	54.7	53.3	54.5
Untreated Zero	51.3	51.9	52.4	51.9	54.9	51.7	50.7	50.2	54.0	52.7	53.0
Mowed Conventional	51.6	52.0	52.5	52.0	53.0	49.9	49.8	49.1	55.3	53.4	54.6
Mowed Zero	53.9	54.1	54.7	54.4	55.0	51.0	50.0	49.3	54.0	52.3	53.2
Burned Conventional	51.1	51.1	51.9	51.5	51.9	49.4	49.6	49.9	53.0	52.3	53.1
Burned Zero	50.8	51.3	51.1	51.2	50.9	48.0	47.7	48.4	52.5	50.9	52.1

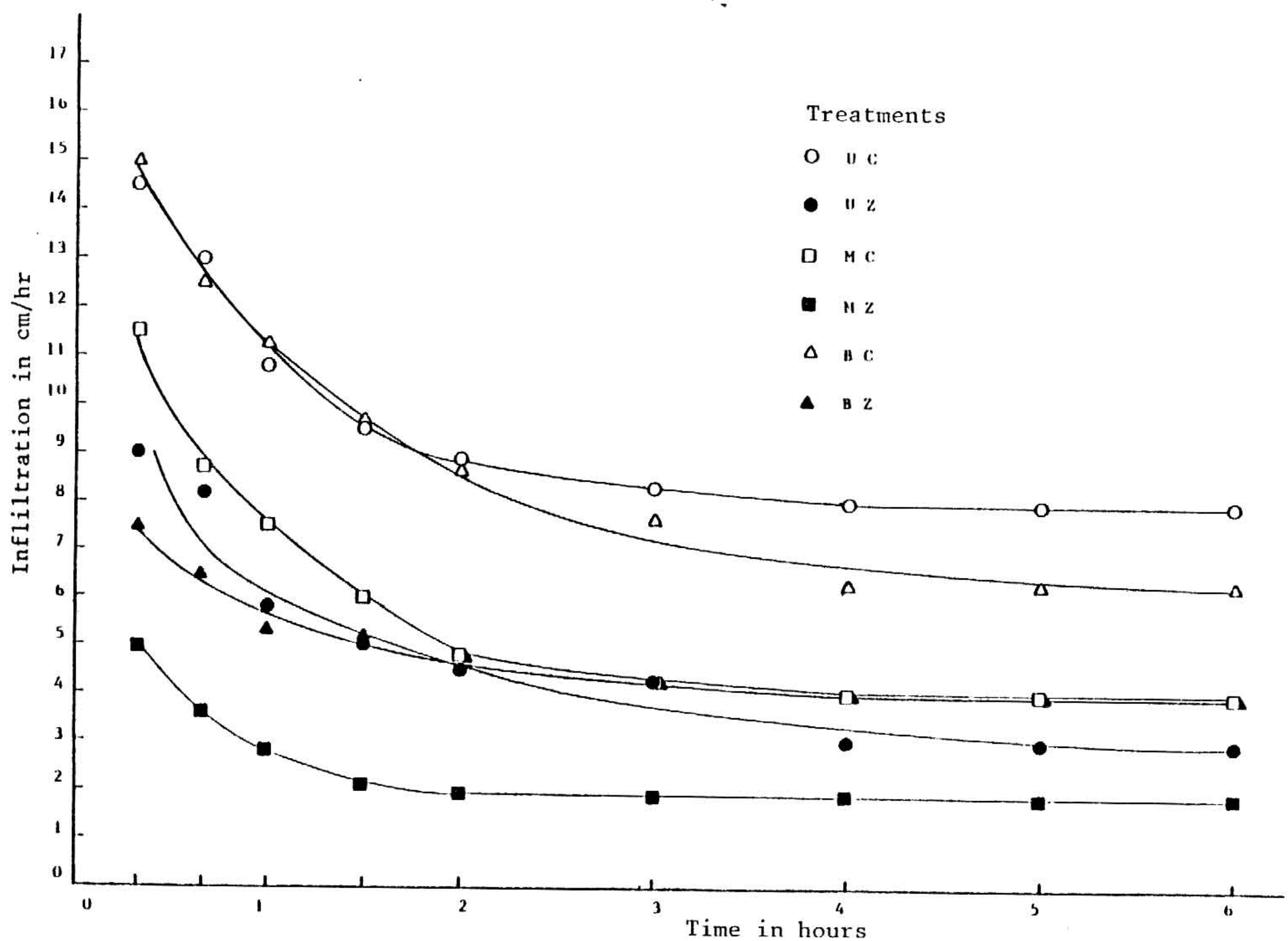

Fig. 11. Infiltration rate curves.

Table 11. Initial and final infiltration rates and total infiltration for residue and tillage treatments.

Treatment	Infiltration		
	Initial (cm/hr)	Final (cm/hr)	Total (cm/6hrs)
Residue			
Untreated	13.80[a]	5.71[a]	42.39[a]
Mowed	11.10[a]	2.95[a]	23.98[a]
Burned	14.82[a]	5.67[a]	42.18[a]
Tillage			
Conventional	17.13[a]	6.41[a]	48.21[a]
Zero	9.33[a]	3.15[b]	24.16[b]

Note: Means followed by the same letter are not significantly different.

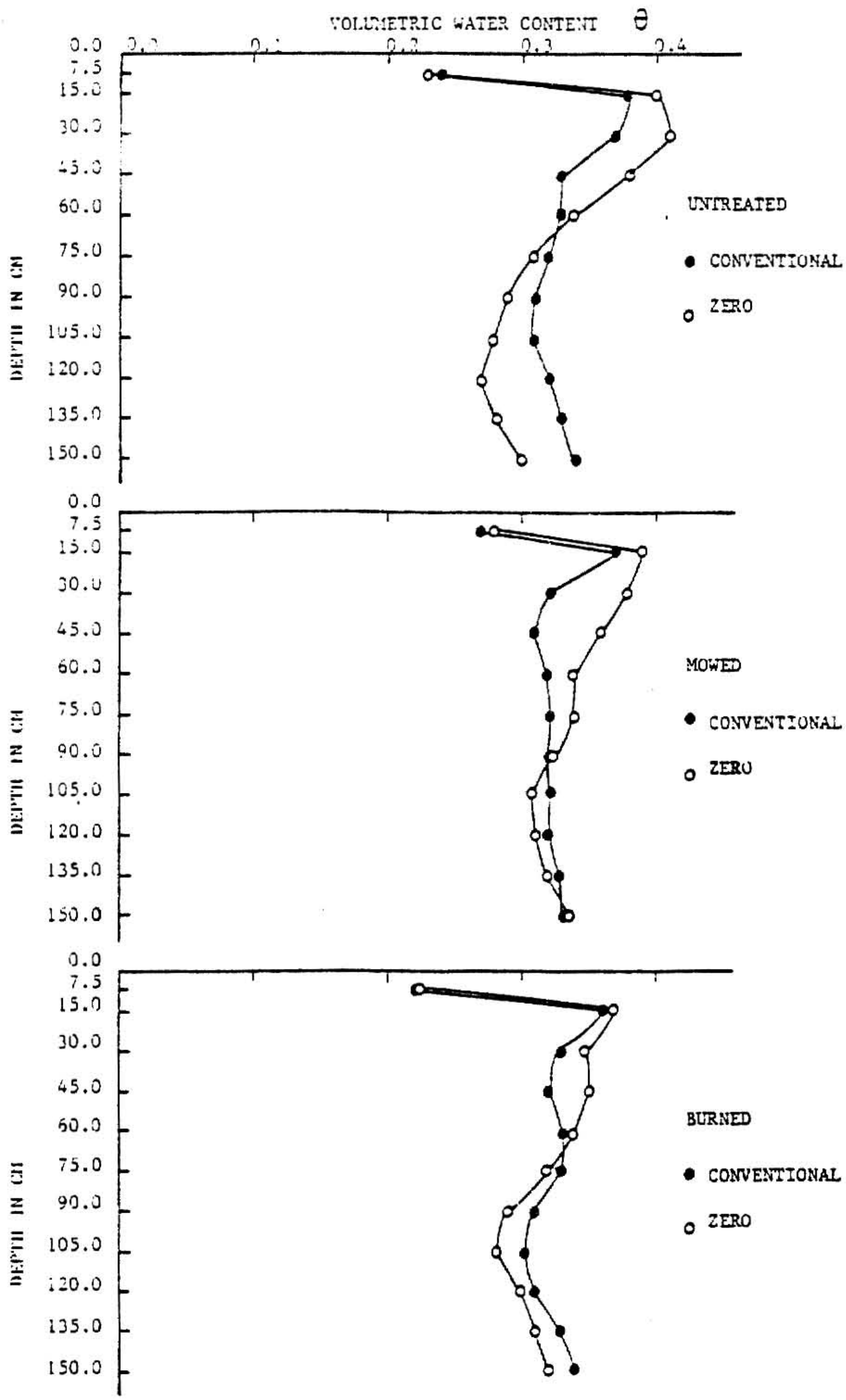

Fig. 12. Soil water to a depth of 160 cm, November 5, 1980.

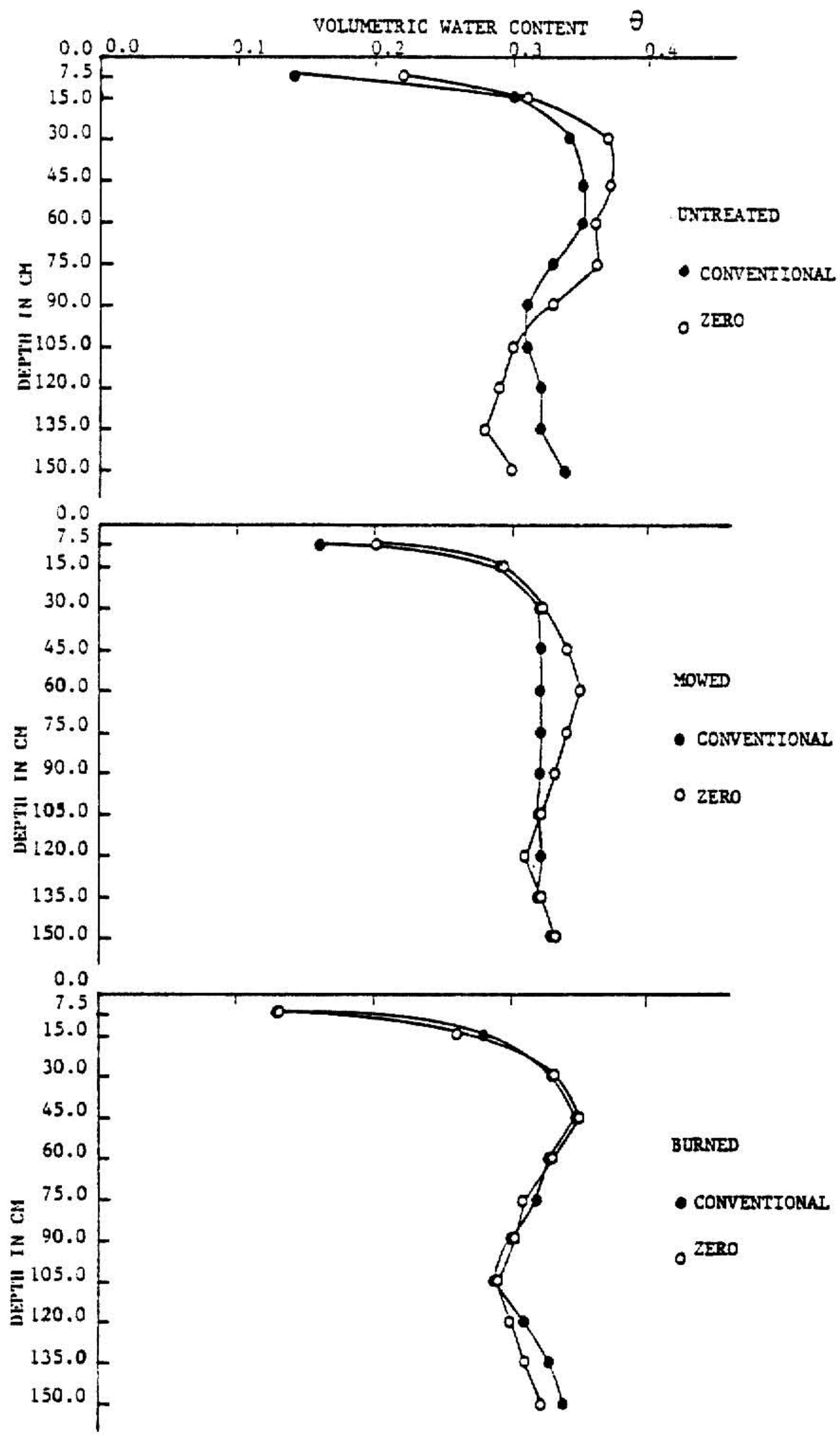

Fig. 13. Soil water to a depth of 160 cm, April 10, 1981.

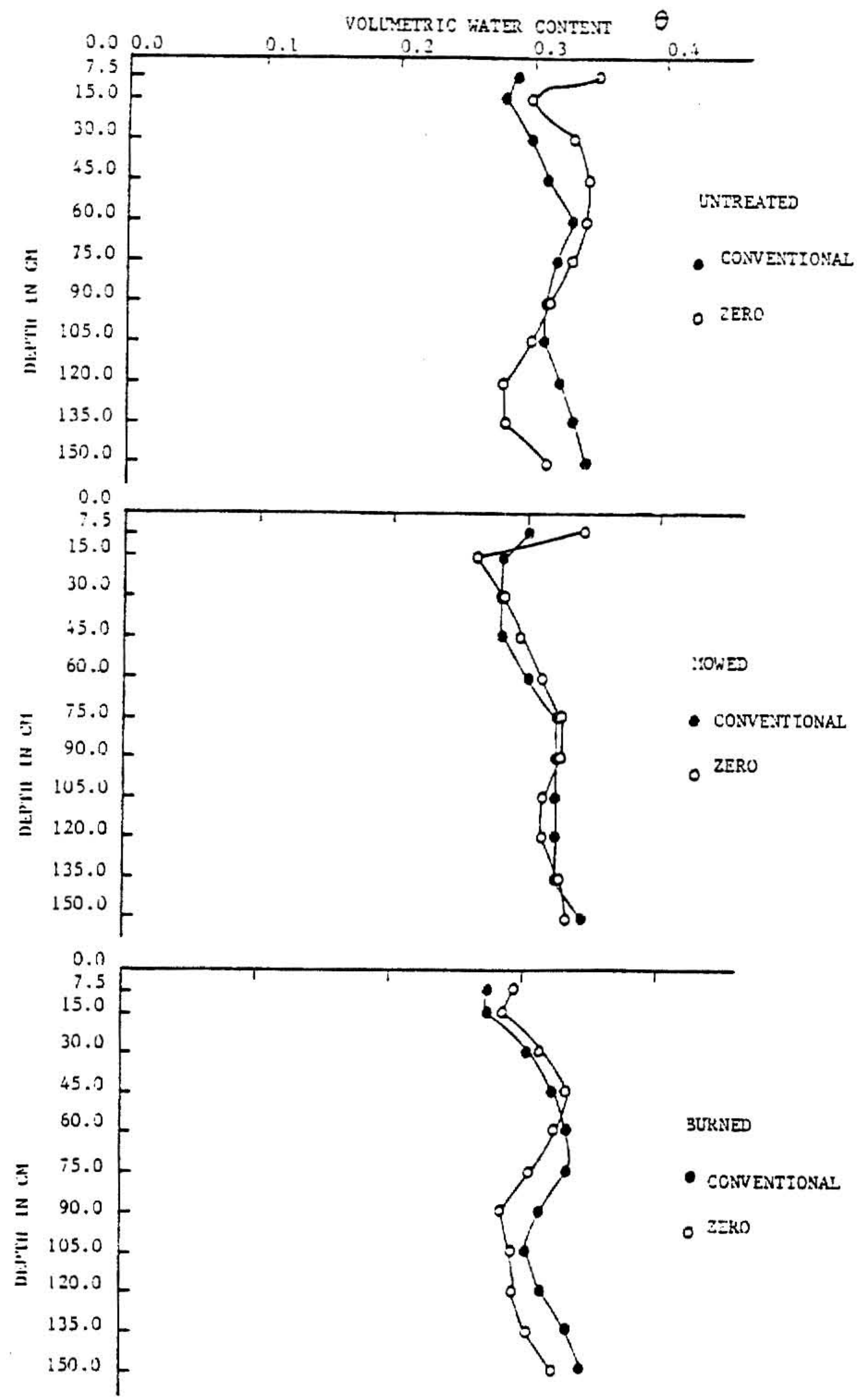

Fig. 14. Soil water to a depth of 160 cm, May 6, 1981.

Table 12. Total soil water to a depth of 84 cm expressed in cm.

Treatment	Date										
	11/5	11/12	11/19	12/5	3/27	4/10	4/24	5/6	5/21	6/4	6/16
Residue											
Untreated	29.2[a]	29.0[a]	29.2[a]	28.6[a]	30.3[a]	27.7[a]	27.5[a]	26.6[a]	31.0[a]	29.7[a]	30.2[a]
Mowed	28.4[a]	28.2[a]	28.3[a]	27.9[a]	28.9[b]	25.9[ab]	26.2[a]	24.8[a]	30.9[a]	28.8[a]	29.7[a]
Burned	27.5[a]	27.4[a]	27.3[a]	27.2[a]	26.7[c]	25.3[b]	25.9[a]	25.7[a]	29.5[b]	29.1[a]	29.4[a]
Tillage											
Zero	29.3[a]	29.1[a]	29.1[a]	28.8[a]	29.2[a]	26.8[a]	26.6[a]	26.1[a]	31.0[a]	29.1[a]	29.8[a]
Conventional	27.4[b]	27.2[b]	27.5[a]	27.0[b]	28.1[a]	25.7[a]	26.4[a]	25.3[a]	30.0[a]	29.2[a]	29.7[a]
Residue/Tillage											
Untreated/ Conventional	28.3	28.0	28.4	27.8	28.9	26.6	26.5	25.6	30.3	29.1	30.0
Untreated/ Zero	30.2	29.9	30.1	29.5	31.6	28.8	28.4	27.6	31.7	30.3	30.5
Mowed/ Conventional	27.1	26.9	27.0	26.5	26.9	25.3	26.5	24.5	30.7	29.2	30.2
Mowed/ Zero	29.7	29.4	29.6	29.3	29.9	26.6	25.8	25.0	31.1	28.3	29.1
Burned/ Conventional	27.0	26.7	27.1	26.8	27.5	25.4	26.7	25.7	28.8	29.4	28.9
Burned/Zero	28.1	28.1	27.6	27.7	26.0	25.2	25.0	25.7	30.2	28.8	29.9

Note: Means followed by a different letter are significantly different.

differences in soil water content to 84 cm. This effect is associated with a reduction in evaporation (Unger and Parker, 1976). These differences decreased in magnitude as the crop approached the reproductive stage with its greater potential for water use. This small supply of extra water appears to be associated with higher yields on the zero tilled plots which had surface residues (mowed or untreated), and may be related to the greater concentration of roots which usually occurs within this depth (Welbank et al, 1974).

Higher infiltration rates in conventional tilled plots are associated with lower soil bulk densities which probably are accompanied by different pore size distribution. Surface compaction during rainfall in conventional tilled plots probably reduced infiltration rate; presence of residues on the zero-till plots reduces evaporation losses. These conflicting effects may explain the rather small differences in water content between tillage and residue treatments which were measured to 160 cm depth. Infiltration results agree with those obtained by Hobbs (1978) and by Gantzer and Blake (1978). Hobbs found that conventionally tilled row crop plots infiltrated twice as much water as chemically treated ones. Gantzer and Blake reported that saturated hydraulic conductivity of surface samples taken from plots after 6 years of no-till corn was less than half that from conventional tilled fields. They also found small but consistent differences in volumetric water content in favor of the no-till conditions.

It is worth pointing out that for the general climatic conditions of the 1980-1981 wheat growing season that more efficient use of water by zero-till treatments with surface residues was important in producing higher wheat yields.

CONCLUSIONS

From the analysis and discussion of the results obtained in this study, the following conclusions were drawn:

a) Surface residues (mowed or untreated) on reduced or no-till systems produced a beneficial rather than a detrimental effect on emergence and wheat yields. This positive result was caused, according to my analysis, by the indirect influence of surface residues upon the soil environment which, in turn, affected final yields.

b) Soil bulk density values increased significantly on no-till systems over reduced or conventional tillage, but did not appear to affect yields negatively. Soil strength values increased at all depths on all no-till plots but negative effects on yield were not detected. Differences in soil temperatures likely had an indirect positive consequence upon soil-root-water relationships. Efficiency in the use of soil water appeared to be an important factor in determining final differences in yields.

c) The experimental drill was a useful machine under reduced or no-till systems. It easily penetrated the soil and surface residue, loosening and creating a seedbed favorable for germination and early growth.

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APPENDIX I

APPENDIX I

Table I-A. Straw cover percentage.

October 6, 1980.

Treatment			Replication			Average
			I	II	III	
Residue	Tillage	Drill				
Untreated	Conventional	Disk	35.0	39.3	27.0	33.8
		Experimental	50.8	37.8	33.5	40.7
	Reduced	Disk	87.5	77.8	76.8	80.7
		Experimental	86.3	81.0	68.8	78.7
	Zero	Disk	99.5	96.5	98.5	98.2
		Experimental	86.0	93.8	85.8	88.5
Mowed	Conventional	Disk	11.5	11.5	10.8	11.3
		Experimental	21.5	13.0	24.5	19.7
	Reduced	Disk	67.0	60.8	75.0	67.6
		Experimental	73.5	57.8	71.3	67.7
	Zero	Disk	97.0	87.8	97.8	94.2
		Experimental	88.3	82.8	82.5	84.5
Burned	Conventional	Disk	0.3	0.8	0.8	0.6
		Experimental	1.0	0.0	0.0	0.3
	Reduced	Disk	1.3	1.0	3.3	1.9
		Experimental	2.5	0.3	1.5	1.4
	Zero	Disk	2.3	2.3	0.5	1.7
		Experimental	1.0	1.0	2.3	1.3

Note: Figures are average of 4 repeated measures.

Table I-B. Wheat emergence (plants/2m row).

October 21, 1980

Treatment			Replication			Average
			I	II	III	
Residue	Tillage	Drill				
Untreated	Conventional	Disk	56	60	58	58
		Experimental	42	49	47	46
	Reduced	Disk	65	47	60	57
		Experimental	46	47	59	51
	Zero	Disk	35	39	31	35
		Experimental	51	49	50	50
Mowed	Conventional	Disk	52	45	47	48
		Experimental	39	36	41	39
	Reduced	Disk	44	51	56	50
		Experimental	30	42	-	38
	Zero	Disk	48	47	52	49
		Experimental	38	40	48	42
Burned	Conventional	Disk	52	50	60	54
		Experiemntal	38	34	49	40
	Reduced	Disk	54	55	52	54
		Experimental	45	37	37	40
	Zero	Disk	57	59	49	55
		Experimental	41	44	50	45

Table I-C. Stem count (number of stems/2m row).

July, 1981

Treatment			Replication			Average
			I	II	III	
Residue	Tillage	Drill				
Untreated	Conventional	Disk	169	141	195	168
		Experimental	179	131	178	163
	Reduced	Disk	209	165	203	192
		Experimental	206	223	219	216
	Zero	Disk	163	144	214	174
		Experimental	217	239	281	246
Mowed	Conventional	Disk	127	134	170	144
		Experimental	136	157	167	153
	Reduced	Disk	115	159	193	156
		Experimental	202	191	-	215
	Zero	Disk	167	187	293	216
		Experimental	195	228	255	226
Burned	Conventional	Disk	137	157	148	147
		Experimental	148	111	193	151
	Reduced	Disk	143	158	170	157
		Experimental	222	201	164	196
	Zero	Disk	159	162	150	157
		Experimental	212	185	192	196

Note: Figures are averages of 4 repeated measures.

Table I-D. Wheat yields expressed in quintals/hectare.

Treatment			Replication			Average
			I	II	III	
Residue	Tillage	Drill				
Untreated	Conventional	Disk	20.0	19.7	17.9	19.2
		Experimental	23.2	23.3	21.3	22.6
	Reduced	Disk	13.4	18.2	28.6	20.1
		Experimental	24.2	19.9	21.6	21.9
	Zero	Disk	18.1	18.7	27.4	21.3
		Experimental	26.0	25.2	29.6	27.0
Mowed	Conventional	Disk	18.5	17.7	16.1	17.5
		Experimental	15.0	22.4	24.2	20.5
	Reduced	Disk	15.6	23.6	22.6	20.6
		Experimental	21.1	23.4	-	23.2
	Zero	Disk	21.1	20.3	22.8	21.4
		Experimental	24.5	26.0	31.1	27.3
Burned	Conventional	Disk	19.9	20.7	21.6	20.7
		Experimental	20.9	20.5	17.7	19.7
	Reduced	Disk	22.8	16.7	27.2	22.4
		Experimental	20.9	23.2	13.2	19.1
	Zero	Disk	19.1	25.6	20.7	21.8
		Experimental	18.9	25.8	25.1	23.3

Note: (-) represents a missing value.

Table I-E. Nitrogen content in wheat grain expressed in percentage.

Treatment			Replication			Average
			I	II	III	
Residue	Tillage	Drill				
Untreated	Conventional	Disk	2.21	2.08	2.81	2.37
		Experimental	2.40	2.18	2.50	2.36
	Reduced	Disk	2.30	2.56	2.79	2.55
		Experimental	2.38	2.70	2.73	2.60
	Zero	Disk	2.47	2.41	2.58	2.49
		Experimental	2.50	2.53	2.58	2.54
Mowed	Conventional	Disk	2.32	2.00	2.66	2.33
		Experimental	2.13	1.95	2.70	2.26
	Reduced	Disk	2.12	2.24	2.20	2.19
		Experimental	2.06	2.68	-	2.50
	Zero	Disk	2.20	2.20	2.79	2.40
		Experimental	2.31	2.40	2.58	2.43
Burned	Conventional	Disk	2.47	2.21	2.85	2.51
		Experimental	2.40	2.57	3.08	2.68
	Reduced	Disk	2.40	2.88	2.67	2.65
		Experimental	2.60	2.80	3.21	2.87
	Zero	Disk	2.31	2.47	2.17	2.32
		Experimental	2.90	2.65	2.83	2.79

Note: (-) represents a missing value.

Table I-F. Phosphorous content in wheat grain expressed in percentage.

Treatment			Replication			Average
			I	II	III	
Residue	Tillage	Drill				
Untreated	Conventional	Disk	0.275	0.310	0.340	0.308
		Experimental	0.278	0.338	0.303	0.306
	Reduced	Disk	0.324	0.380	0.302	0.335
		Experimental	0.340	0.348	0.358	0.349
	Zero	Disk	0.406	0.352	0.310	0.356
		Experimental	0.372	0.357	0.313	0.347
Mowed	Conventional	Disk	0.356	0.326	0.326	0.336
		Experimental	0.371	0.320	0.332	0.341
	Reduced	Disk	0.328	0.303	0.359	0.330
		Experimental	0.320	0.352	-	0.343
	Zero	Disk	0.323	0.347	0.370	0.347
		Experimental	0.308	0.309	0.357	0.325
Burned	Conventional	Disk	0.262	0.320	0.284	0.289
		Experimental	0.263	0.294	0.331	0.296
	Reduced	Disk	0.271	0.268	0.278	0.272
		Experimental	0.292	0.328	0.378	0.333
	Zero	Disk	0.300	0.302	0.288	0.297
		Experimental	0.300	0.302	0.288	0.297

Note: (-) represents a missing value.

APPENDIX II

APPENDIX II

Table II-A. Soil bulk densities (g/cm^3) (October through November, 1980).

Treatment			Replication			Average
			I	II	III	
Residue	Tillage	Drill				
Untreated	Conventional	Disk	1.19	1.30	1.16	1.22
		Experimental	1.12	1.12	1.16	1.13
	Reduced	Disk	1.18	1.28	1.15	1.20
		Experimental	1.11	1.15	1.24	1.17
	Zero	Disk	1.18	1.34	1.25	1.26
		Experimental	1.16	1.22	1.18	1.19
Mowed	Conventional	Disk	1.19	1.22	1.28	1.23
		Experimental	1.16	1.00	1.20	1.12
	Reduced	Disk	1.24	1.14	1.23	1.20
		Experimental	1.16	1.19	1.23	1.19
	Zero	Disk	1.33	1.33	1.34	1.33
		Experimental	1.28	1.20	1.23	1.24
Burned	Conventional	Disk	1.04	1.32	1.15	1.17
		Experimental	1.00	1.07	1.11	1.06
	Reduced	Disk	1.31	1.12	1.16	1.20
		Experimental	1.13	1.10	1.17	1.13
	Zero	Disk	1.33	1.23	1.16	1.24
		Experimental	1.30	1.14	1.14	1.19

Table I-B. Soil strength (Kg/cm^2) (September 22, 1980).

Treatments				Replications			Average
				I	II	III	
Residue	Tillage	Drill	Depth				
Untreated	Conventional	Disk	1	0.00	0.00	0.00	0.00
			2	0.00	0.00	0.00	0.00
			3	2.13	5.00	6.25	4.46
		Experimental	1	0.00	0.00	0.00	0.00
			2	0.00	0.63	0.00	0.21
			3	2.50	5.13	0.75	2.79
	Zero	Disk	1	4.63	3.63	7.13	5.13
			2	15.88	14.88	18.38	16.38
			3	29.75	26.88	23.00	26.54
		Experimental	1	0.88	4.63	3.00	2.83
			2	10.00	24.00	17.33	17.04
			3	20.38	42.38	25.38	29.38
Mowed	Conventional	Disk	1	0.00	0.00	0.00	0.00
			2	0.00	0.00	0.00	0.00
			3	2.13	1.13	1.25	1.50
		Experimental	1	0.00	0.00	0.00	0.00
			2	0.00	0.38	0.00	0.13
			3	0.00	1.00	0.88	0.63
	Zero	Disk	1	3.25	8.00	7.50	3.58
			2	19.13	6.25	18.00	14.46
			3	29.63	22.63	27.75	26.67
		Experimental	1	0.38	3.50	0.75	1.54
			2	15.63	14.13	14.75	14.83
			3	27.75	24.25	25.63	25.88
Burned	Conventional	Disk	1	0.00	0.00	0.00	0.00
			2	0.00	0.00	0.25	0.08
			3	2.50	3.50	0.75	2.25
		Experimental	1	0.00	0.00	0.00	0.00
			2	0.63	0.00	0.00	0.21
			3	0.88	3.00	4.75	3.54
	Zero	Disk	1	0.00	3.25	10.38	4.54
			2	9.63	15.13	21.13	15.29
			3	32.13	36.00	49.38	39.17
		Experimental	1	0.50	2.63	6.00	3.04
			2	9.25	15.88	16.63	13.92
			3	31.00	41.75	32.13	34.94

Note: Figures are averages of six repeated measures.

Table II-C. Soil temperature at 5 cm depth.

Residue untreated

Tillage	Drill	Replications	Meridian	1980 November 9	10	11	12	13	14	1981 April 2	3	4	5	7	8	24	25	26	May 22	June 6
C	D	II	am	7.5	6.4	11.0	11.4	12.2	5.2	11.4	16.5	11.3	8.0	11.4	15.5	12.0	15.0	16.0	15.5	21.4
			pm	17.0	15.3	18.0	18.0	8.2	5.6	19.5	19.5	15.5	16.5	23.0	21.6	21.4	24.5	28.4	26.6	29.6
	D	III	am	9.2	7.4	11.4	11.4	13.0	5.5	11.1	16.0	10.0	6.5	10.9	14.0	10.3	13.3	15.1	15.0	21.0
			pm	17.1	14.0	18.1	17.0	8.5	5.6	20.0	19.0	14.4	15.5	22.4	22.3	20.0	23.0	27.4	24.7	29.4
	E	II	am	7.5	6.8	10.6	11.2	12.2	6.6	11.6	16.5	10.4	6.7	10.6	15.0	10.5	13.9	16.2	14.9	20.9
			pm	17.5	14.6	18.0	17.5	9.4	6.4	22.5	20.0	16.0	18.5	25.0	25.1	23.2	26.0	30.4	28.0	31.7
	E	III	am	9.2	6.9	11.2	11.6	12.6	5.2	11.6	16.4	10.5	6.6	11.0	14.4	10.4	13.0	15.5	14.9	20.9
			pm	17.0	14.0	17.5	17.2	8.0	5.0	21.5	19.5	15.5	17.9	23.5	23.4	21.5	24.8	29.5	26.0	30.3
Z	D	II	am	8.0	7.5	9.4	10.5	11.5	6.2	10.2	15.0	11.0	8.0	10.2	14.6	13.2	16.4	16.0	15.5	20.9
			pm	13.5	12.0	14.5	14.6	8.6	6.4	19.6	18.0	13.7	14.3	21.8	18.0	23.0	21.0	23.0	24.8	26.0
		III	am	9.8	8.0	10.0	10.8	12.2	6.0	10.5	15.0	9.3	6.0	9.6	12.6	10.5	13.5	15.1	14.9	20.2
			pm	13.4	11.2	14.2	14.0	8.5	6.0	17.5	18.3	13.7	14.5	21.0	20.8	19.1	21.4	25.9	24.4	29.0
	E	II	am	8.5	8.0	10.0	10.9	12.0	5.6	11.6	16.0	10.5	7.6	10.3	13.9	12.0	14.4	15.9	15.4	21.0
			pm	13.8	12.1	14.5	15.0	9.2	7.6	20.0	19.4	16.3	17.5	23.5	23.0	21.0	22.8	27.0	25.5	31.2
		III	am	9.8	7.6	10.8	11.3	12.4	5.6	10.6	15.2	9.6	6.6	10.1	13.0	10.0	12.8	15.0	14.6	20.2
			pm	15.0	13.0	16.0	15.5	8.5	5.8	17.0	18.0	13.5	14.4	19.8	19.0	18.6	20.0	24.0	23.5	27.5

Note: C = conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill

Table II-C. (continued)

Residue mowed

Tillage	Drill	Replications	Meridian	1980						1981										
				November						April									May	June
				9	10	11	12	13	14	2	3	4	5	7	8	24	25	26	22	6
C	D	II	am	8.3	7.1	11.3	11.2	12.5	6.2	11.4	16.5	10.6	7.0	11.0	14.9	10.5	14.5	16.7	15.0	21.0
			pm	17.5	14.6	17.5	17.2	8.9	5.9	21.8	19.7	16.5	17.5	23.5	23.0	22.6	25.5	28.2	27.0	30.0
		III	am	9.5	7.4	11.3	11.6	13.0	6.4	11.5	16.5	10.1	6.0	11.0	14.5	10.8	13.4	16.0	15.0	21.2
			pm	17.0	14.0	17.0	17.0	9.3	6.3	21.0	19.5	15.0	16.0	23.4	22.5	21.0	24.5	28.4	26.3	29.9
	E	II	am	7.8	6.9	11.0	11.4	12.4	6.0	11.5	16.5	10.5	6.7	11.0	14.6	10.5	14.2	16.1	15.0	21.0
			pm	17.5	14.7	18.0	17.5	9.0	6.0	22.4	20.0	16.0	18.5	24.9	24.5	22.3	25.0	30.0	27.0	30.0
		III	am	8.1	6.6	11.0	11.5	12.5	5.6	11.4	16.3	9.8	6.0	10.6	13.6	10.0	13.2	15.3	14.9	21.0
			pm	17.0	14.0	17.5	17.0	8.4	6.0	21.5	19.5	15.5	17.5	24.6	25.0	19.5	22.5	28.4	26.8	30.0
Z	D	II	am	8.0	7.1	10.5	11.3	12.2	6.0	11.0	15.5	10.6	7.9	10.7	14.0	11.0	14.0	15.5	15.1	21.0
			pm	16.0	13.5	16.3	16.2	9.0	6.5	19.5	18.4	15.0	15.6	21.4	21.2	20.5	22.0	26.2	25.5	29.6
		III	am	8.5	6.9	9.8	10.5	11.8	6.2	10.2	14.4	10.3	7.5	10.0	13.0	11.8	13.0	15.4	14.6	20.6
			pm	13.6	11.6	14.5	14.5	8.5	6.1	17.0	17.0	14.0	14.7	18.9	19.2	17.5	19.0	23.0	21.2	25.6
	E	II	am	8.0	7.4	10.6	11.0	12.1	6.8	11.0	15.8	10.1	6.9	10.5	14.1	10.0	14.0	15.6	15.1	20.8
			pm	15.5	13.4	16.2	16.3	9.6	6.4	19.6	18.8	15.3	16.4	22.1	21.5	21.5	23.5	27.6	26.0	30.0
		III	am	7.5	6.6	10.4	11.0	12.0	5.5	10.7	15.0	10.2	7.4	10.6	13.5	10.3	13.6	15.5	14.7	20.8
			pm	16.0	13.6	16.7	16.5	8.3	5.5	18.9	18.0	14.5	15.5	19.6	20.5	19.4	21.0	24.7	24.0	28.5

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill

Table II-C. (continued)

Residue burned

Tillage	Drill	Replications	Meridian	1980						1981										
				November						April									May	June
				9	10	11	12	13	14	2	3	4	5	7	8	24	25	26	22	6
C	D	II	am	7.4	6.7	11.2	11.5	12.6	5.6	11.5	16.5	10.8	7.2	11.1	15.0	10.5	14.0	16.1	15.0	21.1
			pm	17.8	15.0	18.0	17.7	8.6	6.0	21.8	19.5	16.0	17.0	25.0	24.7	22.5	25.5	30.0	27.0	31.2
		III	am	7.7	5.7	11.0	10.7	13.0	4.4	11.4	16.5	10.3	6.3	11.0	14.6	10.0	13.0	15.5	15.0	21.0
			pm	18.2	15.0	19.0	18.2	7.4	5.0	22.0	20.0	16.3	17.5	24.5	24.1	20.8	24.6	28.6	26.5	29.1
	E	II	am	8.1	7.0	11.5	11.6	12.6	6.0	11.5	16.7	10.3	6.5	11.1	14.5	10.2	13.6	16.0	14.9	21.1
			pm	18.0	15.0	18.0	17.7	9.0	6.5	21.8	20.0	16.0	17.0	24.1	23.5	21.0	24.4	28.5	25.4	30.4
		III	am	7.6	6.0	10.8	10.9	12.7	4.8	11.5	16.5	10.2	6.0	11.0	14.5	10.2	13.0	15.8	14.6	20.9
			pm	18.3	15.0	18.7	18.0	7.4	5.0	21.5	19.5	15.0	16.5	23.8	22.5	20.3	24.5	28.7	25.6	29.0
Z	D	II	am	8.6	7.6	11.0	11.8	12.8	6.1	11.6	16.1	10.9	7.5	11.2	14.9	10.9	14.0	16.4	15.1	21.1
			pm	17.5	14.6	17.4	17.2	9.0	6.1	20.0	18.6	14.9	15.6	21.8	21.5	20.6	22.5	26.0	24.5	29.3
		III	am	9.1	7.5	11.6	11.7	13.1	5.5	11.4	16.5	10.2	6.5	10.8	14.3	10.5	13.5	16.0	15.0	21.1
			pm	17.7	15.0	17.7	17.4	8.6	5.9	20.5	19.4	15.1	17.0	23.7	22.7	19.6	23.8	28.4	25.5	28.9
	E	II	am	8.2	7.4	11.4	12.0	12.8	5.9	11.5	16.4	10.8	6.6	11.1	14.5	10.5	13.8	15.6	14.9	20.9
			pm	17.6	14.8	17.8	17.5	9.0	6.5	21.0	19.5	15.7	16.8	23.0	23.0	20.6	23.0	26.5	24.5	28.4
		III	am	8.4	7.0	11.1	11.5	13.0	5.0	11.2	16.6	9.6	5.6	10.7	14.0	10.0	13.0	15.5	15.0	20.8
			pm	18.0	15.0	18.0	17.6	8.4	5.9	22.5	20.0	16.0	18.2	25.5	25.6	20.0	23.6	29.6	26.7	31.0

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill

Table II-D. Soil water content (cm).

November 5, 1980

Residue	Tillage	Drill	Replications	0.00-7.6	7.6-22.9	22.9-38.1	38.1-53.3	53.3-68.6	68.6-83.8	83.8-99.1	99.1-114.3	114.3-129.5	129.5-144.8	144.8-160.0
				Depth in cm										
U	C	D	II	2.0	6.0	6.1	5.2	4.7	4.6	4.4	4.5	4.4	4.6	5.2
			III	1.8	5.4	4.5	3.7	4.8	5.3	5.3	5.0	5.0	5.1	5.2
		E	II	1.8	6.0	5.5	5.0	5.0	4.8	4.6	4.6	4.8	4.9	4.9
			III	1.8	5.9	6.6	6.3	5.4	4.8	4.3	4.9	5.1	5.2	5.4
	Z	D	II	2.5	6.2	6.3	5.3	4.9	4.6	4.2	4.0	4.0	4.0	4.2
			III	2.3	5.5	5.9	5.6	5.3	5.0	4.8	4.5	4.3	4.5	4.8
		E	II	2.1	6.3	6.5	6.3	5.4	4.8	4.4	4.2	4.3	4.3	4.6
			III	2.0	6.2	6.5	5.6	4.9	4.6	4.4	4.1	4.2	4.1	4.5
M	C	D	II	2.0	6.0	5.8	5.4	5.0	4.8	5.1	5.1	5.2	5.3	5.4
			III	2.2	5.8	5.2	4.8	4.9	4.7	4.4	4.7	4.7	4.7	4.8
		E	II	1.7	6.0	5.3	4.7	4.6	4.4	4.6	4.8	5.1	5.5	5.4
			III	2.2	4.6	3.5	4.1	5.0	5.3	5.2	4.9	4.4	4.6	4.6
	Z	D	II	2.3	5.4	4.9	4.7	4.7	4.9	5.0	5.1	5.1	5.4	5.3
			III	2.1	5.7	5.4	5.2	5.0	5.3	5.1	5.0	4.7	4.7	5.2
		E	II	2.0	6.4	6.6	6.5	6.2	5.9	5.1	4.9	5.1	5.3	5.4
			III	2.0	6.0	6.4	5.8	4.9	4.6	4.2	4.0	4.0	3.9	4.4
B	C	D	II	2.1	6.0	5.7	5.0	5.0	4.8	4.5	4.7	5.2	5.1	5.1
			III	1.6	5.4	5.3	5.2	5.0	4.9	4.5	4.0	4.3	4.6	5.2
		E	II	1.7	5.8	5.7	5.3	5.2	4.9	4.4	4.3	4.5	5.0	5.1
			III	1.5	4.7	3.6	3.9	4.7	5.2	5.2	5.0	4.9	5.1	5.5
	Z	D	II	1.9	6.3	6.2	6.0	5.8	5.4	4.7	4.7	4.9	5.2	5.2
			III	1.7	4.6	4.1	5.1	5.2	5.0	4.6	4.3	4.8	5.1	5.1
		E	II	1.5	5.9	5.4	5.1	4.9	4.6	4.3	4.1	4.3	4.4	4.6
			III	1.5	5.9	5.7	5.1	4.7	4.5	4.0	3.9	4.0	4.1	4.5

Note: C = Conventional tillage; Z = Zero tillage; D.= Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

November 12, 1980

Residue	Tillage	Drill	Replications	0.00-7.6	7.6-22.9	22.9-38.1	38.1-53.3	53.3-68.6	68.6-83.8	83.8-99.1	99.1-114.3	114.3-129.5	129.5-144.8	144.8 160.0
				Depth in cm										
U	C	D	II	1.4	5.7	6.2	5.2	4.8	4.6	4.3	4.4	4.4	4.7	5.1
			III	1.3	5.2	4.5	3.8	5.2	5.4	5.3	5.0	5.1	5.2	5.4
		E	II	1.5	6.0	5.6	5.2	5.0	4.8	4.7	4.7	4.8	4.9	5.1
			III	1.4	5.8	6.5	6.4	5.7	4.9	4.5	4.8	5.1	5.2	5.5
	Z	D	II	2.0	6.0	6.2	5.4	4.9	4.6	4.3	3.9	4.0	4.0	4.3
			III	2.1	5.7	6.0	5.7	5.4	5.2	5.0	4.7	4.5	4.5	5.1
		E	II	1.7	6.1	6.4	6.2	5.4	4.9	4.5	4.4	4.3	4.3	4.6
			III	1.5	6.2	6.6	5.9	5.0	4.7	4.5	4.1	4.0	4.2	4.7
M	C	D	II	1.7	6.0	5.8	5.5	5.1	5.0	5.1	5.2	5.2	5.2	5.3
			III	1.5	5.6	5.2	5.0	5.1	4.7	4.5	4.8	4.9	4.8	4.9
		E	II	1.3	6.0	5.5	4.8	4.6	4.5	4.7	4.9	5.3	5.5	5.5
			III	1.4	5.6	4.7	3.6	4.0	5.2	5.3	5.2	4.9	4.5	4.7
	Z	D	II	1.9	5.5	4.8	4.8	4.6	4.9	5.3	5.3	5.2	5.4	5.3
			III	2.0	5.8	5.4	5.2	5.1	5.3	5.2	5.1	4.7	5.9	5.3
		E	II	1.5	6.4	6.5	6.5	6.2	6.1	5.6	4.9	5.1	5.4	5.5
			III	0.9	6.0	6.4	5.8	5.1	4.7	4.2	4.0	4.0	4.1	4.5
B	C	D	II	1.6	6.1	5.8	5.1	4.9	4.7	4.5	4.7	5.2	5.3	5.3
			III	1.0	5.3	5.4	5.2	4.9	5.0	4.5	4.2	4.3	4.9	5.2
		E	II	1.5	5.8	5.6	5.4	5.1	4.9	4.5	4.3	4.5	4.9	5.0
			III	1.2	4.3	3.8	4.0	4.8	5.3	5.3	5.0	5.1	5.3	5.5
	Z	D	II	1.5	6.0	6.4	6.0	5.9	5.4	4.9	4.8	5.1	5.2	5.3
			III	1.2	4.5	4.2	5.3	5.3	5.3	4.7	4.4	5.0	5.1	5.2
		E	II	1.6	5.5	5.7	5.1	5.0	4.8	4.3	4.3	4.3	4.5	4.8
			III	1.6	5.8	5.9	5.1	4.9	4.5	4.1	4.2	4.0	4.2	4.6

Note: C = Conventional tillage; Z = Zero Tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

Residue	Tillage	Drill	Replications	November 19, 1980 Depth in cm 0.00-7.6	7.6-22.9	22.9-38.1	38.1-53.3	53.3-68.6	68.6-83.8	83.8-99.1	99.1-114.3	114.3-129.5	129.5-144.8	144.8-160.0
U	C	D	II	1.5	5.8	6.3	5.4	4.9	4.6	4.4	4.3	4.5	4.2	5.3
			III	1.4	5.2	4.5	4.0	5.2	5.6	5.3	5.2	5.2	5.2	5.5
		E	II	1.4	6.0	5.6	5.1	5.1	4.8	4.7	4.9	4.9	4.9	5.1
			III	1.5	5.8	6.7	6.6	5.7	4.9	4.5	4.9	5.2	5.3	5.5
	Z	D	II	2.1	6.1	6.3	5.4	4.9	4.8	4.4	4.2	4.2	4.1	4.4
			III	1.9	5.6	6.0	5.8	5.3	5.2	5.0	4.7	4.4	4.5	5.0
		E	II	1.6	6.3	6.5	6.3	5.5	4.9	4.6	4.4	4.4	4.4	4.7
			III	1.5	6.2	6.6	5.8	5.2	4.7	4.4	4.3	4.2	4.3	4.8
M	C	D	II	1.5	6.0	5.7	5.5	5.2	5.0	5.1	5.3	5.3	5.4	5.4
			III	1.5	5.6	5.3	5.0	5.2	4.7	4.6	4.8	4.9	4.9	4.8
		E	II	1.2	6.1	5.6	4.9	4.7	4.5	4.6	5.6	5.2	5.5	5.6
			III	1.5	5.5	4.8	3.7	4.2	5.3	5.4	5.4	5.0	4.6	4.8
	Z	D	II	1.8	5.4	5.0	4.7	4.8	4.9	5.4	5.3	5.4	5.6	5.4
			III	1.9	5.6	5.5	5.3	5.1	5.4	5.3	5.1	4.8	5.0	5.2
		E	II	1.8	6.2	6.8	6.4	6.2	5.9	5.6	5.3	5.3	5.4	5.5
			III	1.7	5.8	6.5	5.8	5.2	4.6	4.1	4.1	4.0	4.1	4.5
B	C	D	II	1.7	6.2	5.8	5.1	5.1	4.8	4.6	4.8	5.3	5.1	5.2
			III	1.1	5.2	5.4	5.5	5.2	5.0	4.5	4.2	4.5	5.0	5.3
		E	II	1.2	5.9	5.7	5.5	5.2	5.0	4.6	4.4	4.7	5.1	5.2
			III	1.1	4.4	3.7	4.0	5.0	5.5	5.3	5.2	5.1	5.5	5.6
	Z	D	II	1.5	6.2	6.5	6.1	5.9	5.4	4.9	4.9	5.1	5.2	5.5
			III	1.3	4.4	4.3	5.4	5.3	5.2	4.7	4.6	5.2	5.2	5.2
		E	II	1.3	5.7	3.0	5.4	5.1	4.1	4.4	4.2	4.4	4.5	5.0
			III	1.3	5.9	5.8	5.1	4.8	4.5	4.1	4.1	4.1	4.2	4.7

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

Residue	Tillage	Drill	Replications	0.00-7.6	7.6-22.9	22.9-38.1	38.1-53.3	53.3-68.6	68.6-83.8	83.8-99.1	99.1-114.3	114.3-129.5	129.5-144.8	144.8-160.0
				December 5, 1980 — Depth in cm										
U	C	D	II	1.2	5.5	6.2	5.4	4.9	4.6	4.4	4.4	4.5	5.0	5.3
			III	0.9	5.0	4.3	3.9	5.3	5.6	5.3	5.1	5.2	5.3	5.3
		E	II	1.2	5.8	5.6	5.2	5.1	4.9	4.6	4.8	4.8	5.0	5.1
			III	1.1	5.5	6.6	6.4	5.6	5.0	4.5	4.9	5.3	5.2	5.5
	Z	D	II	1.7	5.9	6.0	5.4	4.9	4.7	4.4	4.1	4.1	4.2	4.5
			III	1.5	5.3	5.9	5.7	5.4	5.2	5.0	4.8	4.8	4.5	5.0
		E	II	1.6	6.1	6.4	6.3	5.6	4.4	4.6	4.3	4.4	4.4	4.7
			III	1.4	6.0	6.6	5.9	5.0	4.6	4.4	4.3	4.2	4.2	4.8
M	C	D	II	1.3	5.8	5.7	5.4	5.1	4.9	5.1	5.2	5.2	5.3	5.4
			III	1.2	5.5	5.3	5.0	5.1	4.7	4.7	4.9	4.9	4.9	5.2
		E	II	1.2	5.8	5.3	4.9	4.8	4.6	4.6	5.1	5.3	5.5	5.6
			III	1.2	5.4	4.6	3.7	4.3	5.1	5.5	5.3	4.9	4.6	4.8
	Z	D	II	1.7	5.4	5.0	4.9	4.7	5.1	5.2	5.3	5.4	5.6	5.5
			III	1.7	5.5	5.2	5.1	5.3	5.5	5.3	5.3	4.8	4.9	5.2
		E	II	1.4	6.2	6.4	6.5	6.1	6.0	5.6	5.2	5.3	5.4	5.6
			III	1.4	5.8	6.4	5.8	5.1	4.7	4.3	4.2	4.1	4.1	4.5
B	C	D	II	1.4	6.1	5.6	5.3	5.1	4.7	4.7	4.7	5.3	5.1	5.3
			III	0.9	5.3	5.2	5.4	5.2	5.0	4.5	4.3	4.5	4.9	5.2
		E	II	1.3	5.8	5.6	5.4	5.2	5.0	5.5	4.3	4.6	5.1	5.3
			III	0.9	4.1	3.6	4.1	5.1	5.4	5.3	5.1	5.1	5.3	5.6
	Z	D	II	1.3	6.1	6.4	6.1	5.9	5.4	5.0	4.9	5.2	5.2	5.3
			III	1.1	4.2	4.3	5.3	5.4	5.2	4.8	4.5	5.1	5.3	5.3
		E	II	1.1	5.3	5.6	5.3	5.1	4.8	4.4	4.2	4.3	4.5	4.6
			III	1.0	5.7	5.8	5.1	4.9	4.5	4.1	4.1	4.2	4.3	4.7

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

March 27, 1981

Residue	Tillage	Drill	Replications	Depth in cm 0.00–7.6	7.6–22.9	22.9–38.1	38.1–53.3	53.3–68.6	68.6–83.8	83.8–99.1	99.1–114.3	114.3–129.5	129.5–144.8	144.8–160.0
U	C	D	II	1.2	5.6	6.1	6.2	5.7	4.9	4.5	4.6	4.6	4.7	5.4
			III	0.9	5.2	6.4	6.2	5.6	5.0	5.0	5.0	5.2	5.2	5.5
		E	II	1.2	5.8	6.2	6.0	5.2	4.9	4.6	4.7	4.9	5.0	4.9
			III	1.1	4.4	4.6	4.8	5.6	5.5	6.3	5.3	5.1	5.2	5.4
	Z	D	II	2.2	6.0	6.4	6.2	6.2	5.9	5.5	4.9	4.3	4.1	4.5
			III	2.0	4.9	5.7	6.4	5.9	5.2	5.0	4.6	4.4	4.5	5.1
		E	II	1.7	5.7	6.4	6.1	6.1	6.0	5.3	4.6	4.4	4.4	4.8
			III	1.4	5.6	6.3	6.1	5.9	5.7	5.1	4.5	4.2	4.3	4.9
M	C	D	II	1.4	5.7	5.8	5.9	5.6	5.5	5.3	5.2	5.1	5.2	5.3
			III	1.2	5.2	5.9	5.5	5.1	4.8	4.6	4.7	4.9	4.9	5.0
		E	II	1.2	5.4	5.8	5.5	4.8	4.6	4.6	4.9	5.1	5.4	5.4
			III	1.3	5.2	5.1	5.0	5.2	5.3	5.4	5.1	4.9	4.5	4.8
	Z	D	II	1.7	5.5	6.0	5.8	5.5	5.2	5.4	5.2	5.1	5.3	5.3
			III	1.9	5.2	5.1	5.5	5.6	5.4	5.2	5.1	4.8	5.0	5.1
		E	II	1.4	5.6	6.2	6.1	6.1	5.9	5.7	5.6	5.4	5.6	5.5
			III	1.6	5.2	6.2	6.3	5.1	4.8	4.3	4.1	4.0	4.1	4.6
B	C	D	II	1.3	6.0	6.2	5.8	5.2	4.9	4.6	4.8	5.1	5.3	5.1
			III	0.8	4.7	5.7	5.7	5.2	5.0	4.5	4.1	4.4	4.8	5.2
		E	II	1.1	5.8	6.4	6.2	5.4	5.1	4.7	4.3	4.5	4.9	5.1
			III	0.8	3.7	3.9	4.3	5.1	5.4	5.4	5.2	5.1	5.3	5.4
	Z	D	II	1.3	5.4	5.9	5.9	5.9	5.5	5.1	4.9	5.1	5.1	5.4
			III	0.9	4.2	4.5	5.3	5.3	5.2	4.7	4.5	5.0	5.1	5.2
		E	II	1.0	4.7	5.7	5.7	5.0	4.8	4.4	4.4	4.3	4.6	4.8
			III	0.8	5.0	5.9	5.9	5.2	4.5	4.7	4.0	4.0	4.3	4.4

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

April 10, 1981

Residue	Tillage	Drill	Replications	Depth in cm 0.00–7.6	7.6–22.9	22.9–38.1	38.1–53.3	53.3–68.6	68.6–83.8	83.8–99.1	99.1–114.3	114.3–129.5	129.5–144.8	144.8–160.0
U	C	D	II	1.2	4.6	5.6	5.6	5.2	4.7	4.4	4.3	4.4	4.8	5.1
			III	0.9	3.7	3.5	3.9	5.2	5.4	5.1	5.0	5.0	5.1	5.2
		E	II	1.3	5.6	5.8	5.8	5.1	4.9	4.8	4.6	4.7	4.8	4.9
			III	0.9	4.3	5.8	6.0	5.7	5.3	4.8	4.9	5.1	5.0	5.3
	Z	D	II	2.0	5.1	5.6	5.7	5.6	5.5	5.2	4.6	4.1	4.0	4.5
			III	1.9	4.6	5.5	5.6	5.1	4.9	4.6	4.3	4.5	4.9	5.1
		E	II	1.6	4.8	5.9	5.8	5.7	5.8	5.3	4.6	4.3	4.2	4.6
			III	1.4	4.5	5.6	5.7	5.5	5.5	4.9	4.4	4.2	4.2	4.8
M	C	D	II	1.4	4.8	5.1	5.2	5.2	5.3	5.1	5.1	5.1	5.0	5.2
			III	1.1	3.9	5.1	5.2	5.1	4.7	4.5	4.6	4.7	4.7	5.0
		E	II	1.1	4.7	5.1	5.0	4.7	4.5	4.5	4.9	5.1	5.3	5.3
			III	1.2	4.5	4.4	4.1	4.5	5.2	5.3	5.1	4.7	4.4	4.8
	Z	D	II	1.8	4.7	5.2	5.4	5.2	5.2	5.2	5.0	5.1	5.3	5.1
			III	1.7	4.2	3.8	4.1	5.3	5.3	5.1	4.9	4.5	4.8	5.1
		E	II	1.4	4.6	5.3	5.5	5.5	5.6	5.6	5.3	5.3	5.3	5.5
			III	1.3	4.2	5.3	5.6	5.4	4.7	4.1	3.9	3.9	4.0	4.5
B	C	D	II	1.3	5.1	5.7	5.5	5.0	4.8	4.4	4.6	5.0	5.2	5.0
			III	0.8	3.6	4.8	5.6	5.1	4.7	4.5	4.1	4.4	4.7	5.2
		E	II	1.0	5.2	6.2	6.1	5.2	4.9	4.4	4.2	4.5	4.8	5.2
			III	0.7	3.0	3.3	4.0	4.9	5.3	5.3	4.8	4.9	5.2	5.3
	Z	D	II	1.3	4.4	5.4	5.4	5.1	5.0	4.8	4.7	5.0	5.0	5.2
			III	0.8	3.5	4.2	5.2	5.2	5.0	4.7	4.5	4.9	5.1	5.1
		E	II	1.0	4.1	5.1	5.1	4.8	4.6	4.3	4.2	4.3	4.5	4.6
			III	0.8	4.1	5.3	5.3	5.0	4.5	5.0	4.0	4.0	4.1	4.5

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

April 24, 1981

Residue	Tillage	Drill	Replications	Depth in cm 0.00–7.6	7.6–22.9	22.9–38.1	38.1–53.3	53.3–68.6	68.6–83.8	83.8–99.1	99.1–114.3	114.3–129.5	129.5–144.8	144.8–160.0
U	C	D	II	2.0	4.4	5.2	5.2	4.9	4.8	4.3	4.4	4.4	4.6	5.2
			III	1.9	3.6	3.3	3.6	5.3	5.4	5.1	5.1	5.0	5.0	5.2
		E	II	2.0	5.6	5.5	5.4	5.2	4.9	4.6	4.5	4.9	4.7	5.0
			III	1.7	4.3	5.5	5.8	5.6	5.2	4.8	4.8	5.1	5.0	5.5
	Z	D	II	2.8	5.6	5.5	5.3	5.4	5.2	5.0	4.4	4.1	4.1	4.0
			III	3.8	3.8	4.5	5.4	5.3	5.1	4.8	4.6	4.3	4.4	4.9
		E	II	2.2	4.9	5.4	5.5	5.4	5.3	5.0	4.5	4.3	4.3	4.5
			III	2.4	4.6	5.5	5.3	5.2	5.1	4.8	4.3	4.3	4.2	4.8
M	C	D	II	2.1	4.8	4.5	4.6	4.8	4.9	5.1	4.9	5.1	5.1	5.2
			III	2.1	4.3	5.0	5.0	5.0	4.7	4.5	4.7	4.7	4.7	5.0
		E	II	1.7	5.0	5.0	5.2	4.8	4.5	4.5	5.0	5.2	5.3	5.4
			III	2.1	4.1	3.6	3.6	4.2	5.1	5.2	5.1	4.7	4.4	4.8
	Z	D	II	2.4	4.8	4.7	5.0	4.9	5.0	5.1	5.1	5.1	5.3	5.2
			III	2.5	3.9	3.2	3.4	4.6	5.3	5.2	4.9	4.6	4.8	5.1
		E	II	2.1	4.6	4.7	4.9	5.2	5.3	5.4	5.2	5.1	5.3	5.3
			III	2.3	4.2	5.1	5.4	5.2	4.7	4.1	3.9	4.0	4.1	4.5
B	C	D	II	2.3	5.3	5.2	52.	5.0	4.8	4.4	4.8	5.1	5.1	5.1
			III	1.6	3.6	4.5	5.1	5.0	4.8	4.4	4.1	4.4	4.9	5.0
		E	II	1.9	5.0	5.7	5.8	5.2	5.0	4.4	4.2	4.5	4.7	4.9
			III	1.6	3.1	3.2	3.8	4.9	5.2	5.1	5.0	4.9	5.2	5.4
	Z	D	II	2.2	4.6	5.0	5.1	5.0	4.7	4.6	4.5	4.7	4.8	5.2
			III	1.7	3.5	4.1	5.2	5.0	5.0	4.3	4.5	4.8	5.0	5.1
		E	II	1.8	4.1	5.2	2.7	4.8	4.8	4.3	4.1	4.2	4.4	4.7
			III	1.8	4.5	5.1	5.0	4.8	4.4	3.9	4.0	4.0	4.1	4.6

Note: C = *Conventional tillage*; Z = *Zero tillage*; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

May 6, 1981

Residue	Tillage	Drill	Replications	Depth in cm 0.00-7.6	7.6-22.9	22.9-38.1	38.1-53.3	53.3-68.6	68.6-83.8	83.8-99.1	99.1-114.3	114.3-129.5	129.5-144.8	144.8-160.0
U	C	D	II	2.4	4.2	4.9	4.8	4.9	4.5	4.4	4.3	4.4	4.9	5.1
			III	2.2	3.4	3.1	3.3	4.9	5.4	5.3	5.1	5.0	5.2	5.2
		E	II	2.2	5.1	5.2	5.0	5.1	4.8	4.6	4.5	4.9	4.8	4.8
			III	2.1	4.0	5.3	5.5	5.2	5.0	4.7	4.9	5.0	5.2	5.3
	Z	E	II	2.9	5.6	5.5	5.4	5.3	5.2	4.9	4.6	4.3	4.2	4.5
			III	2.7	3.5	4.1	5.1	5.2	5.2	4.9	4.6	4.3	4.5	5.0
		E	II	2.5	4.8	5.3	5.2	5.1	5.0	4.7	4.4	4.3	4.3	4.6
			III	2.5	4.4	5.0	5.1	5.0	4.8	4.5	4.3	4.3	4.3	4.7
M	C	D	II	2.4	4.5	4.2	4.3	4.5	4.6	4.9	4.8	4.9	4.9	5.2
			III	2.4	4.3	4.7	4.8	5.0	4.8	4.6	4.8	4.8	4.8	5.0
		E	II	1.9	4.4	4.5	4.7	4.6	4.6	4.6	4.9	5.3	5.5	5.4
			III	2.4	4.0	3.4	3.3	4.2	5.2	5.3	5.1	4.7	4.5	4.7
	Z	D	II	2.7	4.6	4.7	4.8	4.6	4.8	5.0	5.2	5.2	5.3	5.2
			III	2.7	3.7	3.0	3.3	4.8	5.3	5.2	4.9	4.7	4.9	5.2
		E	II	2.4	4.2	4.5	4.5	4.5	4.8	5.1	5.0	5.1	5.1	5.2
			III	2.6	4.1	4.9	5.1	5.0	4.6	4.1	4.0	4.1	4.0	4.6
B	C	D	II	2.5	4.9	5.0	5.1	5.0	4.7	4.6	4.7	5.1	5.1	5.1
			III	1.9	3.6	4.4	5.0	4.9	4.8	4.5	4.2	4.4	4.9	5.2
		E	II	2.0	5.1	5.6	5.8	5.5	5.1	4.6	4.3	4.5	5.8	5.0
			III	1.7	3.1	3.0	3.7	4.7	5.3	5.3	5.1	4.9	5.3	5.4
	Z	D	II	2.4	4.4	4.8	4.8	4.6	4.5	4.2	4.2	4.4	4.5	5.2
			III	2.2	3.7	4.0	5.1	5.2	5.1	4.7	4.5	5.0	5.1	5.2
		E	II	2.1	4.4	5.0	5.0	4.8	4.6	4.3	4.9	4.3	4.4	4.7
			III	2.2	4.8	4.9	5.0	4.8	4.4	4.1	4.1	4.1	4.4	4.7

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

May 21, 1981

Residue	Tillage	Drill	Replications	Depth in cm 0.00-7.6	7.6-22.9	22.9-38.1	38.1-53.3	53.3-68.6	68.6-83.8	83.8-99.1	99.1-114.3	114.3-129.5	129.5-144.8	144.8-160.0
U	C	D	II	2.7	6.1	6.6	5.8	4.8	4.5	4.3	4.3	4.5	4.9	5.3
			III	2.6	5.8	5.5	4.6	5.0	5.3	5.3	5.2	5.2	5.1	5.4
		E	II	2.3	6.2	6.3	5.5	5.1	4.9	4.6	4.6	4.7	4.8	4.9
			III	2.4	6.0	6.6	6.0	5.3	5.0	4.6	4.8	4.9	5.1	5.4
	Z	D	II	2.9	6.4	6.5	6.1	6.0	5.9	5.2	4.5	4.2	4.0	4.4
			III	2.8	5.7	6.0	5.7	5.4	5.2	5.0	4.6	4.5	4.6	3.7
		E	II	2.6	6.1	6.4	5.7	5.2	5.1	4.7	4.4	4.2	4.2	4.7
			III	2.7	6.4	6.4	6.1	5.0	4.7	4.5	4.2	4.2	4.3	4.8
M	C	D	II	3.0	6.6	6.3	6.1	5.7	4.9	4.7	4.8	5.0	5.1	5.1
			III	2.8	6.6	6.3	5.5	5.2	4.6	4.6	4.7	4.7	4.8	4.9
		E	II	2.5	6.6	6.5	6.1	5.4	4.7	4.6	4.9	5.1	5.4	5.2
			III	2.5	5.5	4.9	4.3	5.0	5.1	5.2	5.0	4.8	4.5	4.7
	Z	D	II	3.1	6.7	5.6	4.9	4.9	4.9	4.9	5.1	5.3	5.3	5.2
			III	2.7	5.9	5.1	3.6	4.6	5.2	5.1	5.0	4.8	5.0	5.2
		E	II	2.1	6.2	6.4	6.3	5.8	5.6	5.1	4.9	4.9	5.1	5.2
			III	2.6	5.9	6.4	5.6	5.1	4.6	4.2	4.0	4.0	4.0	4.5
B	C	D	II	2.9	6.3	5.5	5.0	4.9	4.7	4.4	4.7	5.1	5.0	5.0
			III	2.3	5.8	6.0	5.3	4.9	4.8	4.6	4.1	4.4	4.9	5.3
		E	II	2.3	6.0	6.3	5.8	5.5	5.1	4.5	4.2	4.4	4.8	5.0
			III	2.3	5.8	5.4	4.4	4.7	5.4	5.2	5.1	5.1	5.3	5.4
	Z	D	II	2.6	6.4	6.2	5.8	5.3	4.6	4.6	4.2	4.3	4.4	4.5
			III	2.3	5.8	5.4	5.3	5.2	5.0	4.8	4.5	5.0	5.0	5.1
		E	II	2.3	6.0	6.0	5.0	4.8	4.5	4.3	4.1	4.3	4.3	4.7
			III	2.4	6.3	6.6	6.2	5.6	4.6	4.0	4.1	4.1	4.2	4.6

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

June 4, 1981

Residue	Tillage	Drill	Replications	Depth in cm 0.00-7.6	7.6-22.9	22.9-38.1	38.1-53.3	53.3-68.6	68.6-83.8	83.8-99.1	99.1-114.3	114.3-129.5	129.5-144.8	144.8-160.0
U	C	D	II	2.9	6.0	6.0	5.6	4.6	4.5	4.3	4.2	4.5	4.7	5.2
			III	2.8	5.2	4.2	4.9	4.9	5.3	5.1	5.2	5.2	5.1	5.3
		E	II	2.6	5.9	6.0	5.4	5.2	5.0	4.6	4.6	4.7	4.8	4.8
			III	2.6	5.3	6.1	5.8	5.3	5.0	4.6	4.8	5.0	5.0	5.3
	Z	D	II	3.1	6.4	6.3	6.0	5.7	5.6	5.0	4.5	4.1	4.1	4.4
			III	3.0	4.5	5.0	5.5	5.3	5.0	4.9	4.5	4.4	4.5	4.9
		E	II	2.8	5.6	6.0	5.6	5.2	5.0	4.8	4.5	4.2	4.2	4.7
			III	2.8	5.7	6.0	5.5	5.0	4.7	4.5	4.1	4.1	4.3	4.6
M	C	D	II	3.0	5.9	5.8	5.5	5.2	4.7	4.7	4.7	4.7	5.1	5.1
			III	3.1	6.5	5.8	5.3	5.1	4.7	4.5	4.7	4.7	4.7	4.8
		E	II	2.4	6.1	6.1	5.8	5.3	4.7	4.6	4.8	5.0	5.3	5.4
			III	2.9	5.1	4.4	3.9	4.6	5.0	5.2	5.0	4.7	4.4	4.7
	Z	D	II	3.2	5.4	5.1	5.0	4.7	4.9	5.1	5.0	5.1	5.3	5.2
			III	3.0	5.4	4.1	3.4	4.6	5.2	5.0	4.9	5.1	4.8	5.2
		E	II	2.7	5.4	5.3	5.3	5.4	5.3	4.9	4.9	4.9	5.1	5.1
			III	2.9	5.5	5.9	5.5	5.0	4.4	4.2	4.0	3.9	4.0	4.5
B	C	D	II	3.2	5.8	5.3	4.9	5.0	4.7	4.5	4.7	5.2	5.2	5.0
			III	2.6	5.6	5.5	5.2	5.0	4.7	4.4	4.2	4.4	4.7	5.0
		E	II	2.5	5.3	5.8	5.6	5.4	5.0	5.1	4.1	3.8	4.9	5.0
			III	2.3	4.9	4.3	4.2	4.8	5.3	5.3	5.1	5.0	5.3	5.4
	Z	D	II	2.9	5.4	5.1	5.4	5.0	4.5	4.2	4.2	4.4	4.5	4.9
			III	2.5	5.2	5.1	5.3	5.1	5.0	4.7	4.5	4.9	5.1	5.1
		E	II	2.5	5.5	5.5	5.1	4.7	4.5	4.2	4.2	4.2	4.3	4.7
			III	2.5	6.3	6.2	5.8	5.3	4.6	4.0	3.9	4.1	4.0	4.6

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

Table II-D. (continued)

June 16, 1981

Residue	Tillage	Drill	Replications	Depth in cm 0.00–7.6	7.6–22.9	22.9–38.1	38.1–53.3	53.3–68.6	68.6–83.8	83.8–99.1	99.1–114.3	114.3–129.5	129.5–144.8	144.8–160.0
U	C	D	II	2.8	6.2	6.4	5.6	4.9	4.7	4.4	4.3	4.4	4.8	5.1
			III	2.7	5.9	5.2	4.0	4.9	5.3	5.2	5.1	5.1	5.1	5.2
		E	II	2.4	6.1	6.0	6.0	5.1	4.9	4.6	4.7	4.9	4.8	5.0
			III	2.6	5.9	6.2	5.9	5.3	5.0	4.7	4.9	5.1	5.1	5.5
	Z	D	II	2.9	6.4	6.4	6.3	6.0	5.5	5.0	4.5	4.2	4.0	4.4
			III	0.9	5.3	5.1	5.4	5.3	5.1	4.8	4.7	4.5	4.6	5.0
		E	II	2.5	6.1	6.0	5.7	5.3	5.0	4.7	4.3	4.2	4.3	4.6
			III	2.7	6.3	6.1	5.4	5.1	4.7	4.4	4.2	4.1	4.4	4.8
M	C	D	II	3.0	6.3	6.3	5.8	5.1	4.8	4.7	4.7	4.8	5.0	5.1
			III	3.1	6.7	6.1	5.4	5.1	4.8	4.6	4.7	4.7	4.8	4.8
		E	II	2.2	6.7	6.4	5.9	5.4	4.8	4.7	5.0	5.1	5.4	5.4
			III	2.6	5.8	5.0	3.9	4.3	5.2	5.3	5.0	4.6	4.4	4.9
	Z	D	II	3.1	6.6	5.4	4.9	4.7	4.9	5.0	5.2	5.1	5.4	5.1
			III	3.0	5.9	4.5	3.4	4.5	5.2	5.2	5.0	4.8	5.0	5.3
		E	II	2.5	6.3	5.9	5.2	5.3	5.1	4.9	4.8	4.9	5.1	5.1
			III	2.8	6.1	6.3	5.5	4.9	4.5	4.2	4.0	4.0	4.2	4.5
B	C	D	II	4.2	6.2	5.4	5.1	4.9	4.5	4.5	4.9	5.1	5.1	5.1
			III	2.6	5.9	6.0	5.2	4.9	4.7	4.5	4.4	4.2	4.5	4.9
		E	II	2.3	5.4	5.7	5.6	5.3	5.1	4.5	4.3	4.6	4.9	5.1
			III	2.5	5.2	4.3	4.3	4.8	5.2	5.2	5.1	5.2	5.4	5.5
	Z	D	II	2.7	6.5	6.0	5.3	5.1	4.4	4.2	4.2	4.3	4.6	5.1
			III	2.3	5.5	5.1	5.3	5.3	5.0	4.8	4.6	5.0	5.2	5.1
		E	II	2.4	6.1	5.6	4.9	4.7	4.5	4.4	4.1	4.2	4.3	4.6
			III	2.4	6.5	6.7	6.5	5.4	4.4	4.0	4.1	4.1	4.2	4.6

Note: C = Conventional tillage; Z = Zero tillage; D = Disk drill; E = Experimental drill; U = Untreated residue; M = Mowed residue; B = Burned residue

REDUCED TILLAGE AND SOIL PHYSICAL PROPERTIES IN CONTINUOUS WHEAT

by

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Conservation tillage is designed to accomplish goals of increased crop production, improved conservation of natural resources (soil and water), and reduced energy requirements. Successful methods for using stubble mulching on wheat-fallow systems are known, but suitable techniques for reducing tillage in continuous wheat production are needed. Reasons cited for decreased yields often produced by reduced tillage are phytotoxic effect of surface residues on wheat growth, difficulties in getting good stands, unsatisfactory weed control, and soil physical problems.

This study was undertaken to assess the effect of surface residues on wheat growth under conventional, reduced, and zero tillage, to evaluate soil physical properties under different tillage practices, and to develop a better method of seed placement through surface trash and into firm soil. The experiment was conducted on a Pachic Argiustoll soil at the Kansas State University Agronomy Farm, North of Manhattan during 1980-1981.

Three methods of residue management (untreated; mowed; and burned), three kinds of tillage (conventional, using chisel and tandem disk; reduced, chemical weed control supplemented by tillage when necessary; and no-till, herbicides only), and two drills (single disk drill and an experimental model) were arranged in a split plot design with three replications. Wheat yields were obtained by combining 2.4-meter swathes from each plot, soil bulk density was determined by the soil core method, soil strength was appraised with a Proctor needle penetrometer, soil temperature with thermocouples, and soil water was monitored with a neutron probe.

Wheat yield differences among residue treatments were not significant (untreated, 22.0; mowed, 21.5; and burned 21.2 q/ha). Average yield of the no-till system (23.7 g/ha) was significantly greater than those of reduced and conventional tillage (21.2 and 20.1 q/ha, respectively). The experimental drill performed significantly better (22.8 q/ha) than the single disk drill

(20.5 q/ha). The best average yield was obtained on the mowed, no-till plots seeded with the experimental drill (27.3 q/ha). Surface residues may have affected wheat emergence on mowed plots temporarily, but emergence count and straw cover percentage did not correlate. Overall results indicate that surface residue increased wheat yield. Nitrogen and phosphorous grain contents generally increased as wheat yields increased, except for a higher N content on burned treatments.

The experimental drill performed well on untilled surfaces cutting through surface trash and soil and placing seeds deep enough to ensure good germination and establishment. Soil bulk densities were different on the various tillage treatments but had little effect on growth and yield. Soil strength values generally paralleled the pattern of bulk densities. Afternoon soil temperatures were lower under protected surfaces (differences of 1.2 to 2.8^{o}C through the growing season). This probably decreased evaporation losses.

Soil water distribution was important in determining final yields. From fall until spring no-till plots had more water in the upper root zone. This favored tillering and effected a better water use efficiency. A higher infiltration rate on conventional tilled plots, measured under ponded surface, may have been neutralized by compaction produced by rainfall and by greater evaporation.

These data indicate that reduced tillage in continuous wheat production can be successful when good management, including proper seed placement and satisfactory weed control is achieved.