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Tillage and Landscape Position Effects on Soil Properties and Crop Production

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TILLAGE AND LANDSCAPE POSITION EFFECTS ON SOIL PROPERTIES AND CROP PRODUCTION

by

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This dissertation is approved as a creditable and independent investigation by a candidate for the Degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirements for that degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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Tillage and Landscape Position Effects on Soil Properties and Crop Production.

By

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The management problems associated with utilizing a single cropping system across an undulating landscape that contains well and poorly drained soils were addressed. Results from this work will aid farmers in making their tillage and crop rotation decisions.

Four tillage treatments (moldboard plow, chisel plow, ridge-till and no-till) and three cropping sequences (continuous corn, corn after soybean, and soybean after corn) were arranged in a split plot design on a well drained Beadle and poorly drained Worthing soils.

Worthing soil surface has a significantly lower hydraulic conductivity and higher volumetric moisture, pH, available phosphorus and potassium than the Beadle soil. Crop emergence and grain yield were significantly reduced in the Worthing soil compared to the Beadle soil across all tillage systems.

Ridge-till and no-till treatments behaved differently from moldboard and chisel plow treatments with respect to overall physical properties in the Beadle soil. Ridge-till and no-till plots had significantly higher volumetric moisture, lower soil temperature and higher bulk

density than the moldboard plow and chisel plow plots. No significant difference in water use (evapotranspiration) was observed between tillage treatments in either soil. Little difference in physical properties of the Worthing soil was observed due to tillage except for a higher bulk density in the ridge and no-till treatments than other tillage treatments. Few differences in chemical properties due to tillage systems were found in these soils. A significantly higher pH was observed in the moldboard plow and chisel plow Beadle plots than in the ridge-till and no-till plots. Ridging in the Worthing soil significantly increased nitrate levels at 0-0.60 m compared to chiseling and no-till treatments.

Little difference in crop development and grain yield was observed in either soil due to tillage in 1986. Moldboard plowed Beadle plots under continuous corn produced significantly higher leaf area most of the growing season and grain yield than other tillage treatments in 1987. Moldboard plow behaved differently from other treatments with respect to agronomic parameters in the Worthing soil in 1987 due to delayed plowing and the resulting cloddy surface. Ridge-till or no-till systems with corn-soybean rotations were found to be the best cropping systems practices in fields comprised of different proportions of well and poorly drained soils.

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INTRODUCTION

Tillage is defined as the mechanical manipulation of soil with the objectives of promoting good tilth and high production. For centuries farmers have tilled the soil for three primary reasons: (1) to control weeds, (2) to prepare a suitable seed bed and (3) to incorporate organic residues.

Prior to this decade, farmers had few tillage options. Starting in the 1970's, a number of tillage systems evolved ranging from no-tillage systems to several reduced tillage systems.

Over the years, conventional tillage systems involving moldboard plowing and extensive secondary tillage prior to planting have been successful over a wide range of soils. Even today, these tillage systems do an excellent job of preparing the seed bed, incorporating crop residues and controlling weeds. However, they contribute to soil erosion, are labor intensive and are ineffective in conserving soil moisture.

Sustainable agriculture depends on wise management of soil and water resources. These resources are endangered as soil erosion becomes a growing problem in many agricultural areas of the world. Soil erosion is severe in areas with steep slopes, intensive rainfall, and poor soil management. Asia has the most severe water

erosion problem of any of the continents (166 t km^{-2} $year^{-1}$), followed by South America and North America (93 and 73 t km^{-2} $year^{-1}$). Nearly 3 billion tons of soil are lost each year from U.S. cropland. In some countries of Asia and South and Central America the damage due to erosion appears to have reached the point of no return.

The conservation compliance provision of the 1985 Food Security Act has increased the interest of farmers in reduced (conservation) tillage systems to bring soil erosion to acceptable levels. Conservation tillage is one of several cost effective tools available to producers in their soil and water conservation efforts. Conservation tillage is defined as any planting and tillage system that retains at least 30% crop residue cover on the soil surface after planting. The benefits of conservation tillage are reduced soil erosion and down stream pollution, potentially higher economic returns in some soils, increased soil organic matter, reduced fuel use, reduced soil compaction, and improved water holding capacity of soils. Conservation tillage practices can reduce soil loss as much as 90% compared to conventional tillage.

Many farmers in the U.S. have adopted conservation tillage practices. The use of conservation tillage (particularly minimum tillage) increased dramatically from 39.1 million acres in 1973 to 88 million acres in 1981. A

1986 conservation tillage survey indicated that 32% of US cropland was under conservation tillage. USDA estimates that 95% of US cropland may be under conservation tillage by the year 2010. Conservation tillage is used primarily on corn, soybean, and small grains.

Performance of specific conservation tillage systems is often inconsistent. They differ from one geographic region to another, from soil to soil, and from one year to the next. Soil and landscape factors are found to dominate the crop yield differences between conservation and conventional tillage systems. Conservation tillage is most suitable on well drained light textured soils. Farmers utilizing no-till systems have had problems in somewhat poorly and poorly drained soils. Yields of continuous no-till corn are generally lower than conventionally tilled corn in such soils. Use of a corn-soybean rotation under no-till has improved yields in some poorly drained soils. Ridge till planting has been suggested as an alternative for no-tillage on poorly drained soils.

Most corn and soybean reduced tillage research has been conducted in eastern corn belt states. South Dakota differs from these states in amount of precipitation, early season temperature, and occurrence of poorly drained soils. Eastern South Dakota receives 610 mm precipitation

annually. This area is usually short of water at some time during the growing season. Frequently drought occurs during a critical growth period of the crop.

The glacial morainic landscape of eastern South Dakota consists of moderately rolling hills with many closed undrained depressions. Due to its rolling topography, the soilscape of eastern South Dakota is an intricate mosaic of soils with varied soil drainage. Well drained, somewhat poorly drained and poorly drained soils are commonly located on the same farm and frequently in the same field.

As farmers make tillage selections, they need reliable findings of replicated tillage trials that transcend soil drainage classes and are comprised of common crop rotations. Therefore, it was essential to conduct a tillage and soil drainage interaction study in the corn and soybean producing region of South Dakota. A study was conducted at the Eastern South Dakota Soil and Water Conservation Research Farm near Madison with the following objectives:

1. To study the interactive effects of tillage systems, and soil drainage class (well and poorly drained soils) on:

   a. Soil physical properties

   b. Soil chemical properties

c. Crop development and grain yield

2. To study the effect of tillage systems, cropping sequence and soil drainage class (well and poorly drained soils) on crop development and grain yield.
3. To evaluate tillage and crop rotation systems best suited for a field comprised of both well and poorly drained soils.

This study was based on the following hypotheses:

1. Conservation tillage plots will have higher surface bulk density, lower surface hydraulic conductivity, higher surface moisture, and lower surface temperature than the conventional tillage plots.
2. The emergence and yield of corn and soybeans will be less in the poorly drained Worthing soil than in the well drained Beadle soil. The yield reduction due to drainage class will be less than those reported in the literature because of drier conditions in South Dakota.
3. The ridged seed beds will dry faster and have warmer soil temperatures than flat seed beds in the other tillage systems on the poorly drained soils.
4. Conservation tillage practices will produce higher (or equivalent) yield than the conventional tillage in the Beadle soil. Ridge till will have better emergence and produce higher yield (equivalent to the conventional and chisel plow) than no-till plots in the Worthing

soils.

5. A corn after soybean rotation will perform better than continuous corn under conservation tillage systems.

The outcome of this research will be applicable to those regions of the northern or western corn belt that have an undulating topography.

LITERATURE REVIEW

I. Tillage Effects on Soil Physical Properties.

A. Soil Structure

Soil structure or aggregation affects soil water and air relationships. The size, shape, and stability of soil aggregates control the pore size distribution and continuity, which in turn affect many other soil physical characteristics. Successful tillage systems depend on suitable soils and the maintenance of optimum soil structure (Carter, 1987). Soil with good structure provides the best conditions for supplying water and nutrients to the plants (Kononova, 1966).

Organic matter is the most important factor in the formation of good soil structure. A good correlation was often observed between organic matter content and improved soil aggregation (Blevins et al., 1985). Soil with good structure maintains aggregate stability upon abrupt changes of moisture and intense rainfall. Therefore, water stable aggregation is sometimes used to evaluate soil structure.

Generally, as tillage intensity increases soil aggregation decreases (Mannering et al., 1975). A higher soil aggregate stability was observed in soils managed under conservation tillage systems as compared to the conventional tillage systems (Mannering et al., 1975). Enhanced surface aggregate stability with no-till and

shallow tine cultivation systems was reported in the United Kingdom (Douglas and Goss, 1982). Burch et al. (1986) observed the highest aggregate stability in the top 0.05-0.1 m of soil with minimum disturbance. After five years of no-tillage, Boone et al. (1976) observed a decrease in small size aggregates and an increase in overall aggregate stability.

All tillage systems enhanced organic matter decomposition and decreased aggregate stability compared to a virgin setting (Douglas and Goss, 1982). However, this trend was minimized by a reduced tillage system compared to a conventional tillage system.

Improved soil structure and aggregate stability associated with conservation tillage systems was due to increased organic matter in these systems as compared to the conventional tillage system (Mannering et al., 1975; and Douglas and Goss, 1982). The increased faunal population under no-till system improved soil structure and increased infiltration (Edwards and Lofty, 1978; and Hopp and Slater, 1961). While feeding on organic materials and burrowing in soils, earthworms secrete gelatincus substances that coat and stabilize soil aggregates.

In addition to increased organic matter, surface mulch also protects soil aggregates from disintegration by sheering forces of falling rain drops (Blevins et al.,

1984). Tilled soils without surface mulch slaked during a rain and formed a surface crust (Ehlers, 1979; Opara Nadi et al., 1987; Vanderweert, 1964; and Roth et al., 1988).

B. Porosity, Bulk Density, Hydraulic Conductivity, and Infiltration.

Bulk density and porosity influence water and air movement in the soil and influence the potential productivity of a given soil. These properties vary with the tillage treatments. Research conducted over a wide range of soil types and climatic conditions show contrasting results.

Total porosity of the surface soil layer (0-0.1m) increased as tillage intensity increased (Ehlers, 1979). A reduction in total porosity under no-till or conservation tillage systems as compared to conventional tillage has been reported by many researchers (Army et al., 1961; Aase et al., 1980; Carter and Rennie, 1984; Cannel et al., 1977; Douglas et al., 1980; and Heard et al., 1988).

Some tillage studies showed no significant change in bulk density between conventional and no-tillage systems (Blevins et al., 1983; Shear, 1969; Hill and Cruse, 1985). Wheel track compaction appeared to be ameliorated by the freezing and thawing cycles in the winter months (Blevins et al., 1983). Bauder et al. (1981) observed no effect

either due to position (row or interrow) or tillage systems on bulk density during the tenth year of a study on a Typic Haplaquoll in Minnesota. Penetrometer resistance or cone index (CI) was found to be a more sensitive indicator of tillage and traffic induced changes than bulk density (Bauder et al., 1981; and Culley et al., 1987). However, application of mulch on Alfisols in Nigeria decreased bulk density of the surface soil and prevented the formation of a surface seal (Opara Nadi et al., 1987; and Vanderweert, 1964).

A significant increase in surface bulk density was observed under no-till (no-till) as compared to a conventional tillage system (Gantzer and Blake, 1978; Roth et al., 1988; NeSmith et al., 1987; Douglas et al., 1980; Pidgeon and Soane, 1977; Ellis et al., 1979; Cannel et al., 1980; and Burch et al., 1986). A significant increase in CI values was also reported under no-till (no-till) as compared to conventional tillage (Pidgeon and Soane, 1977; Tollner et al., 1984; Bauder et al., 1981; Hamlin et al., 1986). The equilibrium bulk density values under no-till were attained within 3 years, but CI of the subsoil continued to increase with time. Some light textured soils (loamy sands) presented more potential compaction hazards with no-till than medium textured soils (Ellis, 1977; and Hamlin et al., 1979). This may be due to limited

opportunity for stable macropore formation in light textured soil. Periodic deep chiseling and moldboard plowing was suggested for the amelioration of tillage pans and increasing infiltration (Bauder et al., 1981; NeSmith et al., 1987; and Campbell et al., 1974).

However, improved aeration and macro-porosity was reported in some soils under no-till (Cannel et al., 1977; Lal et al., 1976; and Vieira, 1981). They also reported that continuous macro channels were formed in no-till soils due to the lack of disturbance by tillage equipment. Macro-pore continuity may also be maintained in no-till systems due to increased earthworm activity (Ehlers, 1975; Mackay et al., 1985; and Lee, 1985), and voids left by decomposing roots (Gantzer and Blake 1978). More bio-channels were found in a no-till system than in a plowed system (Ehlers, 1975; Boone et al., 1976; and Shipitalo et al., 1987). Zoological activity, which consisted mainly of burrowing earthworms, resulted in 2-9 times more bio-porosity in no-till pedons than in conventionally tilled pedons. Although fewer channels were observed at the 0.1-0.3 m depth of a no-till soil than of a plowed soil in Indiana; the channels were mostly continuous under no-till (Heard et al.,1988).

Contrary to the above findings, many researchers reported a decrease in macro-porosity under no-till systems

as compared to a conventional system (Pidgeon and Soane, 1977; Douglas et al., 1980; Gantzer and Blake 1978; and Van Ouwerkerk et al., 1970). Ehlers et al. (1979) in Germany observed an increased volume of macro-pores (>5 micron) by plowing compared to no-till but the continuity between top soil and subsoil was reduced.

No-till not only reduced total pore space but also changed the pore size distribution. Larger pores disappeared and the finer pores predominated with time (Van Ouwerkerk et al., 1970). Hill et al., (1985) observed that soil under conventional tillage had a larger proportion of its pore volume in space >15 micron radius as compared with soils under conservation tillage. Conservation tilled soils on the other hand contained a larger proportion of pores in the 1-15 micron pore radius interval. A micro-morphometric analysis indicated that the surface horizon of no-till plots contained approximately half the macro-porosity (pores >=200 micron equivalent circular diameter) of those of conventionally tilled plots (Shipitalo and Portz, 1987). Less macro-porosity was characterized by a decrease in the mean pore size and a tendency for pores to become elongated, less tortuous, and oriented parallel to the soil surface. Since conventionally tilled soils contained the greater proportion of larger pores, these soils seemed to be more

susceptible to compaction than the soils under conservation tillage systems (Hill et al., 1985).

Many researchers reported an increase in saturated hydraulic conductivity (K-sat) and infiltration rate under no-till as compared to the conventional tillage system (Tyler, 1977; Lee et al., 1985; Barnes et al., 1979; Ehlers et al., 1975; Blevins et al., 1983; Tollner et al., 1985; Lee et al., 1985; Ehlers, 1975; and Goss et al., 1978). Maintaining mulch on the surface usually increased the infiltration capacity of soil under no-till (Triplett et al., 1968; Lal, 1981; Opara Nadi and Lal, 1987; and Roth et al., 1988). The increased infiltration with the no-till system was attributed to a greater concentration of organic matter at the soil surface (Triplett et al., 1968; Lal, 1974). Infiltration was also influenced by surface seal (Roth et al., 1988). Residue protected the soil surface against rain drop impact energy therefore maintaining surface soil structure (Smika and Unger, 1986). In soils with poor structure and low organic matter, the mechanical loosening effects from tillage were soon lost by rain drop impact (Blevins et al., 1984). Application of mulch on the surface decreased formation of surface seal and increased infiltration (Army et al., 1961; and Roth et al., 1988). One hundred percent cover on the surface of an Oxisol in Brazil led to complete infiltration of a 60 mm rain,

whereas only 20% of the applied rain infiltrated when the soil was bare (Roth et al., 1988).

Other researchers attributed the increased infiltration under no-till to increased earthworm activity (Lee, 1985; Ehlers, 1975; and Mackay et al., 1985). A 2-15 fold increase in infiltration rate was reported in some field and greenhouse studies due to earthworm activity (Kladivko et al., 1986; Lee, 1985; and Ehlers, 1975). Rapid water movement was reported under no-till through macro-pores (Taylor et al., 1977). Even at low rainfall rates, water moved rapidly through vertical, continuous macro-pores (mainly earthworm burrows) in a field that was not tilled for more than twenty years (Edwards et al., 1988). Even though the continuity of the macro-pores was a factor, the lack of disturbance by tillage equipment under no-till favored the maintenance of a continuous hydraulic system of finer pores from one layer to the next (Ehlers, 1975; Ellis, 1979; and Blevins et al., 1984)

In other studies, K-sat and infiltration rates decreased as tillage intensity decreased. Lower surface K-sat and infiltration values were reported for no-till as compared to conventionally tilled systems (Lindstrom et al., 1984; Lindstrom et al., 1981; and Heard et al., 1988). In a long term conservation tillage study in Indiana, Heard et al. (1988) observed significantly greater K-sat values

in the moldboard plow treatment as compared to other treatments (chisel plow, ridge-till, and no-till). The difference in K-sat values between two soils (Typic Haplaquoll and Typic Ochraqualf) was greater than the difference among the tillage treatments (Heard et al., 1988). However, during a heavy rain period (93 mm), profile recharge for conventional tillage, till plant, and no-till was found to be 34%, 34%, and 44% less than chisel plow, respectively (Johnson et al., 1984).

Tillage effects on soil physical properties (such as bulk density and K-sat) also depend on time of the year when the measurements are taken and soil depth. Lower surface K-sat values were observed under no-till soon after planting while no significant difference was observed at harvest between the no-till and conventional tillage systems (Gantzer and Blake, 1978). No significant difference in K-sat values was observed below a depth of 0.3 m due to tillage practices (Blevins et al., 1984).

Generally reduced tillage lessens soil compaction due to wheel traffic. Traffic pans were observed under all tillage systems (fall moldboard plowing, spring disking, and no-till) except fall chisel plowing in Minnesota (Bauder et al., 1981). Traffic pan development was also reported in Piedmont soils under continuous conventional tillage (Tollner et al., 1984); and in Oxisols of Brazil

under conventional and, to a lesser extent, minimum tillage (Roth et al., 1988). In a controlled wheel traffic experiment, normal wheel traffic had soil compactive effects to a depth of 0.45 m (Voorhees et al., 1978; and Voorhees, 1983). The subsoil compaction persisted for long periods even in regions subjected to annual freeze-thaw cycles (Blake et al., 1976).

An increase in bulk density was reported due to wheel traffic (Voorhees and Lindstrom 1984). Under normal cereal harvesting conditions in Scotland, a single pass with a combine harvester across a variably drained sandy clay loam soil increased the bulk density to the depth of previous primary tillage; with no-till, no significant increase in moist bulk density occurred beyond a depth of 0.06 m (Pidgeon and Soane, 1978). Soane et al. (1982) suggested that no-till soil becomes pre-compacted (consolidated) and acquires sufficient strength to carry traffic without more compaction.

Significanty lower K-sat values were observed for the traffic interrow compared to the non-traffic interrow and row areas (Cassel, 1983). Wheel track effects on infiltration soon after planting was greater than those due to tillage, but there was no wheel tracking effect observed on no-till (Lindstrom et al., 1981). Saturated hydraulic conductivity values measured in vertically oriented soil

C. Soil Moisture

Conservation of soil moisture is one of the major advantages of reduced tillage systems. Numerous studies have shown greater volumetric water content at the surface layer of soils under conservation tillage practices than conventional tillage (Tollner et al., 1984; Mielke et al., 1986; NeSmith et al., 1987; Mannering et al., 1975; Blevins et al., 1983; Negi et al., 1981; Gantzer and Blake, 1978; and Lal, 1981; Hill et al., 1986b; Izaurralde et al., 1986; Aase and Siddoway, 1980; and Agboola, 1981).

No-till soil contained higher surface moisture compared to conventional tillage during most of the growing period (Mannering et al., 1975; Johnson et al., 1984; Phillips, 1984; Lal, 1974; and Agboola, 1981). The subsoil (0.15-0.90 m) water content for no-till was also reported as high or higher than the conventional treatment (Phillips, 1984; Nelson et al., 1977; and Izaurralde et al., 1986). Surface (0-0.076 m) volumetric water content at planting for no-till, chisel plow, till-plant, and conventional tillage was reported as 0.324, 0.279, 0.267, and 0.246 $m^3 m^{-3}$, respectively on a silt loam soil (Typic Argiudoll) in Wisconsin (Johnson et al., 1984). Research conducted at five locations from East Central USA to the Great Plains indicated that volumetric water content for 0-.15 m surface layer ranged from 8-66% higher in no-till

than in plowed soils (Mielke et al., 1986).

A tillage study on a clay soil in the U.K. demonstrated that yearly variation in moisture storage depended upon the amount of winter rainfall (Goss et al., 1978). When the winter rainfall was close to or greater than the long term average, the maximum soil water content of the upper 1 m differed little between the cultivation treatments. In contrast, after a dry winter, about 10% more water was stored in the no-till soils as compared to the plowed soil.

Increased moisture in the no-till and conservation tillage systems was attributed to reduced evaporation from the residue covered surface (Blevins et al., 1971, 1985; Phillips, 1984; Triplett et al., 1968; Griffith et al., 1977; and Unger et al., 1978), greater ability to store moisture due to pore size distribution (Blevins et al.,1971), better infiltration (Griffith et al., 1977) and catching more snow (Smika et al., 1986). Increasing quantities of crop residue on the soil surface reduced the evaporation rate, and lengthened the duration of the first stage drying (Bond et al., 1969; Russel, 1939; Army et al., 1961; Aase et al., 1980; Cannel et al., 1980; and Tonaka et al., 1985). A positive correlation was found between soil water content at planting time and the amount of wheat residue on the soil surface during fallow (Unger et al.,

1986). The presence of mulch on no-till corn plots almost eliminated the loss of moisture by direct evaporation from the soil surface prior to the crop canopy closure (Hill and Blevins, 1973). Maintaining crop residue at the soil surface shaded the soil and served as a vapour barrier against water loss (Triplett et al., 1968).

In an evaporation comparision study in the Northern Great Plains, Aase et al. (1986) reported that soil water evaporation during summer months was about the same for all tillage treatments. However, field and laboratory studies showed that the drying rate of 0-12.7 mm portion of the soil profile was greatly reduced by the presence of plant residue on the surface. Under field conditions, soil moisture content below 51 mm was not materially increased by surface residue. By using a numerical dynamic model, Ross et al. (1985) in Australia predicted a 15% reduction in water loss by mulch over 6 days.

There are disagreements as to whether the increase in soil water retention occurring with conservation or no-till systems actually benefits plant growth. Tollner et al. (1984) observed significantly less plant available water in the surface of a no-tilled soil as compared to a conventionally tilled soil. They indicated that some tillage at an appropriate time might result in more plant available water. In another study in Europe, no difference

in plant available water was found between tillage treatments although total soil water retention was greater for no-tillage (Van Ouwerkerk and Boone, 1970). However, Negi et al. (1981) observed twice as much plant available water in no-till as in the conventionally tilled plots. It was also implied from a soil water retention and pore size distribution study that conservation tilled soil should retain more plant available water than conventionally tilled soil (Hill et al., 1985). During years of either low or favorable rainfall, increased water retention capabilities of no-till soil increased crop yield (Blevins et al., 1971; and Tollner et al., 1984). In a dry summer followed by a dry winter, winter wheat extracted up to 22 mm more water from no-tilled soils than plowed soils (Goss et al., 1978).

The extra water conserved under no-till could occasionally be disadvantageous (Blevins et al., 1983; and Tollner et al., 1984). Excessive soil water contributed to denitrification loss of nitrogen fertilizer (Blevins et al., 1983). Water and nitrogen can be lost through drainage from the soil profile under no-till system (Tollner et al., 1984).

A simple water budget model and the more sophisticated Nitrogen Tillage Residue Management (NTRM) model proved satisfactory for predicting soil water

contents under both moldboard and no-till systems (Culley et al., 1987).

D. Soil Temperature

Conservation tillage systems leave most or a portion of the previous crop residue on the soil surface and tend to minimize soil disturbance. These practices influence soil temperature.

Energy losses by reflection, conduction, convection, radiation, and evaporative cooling were all found important in balancing incoming radiation and determining soil surface temperature (Ross et al., 1985a). Surface residues were reported to reduce surface soil temperature by:

1. reflecting a greater fraction of incoming solar radiation back to the atmosphere.
2. acting as an insulating layer between the air and soil.
3. altering the soil water balance which in turn affects soil thermal properties (Van Wijk et al., 1959).

Much of the effect of residue on soil temperature is caused by surface reflectance. Surface reflectance varied with type of material on the surface, color of the material and soil water content (Van Wijk et al., 1959). Surface residue had higher solar reflectivity and lower thermal conductivity compared to soil (Van Wijk et al.,

1959). Light colored surfaces reflected more than dark colored surfaces (Van Wijk et al., 1963). Similarly, wet soils had a lower reflectivity than drier soils. Therefore, aging and decomposition of residue after crop harvest can change the reflective characteristics of the crop residue. Generally, as the reflectance increases soil temperature decreases (Van Doren and Allmaras, 1978). The insulating effect increases as the residue mulch thickness increases (Unger, 1978).

Although the amount of surface crop residue was the most important factor controlling soil temperature in different tillage systems, the difference in thermal properties of the plow layer due to tillage might also affect soil temperature (Wierenga et al., 1982). Bulk density and water content of the plow layer could be amended by tillage which in turn could influence soil thermal conductivity, heat capacity and therefore, thermal diffusivity (Allmaras, 1977). Thermal diffusivity and conductivity were significantly greater for no-till than for conventional and chisel systems (Potter et al., 1985). Prevalence of wind and soil surface roughness could also cool the soil (Ross et al., 1985b).

Percent surface residue had a greater influence on soil temperature (soil heat flux) than soil thermal properties influenced by tillage practices (Gupta et al.,

1983; and Potter et al., 1985). Only a minimal difference in spring soil temperature was observed due to tillage induced modification of thermal properties (Gupta et al., 1983). Since mulched soil lost less water by evaporation, it generally contained higher soil water. Its thermal conductivity was greater, conducting heat to the greater depths, and thus warming the seed zone less. The heat capacity of wet soil was greater than that of dry soil because the heat capacity of water is greater than that of air. Therefore, the radiant energy increased the temperature of dry soil more than that of wet soil (Gupta et al., 1983; and Potter et al., 1985).

A lower surface temperature (4-7 ^{o}C) was observed with mulched soil than a bare soil under different agroclimatic conditions (Burrows and Larson, 1962; Gupta et al., 1983; Kamara, 1986; Gupta and Gupta, 1986; Potter et al., 1986). The average soil temperature under a specific amount of crop residue was linearly related to air temperature between 10-30 ^{o}C (Blackow, 1972). The effect of surface residue was greater on the daily maximum soil temperature than on the daily minimum (Gupta et al., 1983). The lesser effect on minimum soil temperature was due to decreased long wave radiation at night from the plant residue covered soil surface.

Many researchers observed a reduction in soil

temperature due to conservation tillage (Tollner et al., 1984; Johnson and Lowery, 1985; Van Wijk et al., 1959; Burrows and Larson, 1962; Griffith et al., 1973; Aase et al., 1980; and Grevers and Bomke, 1985). Johnson and Lowery (1985) in Wisconsin reported that the in-row soil temperature at 50 mm depth was the highest in conventional tillage, slightly lower in chisel, and the lowest in a no-till system of corn production. The no-till system with residue resulted in 5-8 ^{o}C lower temperature than in the conventionally tilled system (NeSmith et al., 1987). Ross et al. (1985a) in Australia reported that mulch could reduce surface temperature up to 20 ^{o}C by intercepting incoming radiation. By the use of a dynamic model, they predicted that mulch canopies that intercept 50-80% of incoming radiation can keep surface temperature within 10-20 ^{o}C of ambient, whereas bare soil temperature may rise 30 ^{o}C above ambient (Ross et al., 1985b). The soil temperature at any particular depth of a conventionally cultivated treatment were warmer during the day and cooler during the night than the soil temperature at the same depth in direct drilled treatments (Aston and Fischer, 1986). Generally, maximum soil temperature was observed to be 1-5 ^{o}C lower for no-till than the conventional tillage during the first 30 days of crop growth for spring wheat in Saskatchewan, Canada (Carter and Rennie, 1984). Difference

in maximum and minimum accumulative heat sum and thermal diffusivity between 25 mm and 200 mm soil depth were related to variation in surface residue, soil moisture, and crop canopy.

The major problem of conservation tillage in corn production in the northern climate was reduced soil temperature (Al-Darby et al., 1987). The optimum average soil temperature at 0.1 m soil depth for corn seedling growth was reported as 24 ^{o}C (Willis et al., 1973). Even a small change in soil temperature of 1 ^{o}C significantly affected corn growth rates (Walker, 1969; Barlow, et al., 1977). Depressed soil temperature often delayed seed germination, slowed corn seedling growth, and ultimately reduced the yield of corn grown in areas with cool and wet springs (Gupta et al. 1983).

Ridge planting could maintain soil temperature between moldboard plow and no-till systems while maintaining the residue cover (Radke, 1982). Soil ridges tended to dry out faster and therefore, provided a warmer seed zone environment which improved germination and early corn growth (Radke, 1982; and Randall, 1987). This method of planting which placed the crop residues in the interrows while leaving the row area free of residue, reduced the temperature induced delay in plant growth while retaining the other benefits of surface residue (Allmaras and Nelson,

1971).

Tillage management also has a marked influence on the amount of snow retained on the soil surface in the northern United States. Aase et al. (1980) observed a 2-4 times greater snow accumulation on short and tall stubble treatments respectively than on bare plots. The coldest winter temperatures often occurred when the ground was bare (without snow). In the absence of snow cover, crop residue on the surface provided thermal insulation for the soil and reduced the depth of soil freezing (Pikul et al., 1986). A 35% reduction in the depth of frost penetration was observed under standing stubble as compared to the bare surface. Another tillage residue management study in West Central Minnesota showed that reduced tillage with residue on the surface increased snow accumulation, which resulted in decreased frost penetration, early frost disappearance, and warmer early spring soil temperature (Benoit et al., 1986).

Soil temperature for some tropical soils are supra-optimal. Surface temperature in these soils reached as high as 41 to 43 °C (Lal, 1974 and 1975; Khera et al., 1976). The decrease in soil surface temperature due to conservation tillage was reported to be beneficial under such conditions (Lal, 1974). The direct planting of grains in chemically killed pasture kept the soil surface

temperature low enough to avoid serious damage to the emerging seedlings and a retardation of their growth in a rapidly drying soil in northern Australia (McCown et al., 1980).

E. Runoff and Erosion

One of the major advantages of conservation tillage is erosion control. Conservation tillage systems left more residue on the soil surface as compared to the conventional tillage (Moldenhaur, 1985). In general, crop residue on the soil surface effectively reduced runoff and soil loss (Laflen et al., 1980; Larson et al., 1978; Mannering and Mayer, 1968). Even a small amount of residue cover reduced soil erosion. A 20-40% reduction in soil erosion was reported for each 10% increase in residue cover (Laflen et al., 1980; Wischmeier and Smith, 1978).

The effectiveness of any tillage method for controlling erosion depends upon the amount of residue left on the soil surface (Laflen et al., 1980). The percent cover of the soil surface was even more important than the amount of surface mulch. Therefore, it might be useful to shred or chop crop residues such as corn stover to acquire a more uniform cover over the soil surface. The correlation between percentage residue cover and soil loss applied equally to all tillage systems (Moldenhauer, 1985).

No-till was generally the most effective means of erosion control because more residue remained using this tillage system. Numerous studies indicated a significantly lower soil erosion loss under no-till as compared to a conventional tillage system (Blevins, 1984; McGroger et al., 1975; Harrold and Edwards, 1972; and Meyer, 1970). The longer a field remained in no-till, the more effective erosion control became. After 10 years of continuous corn, soil loss was 18 fold higher in a plowed system than in a no-till system. When ridge planting was done correctly (making ridges across the slope), run-off moved down to the ridges through the residue, accumulated in furrow bottoms, and soil erosion was controlled effectively (Moldenhauer, 1985).

The percent residue cover under different tillage systems was not always correlated to run-off loss. Harrold and Edwards (1972) observed almost equivalent amounts of run-off from both conventional and no-till systems. Another study indicated that the no-till system produced the greatest amount of run-off regardless of residue harvesting (Lindstrom et al., 1984; and Lindstrom and Onstad, 1984). Under such conditions soil erosion could be a serious problem when residue is not present to reduce flow velocity under no-till. Mueller et al. (1984) observed lower run-off losses for the chisel system than

the other tillage treatments. In their study, significantly lower runoff occurred for conventional and chisel tillage systems relative to a no-till system immediately after planting. At a later sampling period run-off significantly increased for conventional tillage and approached that for no-till.

Conservation tillage systems strongly influenced the first stage of water erosion (Blevins et al., 1984). The reduced erosion under no-till or conservation tillage was due to:

1. Residue maintained on the soil surface effectively dissipating the energy from rain drop impacts during a storm.
2. Improved soil structure and better infiltration. Stable aggregates are not pulverized and destroyed by excessive tillage.
3. The residue acting as a filter. Finer soil particles and organic fractions moved by run-off water are redeposited before they moved out of the area. Therefore, run-off water from no-till plots do not carry heavy loads of sediments.
4. The mulch keeping the soil surface wetter and preventing problems associated with drying and crusting of the soil surface.

The erosion control became less effective with

conservation tillage after soybeans than after corn. The reduced amount of residue and quicker decay offered less protection after soybeans (Moldenhauer, 1985). However, there was no indication that no-till was less effective following soybeans than following corn at equal residue cover (Van Doren, 1984).

A successful living mulch system (living grass) was found to be even more successful than the standard no-till system in minimizing soil erosion and run-off, particularly on sloping erosive land. This system could help meet non-point pollution goals (Elkins et al., 1983).

II. Tillage Effects on Soil Chemical Properties.

A. Organic Matter and Nitrogen

No-till or conservation tillage systems leave all or a portion of the crop residue on or near the soil surface without (or with very little) mixing into the soil. The distribution of total and organic nitrogen (N) followed a trend similar to that of organic matter (Blevins et al., 1985; Dick, 1983).

Both the total amount of organic matter and its distribution were influenced by different tillage systems (Blevins et al., 1983 and 1984). Many research results showed a higher organic matter and organic N content at the soil surface under no-till as compared to the conventional

tillage systems (Lal, 1974; Blevins et al., 1983 and 1977; Dick, 1983; and Ike, 1987). The research conducted at five locations from East Central USA to the Great Plains showed that organic carbon content of 0-0.15 m depth ranged 12-75% higher for no-till as compared to the conventional tillage (Mielke et al., 1986). After 10 years of corn production in Lexington, Kentucky, the organic matter in the 0-0.05 m soil layer under no-till was about twice as high as that of conventional tillage (Blevins et al., 1983). However, no significant difference in organic matter was observed below 0.075 m depths (Blevins et al., 1983; Dick, 1983). A significantly lower organic carbon content was also reported under no-till as compared to the conventional tillage system below a 0.15 m depth of Hoytville (Mollic Ochraqualf) soil in Ohio (Dick, 1983). The total amount of N in 0-0.3 m soil profile was also reported to be significantly greater under no-till than under plowed treatment (Dick, 1983). The amount of organic N increased with increasing N fertilization in no-till. A rapid decline in soil organic matter of the unprotected bare soil surface was reported in the tropics due to surface erosion of soil high in organic matter (Jenkinson and Ayanaba, 1977).

The rate of decay of plant residue returned to the soil in no-tillage or conservation tillage system was a key

factor in how well the total soil organic matter level was maintained or even increased. Lucas et al. (1977) in Michigan related changes in percent soil organic carbon to cropping system over time. They postulated that soils had a steady state or equilibrium level of soil organic matter. This level was reported to change with cropping or type of tillage. The steady state for a soil with 6% slope under a continuous corn system in Michigan was reported to be 1.4% organic carbon for spring plowed and about 2.3% for no-till. Several earlier studies indicated faster organic matter decomposition when residues were buried than when they were left on the surface (Parker, 1962; Brown and Dicky, 1970; and Sain and Broadbent, 1977). A faster residue decomposition rate was also observed under a conventional tillage system as compared to a no-till system (Rice and Smith, 1982). After 18-19 years of corn production, a 0-11% and 14-25% decrease in organic carbon was observed under no-till and conventional tillage systems, respectively, from the base level (Dick, 1983). Since a comparable amount of plant material was synthesized under both no-till and plowed systems, the reason for no-till having more organic matter was concluded to be due to a slower microbial decomposion of organic matter (Blevins et al., 1984).

Plowing and other tillage operations increased the

rate of decomposition (Blevins et al., 1985) and the rate of loss of organic matter from the soil. Some reasons for this are:

1. Disruption of soil aggregates which increases microbial access to organic compounds.
2. Tillage breaks larger pieces of plant residue, thereby increasing the surface area for microbial attack.
3. Mixing plant material with soil may result in a greater or more uniform initial inoculation with saprophytic microbes.
4. Aeration and physical environment in the soil surface are favorable for microbial activity.
5. Incorporation of organic residue into soil usually places it in a constantly moist environment while residue on the soil surface is subjected to desiccation, an effective method of preserving organic materials (Giddens, 1957).

The slower rate of organic matter decomposition observed for no-till contradicted the finding that a no-till system compared to a conventional tillage system usually had a greater or equal microbial population or activity (Blevins et al., 1984). The slower decomposition in the no-till was probably due to the greater microbial activity and population in conventionally tilled soils immediately after plowing, a time when organic matter

decomposition was rapid. More favorable moisture status, and greater quantity of substrate remaining in the no-till soil could lead to a greater microbial activity in no-till than in the moldboard plowed soil later in the season.

The immobilization and mineralization rates of N in the soil control N availability. Immobilization of N is expected under no-till because N fertilizer is often placed on the soil surface where there is an accumulation of decomposable organic material. The N immobilization during a five week period in the spring was observed to be about twice as great in no-till soils as in conventionally tilled soils (Blevins et al., 1983). Lower N mineralization was also evidenced in direct drilled wheat (Dowdell and Cannel, 1975).

Although enhanced immobilization did not result in a net loss of N from the soil, it influenced N availability to plants and might partly account for lower yields of no-till corn at low nitrogen rates (Blevins et al., 1983). Adding N fertilizer in excess of that normally recommended for a conventional tillage system is a common practice to alleviate immobilization of nutrients (Moschler ét al., 1975; Davis and Cannel, 1975).

N mineralization and availability was at least as great in long term (10 years) no-till as in long term conventional tillage plots (Rice and Smith, 1982). Total

amount of nitrification in the soil surface (0-0.21 m) was not significantly different between tillage treatments on an annual basis (Groffman, 1984). However, consistantly higher nitrification activity was reported in the top 0.05 m of the no-till soils than in plowed soils; and a reverse pattern was observed at lower depths (Groffman, 1984).

Denitrification and leaching of nitrate were other processes influencing N availability in the soil (Rice and Smith, 1982; and Tyler and Thomas, 1977). Excess moisture in the poorly drained or slowly permeable no-till soil promoted denitrification losses (Rice and Smith, 1982). Consistantly higher denitrification was observed in the surface (0-0.05 m) of no-till soil than in the plowed soil (Groffman, 1984); and a reverse the pattern was observed at the lower depths. Lemme (1988) reported a higher denitrification loss from the surface (0-.05 m) of ridge-till than other tillage treatments (Moldboard, chisel plow and no-till) in Eastern South Dakota. However, total denitrification in 0-0.21 m was not found significantly different on an annual basis. A lysimeter study in Kentucky showed a deeper movement of nitrate in no-till than in conventional tillage systems early in the growing season (Tyler and Thomas, 1977). However, the no-till system more closely approximated the virgin grassland in total soil N and nitrate over ammonium ratio than the

conventional tillage (Stinner et al., 1983). Dowdell and Cannel (1975) on the other hand, indirectly concluded that the rate of N mineralization was more responsible for lower levels of nitrate than denitrification or leaching under no-till soils as compared to the moldboard plowed soil.

B. Soil Reaction (pH).

Conservation tillage systems (such as ridge-till and no-till) involved less mixing of surface applied amendments/fertilizers (Blevins et al., 1985). Continuous use of ammonium nitrogen on the surface acidified the surface soil. The acidification is primarily due to the nitrification process which produces two hydrogen ions for each nitrate ion formed (Blevins et al., 1984; and Dick, 1983).

Tillage and nitrogen fertilization studies showed a rapid acidification (lowering of soil pH) of the soil surface under a no-till system as compared to a plowed one (Blevins et al., 1977 and 1983; and Dick, 1983). The acidification was found to be more pronounced at high nitrogen rates. Associated with the reduced soil pH were increased levels of aluminum and manganese, and decreased levels of calcium and magnesium (Blevins et al., 1977 and 1983). Aluminum toxicity could become a serious problem in areas with a humid climate. An acid soil surface also

rapidly deactivated triazines, a common herbicide for corn production (Kells, et al., 1980). The acidification problem could be easily corrected or prevented by lime application on the surface of no-till soils. Since acidification of no-till soils was strongly influenced by the addition of nitrogen fertilizer, the problem would be less severe in soybeans and other crops which require less N fertilizer than corn (Blevins et al., 1983; and Muzilli, 1981).

Contrary to the above findings, no significant difference in pH was observed between the no-till and moldboard plow systems in a Nigerian Alfisol (Juo and Lal, 1979). Instead, they observed a significantly higher level of exchangable Ca in the surface 0-0.05 m layer. In areas where rainfall did not greatly exceed evapotranspiration, the effect of no-tillage on acidity could be reversed (Blevins et al., 1984). Under such conditions, higher pH values were obtained with no-till than with conventional tillage (Lal, 1981; and Muzilli, 1981). Therefore, there is a need for further investigation to relate soil acidity to soil characteristics, climate, and cropping system used.

C. Phosphorus and Potassium.

The movement of surface applied phosphorus and potassium into the soil under no-tillage could take place

only by water and much more slowly by diffusion (Blevins et al., 1983 and 1984). Therefore, concentrations of P and K were found to be the highest at the 0-0.05 m depth (Blevins et al., 1983; Cruse et al., 1983; Ike, 1987; and Shear and Moschler, 1969) and decline rapidly with depth (Blevins et al., 1984). Fertilizers were thoroughly mixed in the plow layer of conventional tillage and consequently there was slow decline in the concentration of P and K with depth (Hargrove et al., 1982; Muzilli, 1981). Very little difference in exchangable K was observed in the top 0-0.3 m of no-till and conventionally tilled soils; but there was a striking difference in distribution (Blevins et al., 1983). Total available P levels were much higher at 0-0.3 m of no-till soils as compared to the plowed soils (Hargrove et al., 1982; and Muzilli, 1981). In the absence of mixing, there was a banding effect (less P fixation) due to the surface P application.

Organic P levels were significantly higher in the 0-0.075 m increment and significantly lower in the 0.225-0.3 m increments of a Wooster (Typic Fragiudalf) soil in Ohio (Dick, 1983). Unlike organic C and N, a localized concentration of organic P under no-till was not observed at the soil surface but in the 0.025-0.15 m depth due to the movement of the organic P compounds in to the soil profile.

III. Tillage Effects on Crop Development and Yield.

The effect of a conservation tillage system on crop development and yield depends on soils, climatic conditions and cropping sequences. Percent residue cover associated with different tillage systems alters soil temperature and moisture conditions which ultimately affect plant growth, maturity, and yield of corn and soybeans. Generally, no-till and conservation tillage systems have been successful in the central and southern corn belts of the United States on well drained soils. Reduced soil temperatures under these systems had greater effect on plant growth and yield in more northern latitudes (Griffith and Mannering, 1985). The effect of depressed soil temperature was more pronounced in early growth and diminished with plant development (Mock and Erbach, 1977).

A. Tillage Effects on Corn Development.

Initial corn emergence rates were more depressed under a no-till system than a conventional tillage system (Al-Darby, 1987). During the first five weeks after emergence, corn growth parameters such as plant height, leaf area, and dry matter production under no-till were consistantly lower (in some cases significantly lower) than conventional tillage systems. These growth parameters were

highly correlated with growing degree days. No-till or conservation tillage systems were also reported to reduce corn emergence, delay corn emergence and silking, lower seedling-juvenile growth and final plant densities, and increase harvest grain moisture compared to conventional tillage for early planting (Mock and Erbach, 1977; and Imholte and Carter, 1987). Imholte and Carter (1987) suggested that recommendations for early planting of continuous corn in the northern United States could be still valid for no-till but seeding rate should be increased to overcome reduced emergence.

Corn emergence and leaf number to six leaf stage were closely related to percent in-row cover and air temperature growing degree days (GDD) with their mutual relationship to soil temperature GDD (Swan et al., 1987). For a given site and year, percent in-row cover following planting was the major factor affecting corn growth rate until six leaf stage. When cumulative air GDD were less than a threshold value of 1319 and water stress was minimal; then in-row cover had a major impact on the growth and development of corn in the northern corn belt.

Al-Darby et al. (1986) observed a higher plant emergence under conservation tillage than conventional tillage in a silt loam (Typic Argiudoll) soil. Final emergence under no-till was lower than other tillage

systems in a loamy sand (Typic Udipsamment) soil. The plant height, leaf area, and dry matter per plant early in the growing season for both soils were highest for conventional tillage and lowest for no-till system (conventional >= chisel > no-till).

Emergence and early growth of corn were related to soil drainage. No-till corn often showed uneven emergence and slower early growth on somewhat poorly drained soils (Griffith et al., 1973; Murdock, 1974). On poorly drained, clay soils in northern Ohio, more corn root damage was observed in no-till plots compared to plowed treatments under continuous corn (Van Doren et al., 1976). A No-till system on a moderately well drained soil (Aquic Fragiudalf) did not show any adverse effect on corn development or yield when the data were averaged over three years (Eckert, 1984). During the drier than normal year, no-till corn silked earlier and yielded more than did conventionally tilled corn, while the reverse was true during a cooler, wetter year. Year to year variation in climate (rainfall and temperature) influenced corn growth parameters and yield more than tillage treatments in well drained silty clay loam soils (Pachic and Abruptic Argiustolls) in the western corn belt (Wilhelm, 1987).

B. Corn and Soybean Yield Responses to Different Tillage Systems.

No-till produced higher corn yields than a plowed system on sloping and well drained soils in a more southerly section of the corn belt (Kladivko et al., 1986; Dick and Van Doren, 1985; and Hargrove, 1985). The yield increase was attributed to conservation of water by mulch at the soil surface and by stabilization of a desirable structure (Van Doren et al., 1976). Power et al. (1986) reported that each Mg ha^{-1} of crop residue on the soil surface increased grain and stover production by 120-270 kg ha^{-1} for corn and 90-300 kg ha^{-1} for soybeans in Nebraska. They also indicated that there were major direct crop growth benefits from leaving crop residue on the surface in addition to reduced soil erosion and enhanced soil organic matter contents. Removal of surface crop residue seriously reduced corn and soybean yields where stressful conditions occurred during the growing season. Corn and soybean yields decreased by 22-24% where crop residues were completely removed. The yield reductions were reported to be the result of decreased soil water storage and excessive soil surface temperature.

Corn yields were found to be remarkably insensitive to tillage over a wide range of soil types, cropping systems, and climates with relatively normal planting

dates, adequate plant densities and weed control (Van Doren et al., 1976; and Mock and Erbach, 1977). In a ten year study in the Midwest, yields of corn, soybeans and oat were affected more by soil type than by tillage systems (Dick et al., 1985). Equivalent corn yields under both tilled and no-tilled systems were also reported in western Nigeria (Lal, 1974). Little yield difference was found between conventional planting, wheel track planting, till planting and lister planting in Eastern South Dakota (Olson and Schoeberl, 1970). Equal or greater corn yields were also reported under conservation tillage systems as compared to conventional tillage in Wisconsin (Al-Darby et al., 1986). No-till yielded more than conventional tillage in a sandy soil in drier than normal years.

No-till treatments suffered more substantial yield loss than conventional treatments on some fine textured poorly and somewhat poorly drained soils especially under continuous corn (Kladivko et al., 1986; Griffith et al., 1973; Fausey, 1984; Dick et al., 1985; and Van Doren et al., 1976). Kladivko et al. (1986) observed a lower yield under no-till continuous corn on poorly structured, low organic matter, poorly drained soils compared to a conventional tillage system during the first several years, but yield improved with time as soil structure improved. Research conducted on moderately well drained soils in Ohio

and Kentucky resulted in a higher corn yield under no-till compared to conventional tillage during a drier growing season, while the reverse was true for a cooler and wetter growing season, especially for early planting dates (Herbek et al., 1986; and Eckert, 1984).

Soybeans planted under no-till or conservation tillage systems produced yields greater than or equal to conventional tillage systems (Bharati et al., 1987; and Campbell, 1984). Webber et al. (1987) reported the amount and distribution of rainfall as the most important factors in determining soybean seed yields. During initial growth, the soil environment under conventional tillage provided soybeans with excellent potential for maximum yield due to greater vegetative dry matter production. In years with inadequate rainfall, soybeans suffered from moisture stress during the flowering and pod formation stages. Soybeans under no-till benefited from both greater soil moisture and the ability to use soil moisture deep in the soil profile.

Several long term studies showed a positive effect of crop rotation on corn and soybean yields (Mannering, 1981). The positive influence became more important when no-till planting was practiced on poorly drained soils. Dick et al. (1985) suggested that reduction of corn and soybean yields associated with no-tillage on heavy clay and poorly drained soils could be reduced by crop rotation or

by the use of disease resistant cultivars. No-till produced almost equal or greater yields than conventional tillage on poorly drained soils after the first several years of soil structural improvement with corn-soybean rotation (Kladivko et al., 1987). Conservation tillage systems (strip or no-tillage) in combination with a corn-soybean rotation gave the most consistant yield increase for both full season and double cropped soybeans (Edwards et al., 1988). Corn yields were affected less by rotation treatment than soybean yields.

There could be several reasons for yield improvements under a corn-soybean rotation. Reduced residue cover after soybeans improved soil drying and warming and ultimately improved corn yields under no-till on poorly drained, cooler soils (Griffith and Mannering, 1985). Rotating crops also showed fewer disease and pest problems by interrupting the life cycle of the disease and pests. Allelopathic (toxic) effects of decaying residue on germination and seedling growth might be an another factor reducing yield under continuous corn. This effect was documented in a greenhouse study but its significance in the field was not well understood (Griffith and Mannering, 1985).

No-till planting on raised beds and ridge-till planting were other alternatives to no-till planting on a

flat soil surface on poorly drained soils. Fausey et al. (1984) obtained a significant crop stand and yield improvement on no-till corn grown on a poorly drained soil on raised beds compared to no-till corn grown on a flat soil surface. The beds provided additional surface drainage. No-till on beds produced yields equivalent to chisel plowing. By evaluating the ridge planting system on a poorly drained soil in Ohio, Eckert (1987) concluded that a ridge planting system was a viable conservation tillage system for poorly drained soils. Corn and soybean yields under ridge-till were found to be equivalent to that of a plowed system. Ridge-till also permitted earlier planting in some years.

IV. Soil Tillage Relationships

The performance of specific conservation tillage systems are not consistent over soil types, years and geographic regions (Benoit and Lindstrom, 1987). The following assumptions were suggested for these inconsistencies.

1. Conservation tillage systems are beneficial and necessary on all crop lands.
2. Data collected at one point in time for a specific soil type would hold true over time, irrespective of past and present conditions.

All soils did not react in the same way to conservation tillage methods (Benoit and Lindstrom, 1987). The results of many site specific tillage studies indicate that a significant, selective relationship existed between soils and tillage systems (Griffith et al., 1973; Triplett, 1970; Triplett et al., 1969 and 1973; and Van Doren, 1962). Generally, well drained, medium textured soils were found to be well suited to conservation tillage (Cosper, 1983). Reduced crop yields under conservation tillage systems were mostly associated with soils having inherent physical limitations such as drainage, wetness level (degree and frequency of wetness), structural stability, and the presence of a restrictive layer in the soil profile. Any conclusions about tillage systems would be of limited value if they were not considered in conjunction with the behavior of soil properties (Benoit and Lindstrom, 1987).

On the basis of site specific tillage studies, soils were catagorized into different tillage suitability groups. Ohio and Indiana soils were divided into tillage groups or crop management groups on the basis of soil properties such as soil slopes, drainage or soil moisture characteristics, soil permeability and profile texture (Triplett, 1973; and Galloway, 1977). Similar soil categorization was done in the U.K. and Romania (Cannel et al., 1978; Canarache, 1987). Lands in Scotland were also

allocated to cultivation groups according to the probability of compaction which would restrict crop performance occurring during the growing season (Ball, 1987). Soil, climate and relief criteria were used to select the most adequate soil tillage methods in Romania (Canarache, 1987).

Cost would not permit conducting an on-site tillage experiment for every soil (Cosper, 1983). A relatively simple, efficient, reliable, reproducable, less time consuming, and cost effective method of estimating soil suitability for conservation tillage was essential. Soils with similar characteristics resulting from soil forming processes should react similarly and therefore, the response of individual soil types to conservation tillage should correlate well with a soil's taxonomic classification. Soil taxanomy could thus be used as a guide to recommending tillage systems for a particular soil.

MATERIAL AND METHODS

I. Plot Establishment and Experimental Design.

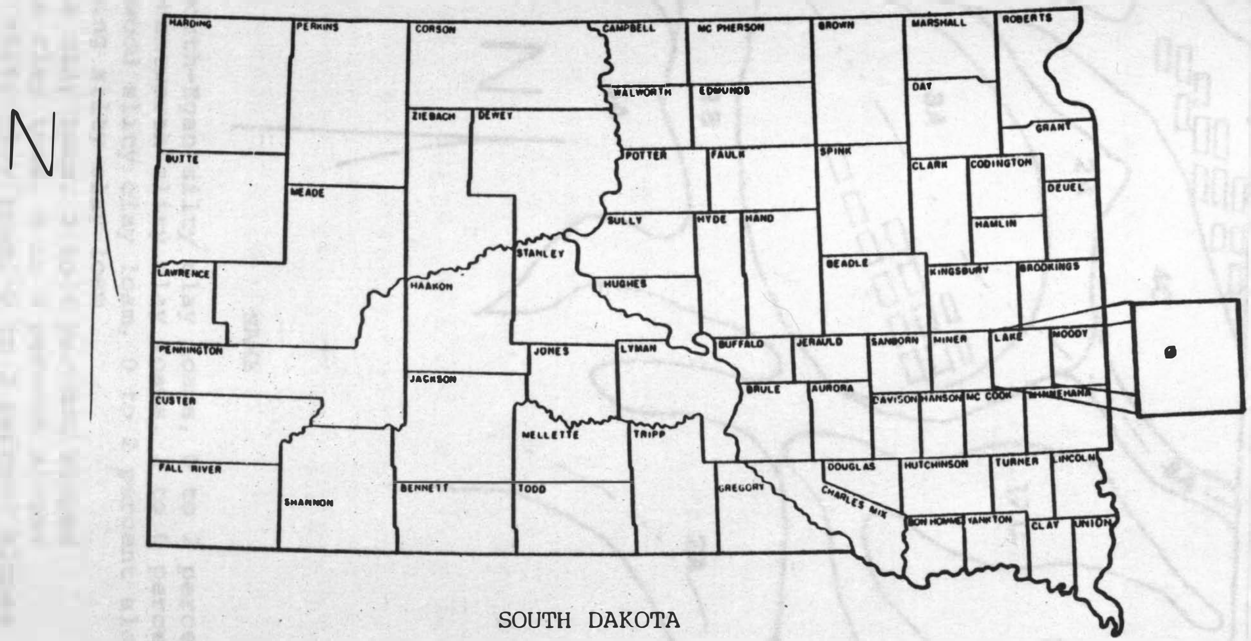
This study was conducted at the Eastern South Dakota Soil and Water Research Farm near Madison (E 1/2, NW 1/4, sec 35, T. 107 N., R. 35 W.) (Figure 1). Two soils involved in this study are a well drained Beadle (Fine loamy, Montmorillonitic, Mesic, Typic Argiustoll) and a poorly drained Worthing (Fine, Montmorillonitic, Mesic, Typic Argiaquoll). The Beadle is a deep, well drained, loamy soil formed in glacial till on nearly level to undulating uplands (SCS, 1973). The Worthing soil on the other hand, is deep, poorly drained, silty soil (with clay subsoil) formed from alluvium in drainageways or flat enclosed depressions. The Beadle and Worthing soils were selected because they represent a continuous toposequence within the area with Beadle soils on the summit and shoulder position and Worthing soils on the toeslope. This represents a typical farm landscape in eastern South Dakota. When farmed, both the soils are managed as a unit under the same tillage system. The distribution of soil mapping units and legends for the mapping units at the research farm is shown in Figure 2.

The tillage plots were established in 1985. The treatments were arranged in a 4*3 factorial arrangement

Table 1. Preciptation and mean air temperature of the research site, Madison, S.D. (30 years average).

Month	Precip. (mm)	Mean temp. (^{o}C)
January	13	-10.1
February	22	-7.3
March	42	-2.3
April	57	7.3
May	83	14.0
June	95	19.1
July	77	22.2
August	86	21.7
September	55	15.7
October	40	10.1
November	23	0.6
December	18	-6.6
Total	609.95	annual av. 7.2

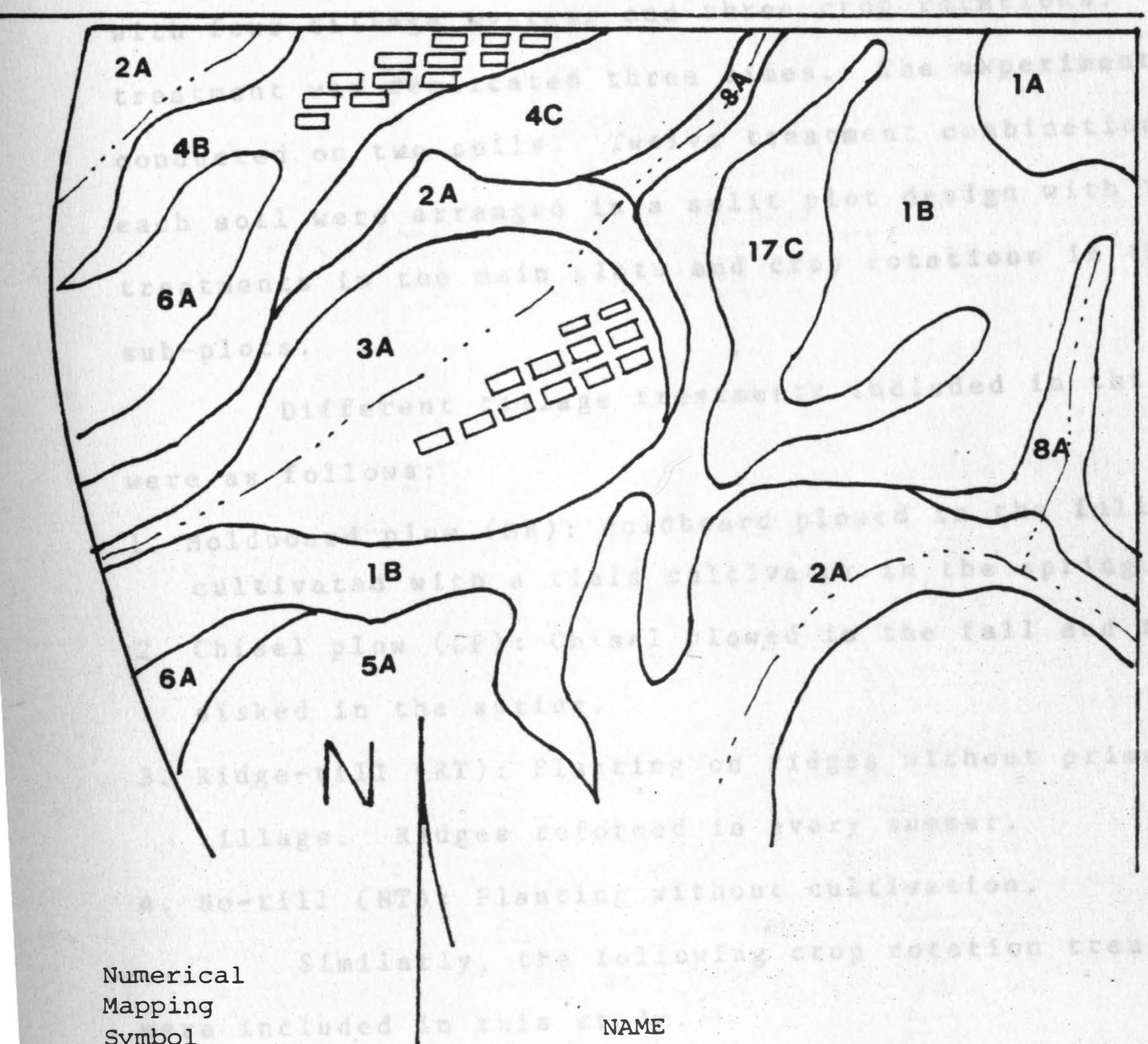
Above data were obtained from Weather Research, Ag. Engineering Dept., SDSU, Brookings.



SOUTH DAKOTA

(Scale 1:3,000,000)

Figure 1. Location of the USDA Eastern South Dakota Soil and Water Research Farm in Lake County, South Dakota.



Numerical Mapping Symbol	NAME
1A	Wentworth-Egan silty clay loams, 0 to 2 percent slopes
1B	Egan-Wentworth slity clay loams, 2 to 6 percent slopes
2A	Whitewood slity clay loam, 0 to 2 percent slopes
3A	Worthing silty clay loam
4B	Beadle clay loam, 2 to 6 percent slopes
4C	Beadle clay loam, 6 to 9 percent slopes
5A	Sinai silty clay loam, 0 to 2 percent slopes
6A	Wentworth silty clay loam, 0 to 2 percent slopes
8A	Viborg silty clay loam, 0 to 3 percent slopes
17C	Egan-Beadle complex, 6 to 9 percent slopes

Figure 2. Soils on the research farm, plot layout, and map unit descriptions.

with four tillage systems and three crop rotations. Each treatment was replicated three times. The experiment was conducted on two soils. Twelve treatment combinations in each soil were arranged in a split plot design with tillage treatments in the main plots and crop rotations in the sub-plots.

Different tillage treatments included in this study were as follows:

1. Moldboard plow (MB): Moldboard plowed in the fall and cultivated with a field cultivator in the spring.
2. Chisel plow (CP): Chisel plowed in the fall and tandem disked in the spring.
3. Ridge-till (RT): Planting on ridges without primary tillage. Ridges reformed in every summer.
4. No-till (NT): Planting without cultivation.

Similarly, the following crop rotation treatments were included in this study.

1. Continuous corn (CC)
2. Corn after soybean (SC)
3. Soybean after corn (CS)

The experimental plan is shown in Figure 3. All measurements taken during two years (1986 and 1987) were used in this study.

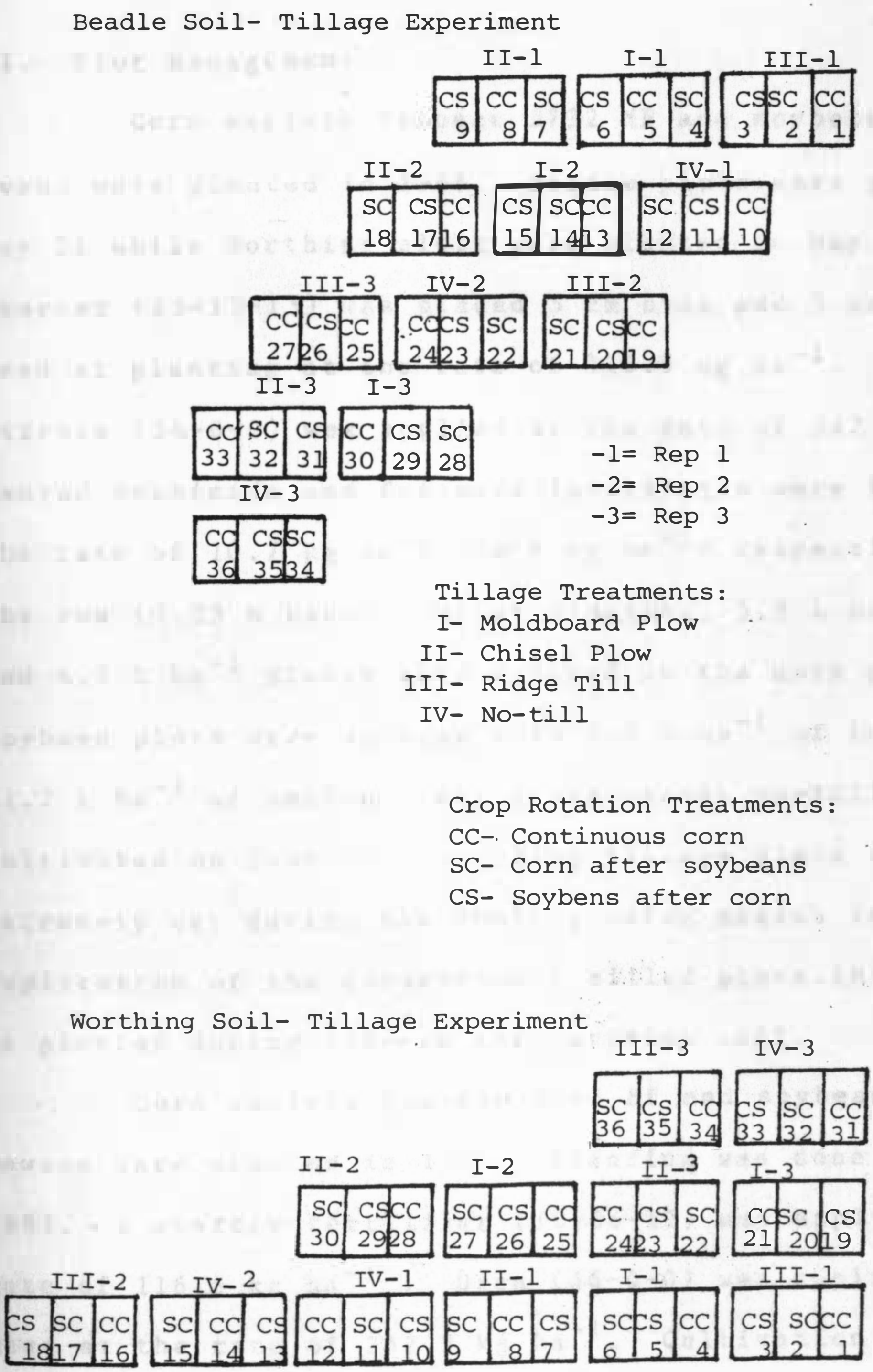


Figure 3 Layout plan of the Beadle and Worthing tillage Experiments

II. Plot Management

Corn variety Pioneer 3732 MF and soybean cultivar Evans were planted in 1986. Beadle plots were planted on May 21 while Worthing plots were planted on May 22. A starter (13-13-13) was placed 5 cm over and 5 cm below the seed at planting at the rate of 116.5 kg ha^{-1}. Ammonium nitrate (34-0-0) was applied at the rate of 342 kg ha^{-1}. Ramrod herbicide and Dyfonate insecticide were banded at the rate of 10.7 kg ha^{-1} and 9 kg ha^{-1}, respectively, over the row (0.23 m band). After planting, 5.9 L ha^{-1} of Lasso and 4.7 L ha^{-1} Bladex were sprayed on the corn plots. Soybean plots were sprayed with 5.9 L ha^{-1} of Lasso and 11.7 L ha^{-1} of Amiben. All plots except no-till were cultivated on June 17. Worthing tillage plots were extremely wet during the whole growing season in 1986. One replication of the conventional tilled plots (MB) could not be planted during 1986 on the Worthing soil.

Corn variety Pioneer 3747 MF and soybean variety Dawson were planted in 1987. Planting was done on May 5, 1987. A starter fertilizer (12-36-12) was applied at the rate of 116.5 kg ha^{-1} . Urea (46-0-0) was applied in a band at the rate of 262.3 kg ha^{-1}. Cultivation was performed on June 19, 1987 on all treatments except no-till. Ramrod herbicide and Furadan insecticide were applied at the rate of 11.2 kg ha^{-1} (0.18 m band). Corn

plots were sprayed with 5.9 L ha^{-1} of Lasso and 4.7 L ha^{-1} of Amiben. Conventional tillage plots (MB) of Worthing soil could not be moldboard plowed in the fall due to excess wetness. The plowing was done in the spring just 2 days before planting and therefore, these plots became more cloddy than other plots.

In both years corn was planted at the rate of 64,245 plants ha^{-1} and soybean was planted at the rate of 67.3 kg ha^{-1}. Fertilizer recommendations were based on South Dakota State University soil test recommendations (Appendix B) (Gerwing et al., 1982). In both years, the cultivation was done immediately after fertilizer application so that in all plots except no-till, fertilizer was mixed into the surface soil by cultivation.

III. Pedon Description and Soil Sampling

Representative pedons from both well drained and poorly drained sites were described in the field according to the standard procedures (Soil Survey Staff, 1975). Bulk samples from each horizon were collected for lab analysis. Four undisturbed core samples were collected from each horizon for bulk density, hydraulic conductivity and moisture retention studies (.03 and .1 MPa) by using an Uhland sampler. Composite soil samples from each experimental unit were collected from 0-150 mm and 150-600

mm depths in the fall for soil fertility tests. Undisturbed surface core samples were also taken for bulk density and hydraulic conductivity measurements by using a Uhland sampler. The core samples were taken from the crop row of the continuous corn plots. Representative soil samples were also obtained from the surface 0-100 mm of corn rows for aggregate stability analysis. These soil samples were taken from both continuous corn and corn after soybean plots. Soil samples were also taken from 0-10, 10-50, 50-100, and 100-200 mm depth increments of the Worthing soil from plots with wilted plants and from plots with normal corn plants for electrical conductivity analysis.

IV. Soil Sample Preparation and Analysis.

Soil samples (bulk samples from pedons and fertility samples) were air dried, crushed, and passed through a 2 mm sieve. Greater than 2 mm fractions were weighed and discarded (Appendix A). Subsamples were taken with a sample splitter for various physical and chemical determinations.

Particle size analysis was performed by the pipette method of Kilmer and Alexander (1949) with modifications as described by Gee and Bauder (1986). Uhland core samples were used for measuring bulk density (Blake, 1986) and

saturated hydraulic conductivity by the constant head method (Klute and Dirksen, 1986). These undisturbed cores were also used to determine water contents at 0.03 and 0.1 MPa pressure moisture retention measurements on a drying cycle (Procedure 4Ale, Soil Survey Staff, 1972). The moisture retention for 0.3, 0.5 and 1.5 MPa were measured from the disturbed samples (Procedure 4B2, Soil Survey Staff, 1972). Aggregate stability was determined by a modification of methods described by Kemper and Rosenau (1986). Aggregate stability measurements were determined on prehumidified, air dried samples.

Readily oxidizable organic matter was determined by the modified Walkley and Black method as described by Nelson and Sommers (1986). A 1:1 soil to water suspension was used for pH measurements. Available phosphorus was extracted by the Bray and Kurtz (1945) method in noncalcareous samples and by the Olson method (Olson et al., 1954) on calcareous samples; and measured with a spectrophotometer. Soil nitrates were determined for both 0-150 mm and 150-600 mm depth soil samples (Gelderman et al., 1980). Available zinc was also measured (Gelderman et al., 1980). Cation exchange capacity was determined by saturating the soil with 1 N ammonium acetate at pH 7, removing the excess salt by ethanol and by macro-Kjeldahl distillation of adsorbed ammonium (Procedure 5A1, Soil

Survey Staff, 1972). Soil-ammonium extract (from a CEC determination) was used for determining extractable cations. Extractable calcium and magnesium were determined by using an atomic absorption unit. Extractable sodium and potassium were determined by using a flame photometer. Percent calcium carbonate equivalent was determined by using a titrimetric method described by Bundy and Bremner (1972). Electrical conductivity was measured by using a conductivity meter (Rhoades, 1986).

V. Field Measurement of Soil Temperature and Soil Moisture

Soil moisture was monitored with a neutron probe throughout the growing season at two week intervals except during rainfall events. Soil moisture measurements were also taken after every rainfall event. Daily maximum and minimum soil temperatures were recorded at a depth of 100 mm with a dial maximum and minimum stem thermometer (3-5 days in a week). Soil temperature readings were also checked by installing thermistors in 1987. Soil water and temperature measurements were taken only for the continuous corn rotation. Precipitation data were obtained from Eastern South Dakota Soil and Water Research Farm. Evapotranspiration or water use (ET) was calculated as follows:

$$ET=R\pm W$$

Where R is the rainfall and W is the measured change in profile soil water. Runoff and drainage water were assumed negligible and were excluded from this calculation.

VI. Other Field Measurements

Percent residue cover was measured immediately after planting by using the rope method (Hartwig and Laflen, 1978). Corn and soybean emergence (total emergence and 50% emergence date) were recorded. Days to 50% silking and 50% maturity were also recorded for corn plots. Days to 50% maturity were recorded by observed milk line and black layer (Crookston, R.K., and J.J. Afuakwa, 1983). Leaf area of corn plants was measured with a portable leaf area meter (Li. Cor. Li.3000). Leaf area values of 5 plants were averaged for each plot. A total of 4 and 6 measurements were taken in 1986 and 1987 respectively at different stages (dates) on the continuous corn plots. Leaf area was measured only once in the corn after soybean rotation in both years. Corn and soybean yields were measured by harvesting two center rows 20 meter in length. Yields were reported on a 15.5% moisture basis.

VII. Tissue Analysis

Twentyfive ear leaf samples were randomly collected from each corn plot. Samples were dried, ground and

analyzed for different macro and micro nutrients (Gelderman, 1978). All macro and micro nutrients were determined in 1986 while only N, P, K and Zn were determined in 1987.

VIII. Statistical Analysis.

The statistical analysis system (SAS) was used for all statistical analyses of this study. The analysis of variance (ANOVA) procedure was used in general to test the significance of differences among treatments by using Proc. ANOVA and Proc. GLM (in cases of missing data). The least significant difference (LSD) was used to make planned comparisions between two treatments if an overall significant difference was found in the ANOVA test. Multi Variate Analysis of Variance (MANOVA) procedures were used to test the soil and tillage interaction effects on soil chemical properties, physical properties, and corn development-yield. Different class variables used in MANOVA test were four tillage treatments (MB, CP, RT and NT) in continuous corn rotation, two soils (Beadle and Worthing) and 2 years (1986 and 1987). Analysis of co-variance was run for corn yield under continuous corn rotation in the Beadle soil and under corn-soybean rotation in the Worthing soil using 1985 corn yield as co-variate. Means were adjusted where there was a significant

correlation. Mean yields (for 1987) for Beadle continuous corn and Worthing corn grown after soybeans were adjusted.

RESULTS AND DISCUSSION

I. Soil Characterization

Typical pedons from Beadle and Worthing tillage sites are described in Appendix A. Clay content of the Beadle soil increases from 35.5% in Ap horizon to 39% in the Bt horizon and decreases with depth deeper in the profile (Table 2). All horizons of the Worthing soil have greater than 40% clay. The clay content gradually increases with depth (43.3% in Ap horizon to 48.8% in Bt5 horizon). The Worthing pedon has less than 5% sand in all horizons. Percent sand increases from less than 10% in the upper part of Beadle soil to 18 and 26.6% in the Bk2 and C horizons respectively. All horizons of the Beadle and Worthing soils (except Beadle C) contain greater than 45% silt. Both pedons from the Beadle and Worthing tillage sites do not contain sufficient illuvial clay in their Bt horizons to qualify as argillic horizons. Therefore, pedons from the Beadle and Worthing tillage sites are considered as Beadle and Worthing taxadjuncts.

In the Beadle soil, bulk density values increase with depth (Table 3). Permeability of the surface layer of the Beadle soil is medium while sub-soil layers have low permeability. All horizons in the Worthing soil have low to very low permeability.

Table 2. Particle size analysis of the Beadle and Worthing soils.

Horizon	VCS	CS	MS	FS	VFS	TS	Silt	Clay	Text. Class
	Percent Size Fraction								
	Sand								
				Beadle soil					
Ap	0.27	0.47	1.21	3.70	3.27	9.1	55.4	35.5	SiCL
Bt	0.28	0.10	0.31	2.43	3.64	6.6	54.4	39.0	SiCL
Bk1	0.03	0.10	0.22	1.63	6.67	8.7	61.4	29.9	SiCL
Bk2	0.20	0.21	0.68	10.49	18.21	29.8	45.2	25.0	L
C	0.40	0.17	1.78	28.36	26.56	56.9	26.2	16.9	VFSL
				Worthing soil					
Ap	0.20	0.41	0.87	1.45	1.71	4.6	51.7	43.7	SiC
Bt1	0.02	0.14	0.39	0.75	1.21	2.5	52.7	44.8	SiC
Bt2	0.15	0.26	0.52	0.80	1.27	3.0	52.7	45.2	SiC
Bt3	0.02	0.02	0.38	0.70	1.14	2.5	52.2	45.3	SiC
Bt4	0.02	0.12	0.29	0.53	0.85	1.8	51.3	46.9	SiC
Bt5	0.13	0.19	0.32	0.56	0.89	2.1	49.1	48.8	SiC

VCS= Very coarse sand CS= Coarse sand MS= Medium sand
FS= Fine sand VFS= Very fine sand TS= total sand

Table 3. Bulk density and saturated hydraulic conductivity distribution of Beadle and Worthing soils.

Soil	Horizon	Bd ($Mg\ m^{-3}$)	K-Sat ($cm\ hr^{-1}$)
Beadle	Ap	1.18	6.62
	Bt	1.24	3.25
	Bk1	1.40	3.50
	Bk2	1.43	2.09
	C	1.56	1.52
Worthing	Ap	1.16	2.96
	Bt1	1.31	0.28
	Bt2	1.28	0.21
	Bt3	1.25	0.32
	Bt4	1.37	0.39
	Bt5	1.37	0.04

Bd= Bulk density K-sat= saturated hydraulic conductivity

Water holding capacity of the Beadle soil at a given tension decreases with depth (Figure 4). This is due to the decrease of organic matter and clay content below the Bt horizon. Although the Bt horizon has the highest clay content, water holding capacity at a given tension is not higher than in the Ap horizon because there is a greater than 50% reduction in organic matter of Bt horizon compared to the Ap horizon. Percent available water in the Bt horizon is lower than in the Ap and Bk horizons of the Beadle soil. The soil horizons with a high clay content contained more moisture at both .033 MPa and 1.5 MPa tensions. Similar water holding capacity is evident in different horizons of the Worthing soil (Figure 5). The available water holding capacity of the Worthing soil is slightly lower than expected, possibly due to higher water content at 1.5 MPa tension.

Surface horizons of the Beadle and Worthing soils have equal amounts of organic matter (Table 4). Organic matter decreases more gradually with depth in the Worthing soil than the Beadle soil. The total organic matter accumulation in the Worthing is greater than in the Beadle soil. This is also indicated by black or dark colors throughout the whole profile of the Worthing soil. Soil reaction is neutral to mildly alkaline in all the horizons of the Worthing soil. Soil reaction is moderately acid in

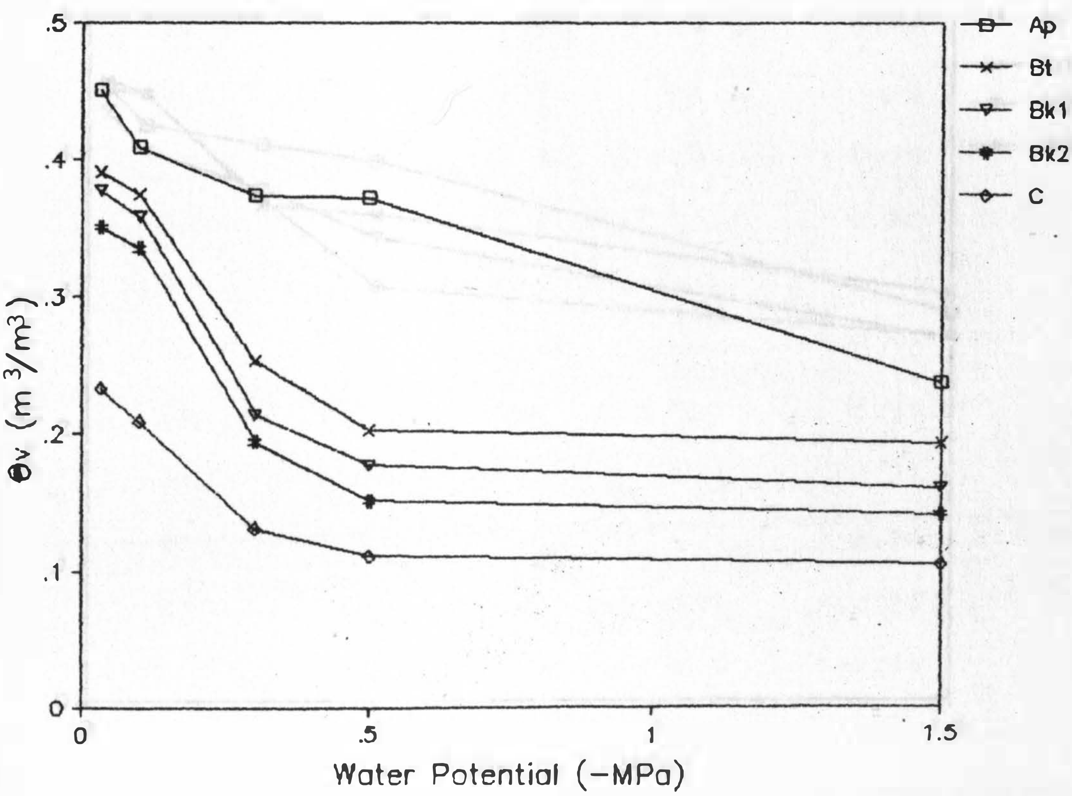


Figure 4. Partial soil moisture characteristic curves for different horizons of Beadle soil.

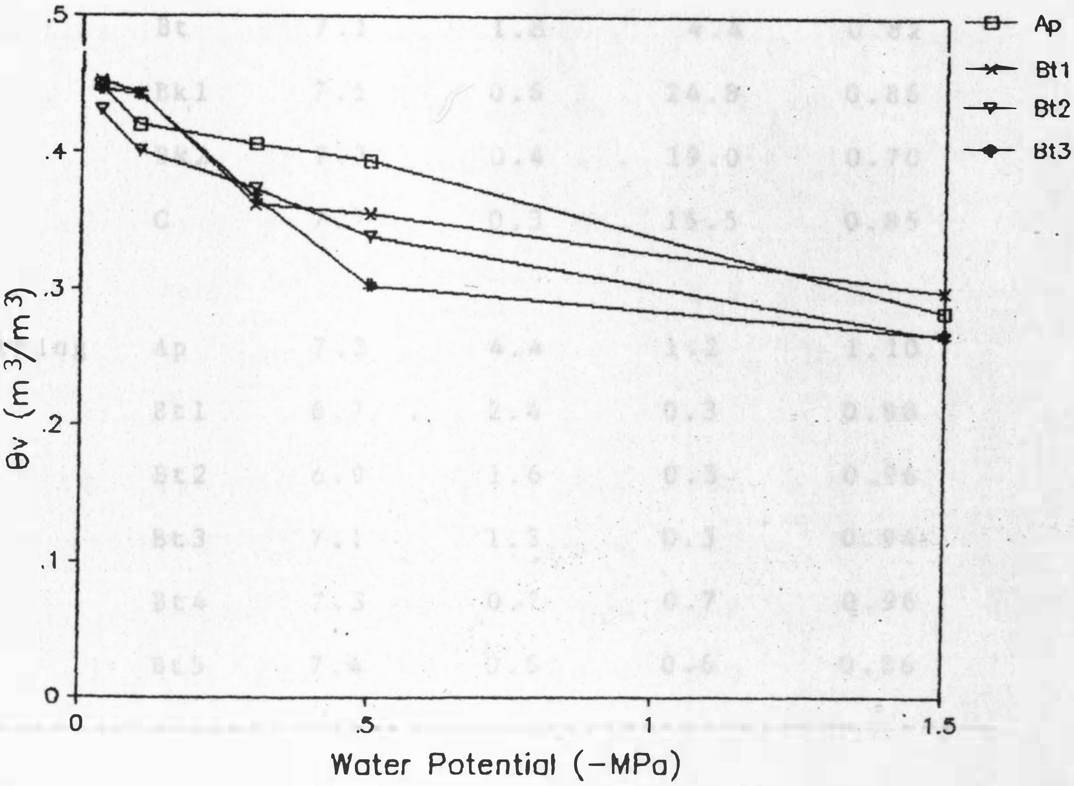


Figure 5. Partial soil moisture characteristic curves for different horizons of Worthing soil.

Table 4. Chemical properties of Beadle and Worthing soils.

Soil	Horizon	Soil pH	% OM	% CaCO3	CEC/clay
Beadle	Ap	5.7	4.4	ND	1.16
	Bt	7.1	1.8	4.4	0.82
	Bk1	7.5	0.6	24.8	0.86
	Bk2	7.7	0.4	19.0	0.70
	C	7.7	0.3	15.5	0.85
Worthing	Ap	7.3	4.4	1.2	1.10
	Bt1	6.7	2.4	0.3	0.98
	Bt2	6.9	1.6	0.3	0.96
	Bt3	7.1	1.3	0.3	0.94
	Bt4	7.3	0.7	0.7	0.96
	Bt5	7.4	0.6	0.6	0.86

Table 5. Cation exchange capacity and extractable cations of Beadle and Worthing Soils.

Soil	Horizon	CEC	Extractable cations			
			Ca^{++}	Mg^{++}	K^{+}	Na^{+}
			Me/100g			
Beadle	Ap	41.1	14.2	5.9	0.9	0.02
	Bt	31.9	23.4	6.4	0.6	0.02
	Bk1	25.8	ND	ND	0.5	0.02
	Bk2	17.4	ND	ND	0.5	0.02
	C	13.7	ND	ND	0.4	0.02
Worthing	Ap	48.4	18.9	6.7	1.1	1.6
	Bt1	43.7	16.8	8.8	0.9	1.1
	Bt2	43.3	23.4	13.4	0.9	1.1
	Bt3	42.8	20.2	14.2	1.0	1.3
	Bt4	45.1	23.2	15.8	1.2	1.7
	Bt5	42.1	19.9	13.1	1.3	2.1

ND= not determined

in the surface horizon of the Beadle soil and neutral to mildly alkaline in sub-surface horizons. The Beadle soil is calcareous below the depth of 0.52 m. The cation exchange capacity of Beadle soil decreases with depth (Table 5). This is due to the decrease in organic matter and clay content (below the Bt horizon) with depth. The cation exchange capacity of the Worthing soil is greater than 40 me/100 g in all horizons. The ratio of CEC/clay is greater than 0.7 in all the horizons of Beadle and Worthing soils (Table 4). This indicates the montmorillonitic mineralogy of these soils.

II. Tillage and Soil Effect on Physical Properties

A. Residue Cover

All conservation tillage systems left a significantly higher percent residue cover than did the moldboard plow system (Table 6). Average residue cover on a conventionally tilled Beadle soil was 5.8% and 11.2% in 1986 and 1987 respectively. Conventionally tilled Worthing soil had an average of 4.7% residue cover. Among conservation tillage systems, no-till plots contained the highest amount of residue cover in both the soils except on Worthing soil in 1986 where ridge-till plots contained a higher residue cover than no-till plots. There was no significant difference in percent residue cover between

ridge-till and no-till plots in 1986. However, no-till plots contained significantly higher percent residue cover than ridge-till plots in 1987. Decomposition of residue might be faster in the ridge-till system than in the no-till system because some of the previous years' residues are mixed with soil when the ridges are made in the ridge-till system. Residue remains on the surface each year in the no-till system and its decomposition is slow; therefore, residue cover tends to increase with the number of years under no-till management. Percent residue cover in the Worthing soil is considerably lower in 1987 because of excessively wet conditions in 1986 resulting in low biomass production and less residue cover left on the soil surface.

Soybeans left significantly lower amounts of residue than did corn (Table 7). There was no significant differences in residue between continuous corn and corn in rotation except for the Beadle soil in 1986 where corn in rotation produced a significantly higher amount of residue than continuous corn.

B. Multivariate Analysis

Bulk density, saturated hydraulic conductivity, surface volumetric water and early season daily mean soil temperature (.10 m) were used as dependent variables in a

Table 6. Percent residue cover under different tillage systems in Beadle and Worthing soils (averaged over rotations).

Soil	Tillage	Percent residue cover	
		1986	1987
Beadle	MB	5.8 a	11.2 a
	CP	35.0 b	42.0 b
	RT	42.8 c	57.6 c
	NT	50.2 c	72.8 d
Worthing	MB	4.6 a	4.8 a
	CP	29.2 b	15.0 b
	RT	41.6 c	22.4 c
	NT	38.7 c	35.3 d

MB= moldboard plow CP= chisel plow

RT= Ridge-till NT= no-till

Within a soil and year means with the same letter are not significant at .05 level. Each mean is an average of 9 observations.

Table 7. Percent residue cover under different crop rotations (averaged over tillage systems).

Soil	Rotation	Percent residue cover	
		1986	1987
Beadle	CC	34 a	54 a
	SC	23 b	31 b
	CS	43 c	53 a
Worthing	CC	34 a	22 a
	SC	15 b	16 b
	CS	35 a	20 a

CC= continuous corn SC= corn after soybeans

SC= soybeans after corn

Within a soil and year means with the same letter are not significant at .05 level. Each mean is an average of 12 observations.

multivariate analysis. Tillage, soil, and tillage*soil interaction effects were described better with multivariate analysis than with individual analysis of these properties (Table 48). Means of individual soil physical properties, the Multivariate equation and discriminant functions are presented in Table 8. Moldboard plow and chisel plow behaved differently from ridge-till and no-till in their physical properties in the Beadle soil (by comparing discriminant functions in Table 8). Moldboard plow and chisel plow behaved similarly with respect to their physical properties. Ridge-till and no-till also behaved similarly in their physical properties. No differences in physical properties of the Worthing soil were observed due to tillage systems.

C. Bulk Density, Hydraulic Conductivity and Aggregate Stability

In general, surface bulk density increased as tillage intensity decreased (Table 9). In both years and both soils, the lowest bulk density values were observed under moldboard plow and the highest were observed under no-till. However, the surface bulk densities were not sufficiently high to substantially limit root growth. Tillage effects on saturated hydraulic conductivity (K-sat) varied from year to year and from soil to soil. Ridge-till

Table 8. Effect of tillage on surface physical properties of the Beadle and Worthing Soils.

Soil	Tillage	Bd ($Mg\ m^{-3}$)	Ksat ($cm\ hr^{-1}$)	θv	Temp. (^{o}C)
Beadle	MB	1.1 a	7.2 ab	0.31 a	21.2 a
	CP	1.1 a	8.9 b	0.33 ab	20.8 ab
	RT	1.2 b	4.9 a	0.36 bc	20.0 c
	NT	1.2 b	5.8 a	0.37 c	20.2 bc
Worthing	MB	1.1 a	2.3 c	0.47 d	20.5 d
	CP	1.1 a	0.7 c	0.49 d	21.0 d
	RT	1.2 b	0.8 c	0.47 d	20.7 d
	NT	1.2 b	1.1 c	0.48 d	21.0 d

MB=moldboard plow CP=chisel plow RT=ridge-till NT=no-till
Means with the same letter are not significant different at .05 level. This designation should be used only with preplanned comparisions. Each Bd and K-sat mean is an average of 8 observations. Each θv mean is an average of 26 observations. Each soil temp. mean is an average of 126 observations.

Discriminant Functions:

Z2=BD*.46833976+Ksat*.14006342-θv*.05174635+Temp*.62264668

Tillage	Discriminant Functions Beadle Soil	Worthing Soil
MB	13.18	11.00
CP	13.06	10.94
RT	11.85	10.87
NT	12.10	11.03

and no-till systems had significantly higher bulk density and lower K-sat values than moldboard and chisel plow systems in the Beadle soil in 1986. Ridge-till and no-till systems also produced a significantly higher bulk density than moldboard plowed systems in the Worthing soil in 1986. The Worthing soil in 1986 did not show any significant difference in the bulk density values of the three conservation tillage systems (chisel, ridge and no-till) and between the moldboard and chisel plowed systems. No significant difference in K-sat values was observed among tillage systems in the Worthing soil in 1986. There was no significant difference in bulk density values among tillage systems in 1987 in both soils. Ridge and no-till systems had significantly higher K-sat values than moldboard and chisel plowed systems in Beadle soil in 1987. The moldboard plowed system had significantly higher K-sat. values than the no-till system in the Worthing soil in 1987.

The increase in K-sat. values in the Worthing in 1987 under moldboard plow might be due to the cloddy surface of moldboard plowed plots. The decrease in K-sat. values of moldboard and chisel plowed systems and increase in K-sat. values of ridge and no-till systems in 1987 compared to 1986 may be due to the difference in date (days

Table 9. Tillage effects on bulk density and saturated hydraulic conductivity of Beadle and Worthing soils.

Soil	Tillage	Bd ($Mg\ m^{-3}$)		K-sat ($cm\ hr^{-1}$)	
		1986	1987	1986	1987
Beadle	MB	1.05 a	1.06 a	10.74 a	3.72 ab
	CP	1.09 a	1.13 a	12.25 a	5.27 a
	RT	1.25 b	1.15 a	2.07 b	7.63 c
	NT	1.28 b	1.15 a	4.16 b	7.34 c
Worthing	MB	1.08 a	1.06 a	0.21 c	4.33 ab
	CP	1.16 ab	1.04 a	0.30 c	1.06 bc
	RT	1.22 b	1.07 a	0.10 c	1.54 bc
	NT	1.23 b	1.14 a	1.42 c	0.81 c

MB= moldboard plow CP= chisel plow

RT= ridge-till NT= no-till

Bd= bulk density K-sat= saturated hydraulic conductivity

Means with the same letter are not significantly different at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of 12 observations.

corn except for the Worthing soil in 1987 where moldboard plowed plots had significantly higher aggregate stability than chisel plow and ridge-till plots (Table 10). Under corn after soybean rotation, no-till Beadle plots had significantly higher aggregate stability than moldboard plow plots in 1986. No-till Beadle plots under the corn after soybean rotation had the highest aggregate stability among all tillage treatments in 1987 but it is only significantly higher than the chisel plow plots. No significant difference in aggregate stability was observed between tillage treatments in the Worthing corn after soybean plots in 1986. However in 1987, moldboard plow treatment had significantly higher aggregate stability than all other tillage treatments. No-till and chisel plow Worthing plots also had significantly higher aggregate stability than ridge-till plots. The higher aggregate stability in the Worthing moldboard plowed plots may be due to the cloddy surface caused by wetness and delayed plowing. The lower aggregate stability of Worthing ridge-till plots compared chisel plow and no-till plots may be due the leaching of salt from the ridge to deeper depths. The aggregate stability differences observed in this study may be partially related to the difference in moisture content at the time of sampling (Gollany, 1986).

Table 10. Percent stable aggregates under different tillage treatments of Beadle and Worthing soils.

Soil	Tillage	Percent water stable aggregates			
		1986		1987	
		CC	SC	CC	SC
Beadle	MB	88.1 a	82.1 b	94.5 a	93.5 ab
	CP	88.8 a	85.0 ab	93.1 ab	91.7 b
	RT	83.1 a	85.7 ab	93.0 a	93.6 ab
	NT	85.2 a	88.0 a	95.4 a	95.2 a
Worthing	MB	93.2 a	90.7 a	94.2 a	95.0 a
	CP	91.2 a	91.7 a	89.8 b	92.2 c
	RT	91.5 a	88.8 a	88.3 b	86.3 b
	NT	90.9 a	89.9 a	92.1 abc	92.4 c

Means with the same letter are not significantly different at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of 3 observations.

MB= moldboard plow CP= chisel plow

RT= ridge-till NT= no-till

CC= continuous corn SC= corn after soybeans

Two years of tillage treatments might not be long enough for conservation tillage systems to develop significantly higher aggregate stability than conventional tillage systems as reported by Mannering et al. (1975).

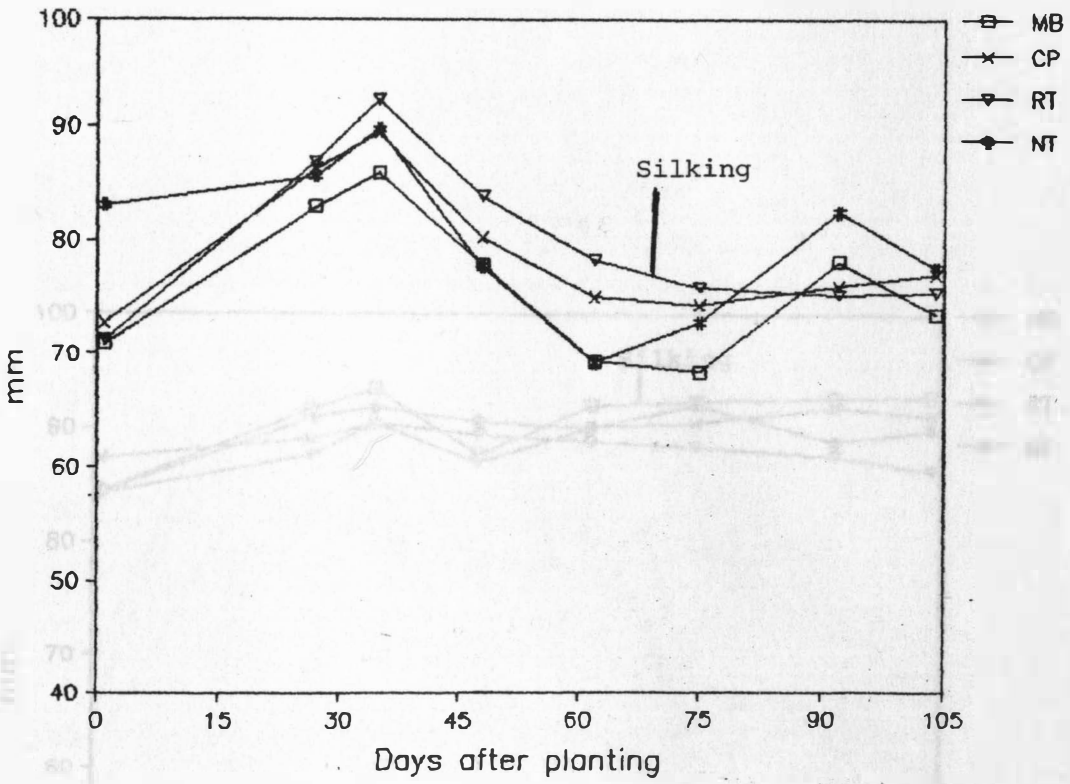
D. Soil Moisture

Two year average volumetric water content for the early growing period is given in Table 8. No-till and ridge-till plots contained significantly higher moisture by volume than moldboard plowed plots in the Ap (0-0.22 m) horizon of the Beadle soil. Surface moisture content was the lowest in the moldboard plowed plots and highest in the no-till plots. Surface moisture content increased as tillage intensity decreased and surface residue cover increased (Tables 8 and 6). Higher residue cover in the conservation tilled plots may have reduced evaporation from the soil surface and increased soil moisture content (Blevins et al., 1971, 1985; Griffith et al., 1977 and Phillips, 1984). This result is in agreement with most of the previous tillage research results (Blevins et al., 1983; Gantzer and Blake, 1971; Lal, 1981; NeSmith et al., 1987; Negi et al., 1981 and Mielke et al., 1986).

There was no significant difference in surface moisture content of the Worthing soil (Table 8). Chisel plow plots had the highest and moldboard plow plots had the

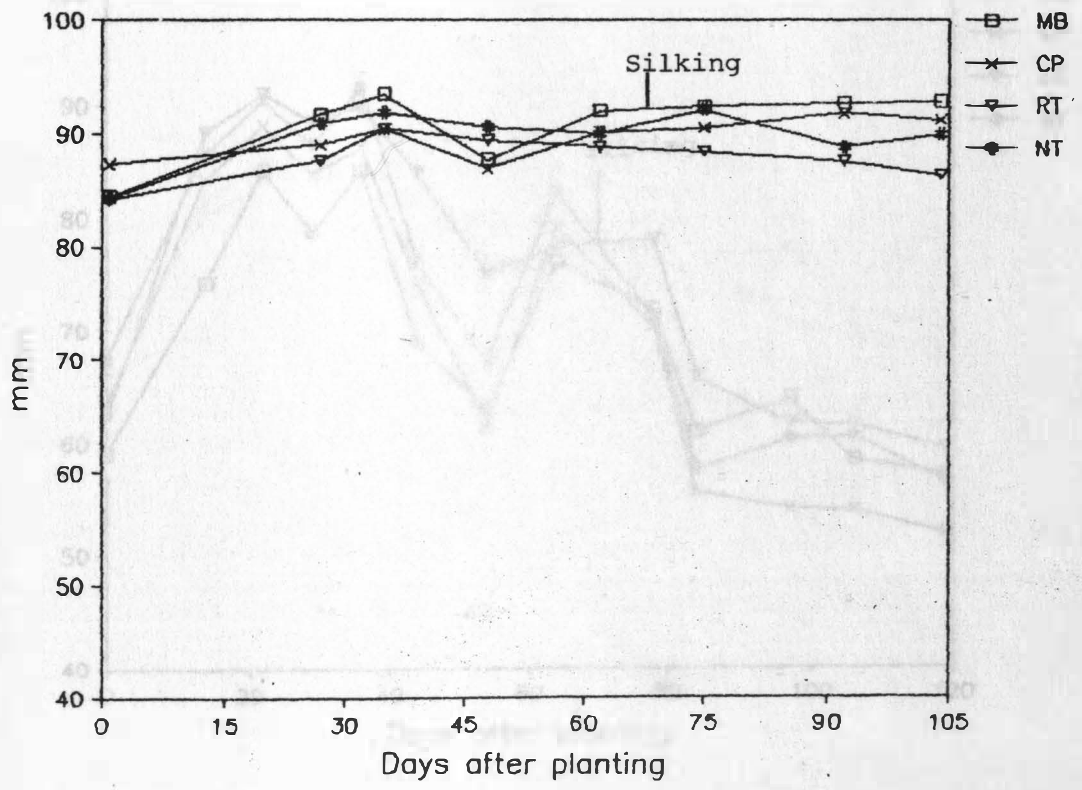
lowest volumetric water content in the surface horizon (0-.18 m) of the Worthing soil (Table 8). Since 1986 was an extremely wet year, the Worthing soil was saturated during most of the 1986 growing season (Figures 24 and 7). Therefore, slight differences in micro relief which caused differences in ponding of water controlled soil moisture rather than by reducing evaporation from residue cover .

The conservation tilled Beadle soil stored a greater amount of water in the Ap (0-0.22 m) horizon than the moldboard plowed soil during the earlier part of the growing season in both years Figures (6 and 8). No till Beadle plots stored 10-13 mm more water in the surface layer than the other three tillage plots at planting in 1986 (Figure 6). However, moldboard plow, chisel plow, ridge-till and no-till plots stored 59, 63, 62 and 67 mm of water respectively, at planting in 1987 (Figure 8). Surface water storage in the Beadle soil at silking was ranked as ridge-till> chisel plow> no-till> moldboard plow in 1986 and no-till= ridge till> chisel plow> moldboard plow in 1987 (Figure 6 and 8). The Worthing soil surface (0-0.18 m) was saturated throughout the whole growing season in 1986 (Figure 7). All conservation tilled Worthing plots stored greater amounts of water in the Ap (0-0.18 m) horizon than the moldboard plowed plots during the early part of 1987 growing season (Figure 9). At silking, water



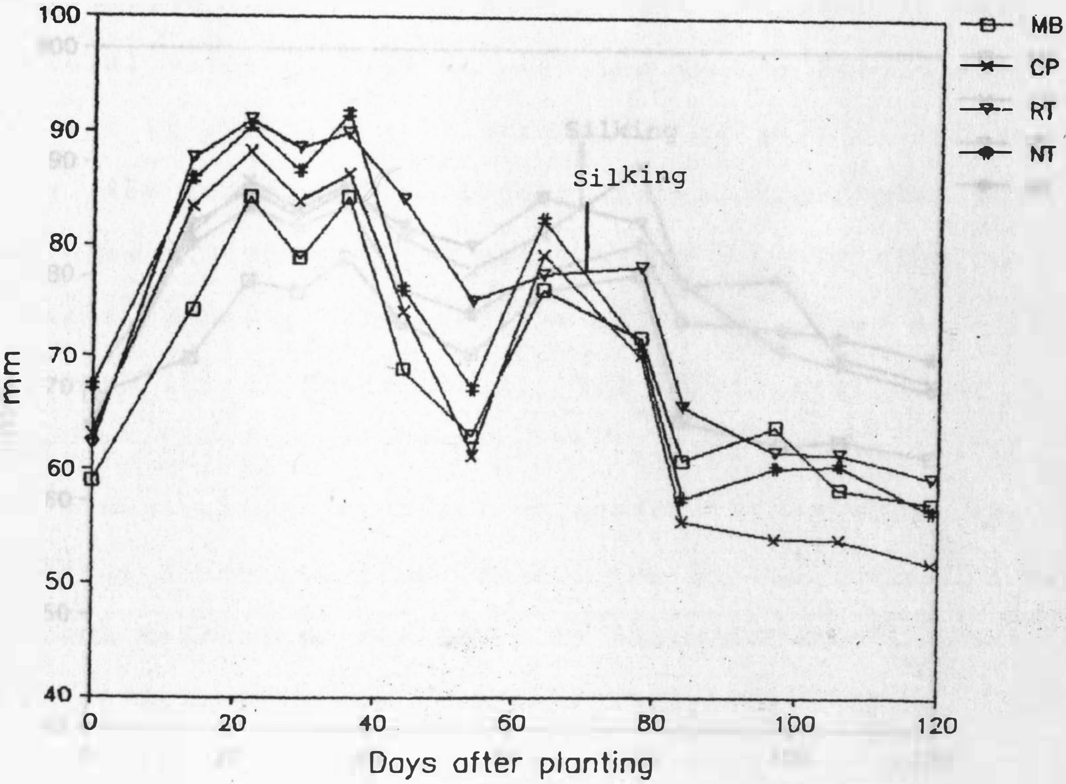
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 6. Water storage in Ap horizon (0-.22 m) of Beadle soil under different tillage treatments during 1986 growing season.



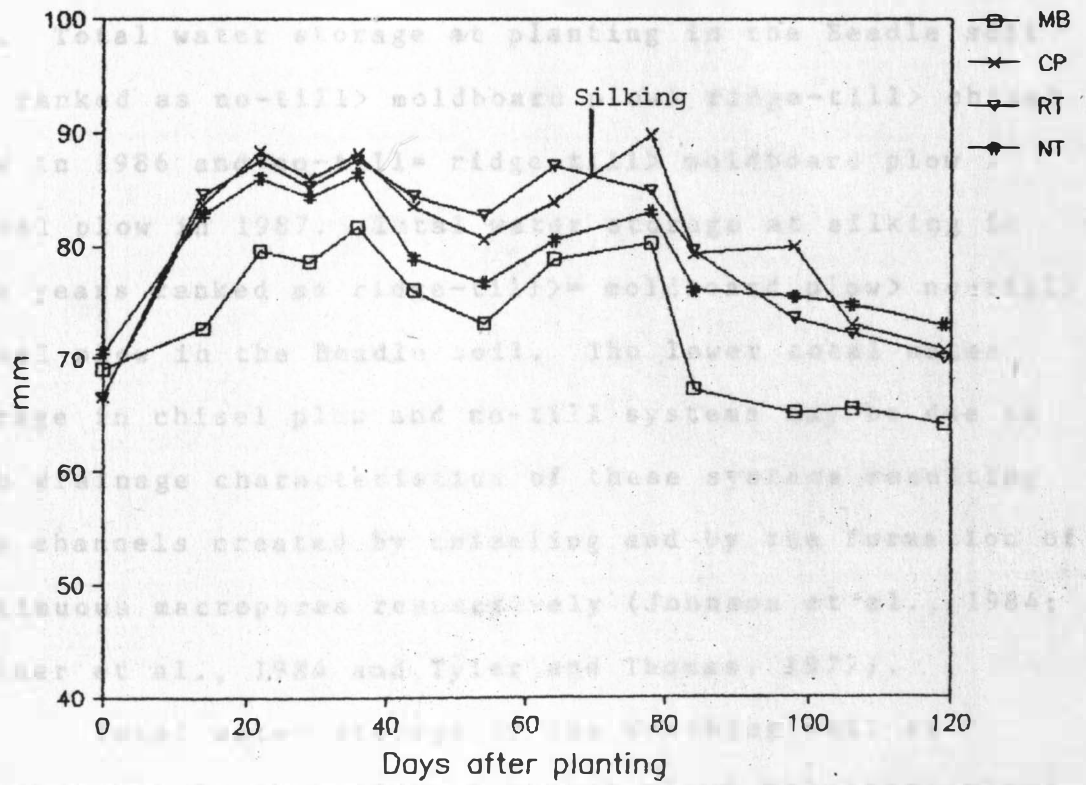
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 7. Water storage in the Ap horizon (0-.18 m) of Worthing soil under different tillage treatments during 1986 growing season.



MB - moldboard plow
CP - chisel plow
RT - Ridge till
NT - No-till

Figure 8. Water storage in the Ap horizon (0-.22 m) of Beadle soil under different tillage treatments during 1987 growing season.



MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

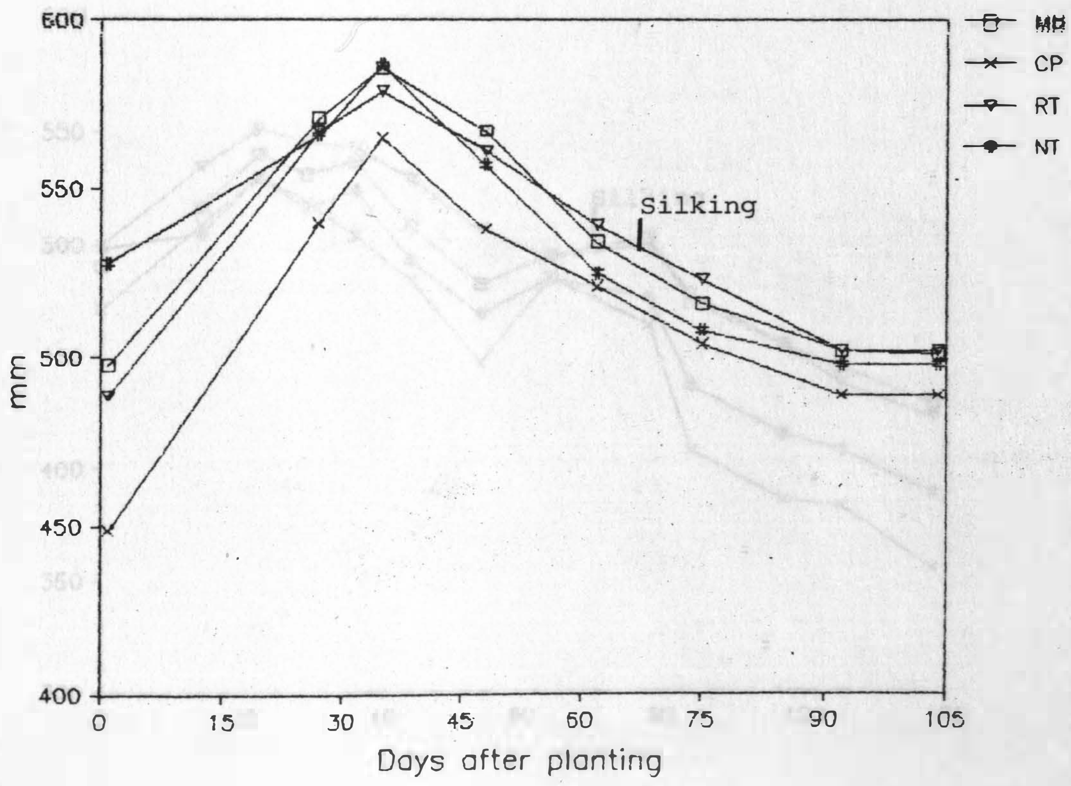
Figure 9. Water storage in the Ap horizon (0-.18 m) of Worthing soil under different tillage treatments during 1987 growing season.

storage in the Ap horizon of Worthing soil ranked as ridge-till= chisel plow> no-till> moldboard plow in 1987.

Chisel plowed plots stored the least amount of water in the soil profile throughout the whole growing season in both years in the Beadle soil (Figures 10 and 11). Total water storage at planting in the Beadle soil was ranked as no-till> moldboard plow> ridge-till> chisel plow in 1986 and no-till= ridge-till> moldboard plow > chisel plow in 1987. Total water storage at silking in both years ranked as ridge-till>= moldboard plow> no-till> chisel plow in the Beadle soil. The lower total water storage in chisel plow and no-till systems may be due to high drainage characteristics of these systems resulting from channels created by chiseling and by the formation of continuous macropores respectively (Johnson et al., 1984; Tollner et al., 1984 and Tyler and Thomas, 1977).

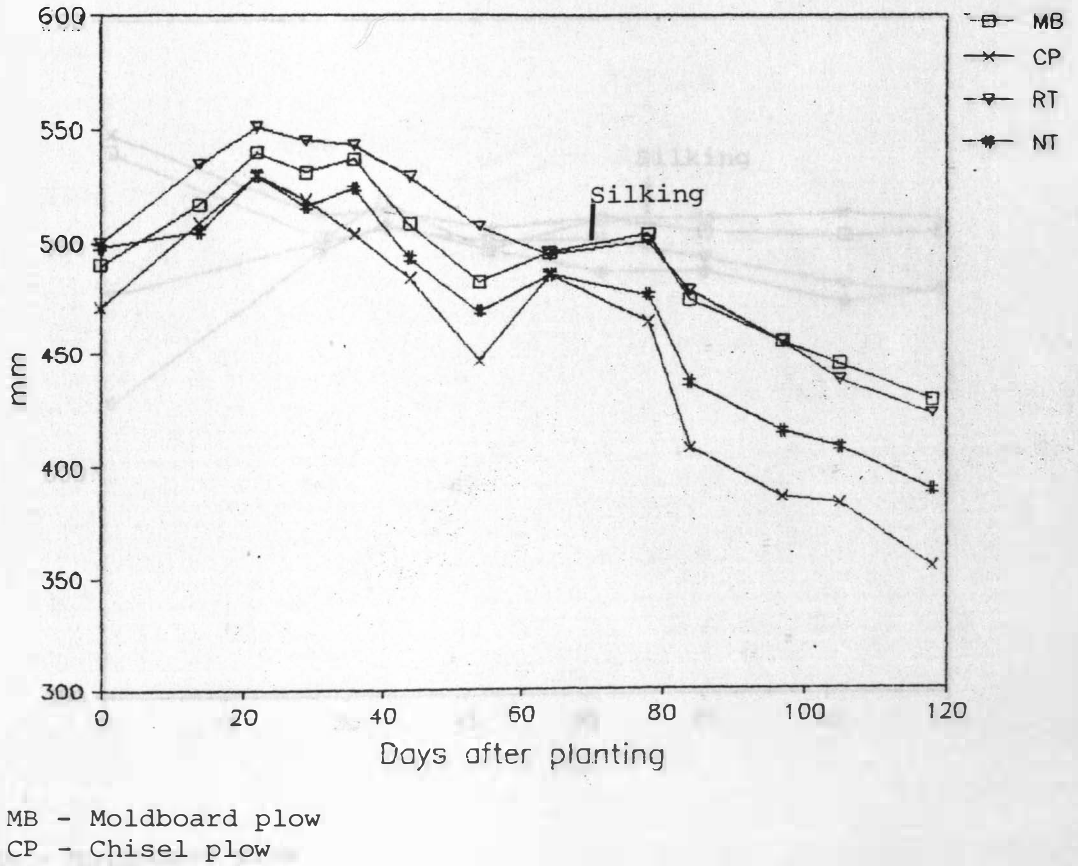
Total water storage in the Worthing soil at planting was in the order of chisel plow> moldboard plow> ridge-till> no-till in 1986 (Figure 12). The same order was observed in 1987 except that the moldboard plow plots stored more moisture than the chisel plow (Figure 13). Total water stored was high throughout the whole growing season in all tillage treatments of the Worthing soil in both years.

No significant difference in water use



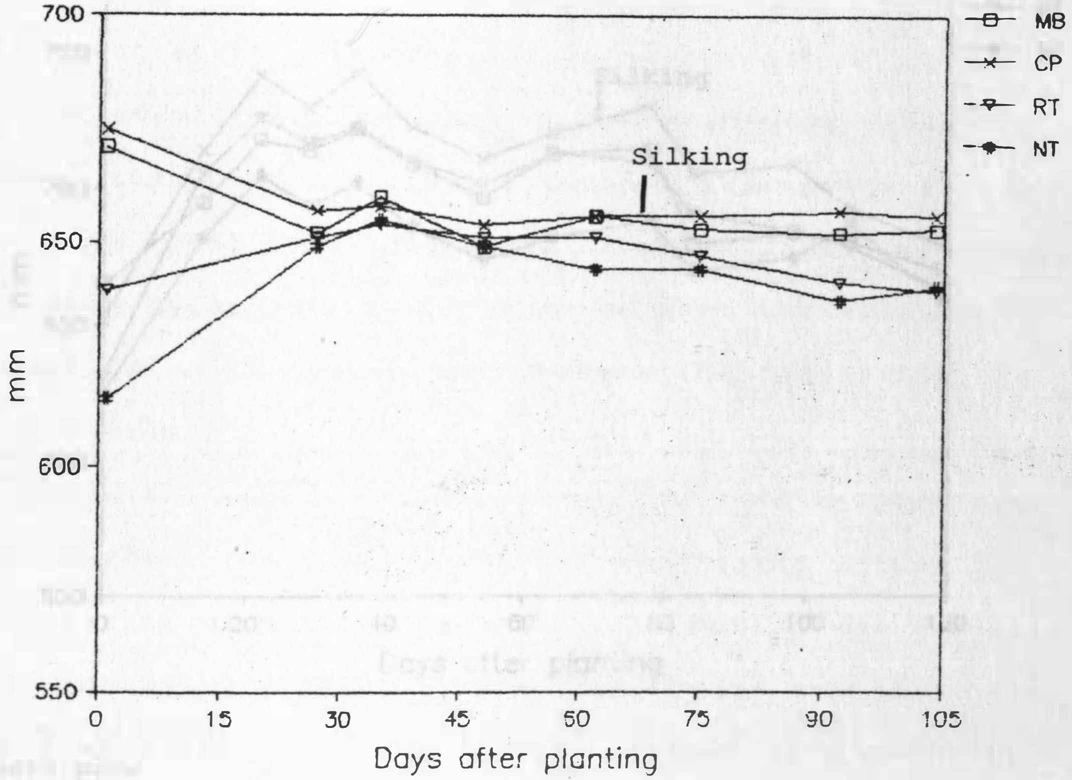
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 10 Total water storage under different tillage treatments of the Beadle soil profile up to a depth of 1.35 m during 1986 growing season.



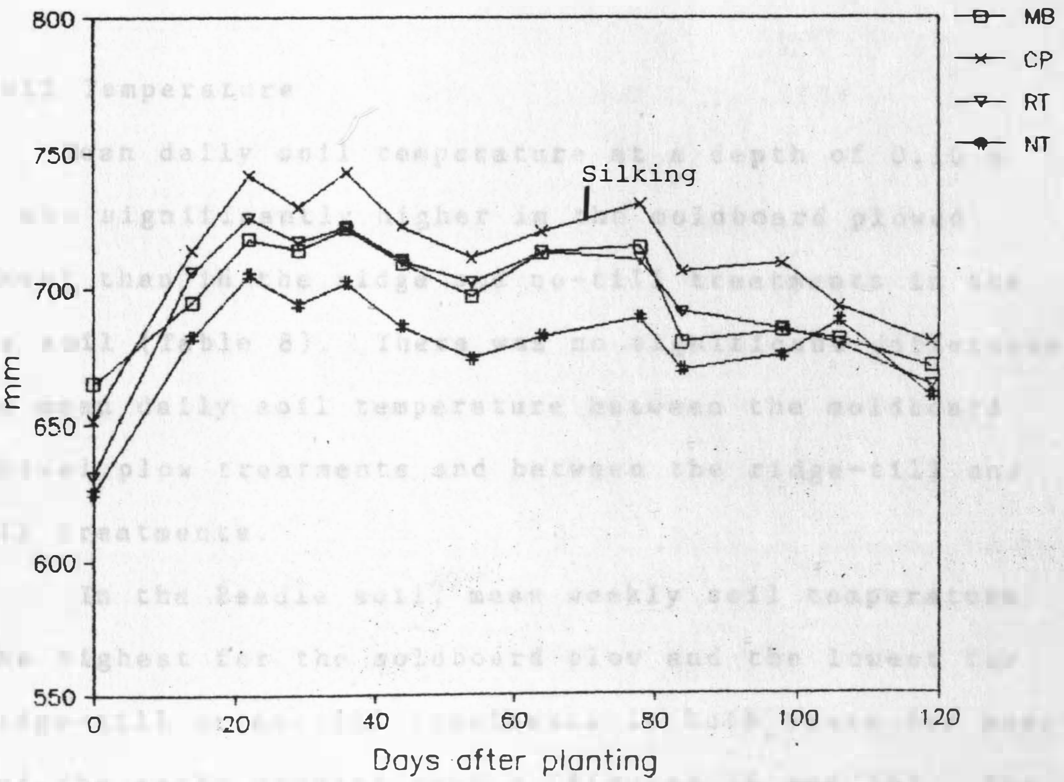
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 11 Total water storage under different tillage treatments of the Beadle soil up to a depth of 1.50 m during 1987 growing season.



MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 12 Total water storage under different tillage treatments of the Worthing soil profile up to a depth of 1.35 m during 1986 growing season.



MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 13 Total water storage under different tillage treatments of Worthing soil up to a depth of 1.50 m during 1987 growing season.

(evapotranspiration) and water use efficiency was observed between the tillage treatments in both soils (Table 11). Research conducted in the same area by Olson and Schoeberl (1970) found no significant difference in water use between tillage systems (conventional, wheel-track, till plant and listed planting) in Beadle-Whitewood soils.

E. Soil Temperature

Mean daily soil temperature at a depth of 0.10 m depth was significantly higher in the moldboard plowed treatment than in the ridge and no-till treatments in the Beadle soil (Table 8). There was no significant difference in the mean daily soil temperature between the moldboard and chisel plow treatments and between the ridge-till and no-till treatments.

In the Beadle soil, mean weekly soil temperature was the highest for the moldboard plow and the lowest for the ridge-till or no-till treatments in both years for most part of the early growing season (Figures 14 and 16). The weekly mean soil temperature for the chisel plow treatment was between the moldboard plow and no-till (ridge-till). The reduction in soil temperature correlates well with the increase in percent residue cover as tillage system changes from conventional to ridge-till or no-till systems. The surface residue cover tends to reflect incoming solar

Table 11. Evapotranspiration and water use efficiency under different tillage systems of Beadle and Worthing soils.

Soil	Tillage	ET (mm) 1986	ET (mm) 1987	Water use efficiency ($kg\ ha^{-1}\ mm^{-1}$) 1986	Water use efficiency ($kg\ ha^{-1}\ mm^{-1}$) 1987
Beadle	MB	381 a	312 ab	26.8 a	36.0 a
	CP	362 a	331 ab	26.0 a	27.2 a
	RT	387 a	329 a	24.0 a	27.5 a
	NT	421 a	366 a	22.5 a	24.8 a
Worthing	MB	414 a	300 b	8.0 b	22.2 a
	CP	428 a	279 b	4.2 b	25.3 a
	RT	417 a	248 b	6.6 b	31.5 a
	NT	382 a	283 b	5.4 b	28.5 a

MB= moldboard plow CP= chisel plow

RT= ridge-till NT= no-till

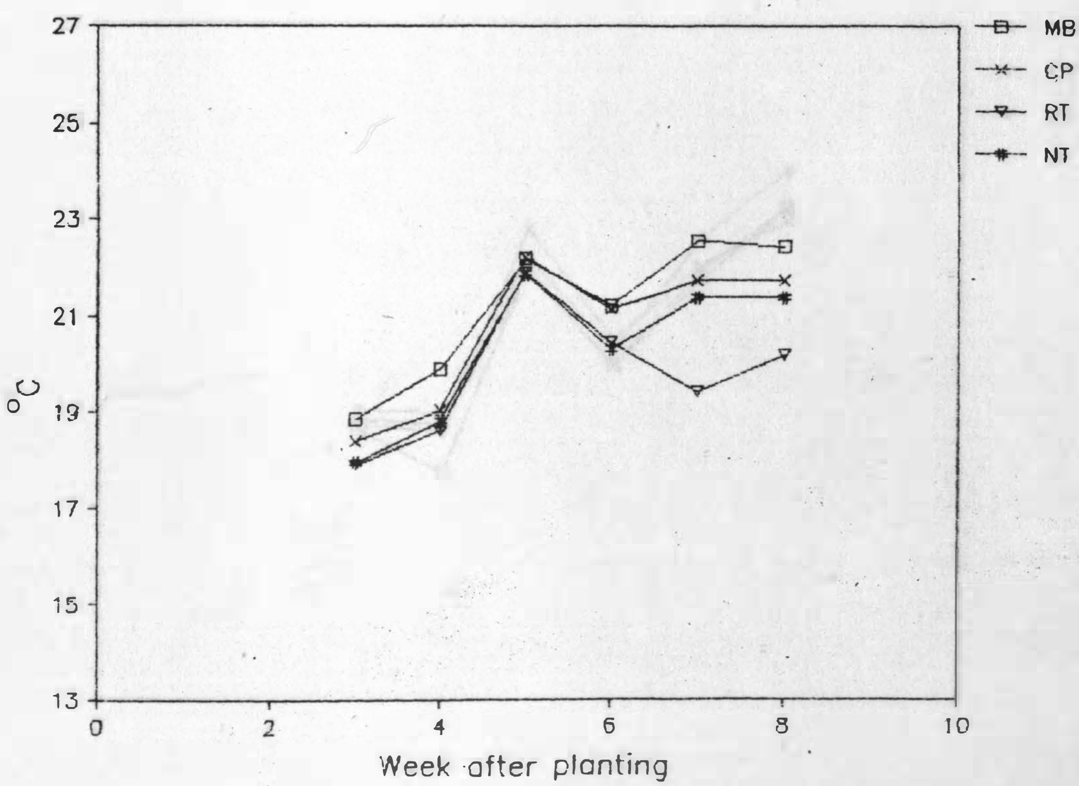
Means with the same letter are not significantly different at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of 3 observations.

radiation and reduce soil temperature (Van Wijk et al., 1959). This soil temperature difference due to tillage in the Beadle soil is in agreement with Johnson and Lowery (1985).

On an average, daily maximum soil temperature (two years average for the early growing period) was reduced by 1.8 °C in ridge-till/no-till system compared to moldboard plowed system in the Beadle soil (Tables 35 and 36). However, average daily minimum soil temperature was reduced only by 0.5 °C. This demonstrates that surface residue cover has a greater effect on daily maximum soil temperature than on daily minimum, as was reported in earlier studies (Gupta et al., 1983). The lesser effect on minimum soil temperature was probably due to decreased long wave radiation at night from the plant residue covered soil surface.

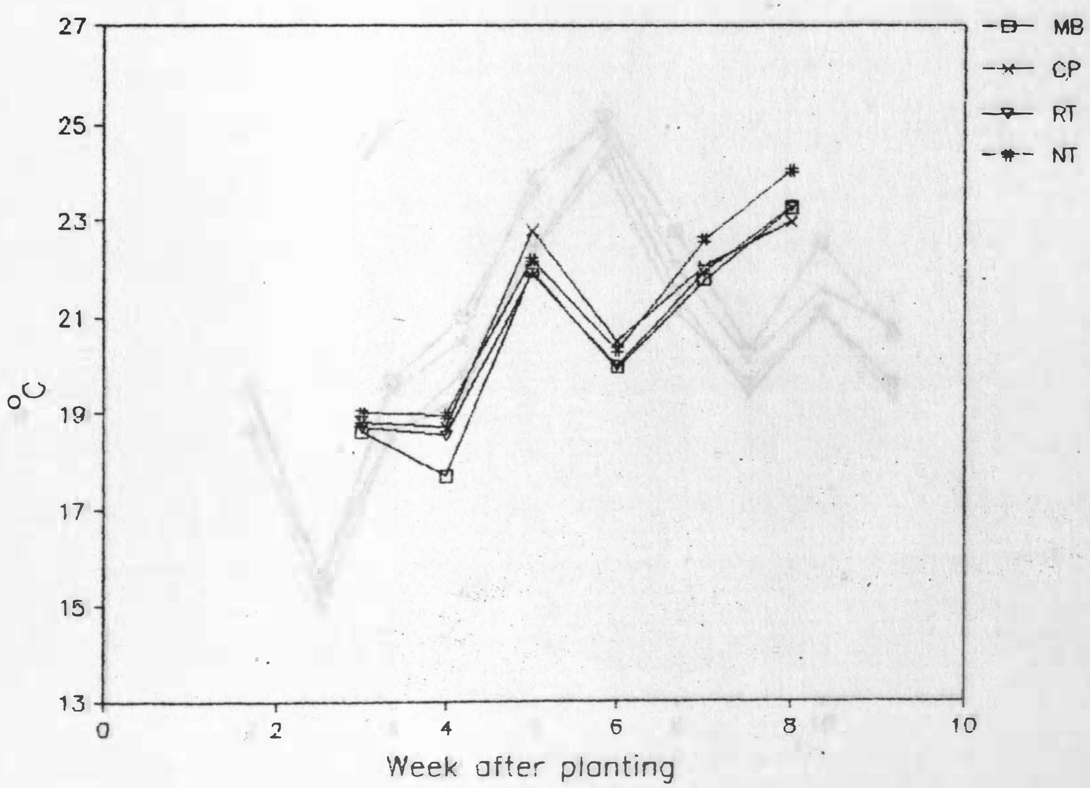
The Beadle soil did not demonstrate warmer soil temperatures under a ridge-till compared to a no-till system as expected (Radke, 1982). This might be due to generally higher water storage in the ridge-till than in the no-till system.

No significant difference in mean daily soil temperature was observed between the tillage systems in the Worthing soil (Table 8). No clear difference in mean weekly soil temperature was observed due to tillage



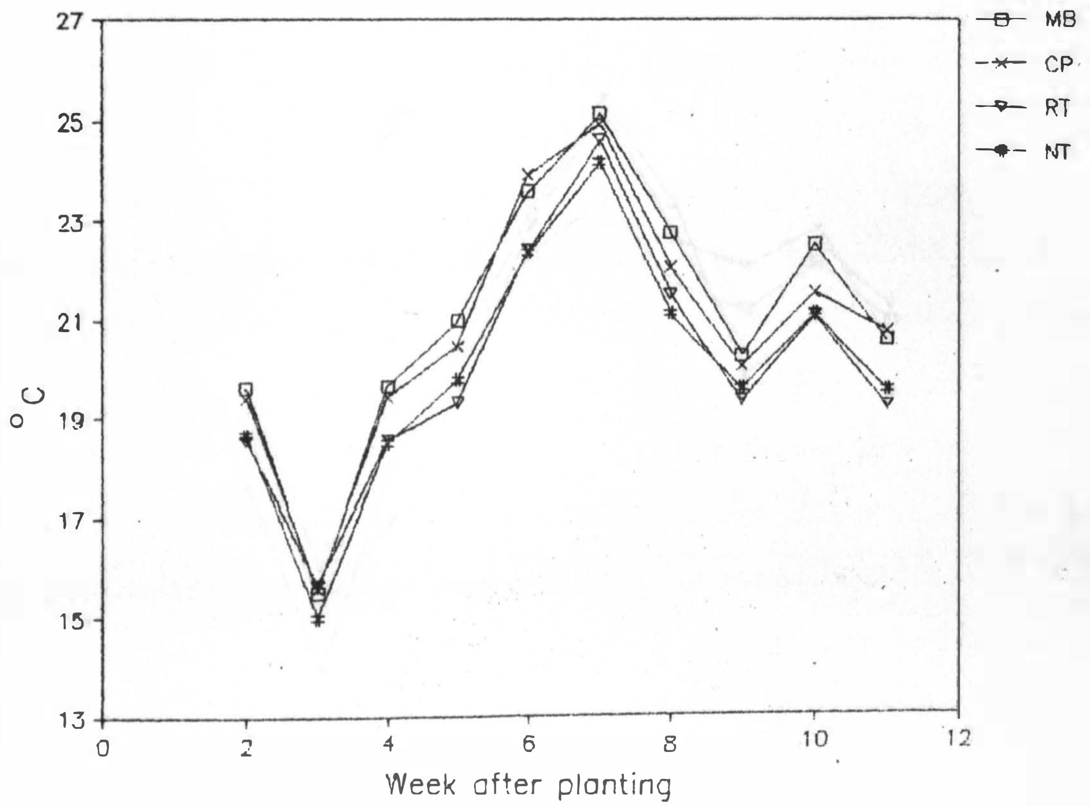
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 14 Weekly mean soil temperature under different tillage treatments of Beadle soil during 1986 growing season at .10 m depth.



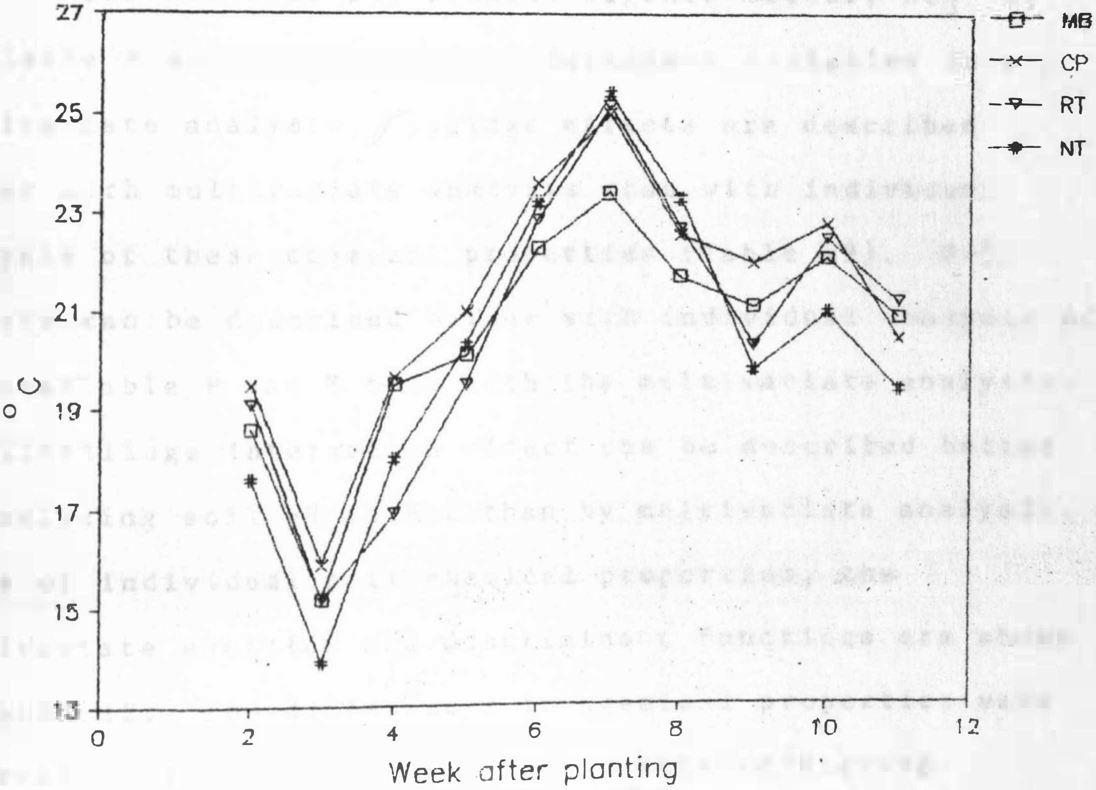
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 15 Weekly mean soil temperature under different tillage treatments of Worthing soil during 1986 growing season at .10 m depth.



MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 16 Weekly mean soil temperature under different tillage treatments of Beadle soil during 1987 growing season at .10 m depth.



MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 17 Weekly mean soil temperature under different tillage treatments of Worthing soil during 1987 growing season at .10 m depth.

treatments in the Worthing soil during the 1986 growing season (Figure 15).

III. Tillage and Soil Effect on Chemical Properties

A. Multivariate Analysis

Surface soil pH, percent organic matter, NO_3^- N, available P and K were used as dependent variables in a multivariate analysis. Tillage effects are described better with multivariate analysis than with individual analysis of these chemical properties (Table 49). Soil effects can be described better with individual analysis of pH, available P and K than with the multivariate analysis. A soil*tillage interaction effect can be described better by analyzing soil pH rather than by multivariate analysis. Means of individual soil chemical properties, the multivariate equation and discriminant functions are shown in Table 12. Few differences in chemical properties were observed to be due to tillage treatments (comparing discriminant functions in table 12). Ridge-till plots appeared slightly different in their chemical properties from chisel plow.

B. Soil pH and Electrical Conductivity

Ridge-till and no-till plots had significantly lower surface pH than did the moldboard and chisel plowed

Table 12. Tillage effects on surface chemical properties of Beadle and Worthing soils (averaged over crop rotations and years).

Soil	Tillage	pH	OM (%)	ANO_3^-	BNO_3^-	P	K
				-----------Kg ha^{-1}			
Beadle	MB	7.1 b	3.88 a	15.0 b	10.3 b	20.9 a	421 a
	CP	7.7 c	3.98 a	14.4 b	10.2 b	15.0 a	445 a
	RT	6.5 a	4.15 a	17.6 b	11.9 b	25.2 a	446 a
	NT	6.8 a	4.46 a	14.1 b	10.7 b	28.4 a	546 a
Worthing	MB	7.6 c	4.36 a	19.6 ab	7.4 a	50.6 a	602 a
	CP	7.6 c	4.09 a	14.7 b	6.5 a	64.3 ab	580 a
	RT	7.5 c	4.38 a	27.1 a	12.2 b	66.7 ab	511 a
	NT	7.6 c	4.05 a	13.0 b	7.0 a	70.8 b	497 a

MB=Moldboard Plow CP=Chisel plow RT=Ridge-till NT=No-till
Means with the same letter are not significantly different at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of six observations.
A= 0-.15 m B= .15-.60 m

Discriminant Functions:

Z=PH*.6064434+%O.M.*.16096-N*.014400-P*.004555+K*.002153

Tillage	Discriminant Functions
MB	5.64
CP	5.77
RT	5.30
NT	5.55

plots (Table 12). There was no significant difference in pH values between ridge-till and no-till treatments. Moldboard plowed plots showed significantly lower soil pH than chisel plowed plots. Acidification of the soil surface under ridge and no-till systems was expected as these tillage systems involved less mixing of surface applied fertilizers (Blevins et al., 1977, 1983 and Dick, 1983). Continuous use of ammonium nitrogen on the surface could acidify the surface soil due to the nitrification process, which produces two hydrogen ions for each nitrate ion formed (Blevins et al., 1984; Dick, 1983).

Acidification of the soil surface due to no-till or ridge-till planting in soils such as the Beadle could be beneficial rather than being detrimental as suggested in other studies (Blevins et al., 1977 and 1983). The lowering of the surface pH might increase the availability of plant nutrients such as P (Table 12).

There was no significant difference in the surface pH values of the Worthing soil due to tillage treatments (Table 12). Soil pH of the Worthing soil was significantly higher than that of Beadle soil in the surface layer (Table 13).

Electrical conductivity (EC) of the surface horizon of the Beadle soil was in the range of 0.3 to 0.76 mmho cm^{-1} which is below the critical range. However, the

Worthing soil had a significantly higher EC than the Beadle soil (Table 45). The EC values for different plots of the Worthing soil varied from 3.5 to 5.2 mmho cm^{-1}, depending on the micro relief. Wilting of corn leaves was observed in some of the plots during both the 1986 and 1987 growing seasons (Table 46). The electrical conductivity of the soil surface of the Worthing soil varied from year to year depending on the fluctuation of the water table (Table 14). The distribution of EC in the upper 0.20 m of the soil surface also varied from year to year (Table 46).

Table 13. Chemical properties of Beadle and Worthing soils (averaged over tillage systems, crop rotations and years).

Soil	pH	OM (%)	ANO_3^-	BNO_3^-	P	K
			----------------Kg ha^{-1}			-----------
Beadle	7.0 a	4.1 a	15.30 a	7.50 a	22.37 a	465 a
Worthing	7.6 b	4.2 a	18.61 a	8.28 a	63.24 b	683 b

Means with the same letter are not significant at .05 level. Each mean is an average of 72 observations.

Table 14. Surface electrical conductivity of the Beadle and Worthing soils

Soil	EC (mmho cm^{-1})			
	1984	1985	1986	1987
Beadle	0.7	0.7	0.7	0.4
Worthing	2.7	3.8	4.0	4.2

C. Organic Matter and Soil Nitrate

No significant difference in surface readily oxidizable organic matter (%) was observed either between different tillage systems or between the Beadle and Worthing soils (Tables 12 and 13). The Beadle soil contained the lowest amount of organic matter in the moldboard plowed plots (3.9%) and the highest in the no-till plots (4.5%). The chisel plow and the ridge-till plots contained 4 and 4.2% organic matter respectively. The no-till plots contained about 15% more organic matter (in the 0-.15 m layer) than the conventional plots which was within the range reported by Mielke et al. (1986).

Neither surface (0-0.15 m) nor sub-soil (0.15-.60 m) nitrate levels were significantly different among tillage treatments in the Beadle soil (Table 12). The

ridge-till Worthing plots contained significantly higher levels of nitrate in both the surface and sub-soil than the no-till and chisel plow plots (Table 12). No significant differences were observed in the surface nitrate levels of the moldboard plowed and ridged Worthing plots. However, sub-soil nitrate was significantly higher in ridged plots than in the moldboard plowed plots. Ridges in the poorly drained Worthing soil might have been better aerated than flat seed beds. Better aeration could have enhanced the decomposition of organic matter in these plots to produce higher levels of nitrate. No significant differences in the nitrate level were observed between the Beadle and Worthing soils.

D. Available Phosphorus, Potassium and Zinc

Ridge-till and no-till Beadle plots contained higher amounts of available P than the moldboard and the chisel plow plots but they were not statistically significant (Table 12). The chisel plow plots had the lowest amount of available P and also the highest soil pH among all the tillage treatments in the Beadle soil. Some of the available P might have been converted to relatively unavailable calcium phosphates due to the high pH. The Worthing no-till plots had a significantly higher amount of available P than the moldboard plowed plots. There was no

significant difference in available P levels between the three conservation tillage systems and between moldboard plow, chisel plow and ridge-till systems in the Worthing soil.

As a general trend, the surface of no-till and ridge-till plots contained more available P and than conventional and chiseled plots on both soils. Again this may be due to the lack of mixing of fertilizers in these treatments (Blevins et al., 1983 and 1984). The Worthing soil contained significantly higher amounts of P and K than the Beadle soil.

No significant difference in available Zn level was observed between the tillage treatments in both soils (Table 44). The Beadle soil had a significantly higher amount of available Zn than the Worthing soil.

IV. Tillage, Soil and Cropping Sequence Effect on Crop Development and Grain Yield.

A. Multivariate Analysis

Percent emergence, leaf area per plant (one date), days to fifty percent silking and grain yield of continuous corn were used as dependent variables in a multivariate analysis. Tillage, tillage*soil interaction and tillage*soil*year interaction effects could be described better with multivariate analysis than with the individual

Table 15. Effect of tillage on corn development and yield of the Beadle and Worthing soils.

Soil	Tillage	PEM	LA (cm^2)	DFS	Yield (Mg ha^{-1})
			1986		
Beadle	MB	94 a	2195 a	68 a	9.97 a
	CP	97 a	1985 a	68 a	9.35 a
	RT	94 a	2199 a	68 a	9.28 a
	NT	89 a	2289 a	66 a	9.59 a
Worthing	MB	50 bc	480 d	82 c	3.617 c
	CP	32 b	479 d	84 c	1.763 c
	RT	62 c	478 d	83 c	2.630 c
	NT	59 bc	529 d	83 c	2.043 c
			1987		
Beadle	MB	98 a	3982 b	74 b	10.75 a
	CP	98 a	2870 c	74 b	9.01 b
	RT	91 a	3217 bc	74 b	9.52 b
	NT	94 a	2480 c	75 b	8.89 b
Worthing	MB	90 a	1369 e	85 d	6.66 d
	CP	96 a	1511 e	78 d	6.93 d
	RT	80 a	1607 e	77 d	7.27 d
	NT	92 a	2144 e	76 d	7.49 d

Means with the same letter are not significant at .05 level. This designation is used only with preplanned comparisions. Each mean is an average of 6 observations. The dates of sampling for leaf area were July 1, 1986 and June 25, 1987.
MB=moldboard plow CP=chisel plow RT=ridge-till NT=no-till
PEM= % emergence LA= leaf area DFS= days to 50% silking

Discriminant Functions:

Z =PEM*.0077125+Yield*.006610+DFS*.116068-LA*.0001627

Tillage	Discriminant Functions			
	Beadle Soil		Worthing Soil	
	1986	1987	1986	1987
MB	9.31	9.74	10.15	11.02
CP	9.28	9.70	10.13	10.27
RT	9.24	9.61	10.33	10.04
NT	8.95	9.90	10.16	9.91

analysis of each of the components (Table 50). Soil effect could be described better by analyzing leaf area, days to 50% silking, and grain yield saperately rather than by multivariate analysis. Means of the individual plant parameters (used in MANOVA), multivariate equation and discriminant functions are shown in Table 15. No difference in corn development-grain yield was observed in 1986 (Compare discriminant functions in Table 15). Similar results were observed in the Beadle soil in 1987. However, Worthing moldboard plowed plots behaved differently from other tillage plots with respect to corn development-yield in 1987. This might be due to the cloddy surface of the moldboard plowed plots caused by delayed plowing.

B. Corn and Soybean Emergence

There was no significant difference in the percent corn emergence between tillage treatments in the Beadle soil (Table 16). Since the Worthing tillage plots were completely flooded by the heavy rain after planting for about a week in 1986, the percent corn emergence was drastically reduced. The highest emergence was observed in the ridged plots (62 and 59%) and the lowest emergence was observed in the chiseled plots (32 and 12%) (Table 16). There was no significant difference in corn emergence between tillage treatments in the Worthing soil in 1987

except in chiseled and ridged plots under continuous corn. Chiseled continuous corn plots had significantly higher corn emergence than the ridged plots.

There was no significant difference in percent soybean emergence between tillage systems in either of the soils and years (Table 17). Both corn and soybean emergence was significantly higher in the Beadle soil than in the Worthing soil in both years (Tables 18 and 19). There was no significant difference in the days to 50% corn emergence due to tillage or crop rotation in the Beadle soil except in the moldboard plow plots in 1987, where days to 50% emergence was significantly increased under continuous corn compared to corn after soybeans (Table 20). The date of 50% emergence was significantly delayed in the Worthing moldboard plowed plots compared to other tillage plots in 1987. This was due to the cloddy surface caused by delayed plowing in these plots.

There was no significant difference in the date of 50% soybean emergence in either soil in 1986. However, the date of soybean emergence in moldboard plowed plots was significantly delayed in both soils in 1987 (Table 17). About a week delay in the date of 50% soybean emergence in the Beadle moldboard plowed plots might be due to low soil moisture in these plots compared to other tillage plots at

Table 16. Percent corn emergence under different tillage systems in the Beadle and Worthing Soils.

Soil	Tillage	Percent emergence			
		1986		1987	
		CC	SC	CC	SC
Beadle	MB	94 a	93 a	98 a	99 a
	CP	97 a	86 a	98 a	93 a
	RT	94 a	92 a	91 a	98 a
	NT	89 a	94 a	94 a	99 a
Worthing	MB	46 b	52 b	90 ab	88 a
	CP	32 b	12 c	96 a	89 a
	RT	62 b	59 b	80 b	92 a
	NT	59 b	49 b	92 ab	91 a

MB= moldboard plow CP= chisel plow

RT= ridge-till NT= no-till

CC= continuous corn SC= Corn after soybean

Within a soil and year, means with the same letter are not significantly different at .05 level. Each mean is an average of 3 observations.

Table 17. Soybean emergence under different tillage systems in the Beadle and Worthing soils.

Soil	Tillage	Percent emergence		Days to 50% emergence	
		1986	1987	1986	1987
Beadle	MB	95 a	98 a	12 a	17 a
	CP	93 a	98 a	13 a	10 b
	RT	100 a	98 a	12 a	9 b
	NT	99 a	93 a	12 a	11 b
Worthing	MB	98 b	64 b	16 a	27 a
	CP	74 b	87 b	19 a	14 b
	RT	87 b	84 b	16 a	12 b
	NT	83 b	83 b	17 a	15 b

MB= moldboard plow CP= chisel plow

RT= ridge-till NT= no-till

Within same soil and year means with the same letter are not significantly different at .05 level. Each mean is an average of three observations.

Table 18. Corn emergence in the Beadle and Worthing soils (averaged over tillage treatments and crop rotations).

Soil	Percent emergence		Days to 50% emergence	
	1986	1987	1986	1987
Beadle	93 a	96 a	12	9 a
Worthing	46 c	90 b	-	15 b

Means with the same letter are not significant at .05 level. Each mean is an average of 24 observations.

Table 19. Soybean emergence in the Beadle and Worthing soils (averaged over tillage treatments).

Soil	Percent emergence		Days to 50% emergence	
	1986	1987	1986	1987
Beadle	97 a	97 a	13 a	12 a
Worthing	83 b	79 b	17 b	17 b

Means with the same letter are not significant at .05 level. Each mean is an average of 12 observations.

Table 20. Days to 50% emergence, silking and maturity of corn under different tillage systems in the Beadle and Worthing soils.

Soil	Tillage	DFE CC	DFE SC	DFS CC	DFS SC	DFM CC	DFM SC
				1986			
Beadle	MB	12 a	12 a	68 a	68 a	113 a	114 a
	CP	12 a	12 a	68 a	68 a	114 a	114 a
	RT	12 a	11 a	68 a	67 a	113 a	114 a
	NT	11 a	11 a	67 a	67 a	114 a	113 a
Worthing	MB	*	*	82 b	81 b	117 a	115 a
	CP	*	*	84 b	84 b	117 a	120 b
	RT	*	*	83 b	83 b	116 a	117 ab
	NT	*	*	83 b	78 c	117 a	116 a
				1987			
Beadle	MB	13 a	8 b	74 a	73 a	117 a	117 a
	CP	10 a	8 ab	74 a	73 a	118 ab	118 ab
	RT	10 a	8 ab	74 a	73 a	118 ab	118 ab
	NT	10 a	8 ab	76 a	74 a	118 b	118 b
Worthing	MB	26 b	26 b	85 b	85 b	127 b	126 b
	CP	11 a	12 a	78 a	80 a	121 a	119 c
	RT	11 a	10 a	77 a	77 a	119 a	119 ac
	NT	10 a	10 a	76 a	75 a	118 a	118 ac

MB= moldboard plow CP= chisel plow RT= ridge-till
NT= no-till CC= continuous corn SC= corn after soybeans
DFE= days to 50% emergence DFS= days to 50% silking
DFM= days to 50% maturity
Within a soil and year means with the same letter are not significantly different at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of 3 observations.
*Emergence was less than 50% for most of the plots in the Worthing soil in 1986.

emergence (Table 17 and Figure 12). Significant delay in 50% emergence in the Worthing moldboard plowed plots in 1987 was again due to the cloddy surface. Date of 50% emergence of soybeans was significantly delayed in the Worthing soil compared to the Beadle soil in both years (Table 19).

C. Corn Leaf Area

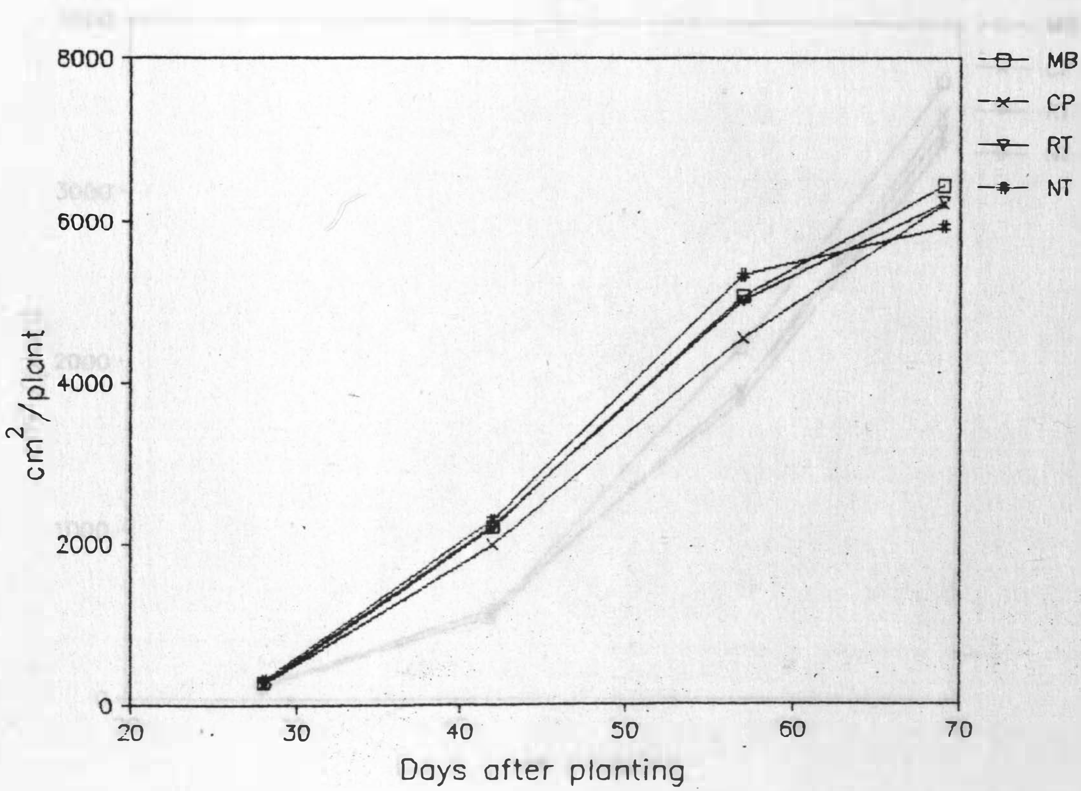
There was no significant difference in the leaf area of corn among the tillage treatments throughout the whole growing season in both Beadle and Worthing soils in 1986 (Figure 18 and 19) and in the Worthing soil in 1987 (Figure21). Corn leaf area was significantly higher under moldboard plow treatment than under chisel plow and no-till treatments for most part of the growing season in the Beadle soil in 1987 (Figure 20). There was no significant difference in leaf area between the moldboard plow and ridge-till treatment during the first two measurements but moldboard plow had significantly higher leaf area than ridge-till system in the later measurements.

The difference in corn growth response to tillage systems between the two years in the Beadle soil may be due to the difference in planting dates in those years. Tillage plots were planted on May 20, in 1986 and on May 6, in 1987.

In general, corn after soybean plots had a higher leaf area than the continuous corn plots (Figure 22 and 23). Continuous corn and soybean-corn Beadle plots did not show any significant difference in Leaf area in 1986 (Sampling Date:7-29-86). However, Worthing moldboard plowed plots had significantly higher leaf area under soybean-corn rotation than under continuous corn in 1986 (Table 21). Soybean-corn rotation plots also had significantly higher leaf area than continuous corn in the Beadle soil in 1987 (Sampling Date-6-19-87) under all tillage treatments except in the ridge-till system. All soybean-corn Worthing plots had higher leaf area values (Sampling Date:6-19-87) than the continuous corn plots but they were statistically significant only under the no-till system (Table 21).

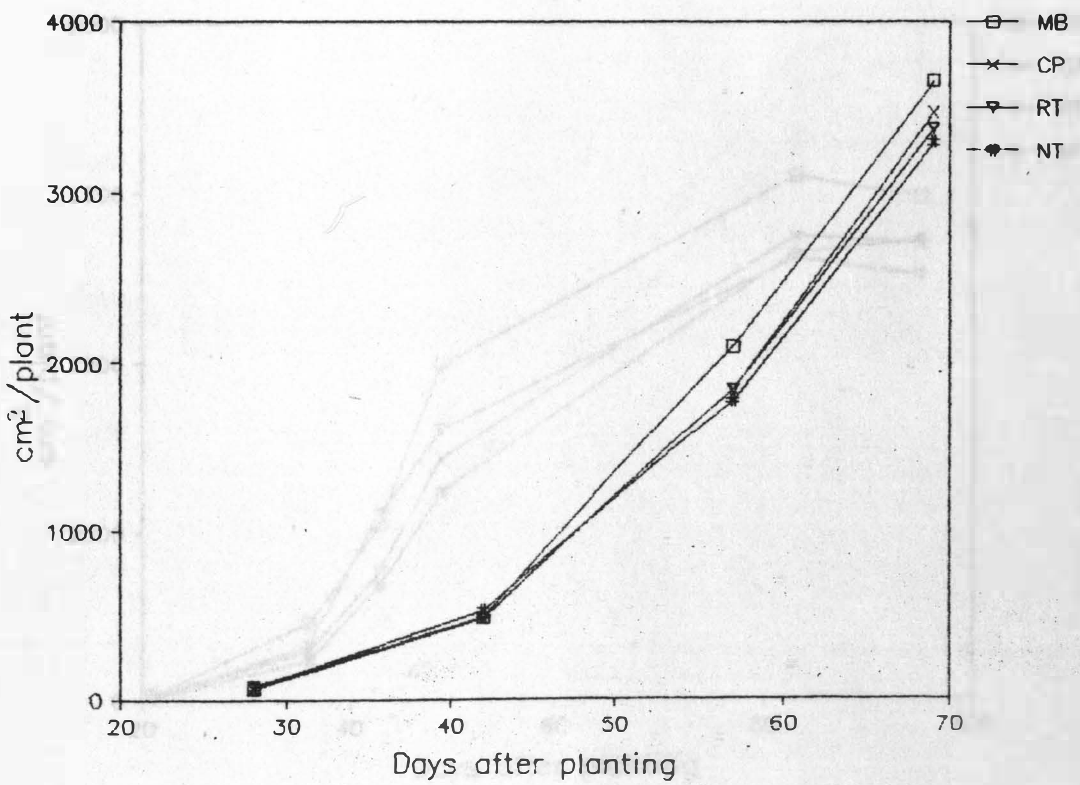
D. Silking (50%) and maturity (50%)

No significant difference in 50% silking and 50% maturity dates was observed either due to tillage treatments or due to cropping sequence in the Beadle soil in both years (Table 20). The silking (50%) and maturity (50%) dates were significantly delayed in the chisel plowed (soybean-corn) Worthing plots compared to the moldboard plow and no-till plots in 1986. These plots also had the lowest emergence in 1986. More micro depressions were



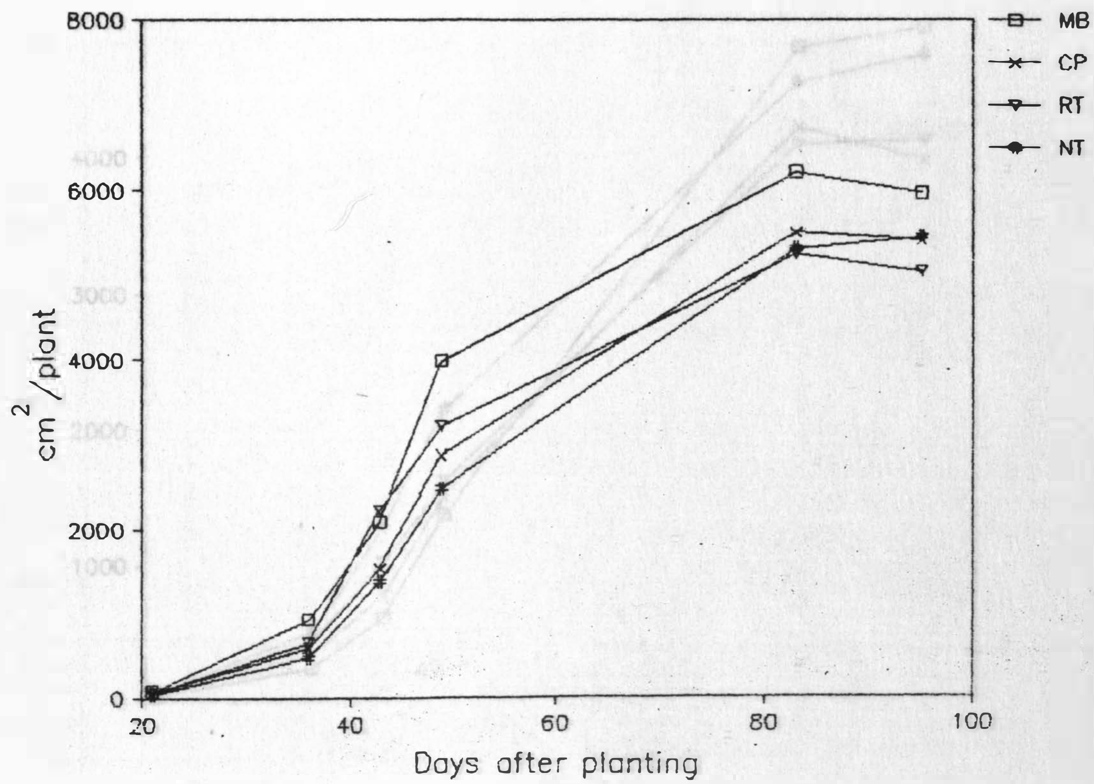
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 18 Corn leaf area under different tillage treatments of Beadle soil during 1986 growing season.



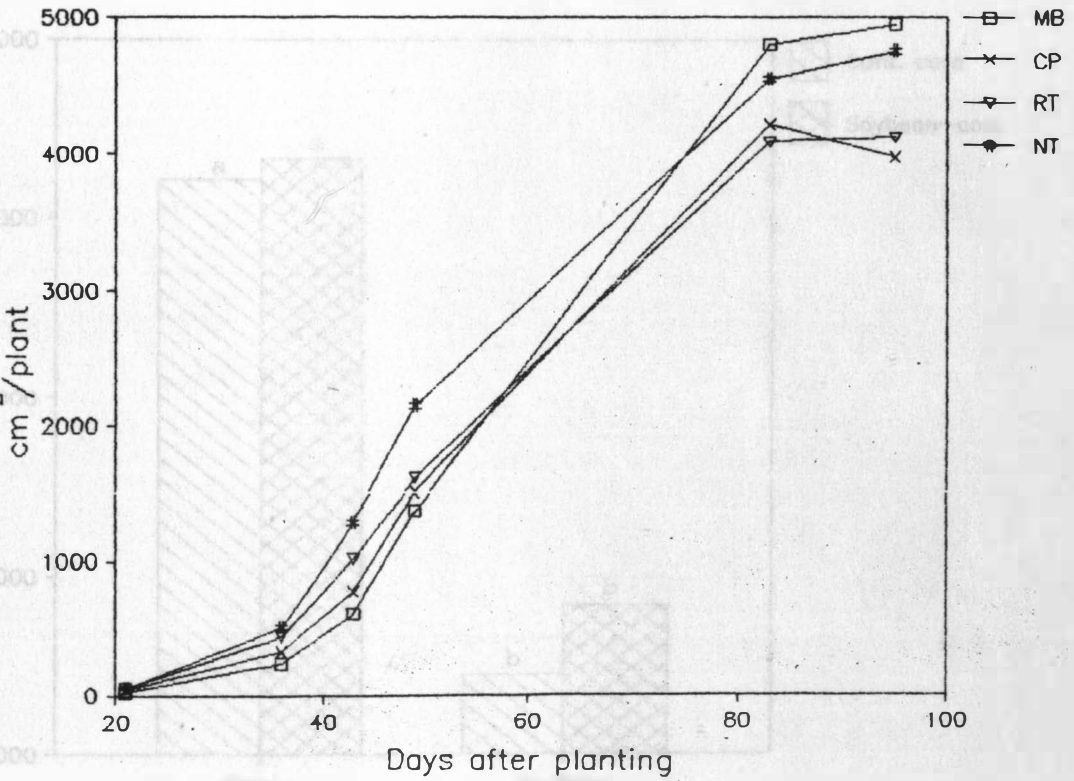
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 19 Corn leaf area under different tillage treatments of Worthing soil during 1986 growing season.



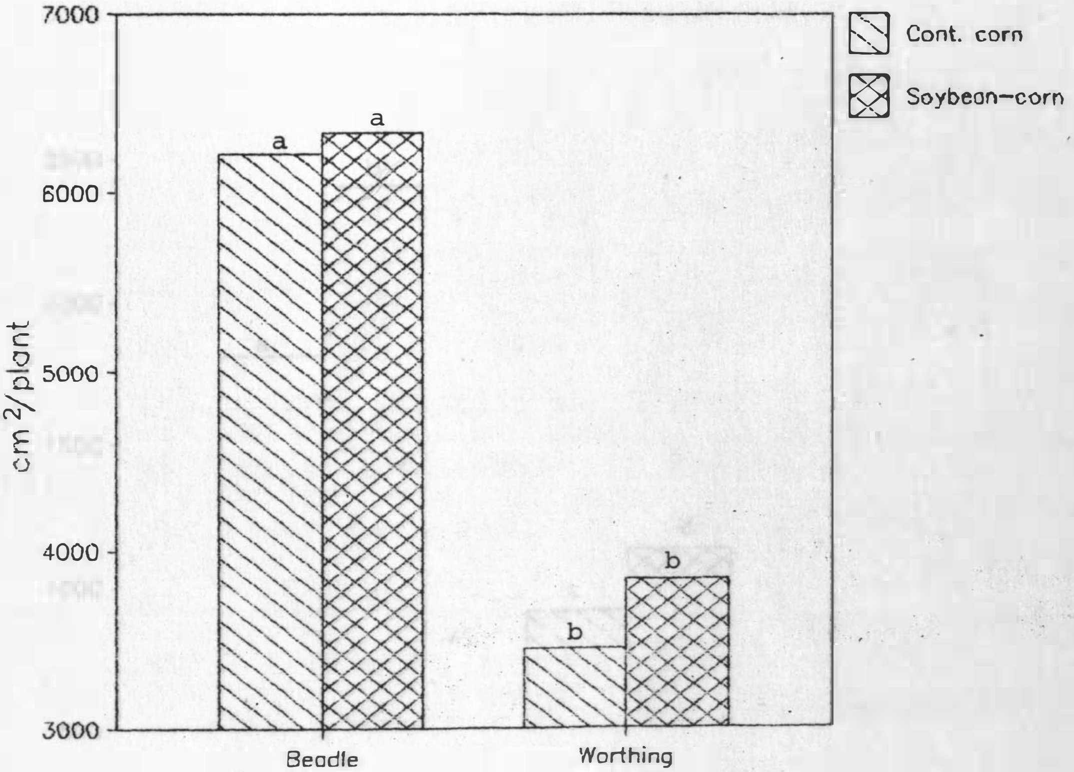
MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 20 Leaf area under different tillage treatments of Beadle soil during 1987 growing season.



MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

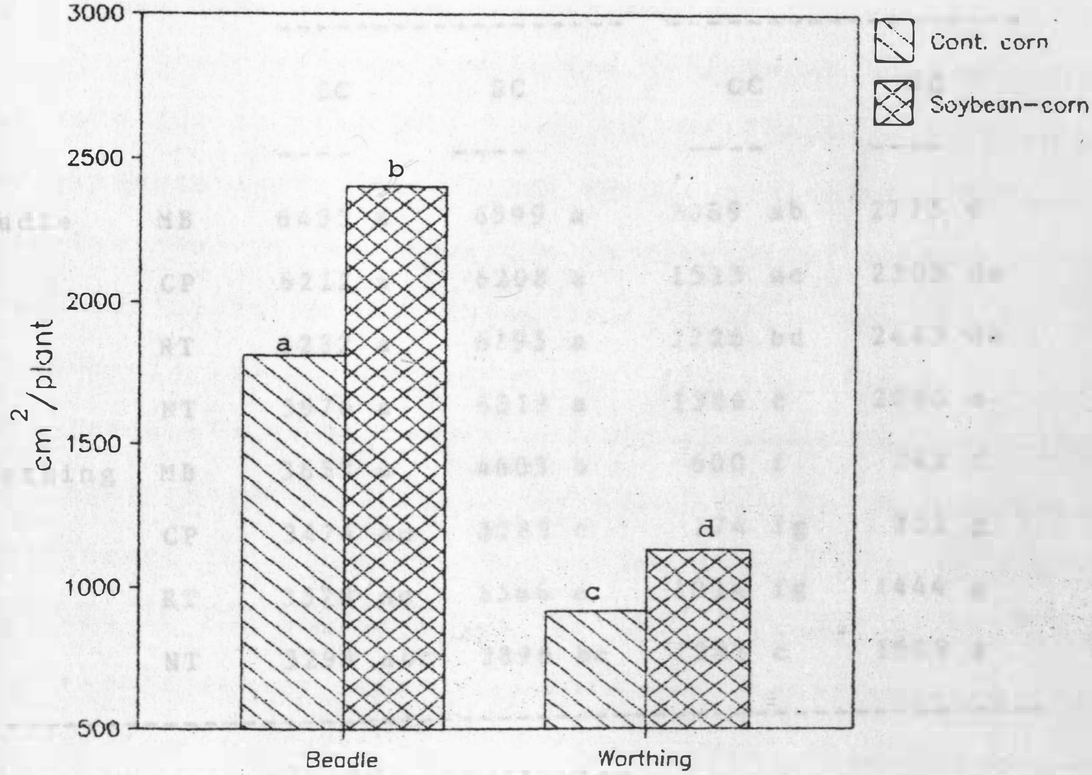
Figure 21 Corn leaf area under different tillage treatments of Worthing soil during 1987 growing season.



Means with the same letter are not significant at .05 level.

MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 22 Corn leaf area under continuous corn and soybean-corn rotation in Beadle and Worthing soils (Date 7-29-86).



Means with different letters are significantly different at .05 level.

MB - Moldboard plow
CP - Chisel plow
RT - Ridge till
NT - No till

Figure 23 Corn leaf area under continuous corn and soybean-corn rotation in Beadle and Worthing soils (Date 6-19-87).

Table 21. Corn leaf area under different tillage treatments in the Beadle and Worthing soils.

Soil	Tillage	Leaf area (cm^2 plant $^{-1}$)			
		Date- 7- 29-86		Date- 6- 19-87	
		CC	SC	CC	SC
Beadle	MB	6433 a	6599 a	2089 ab	2775 d
	CP	6212 a	6208 a	1515 ac	2305 de
	RT	6232 a	6195 a	2226 bd	2443 de
	NT	5970 a	6319 a	1386 c	2090 e
Worthing	MB	3652 a	4603 b	600 f	243 f
	CP	3474 ac	3283 c	774 fg	931 g
	RT	3378 ac	3566 c	1014 fg	1444 g
	NT	3294 abc	3898 bc	1281 c	1909 g

MB= moldboard plow CP= chisel plow

RT= ridge-till NT= no-till

Means with the same letter are not significantly different at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of 3 observations.

observed in these plots which caused more ponding of water and delayed corn development. However, in 1987, moldboard plowed plots showed a significant delay in silking (50%) and maturity (50%) compared to other tillage treatments due to the cloddy surface caused by late plowing (Table 20).

E. Grain Yield of Corn and Soybeans

There was no significant difference in grain yield of corn due to tillage systems in the first year of experimentation (1986) in the Beadle soil (Table 22). Similar results were observed in corn after soybean rotation plots in the second year (1987). However, moldboard plowed, continuous corn plots produced significantly higher grain yield than other conservation tillage systems in 1987 in the Beadle soil. No significant difference in corn yield was observed between tillage systems in the Worthing soil in 1987. Chisel plowed plots had significantly lower yield than all other tillage plots in the Worthing soil in 1986 (Table 22). This was due to reduced emergence and corn growth in these plots because of excessively wet conditions caused by ponding of water in the micro depressions. The corn after soybean plots yielded higher than continuous corn plots in both soils but they were not statistically significant except in the Worthing no-till plots in 1987 (Table 22 and 23). Better

yield performance of conservation tillage systems under corn after soybeans than under continuous corn might be due to reduced residue cover from soybeans and improved soil drying (Griffith and Mannering, 1985). Significant yield reduction (as in the Beadle soil 1987) in the conservation tillage systems compared to the moldboard plow system under continuous corn might be due to the allelopathic effect of decaying residue (Griffith and Mannering, 1985).

There was no significant difference in soybean yield among tillage systems in both Beadle and Worthing soils in 1987 (Table 24). Moldboard plowed Beadle plots produced significantly higher soybean yield than chiseled plots in 1986. However, there was no significant difference in soybean yield between the three conservation tillage systems and between moldboard plow, ridge and no-till systems. Moldboard plow and no-till treatments produced significantly higher soybean yields than chiseled plots in the Worthing soil in 1986. The lower soybean yields in these plots compared to other plots (moldboard and no-till) was due to more wetness, disease and salinity problems in some replications of these plots. The disease Phytophtora root and stem rot was quite prevalent in most of the Worthing soybean plots in both years due to wet conditions.

Table 22. Grain yield of corn under different tillage systems in the Beadle and Worthing soils.

Soil	Tillage	Yield (Mg ha^{-1})			
		1986		1987	
		CC	SC	CC	SC
Beadle	MB	9.97 a	10.37 a	10.75 a	10.42 a
	CP	9.35 a	10.56 a	9.01 b	9.86 ab
	RT	9.28 a	10.05 a	9.52 b	10.85 ab
	NT	9.59 a	9.85 a	8.89 b	10.22 a
Worthing	MB	3.35 c	3.62 c	6.66 d	7.87 d
	CP	1.76 b	1.42 b	6.93 d	8.69 d
	RT	2.63 c	3.13 c	7.27 d	6.69 d
	NT	2.04 c	3.41 c	7.49 d	7.81 d

MB= Moldboard Plow CP= Chisel plow RT= ridge-till
NT= no-till CC= continuous corn SC= corn after soybean
Within the same year and soil, means with the same letter are not significant at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of 3 observations.

Table 23. Grain yield of corn under different crop rotations in the Beadle and Worthing Soils.

Soil	Rotation	Yield (Mg ha^{-1}) 1986	1987
Beadle	CC	9.55 a	9.54 a
	SC	10.21 a	10.34 a
Worthing	CC	2.45 b	7.09 c
	SC	2.89 b	7.77 c

CC= Continuous corn SC= corn after soybeans
Means with the same letter are not significantly different at .05 level. Each mean is an average of 12 observations.

Table 24. Grain yield of soybean under different tillage systems in the Beadle and Worthing soils.

Soil	Tillage	Soybean yield ($Mg\ ha^{-1}$) 1986	1987
Beadle	MB	3.45 a	3.11 a
	CP	2.99 b	2.92 a
	RT	3.06 ab	3.16 a
	NT	3.18 ab	2.99 a
Worthing	MB	1.06 cd	1.05 c
	CP	0.30 e	0.96 c
	RT	0.67 de	1.63 c
	NT	1.42 c	1.09 c

MB= moldboard plow CP= chisel plow

RT= ridge-till NT= no-till

Within the same soil and year means with the same letter are not significant at .05 level. This designation should be used only with preplanned comparisions. Each mean is an average of 3 observations.

In all years, corn and soybean yields were significantly higher in the Beadle soil than in the Worthing soil (Tables 25 and 26). The extremely low yields in the Worthing soil in 1986 were due to ponding water in most of the plots during most of the growing season (Figures 7 and 12).

Since well drained and poorly drained soils are frequently located in the same field in eastern South Dakota, it is essential to visualize the tillage and cropping sequence effects on the average crop yield from the field as a whole. Average corn and soybean yields for a field comprised of different proportions of the Beadle and Worthing soils (85:15, 80:20 and 75:25) were calculated for different tillage treatments (Table 27). The proportion of well and poorly drained soils in eastern South Dakota was assumed to be in the above range. Moldboard plowed field produced about 12%, 8.5%, and 10% higher corn yield than chisel plow, ridge-till and no-till fields respectively under continuous corn. However, moldboard plowed fields had only about 3%, 1.3% and 3% higher yield than chisel plow, ridge-till and no-till fields respectively for corn grown after soybeans. Ridge-till under corn-soybean rotation produced higher corn yield than all other treatments except moldboard plow treatment under corn-soybean rotation. Soybean yields for

Table 25. Grain yield of corn in the Beadle and Worthing soils (averaged over different tillage systems and crop rotations).

Soil	Yield (Mg ha^{-1})		
	1985	1986	1987
Beadle	8.20 a	9.88 a	9.94 a
Worthing	7.36 c	2.67 b	7.43 c

Means with the same letter are not significantly at .05 level. Each mean is an average of 24 observations.

Table 26. Grain yield of soybean in Beadle and Worthing soils (averaged over tillage systems).

Soil	Yield (Mg ha^{-1})		
	1985	1986	1987
Beadle	2.84 a	3.15 a	3.05 a
Worthing	2.23 b	0.86 b	1.18 b

Means with the same letter are not significant at .05 level. Each mean is an average of 12 observations.

Table 27. Average corn and soybean yields (1986, 1987) under different tillage treatments in a field comprised of different proportions of Beadle and Worthing soils.

Tillage	Yield (Mg ha^{-1})								
B:W	85 : 15			80 : 20			75 : 25		
	CC	SC	CS	CC	SC	CS	CC	SC	CS
MB	9.56	9.70	2.95	9.29	9.47	2.72	9.02	9.23	2.84
CP	8.45	9.44	2.61	8.21	9.18	2.49	7.97	8.92	2.38
RT	8.73	9.62	2.82	8.51	9.34	2.72	8.29	9.07	2.62
NT	8.57	9.37	2.81	8.35	9.15	2.72	8.12	8.93	2.63

MB=moldboard plow CP=chisel plow RT=ridge-till NT=No-till

CC= continuous corn SC= corn after soybeans CS= Soybeans

B:W= ratio of Beadle to Worthing soils

chisel plow, ridge-till and no-till fields were 11-16%, 4-7% and 4-7% lower respectively than for moldboard plowed fields.

F. Economic Analysis

The production costs of corn and soybean crops under different tillage systems were tabulated (Table 54). The actual costs of fertilizer and seeds were used in the calculation. Other costs such as herbicide, insecticide, fuel and oil, machine repair and total fixed costs were adopted from Allen (1985). Gross income from the continuous corn and corn-soybean rotation plots were calculated (Table 55). Actual selling price of corn and soybeans were used for the gross income calculations. Net return (to land, labor, capital and management) was calculated by subtracting total costs from the gross income (Table 28).

Two years overall net return varied from \$168 to \$224 per hectare in the Beadle soil while there was a loss in the Worthing soil. The highest net return was obtained from the ridge-till plots under corn-soybean rotations and the lowest net return was from the chisel plow continuous corn plots of the Beadle soil. Corn-soybean rotation plots provided higher net return (\$56.0 to \$85.0) than the continuous corn plots under all tillage treatments. The

Table 28. Economics of growing continuous corn and corn-soybean in rotation under different tillage treatments of the Beadle and Worthing soils.

Tillage	Total cost		Gross income		Net return	
	-------------------------------$/ha/year-------------					
	CC	C-SB	CC	C-SB	CC	C-SB
			Beadle Soil			
MB	344.85	281.43	512.48	505.38	167.63	223.90
CP	307.68	251.67	450.92	475.41	143.24	223.70
RT	302.36	249.98	463.58	495.92	161.22	245.94
NT	296.98	248.14	452.70	472.90	155.72	223.96
			Worthing			
MB	344.85	281.43	240.92	228.13	-103.93	-53.30
CP	307.68	251.67	229.37	183.29	-78.31	-68.38
RT	302.36	249.98	257.54	214.24	-44.82	-35.74
NT	296.98	248.14	250.83	240.12	-46.15	-8.02

MB=moldboard plow CP=chisel plow RT=ridge-till NT=no-till

CC= continuous corn C-SB= corn soybean rotation

Net Return = Net return to land, labor, capital and management

loss of dollars in the Worthing soil was partially caused by the low yield of corn and soybeans in 1986 due to excessive wetness. The overall low net return in the Beadle soil even with good yields during both years was due to very low selling prices of corn and soybeans. The rotational yield for 1986 and 1987 results in a negative return because of the low yields experienced in 1986. A positive return would be possible with 1987 rotational yields. Corn-soybean plots suffer less loss than continuous corn plots under all tillage treatments of the Worthing soils. Fewer losses were observed under no-till and ridge-till systems compared to the chisel plow and moldboard plow systems in the Worthing soil.

Net return from a field comprised of different proportions of the Beadle and Worthing soils (85:15, 80:20 and 75:25) were calculated by using yield data in Table 27 (Table 29). Corn-soybean rotation plots produced higher net return (\$55 to \$73 ha^{-1}) than continuous corn plots under all three soil proportions. Ridge-till plots under corn-soybean produced the highest profit compared to all other treatments.

Table 29. Net Return from growing continuous corn and corn-soybean rotation (average of 1986 and 1987) under different tillage treatments in a field comprised of different proportions of the Beadle and Worthing soils.

Tillage	Net profit ($ ha^{-1} $year^{-1}$)					
B:W	85 : 15		80 : 20		75 : 25	
	CC	C-SB	CC	C-SB	CC	C-SB
MB	126.91	187.37	113.33	168.50	99.75	154.64
CP	110.08	179.95	99.00	165.35	87.92	150.74
RT	130.35	203.76	120.05	189.67	109.75	175.59
NT	125.44	189.83	115.36	178.19	105.25	166.55

MB=moldboard plow CP=chisel plow RT=ridge-till NT=No-till

CC= continuous corn C-SB= corn soybean rotation

B:W= ratio of Beadle to Worthing soils

SUMMARY AND CONCLUSIONS

The effects of tillage systems, well and poorly drained soils and cropping sequence on soil properties and crop development-grain yield were investigated over a two year period in Lake County, South Dakota. Two soils included in this study were Beadle and Worthing series. Beadle and Worthing soils differ in their properties because of their position in the landscape. The Beadle is a well drained soil in the upland position that contains 39% clay in the sub-soil and is calcareous below a depth of 0.52 m. It has medium to low permeability. The Worthing soil on the other hand, is a poorly drained soil in the footslope position that contains greater than 40% clay in all horizons with low to very low permeability.

The surface horizon of the Worthing soil contained significantly lower hydraulic conductivity (K-sat) and a significantly higher volumetric moisture (46.6% vs 30.7%), soil pH, available phosphorus and potassium than the Beadle soil. The Worthing soil also had significantly higher surface electrical conductivity values than the Beadle soil which varied from year to year depending on the depth to water table. Higher water tables resulted in higher surface electrical conductivity values.

Corn and soybean emergence and corn growth (as indicated by leaf area) were significantly reduced

(delayed) in the Worthing soil compared to the Beadle soil because of the poorly drained conditions in the Worthing soil. Significantly lower corn and soybean yields were obtained from the Worthing soil compared to the Beadle soil.

Ridge-till and no-till treatments produced different physical properties than the moldboard and chisel plow treatments in the Beadle soil (comparing discriminant functions in Table 8). However, there few differences in the physical properties of the Worthing soil which could be attributed to the tillage systems.

Surface residue cover increased as tillage intensity decreased. Chiseled, ridged and no-till plots contained about 5, 7 and 8 times respectively higher surface residue cover than moldboard plowed plots. The difference in surface residue cover is well reflected in surface water storage and surface soil temperature in the Beadle soil. Surface volumetric water in the Beadle soil increased as tillage intensity decreased with the highest water in the no-till and the lowest in the moldboard plowed plots. Surface water storage in both soils at silking was ranked as no-till=ridge-till> chisel plow> moldboard plow in 1987. Surface water storage in the Beadle soil at silking was in the order of ridge-till> chisel plow> no-till> moldboard plow in 1986. No significant difference

in water use (ET) was observed between tillage treatments in both Beadle and Worthing soils.

Surface soil temperature was the lowest in ridge and no-till, slightly higher for the chisel plow, and the highest for the moldboard plow Beadle plots. No significant difference in soil temperature was observed in Worthing soil due to tillage treatments.

In both years, surface bulk density increased as tillage intensity decreased. In-row surface hydraulic conductivity (K-sat) was significantly higher for the moldboard and chisel plow plots than ridge-till and no-till Beadle plots in 1986. Hydraulic conductivity for the no-till and ridge-till Beadle plots increased in the second year, possibly due to the formation of continuous root and worm channels.

Few differences in soil chemical properties due to tillage systems were found within these soil. However, ridge-till and no-till systems significantly acidified the Beadle soil surface compared to moldboard plow and chisel plow systems. No-till Beadle plots showed a 15% increase in the surface (0-0.15 m) organic matter compared to the conventional plots. Ridging in the poorly drained Worthing plots significantly increased surface (0-0.15 m) and sub-soil (0.15-0.60) nitrate levels compared to chiseling and no-till treatments possibly due to improved aeration

and enhancement of the nitrification process in the ridge. Ridge and no-till plots had higher available P levels than moldboard plowed plots in both soils. No-till Worthing plots contained significantly higher available P levels than the conventional plots. A similar trend was observed for available K in the Beadle soil.

No significant difference in corn development (emergence, leaf area, silking and maturity dates) and grain yield was observed in either soil in 1986 due to tillage treatments. There was no significant difference in corn emergence due to tillage in the Beadle soil in 1987. Moldboard plowed Beadle plots had significantly higher leaf area than other tillage treatments for most of the growing period and produced a significantly higher yield under the continuous corn rotation. However, no significant difference in corn yield was observed due to tillage under corn after soybeans. Ridge-till Beadle plots under the soybean-corn rotation produced higher corn yields than other treatments (except moldboard plowed plots under soybean-corn rotation). No significant decrease in crop emergence or grain yield was observed solely due to conservation tillage systems in the poorly drained Worthing soil. Delayed plowing of the Worthing conventional plots in 1987 caused a cloddy surface which may have delayed corn growth, silking and maturity compared to other tillage

treatments. This indicates that after a wet year such as 1986, timely moldboard plowing could be a major problem in a poorly drained soil such as Worthing. Conversely a significant delay in soybean emergence of moldboard plowed Beadle plots may be due to the low soil moisture of these plots compared to other tillage plots in 1987.

Corn after soybean plots in general produced higher leaf area and higher corn yield than continuous corn plots. The leaf area was significantly higher for corn after soybeans than continuous corn only under no-till treatment in both soils in 1987. Corn after soybean yield was also significantly higher than continuous corn yield only under no-till in the Beadle soil in 1987.

As mentioned earlier, all conservation tillage systems (especially ridge-till and no-till) stored higher moisture than the conventional tillage in the surface layer of a well drained soil. Since both 1986 and 1987 were relatively wet years, the advantage of moisture conservation was not reflected in grain yields. However, greater amounts of soil moisture conserved under ridge-till or no-till systems could be advantageous during dry years. The assumed disadvantages of the no-till and ridge-till systems for poorly drained soils should have been maximized during the wet years of 1986 and 1987. However, these systems performed as well or better on the Worthing soil

indicating that ridge or no-till systems could be considered for use in comparable landscapes. Conservation tillage systems also have other additional advantages such as erosion control.

Economic analysis showed a positive net return (to land, labor, capital and management) in the Beadle soil and loss in the Worthing soil. The corn-soybean rotation produced higher net return than the continuous corn under all tillage treatments. Ridge-till plots under corn-soybean rotation produced the highest net return of all other treatment combinations in the Beadle soil. The loss was the lowest in the no-till plots of the Worthing soil under corn-soybean rotation.

Estimated corn yields for a field comprised of different proportions of the Beadle and Worthing soils (85:15, 80:20, 75:25) was higher for ridge-till corn-soybean rotation plots than for all other plots except moldboard plow plots with corn-soybean rotation. The net return from such fields was also the highest for the ridge-till plots under corn-soybean rotation.

Therefore, if I have to choose only one tillage method for both poorly drained and well drained soils located in the same field as in this research site, my choice from two years experience with this project would be a ridge-till with corn-soybean rotation. However, there is

a need for longer term tillage research to better describe soil physical and soil chemical steady states of these systems. This study indicates that some changes in the soil properties are occurring due to tillage systems in a relatively short time period. Many of these are unlikely to be at a steady state after two years of treatment. The major relative effects of the tillage systems on the productivity of the different soils in the landscape systems however, are probably reflected in the current data.

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APPENDIX A
PEDON DESCRIPTION

Appendix A Pedon Description

Pedon 1 - Beadle Tillage site.

Ap 0-22 cm; very dark gray (10YR 3/1) moist and very dark grayish brown (10YR 3/2) dry silty clay loam, moderate fine granular structure; friable; common fine roots; abrupt and smooth boundary.

Bt 22-52 cm; very dark grayish brown (10YR 3/2) moist and dark grayish brown (10YR 4/2) dry silty clay loam; weak medium prismatic structure parting to moderate medium sub-angular blocky structure; firm; common fine roots; clear and wavy boundary.

Bk1 52-83 cm; olive brown (2.5Y 4/4) moist and brown (10YR 5/3) dry silty clay loam; weak medium prismatic structure parting to moderate medium sub-angular blocky structure; firm; few fine dark yellowish (10YR 4/4) mottles; common and medium accumulations of calcium carbonate; strong effervescent; mildly alkaline; clear and wavy boundary.

Bk2 83-113 cm; grayish brown (2.5Y 5/2) moist and pale brown (10YR 6/3) dry loam; week medium prismatic structure parting to moderate medium sub-angular blocky structure; friable; common medium strong brown (7.5YR 4/6) mottles; common fine accumulation of calcium carbonates; strong effervescent; mildly alkaline; abrupt and wavy boundary.

C 113-130 cm; grayish brown (2.5Y 5/2) moist and light brownish gray (2.5Y 6/2) dry; and dark yellowish brown (10YR 4/4) moist and yellowish brown (10YR 5/4) dry very fine sandy loam; structureless massive; friable; strongly effervescent; mildly alkaline.

Described by: B.R. Khakural.

Date: 9-25- 1986.

Pedon 2 - Worthing tillage site

Ap 0-18 cm; black (10 YR 2/1) moist and very dark gray (10YR 3/1) dry silty clay; moderate fine granular and moderate medium sub-angular blocky structure; firm; common fine roots; abrupt and smooth boundary; common white crust on pit faces when dry.

Bt1 18-40 cm; black (10YR 2/1) moist and very dark gray (10YR 3/1) dry silty clay; moderate medium prismatic breaking to strong medium sub-angular blocky and moderate medium fine angular blocky structure; very firm; continuous black pressure faces on all ped faces; few fine roots; clear and wavy boundary; common white crust on pit faces when dry.

Bt2 40-55 cm; Black (10 YR 2/1) moist and very dark gray (10YR 3/1) dry silty clay; moderate medium prismatic structure breaking to moderate medium sub-angular blocky and moderate fine angular blocky structure; very firm; continuous black pressure faces on all ped faces; few fine roots; clear and wavy boundary; many white crust on ped faces when dry.

Bt3 55-81 cm; Black (10YR 2/1) moist and very dark gray (10YR 3/1) dry silty clay; weak medium prismatic structure parting to moderate medium sub-angular blocky structure; very firm; continuous black

pressure faces on all ped faces; clear and wavy boundary; many white crust on pit faces when dry.

Bt4 81-105 cm; black (10YR 2/1) moist and dark gray (10YR 4/1) dry silty clay; weak medium prismatic parting to moderate medium sub-angular blocky structure; very firm; continuous black pressure faces on all ped faces; clear and wavy boundary; many white crust on pit faces up to 90 cm when dry.

Bt5 105- 130 cm; very dark gray (10 YR 3/1) moist and dark gray (10YR 4/1) dry silty clay; weak medium prismatic parting to moderate medium sub-angular blocky structure; very firm; continuous black pressure faces on all ped faces.

Described by- B.R. Khakural

Date-8-4-1988.

APPENDIX B

RESIDUE COVER, SOIL MOISTURE AND SOIL TEMPERATURE

Table 30. Percent residue cover under different tillage systems of the Beadle and Worthing soils.

Soil	Tillage	Percent residue cover CC	SC	CS
		1986		
Beadle	MB	7.7 a	3.3 a	6.3 a
	CP	41.0 b	21.7 c	39.0 b
	RT	34.7 b	22.7 bc	68.0 de
	NT	53.0 c	37.3 d	60.3 e
Worthing	MB	6.0 a	3.0 a	6.0 a
	CP	34.7 b	14.7 d	38.3 be
	RT	50.3 c	23.3 d	51.0 c
	NT	48.0 c	20 0 d	48.0 ce
		1987		
Beadle	MB	14.7 a	5.3 a	13.7 a
	CP	56.0 b	16.3 a	53.7 b
	RT	65.3 b	50.0 c	57.3 bc
	NT	81.3 d	51.3 c	85.7 d
Worthing	MB	6.0 a	3.5 a	4.5 a
	CP	22.7 b	10.0 ab	12.3 a
	RT	24.7 bc	20.0 bc	22.7 b
	NT	35.7 c	31.3 c	38.7 c

MB-moldboard plow CP- Chisel plow RT-ridge till NT-no-till
CC- continuous corn SC- corn after soybeams CS- soybeans
Within a soil and a year means with the same letter are not significantly different at .05 level.

Table 31. Moisture storage under different tillage treatments of the Beadle soil during 1986 growing season.

Date	Horizon	Depth (m)	Water storage (mm)			
			MB	CP	RT	NT
5-21	Ap	0-0.22	70.09	72.65	71.20	82.97
	Bt	0.22-0.52	110.35	91.34	104.07	117.46
	Bk1	0.52-0.83	117.96	103.58	112.47	121.77
	Bk2	0.83-1.13	110.40	104.52	116.10	118.83
	C	1.13-1.35	80.96	76.65	85.14	87.14
	Total		498.76	448.74	488.98	528.17
6-17	Ap	0-0.22	82.92	86.26	86.91	85.63
	Bt	0.22-0.52	123.78	113.49	121.17	119.11
	Bk1	0.52-0.83	133.17	123.05	134.65	131.46
	Bk2	0.83-1.13	135.14	126.76	129.75	131.29
	C	1.13-1.35	96.43	90.86	94.64	98.08
	Total		571.44	540.24	567.12	565.57
6-25	Ap	0-0.22	85.92	89.37	92.33	89.74
	Bt	0.22-0.52	129.03	119.32	126.12	125.33
	Bk1	0.52-0.83	136.96	130.27	136.11	137.84
	Bk2	0.83-1.13	136.66	131.60	130.38	134.82
	C	1.13-1.35	97.17	94.56	94.37	98.96
	Total		585.74	565.12	579.41	586.69
7-8	Ap	0-0.22	77.76	80.20	83.84	77.64
	Bt	0.22-0.52	123.55	113.06	119.95	116.83
	Bk1	0.52-0.83	133.55	123.30	133.54	131.25
	Bk2	0.83-1.13	134.83	127.32	129.13	131.93
	C	1.13-1.35	96.87	94.07	94.73	99.20
	Total		566.56	537.95	561.19	556.85
7-22	Ap	0-0.22	69.30	74.85	78.23	69.19
	Bt	0.22-0.52	111.86	107.04	110.14	107.60
	Bk1	0.52-0.83	125.66	120.68	129.24	124.15
	Bk2	0.83-1.13	130.33	124.78	127.9	126.00
	C	1.13-1.35	97.17	93.28	93.28	97.86
	Total		534.32	520.63	538.79	524.80

Table 31 (continued)

8-4	Ap	0-0.22	68.42	74.16	75.78	72.72
	Bt	0.22-0.52	105.94	102.04	104.52	106.28
	Bk1	0.52-0.83	121.79	115.46	124.78	119.25
	Bk2	0.83-1.13	126.12	120.24	125.41	116.62
	C	1.13-1.35	93.54	91.61	92.86	93.04
	Total		515.81	503.51	523.35	507.91
8-21	Ap	0-0.22	78.01	75.90	75.10	82.37
	Bt	0.22-0.52	102.18	97.37	98.98	102.44
	Bk1	0.52-0.83	116.90	116.13	120.63	113.91
	Bk2	0.83-1.13	119.14	117.37	122.53	106.38
	C	1.13-1.35	89.69	89.54	91.63	83.73
	Total		505.92	496.31	508.87	488.83
9-2	Ap	0-0.22	73.43	76.91	75.30	77.46
	Bt	0.22-0.52	99.31	97.41	99.62	98.75
	Bk1	0.52-0.83	117.46	112.70	118.32	117.33
	Bk2	0.83-1.13	118.94	117.36	119.32	117.17
	C	1.13-1.35	92.38	84.92	89.28	87.58
	Total		501.52	489.30	501.84	498.29

MB-moldboard plow CP-Chisel plow RT-Ridge till NT-No-till

Table 32. Moisture storage under different tillage treatments of the Worthing soil during 1986 growing season.

Date	Horizon	Depth (m)	Water storage (mm) MB	CP	RT	NT
5-21	Ap	0-0.18	84.37	87.32	84.13	84.31
	Bt1	0.18-0.40	105.26	109.45	102.43	104.17
	Bt2	0.40-0.55	73.53	76.86	69.51	71.94
	Bt3	0.55-0.81	130.07	131.81	122.59	119.78
	Bt4	0.81-1.05	123.56	119.88	115.8	104.38
	Bt5	1.05-1.35	154.20	149.85	144.75	130.74
	Total		670.79	675.17	639.21	615.05
6-17	Ap	0-0.18	91.73	88.97	87.55	90.86
	Bt1	0.18-0.40	111.45	113.53	111.89	118.81
	Bt2	0.40-0.55	74.18	75.71	75.54	76.76
	Bt3	0.55-0.81	125.68	126.83	127.19	125.02
	Bt4	0.81-1.05	112.27	111.96	111.34	110.21
	Bt5	1.05-1.35	136.67	139.67	137.66	131.99
	Total		651.98	656.67	651.52	653.65
6-24	Ap	0-0.18	93.47	90.38	90.40	91.89
	Bt1	0.18-0.40	115.90	114.13	112.58	118.63
	Bt2	0.40-0.55	76.18	75.66	75.12	76.81
	Bt3	0.55-0.81	126.91	126.56	126.57	125.44
	Bt4	0.81-1.05	111.14	112.03	111.91	109.92
	Bt5	1.05-1.35	136.63	139.28	137.48	132.05
	Total		660.23	658.04	654.06	654.74
7-8	Ap	0-0.18	87.70	86.90	89.44	90.61
	Bt1	0.18-0.40	112.57	112.91	111.63	116.80
	Bt2	0.40-0.55	75.14	75.54	74.69	76.18
	Bt3	0.55-0.81	125.75	126.55	126.15	125.03
	Bt4	0.81-1.05	110.78	112.32	112.01	109.15
	Bt5	1.05-1.35	137.39	140.06	137.35	131.06
	Total		649.33	654.28	651.27	648.83

Table 32. (continued)

7-22	Ap	0-0.18	92.00	90.05	88.78	89.98
	Bt1	0.18-0.40	113.04	113.08	110.85	115.13
	Bt2	0.40-0.55	74.85	75.11	74.56	75.27
	Bt3	0.55-0.81	125.93	125.93	126.38	123.82
	Bt4	0.81-1.05	111.96	111.36	112.3	107.57
	Bt5	1.05-1.35	138.05	140.77	138.13	132.47
	Total		655.83	656.30	651.00	644.24
8-4	Ap	0-0.18	92.41	90.45	88.36	92.11
	Bt1	0.18-0.40	112.15	112.93	110.72	113.58
	Bt2	0.40-0.55	74.49	75.04	74.15	74.60
	Bt3	0.55-0.81	125.72	125.91	125.25	124.22
	Bt4	0.81-1.05	111.05	111.07	111.43	108.58
	Bt5	1.05-1.35	137.10	140.46	137.33	130.82
	Total		652.92	655.86	647.24	643.91
8-21	Ap	0-0.18	92.65	91.75	87.5	88.78
	Bt1	0.18-0.40	113.27	113.05	108.85	111.48
	Bt2	0.40-0.55	74.40	74.80	73.30	74.00
	Bt3	0.55-0.81	124.58	125.67	124.46	123.59
	Bt4	0.81-1.05	110.71	111.16	110.64	107.59
	Bt5	1.05-1.35	136.63	140.42	136.2	131.13
	Total		652.24	656.85	640.95	636.57
9-2	Ap	0-0.18	92.81	91.21	86.26	89.91
	Bt1	0.18-0.40	112.51	113.62	108.57	113.05
	Bt2	0.40-0.55	74.67	75.53	73.80	73.84
	Bt3	0.55-0.81	126.00	126.75	125.39	122.66
	Bt4	0.81-1.05	111.36	111.43	109.75	109.97
	Bt5	1.05-1.35	135.78	137.39	134.87	130.82
	Total		653.13	655.93	638.64	640.25

MB-moldboard plow CP-chisel plow RT-ridge till NT- no-till

Table 33. Moisture storage under different tillage treatments of the Beadle Soil during 1987 growing s season.

Date	Horizon	Depth (m)	MB	CP	RT	NT
			Moisture storage (mm)			
5-6	Ap	0-0.22	59.03	63.18	62.06	67.43
	Bt	0.22-0.52	84.93	78.04	89.40	95.85
	Bk1	0.52-0.83	102.50	89.98	101.85	101.25
	Bk2	0.83-1.13	109.05	107.31	110.55	104.40
	C	1.13-1.50	134.50	132.35	136.35	128.76
	Total		490.01	470.86	500.21	497.69
5-20	Ap	0-0.22	74.21	83.41	87.65	85.77
	Bt	0.22-0.52	113.25	112.32	116.48	113.73
	Bk1	0.52-0.83	121.49	115.56	115.82	116.07
	Bk2	0.83-1.13	119.41	116.11	122.19	109.78
	C	1.13-1.50	88.41	81.45	93.13	79.99
	Total		516.79	508.86	535.30	505.36
5-28	Ap	0-0.22	84.18	88.19	90.97	90.50
	Bt	0.22-0.52	119.74	116.72	120.13	119.01
	Bk1	0.52-0.83	124.66	119.22	119.83	122.57
	Bk2	0.83-1.13	121.86	119.91	125.05	113.54
	C	1.13-1.50	89.79	85.54	94.87	84.13
	Total		540.25	529.58	550.87	529.76
6-4	Ap	0-0.22	78.81	83.93	88.60	86.59
	Bt	0.22-0.52	116.38	115.04	118.44	117.05
	Bk1	0.52-0.83	123.55	118.61	118.68	119.59
	Bk2	0.83-1.13	121.79	119.01	124.65	112.37
	C	1.13-1.50	90.35	82.70	94.68	80.76
	Total		530.89	519.29	545.06	516.37
6-11	Ap	0-0.22	84.17	86.26	89.88	91.60
	Bt	0.22-0.52	118.02	111.58	118.03	119.07
	Bk1	0.52-0.83	123.32	112.66	117.63	119.34
	Bk2	0.83-1.13	121.51	114.33	123.35	111.13
	C	1.13-1.50	89.48	79.32	93.80	82.69
	Total		536.50	504.14	542.69	523.84

Table 33. (continued)

6-19	Ap	0-0.22	68.94	74.06	84.13	76.06
	Bt	0.22-0.52	109.06	106.37	115.31	111.10
	Bk1	0.52-0.83	120.09	111.51	116.29	116.69
	Bk2	0.83-1.13	120.10	113.40	119.83	109.57
	C	1.13-1.50	89.07	78.86	93.17	79.17
	Total		507.26	484.21	528.73	492.60
6-29	Ap	0-0.22	62.94	61.30	75.02	67.19
	Bt	0.22-0.52	98.96	93.25	107.81	103.03
	Bk1	0.52-0.83	115.37	106.32	111.91	113.39
	Bk2	0.83-1.13	117.57	110.58	120.17	107.47
	C	1.13-1.50	87.37	75.87	92.58	78.33
	Total		482.22	447.34	507.49	469.41
7-9	Ap	0-0.22	76.01	79.19	77.44	82.31
	Bt	0.22-0.52	101.48	96.59	95.95	108.62
	Bk1	0.52-0.83	113.56	102.90	109.52	112.97
	Bk2	0.83-1.13	116.89	108.82	118.88	105.64
	C	1.13-1.50	86.62	97.39	92.24	75.93
	Total		494.58	484.89	494.03	485.48
7-23	Ap	0-0.22	71.78	70.17	78.06	71.06
	Bt	0.22-0.52	109.91	97.06	108.73	101.03
	Bk1	0.52-0.83	115.67	104.95	112.05	110.71
	Bk2	0.83-1.13	118.58	111.36	112.42	111.24
	C	1.13-1.50	86.99	80.48	89.03	81.68
	Total		502.93	464.03	500.30	475.72
7-31	Ap	0-0.22	60.93	55.55	65.74	57.57
	Bt	0.22-0.52	92.36	77.40	97.06	87.13
	Bk1	0.52-0.83	109.80	96.61	105.44	106.37
	Bk2	0.83-1.13	122.62	105.79	118.00	103.24
	C	1.13-1.50	87.82	72.65	91.56	82.71
	Total		473.53	408.00	477.80	437.03
8-13	Ap	0-0.22	63.92	54.10	61.67	60.26
	Bt	0.22-0.52	90.75	70.77	87.93	80.90
	Bk1	0.52-0.83	107.03	87.37	96.12	101.07
	Bk2	0.83-1.13	114.09	102.20	116.55	99.32
	C	1.13-1.50	79.41	71.56	92.29	73.01
	Total		455.19	386.00	454.57	414.57

Table 33. (continued)

8-21	Ap	0-0.22	58.38	53.97	61.49	60.53
	Bt	0.22-0.52	87.36	70.03	82.75	80.49
	Bk1	0.52-0.83	104.46	82.75	90.56	98.58
	Bk2	0.83-1.13	112.01	104.19	112.30	97.22
	C	1.13-1.50	82.49	71.69	90.57	71.56
	Total		444.71	382.63	437.68	408.39
9-3	Ap	0-0.22	57.18	51.85	59.42	56.52
	Bt	0.22-0.52	85.15	67.59	79.27	77.14
	Bk1	0.52-0.83	97.92	75.83	85.00	93.41
	Bk2	0.83-1.13	108.27	92.52	109.81	92.88
	C	1.13-1.50	80.58	67.63	89.76	69.19
	Total		429.1	355.42	423.26	389.13

MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till

Table 34. Moisture storage under different tillage treatments of the Worthing soil during 1987 growing season.

Date	Horizon	Depth (m)	Moisture storage (mm)			
			MB	CP	RT	NT
5-6	Ap	0-0.18	69.06	66.55	66.58	70.56
	Bt1	0.18-0.40	91.91	87.82	88.22	90.34
	Bt2	0.40-0.55	68.87	65.28	65.93	64.95
	Bt3	0.55-0.81	119.19	115.75	113.28	110.93
	Bt4	0.81-1.05	109.80	110.11	103.32	100.32
	Bt5	1.05-1.50	205.88	206.46	193.73	188.10
	Total		664.71	651.97	631.06	625.20
5-20	Ap	0-0.18	72.07	83.66	84.46	82.67
	Bt1	0.18-0.40	97.21	104.37	103.96	99.92
	Bt2	0.40-0.55	73.74	72.89	71.49	67.22
	Bt3	0.55-0.81	127.69	126.82	124.08	120.27
	Bt4	0.81-1.05	115.02	115.38	112.09	109.93
	Bt5	1.05-1.50	209.34	211.26	209.69	202.47
	Total		695.07	714.37	705.75	682.48
5-27	Ap	0-0.18	79.60	88.36	87.46	85.98
	Bt1	0.18-0.40	103.35	111.29	107.73	104.24
	Bt2	0.40-0.55	75.44	78.59	74.15	70.38
	Bt3	0.55-0.81	130.45	132.42	128.29	124.32
	Bt4	0.81-1.05	117.22	118.02	114.96	112.69
	Bt5	1.05-1.50	211.60	213.63	213.06	207.07
	Total		717.65	742.30	725.64	704.69
6-3	Ap	0-0.18	78.63	85.86	85.24	84.32
	Bt1	0.18-0.40	102.58	107.43	105.59	101.46
	Bt2	0.40-0.55	75.25	75.29	73.14	67.88
	Bt3	0.55-0.81	130.42	130.37	126.64	123.27
	Bt4	0.81-1.05	117.21	117.39	113.88	111.89
	Bt5	1.05-1.50	210.33	213.44	212.77	205.06
	Total		714.41	729.77	717.26	693.88
6-11	Ap	0-0.18	81.68	88.10	87.61	86.33
	Bt1	0.18-0.40	105.19	111.13	107.62	104.31
	Bt2	0.40-0.55	76.11	78.59	73.82	70.13
	Bt3	0.55-0.81	130.68	133.23	127.05	124.11
	Bt4	0.81-1.05	116.75	118.18	114.18	112.14
	Bt5	1.05-1.50	211.83	213.50	212.80	205.41
	Total		722.22	742.72	723.08	702.43

Table 34. (continued)

6-18	Ap	0-0.18	75.96	83.48	84.43	78.91
	Bt1	0.18-0.40	100.85	105.78	104.95	98.84
	Bt2	0.40-0.55	75.32	75.18	73.00	69.35
	Bt3	0.55-0.81	129.78	129.58	124.54	123.07
	Bt4	0.81-1.05	116.08	116.40	112.68	111.40
	Bt5	1.05-1.50	210.69	212.19	210.67	204.83
	Total		708.68	722.61	710.27	686.39
6-29	Ap	0-0.18	73.08	80.57	82.63	76.68
	Bt1	0.18-0.40	98.23	103.24	102.65	96.19
	Bt2	0.40-0.55	74.26	74.29	71.35	67.61
	Bt3	0.55-0.81	127.31	127.12	122.68	120.30
	Bt4	0.81-1.05	115.00	114.99	111.89	109.66
	Bt5	1.05-1.50	209.59	210.48	210.31	203.30
	Total		697.47	710.68	701.50	673.73
7-8	Ap	0-0.18	78.79	83.94	87.06	80.47
	Bt1	0.18-0.40	102.67	105.49	105.73	99.00
	Bt2	0.40-0.55	75.23	74.30	71.54	68.04
	Bt3	0.55-0.81	128.50	128.79	123.31	121.15
	Bt4	0.81-1.05	115.23	115.85	112.16	110.13
	Bt5	1.05-1.50	212.14	212.39	213.14	202.72
	Total		712.55	720.76	712.93	681.51
7-24	Ap	0-0.18	80.33	89.89	84.94	82.95
	Bt1	0.18-0.40	104.41	111.23	105.32	102.40
	Bt2	0.40-0.55	76.29	76.95	73.05	70.66
	Bt3	0.55-0.81	129.95	129.30	124.88	121.14
	Bt4	0.81-1.05	115.46	115.12	112.32	109.61
	Bt5	1.05-1.50	208.38	208.70	209.02	202.28
	Total		714.80	731.19	709.53	689.03
7-30	Ap	0-0.18	67.28	79.44	79.64	76.12
	Bt1	0.18-0.40	93.89	102.44	100.28	96.07
	Bt2	0.40-0.55	73.56	74.22	70.78	68.00
	Bt3	0.55-0.81	126.26	126.66	122.03	120.50
	Bt4	0.81-1.05	113.48	114.39	110.92	108.90
	Bt5	1.05-1.50	205.94	208.89	207.79	200.64
	Total		680.40	706.03	691.44	670.23

Table 34. (continued)

8-13	Ap	0-0.18	65.23	79.96	73.46	75.52
	Bt1	0.18-0.40	92.69	102.11	95.68	95.16
	Bt2	0.40-0.55	73.80	73.22	70.05	67.23
	Bt3	0.55-0.81	127.06	127.31	123.02	121.07
	Bt4	0.81-1.05	115.01	115.41	112.53	110.51
	Bt5	1.05-1.50	210.25	211.42	210.74	205.15
	Total		684.04	709.42	685.48	674.63
8-21	Ap	0-0.18	65.56	73.07	72.19	74.77
	Bt1	0.18-0.40	92.52	96.60	94.06	94.16
	Bt2	0.40-0.55	73.23	71.83	68.90	66.46
	Bt3	0.55-0.81	126.41	125.50	121.32	119.99
	Bt4	0.81-1.05	114.30	115.38	111.88	109.72
	Bt5	1.05-1.50	209.21	210.84	210.82	203.22
	Total		681.22	693.22	679.17	668.32
9-3	Ap	0-0.18	64.17	70.84	69.96	72.98
	Bt1	0.18-0.40	91.07	93.61	91.63	92.81
	Bt2	0.40-0.55	72.44	69.57	67.49	66.24
	Bt3	0.55-0.81	124.46	123.30	119.20	118.29
	Bt4	0.81-1.05	112.60	112.86	108.90	108.01
	Bt5	1.05-1.50	205.83	209.37	206.41	201.35
	Total		670.56	679.55	663.58	659.67

MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till

Table 35. Average weekly soil temperature under different tillage systems in the Beadle and Worthing soils during 1986 growing season.

WAP Soil temperature at 0.01 m depth (^{o}C)

WAP	MB			CP			RT			NT		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
						Soil-Beadle						
3	21.4	16.3	18.9	20.4	15.8	18.4	20.2	15.6	17.9	19.4	16.5	18.0
4	23.4	16.2	19.9	21.9	16.1	19.0	21.3	15.9	18.6	21.0	16.6	18.8
5	25.6	18.7	22.2	25.6	18.9	22.2	25.3	18.5	21.9	24.6	19.1	21.9
6	24.5	17.9	21.2	24.0	18.3	21.1	22.9	17.9	20.4	22.7	17.9	20.3
7	26.0	19.0	22.5	25.0	18.4	21.7	21.7	17.1	19.4	24.3	18.4	21.4
8	24.8	20.0	22.4	23.2	20.3	21.7	21.4	19.0	20.2	22.9	19.8	21.4
						Soil-Worthing						
3	21.5	15.8	18.6	21.3	16.3	18.8	21.6	15.8	18.8	22.0	16.0	19.0
4	20.6	14.8	17.7	21.6	15.9	18.7	21.4	15.6	18.5	22.1	15.8	19.0
5	25.6	18.3	21.9	25.6	20.0	22.8	25.3	18.5	21.9	25.3	19.1	22.2
6	22.9	16.9	19.9	23.7	17.3	20.5	23.6	16.3	20.0	23.7	16.9	20.3
7	24.8	18.7	21.8	25.2	18.9	22.0	25.6	18.3	21.9	26.3	18.9	22.6
8	26.1	20.4	23.2	25.7	20.3	23.0	26.3	20.3	23.3	27.0	21.0	24.0

MB- moldboard plow CP- chisel plow RT- ridgetill NT- no-till
WAP= Week after planting

Table 36. Average weekly soil temperature under different tillage systems in Beadle and Worthing soils during 1987 growing season.

WAP	Soil temperature at 0.01 m depth (° C)											
	MB			CP			RT			NT		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
	Soil-Beadle											
2	23.6	15.6	19.6	23.2	15.7	19.5	22.0	15.1	18.6	22.3	15.1	18.0
3	19.4	11.7	15.6	18.7	12.5	15.6	19.1	12.2	15.7	19.4	10.6	15.0
4	23.8	15.4	19.6	22.6	16.3	19.5	21.2	16.0	18.6	21.3	15.3	18.3
5	25.7	16.2	21.0	23.7	16.3	20.0	21.9	15.4	18.7	22.4	15.9	19.2
6	28.4	19.7	24.1	28.2	19.7	24.0	25.9	19.1	22.5	27.3	17.5	22.4
7	27.3	23.0	25.2	27.3	22.6	25.0	26.6	22.6	24.6	25.8	21.6	23.7
8	25.0	20.5	22.8	24.3	19.8	22.1	23.1	19.9	21.5	23.5	18.6	21.1
9	22.8	17.7	20.3	22.5	17.6	20.1	21.4	17.3	19.4	22.0	17.2	19.6
10	24.4	20.6	22.5	24.0	19.1	21.6	23.0	19.1	21.1	23.1	19.1	21.1
11	23.0	18.1	20.6	23.1	18.3	20.7	20.9	17.5	19.2	21.2	17.9	19.6
	Soil-Worthing											
2	21.0	16.1	18.6	21.9	17.1	19.5	22.5	15.7	19.1	19.3	15.8	17.6
3	18.0	12.4	15.2	18.8	12.9	15.9	16.5	13.8	15.2	15.9	11.9	13.9
4	22.1	16.8	19.5	21.9	17.4	19.7	19.3	14.5	16.9	20.1	15.8	18.0
5	23.1	17.0	20.1	23.8	18.1	21.0	23.9	15.0	19.5	23.3	17.2	20.3
6	25.1	19.4	22.3	26.5	20.7	23.6	26.6	19.1	22.9	26.0	20.3	23.2
7	25.1	21.6	23.4	26.6	23.4	25.0	27.0	23.3	25.2	27.1	23.7	25.4
8	23.5	19.9	21.7	24.3	20.8	22.6	25.1	20.3	22.7	25.1	21.5	23.3
9	22.8	19.3	21.1	23.9	20.0	22.0	22.6	18.0	20.3	21.5	18.1	19.8
10	23.9	20.3	22.1	25.0	20.6	22.8	24.9	20.1	22.5	22.6	19.4	21.0
11	22.4	19.3	20.9	21.9	19.1	20.5	23.0	19.4	21.2	20.7	18.1	19.4

MB- moldboard plow CP- chisel plow RT- ridge till NT- no-till
WAP-week after planting

Table 37. Moisture retention characteristics of the Beadle and Worthing Soils.

Soil	Horizon	θv				
MPa		0.033	0.100	0.300	0.500	1.500
Beadle	Ap	0.451	0.409	0.374	0.372	0.237
	Bt	0.391	0.375	0.253	0.203	0.193
	Bk1	0.378	0.358	0.214	0.177	0.160
	Bk2	0.351	0.335	0.194	0.151	0.141
	C	0.233	0.209	0.131	0.111	0.105
Worthing	Ap	0.450	0.420	0.406	0.394	0.284
	Bt1	0.454	0.444	0.362	0.355	0.299
	Bt2	0.457	0.434	0.376	0.363	0.270
	Bt3	0.431	0.401	0.374	0.339	0.266
	Bt4	0.433	0.426	0.381	0.322	0.252
	Bt5	0.447	0.443	0.367	0.303	0.267

APPENDIX C

SOIL CHEMICAL PROPERTIES AND TISSUE TEST RESULTS

Table 38. Tillage and cropping sequence effects on soil pH of the Beadle and Worthing soils.

Soil	Tillage	Soil pH CC	Soil pH SC	Soil pH CS	Tillage mean	Soil Mean
			1986			
Beadle	MB	7.3 ac	7.1 a	7.5 ac	7.3 b	7.2 a
	CP	7.7 ac	7.9 c	7.9 c	7.8 c	
	RT	6.7 b	6.6 b	7.0 b	6.7 a	
	NT	7.2 cd	6.8 abd	6.8 bd	7.0 a	
	Mean	7.2 a	7.1 a	7.3 a		
Worthing	MB	7.6 a	7.8 a	7.6 a	7.7 c	7.6 b
	CP	7.6 a	7.5 a	7.8 a	7.6 c	
	RT	7.4 a	7.6 a	7.5 a	7.5 c	
	NT	7.6 a	7.7 a	7.7 a	7.6 c	
	Mean	7.6 a	7.6 a	7.6 a		
			1987			
Beadle	MB	7.0 c	6.9 bc	6.5 b	6.8 a	6.8 a
	CP	7.3 ac	7.5 a	7.5 a	7.5 b	
	RT	6.4 d	6.3 d	6.2 d	6.3 c	
	NT	6.6 d	6.4 d	6.4 d	6.5 c	
	Mean	6.8 a	6.8 a	6.7 a		
Worthing	MB	7.5 a	7.5 a	7.6 a	7.5 b	7.6 b
	CP	7.7 a	7.7 a	7.4 a	7.6 b	
	RT	7.5 a	7.4 a	7.6 a	7.5 b	
	NT	7.6 a	7.5 a	7.6 a	7.5 b	
	Mean	7.6 a	7.5 a	7.5 a		

MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till
CC- continuous corn SC- corn after soybeans CS- soybean
Within a year and soil means with the same letters are not significantly different at .05 level.

Table 39. Tillage and cropping sequence effects on soil organic matter of Beadle and Worthing soils.

Soil	Tillage	%OM CC	SC	CS	Tillage mean	Soil Mean
				1986		
Beadle	MB	4.06 ac	3.77 a	4.30 c	4.04 a	4.34 a
	CP	4.27 ab	4.37 bc	4.17 bc	4.27 a	
	RT	4.23 ab	4.43 bd	4.47 bc	4.38 a	
	NT	4.67 b	4.70 b	4.63 bc	4.67 a	
	Mean	4.31 a	4.31 a	4.39 a		
Worthing	MB	4.30 a	4.40 a	4.17 a	4.29 a	4.24 a
	CP	4.27 a	4.20 a	3.93 a	4.13 a	
	RT	4.20 a	4.60 a	4.37 ac	4.39 a	
	NT	4.20 ab	3.80 b	4.47 c	4.16 a	
	Mean	4.24 a	4.25 a	4.23 a		
				1987		
Beadle	MB	3.53 ac	3.87 a	3.73 a	3.71 a	3.90 a
	CP	3.23 c	3.87 a	3.93 a	3.68 a	
	RT	4.16 b	3.70 ab	4.00 ab	3.95 a	
	NT	4.00 abd	4.46 d	4.27 ad	4.24 a	
	Mean	3.73 a	3.98 a	3.98 a		
Worthing	MB	4.43 a	4.50 a	4.33 a	4.42 a	4.19 a
	CP	4.03 a	3.97 a	4.17 a	4.05 a	
	RT	4.40 a	4.17 a	4.53 a	4.37 a	
	NT	3.93 ab	4.07 ab	3.80 b	3.93 a	
	Mean	4.20 a	4.18 a	4.20 a		

MB- moldboard plow CP- chisel plow
RT- ridge till NT- no-till
CC- continuous corn SC- corn after soybeans CS- soybeans
Within a year and soil means with the same letters are not significantly different at .05 level.

Table 40. Surface (0-.15 m) nitrate nitrogen levels in different tillage treatments of the Beadle and Worthing soils.

Soil	Tillage	$NO3^-$ (kg ha^{-1}) CC	SC	CS	Tillage mean	Soil mean
			1986			
Beadle	MB	11.43 a	9.13 a	8.57 a	9.71 a	13.18 a
	CP	11.28 a	9.13 a	15.42 a	11.62 a	
	RT	17.14 a	16.57 a	17.14 a	16.93 a	
	NT	11.43 a	15.98 a	15.42 a	14.27 a	
	Mean	12.56 a	12.72 a	14.14 a		
Worthing	MB	23.99 a	20.0 a	25.14 a	23.03 ab	22.28 a
	CP	18.29 a	17.7 a	19.42 a	18.47 a	
	RT	19.42 a	48.6 b	21.13 a	29.70 b	
	NT	17.70 a	17.7 a	18.29 a	17.89 a	
	Mean	19.84 a	26.00 a	20.99 a		
			1987			
Beadle	MB	18.29 ab	27.42 a	15.42 b	20.36 a	17.41 a
	CP	17.70 a	16.57 ab	17.14 ab	17.14 a	
	RT	17.70 a	23.43 ab	13.71 ab	18.29 a	
	NT	12.28 ab	13.71 b	17.70 b	13.90 a	
	Mean	15.99 a	20.27 a	15.99 a		
Worthing	MB	12.56 ab	17.70 a	18.29 a	16.18 ab	14.94 a
	CP	9.71 a	9.72 a	13.14 a	10.84 b	
	RT	22.28 bc	17.70 ac	33.71 b	24.56 a	
	NT	6.86 a	7.42 a	10.28 a	8.19 b	
	Mean	12.85 a	13.14 a	18.85 b		

MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till CC- continuous corn SC- corn after soybeans CS- soybeans Within a year and soil means with the same letter are not significantly different at .05 level.

Table 41. Subsoil (.15-.60 m) nitrate N levels under different tillage treatments of the Beadle and Worthing soils.

Soil	Tillage	$NO3^{-}$ N (kg ha^{-1}) CC	SC	CS	Tillage mean	Soil mean
		1986				
Beadle	MB	8.86 ac	5.71 ac	3.99 c	9.71 a	6.65
	CP	6.29 a	8.00 a	8.00 a	11.62 a	
	RT	7.42 a	12.00 b	5.71 ac	16.93 a	
	NT	4.58 a	6.86 a	4.58 ac	14.27 a	
	Mean	6.27 a	7.28 b	5.57 a		
Worthing	**					
		1987				
Beadle	MB	9.72 ab	13.71 a	9.13 b	10.85 a	8.36
	CP	12.00 a	6.86 b	7.42 b	8.76 a	
	RT	7.42 b	6.86 b	6.29 b	6.86 a	
	NT	5.71 b	7.42 b	6.86 b	7.04 a	
	Mean	8.71 a	8.00 a	7.71 a		
Worthing	MB	6.86 a	8.00 a	7.42 a	7.42 a	8.28
	CP	4.58 a	6.86 a	8.00 a	6.47 a	
	RT	13.14 b	9.72 ab	13.71 b	12.18 b	
	NT	6.29 a	7.42 a	7.42 a	7.04 a	
	Mean	7.71 a	8.00 a	9.13 a		

MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till CC- continuous corn SC- corn after soybeans CS- soybeans Within a year and soil means with the same letters are not significantly different at .05 level.

** Worthing soil was extreemly wet in fall of 1986 and no subsoil samples were taken.

Table 42. Tillage and cropping sequence effects on soil available phosphorus in the Beadle and Worthing soils.

Soil	Tillage	P ($kg\ ha^{-1}$) CC	SC	CS	Tillage mean	Soil mean
			1986			
Beadle	MB	17.14 a	19.42 a	15.99 a	17.51 a	17.46 a
	CP	13.20 a	15.99 a	13.71 a	14.28 a	
	RT	22.84 a	15.99 a	15.99 a	18.29 a	
	NT	18.29 a	21.13 a	20.00 a	19.81 a	
	Mean	17.89 a	18.13 a	16.41 a		
Worthing	MB	59.98 a	32.90 b	19.81 b	40.75 a	56.13 b
	CP	53.69 ab	86.25 c	37.70 b	59.22 ab	
	RT	54.84 ab	63.97 a	44.56 b	54.48 ab	
	NT	81.69 c	50.28 a	78.27 c	68.55 b	
	Mean	62.55 a	58.11 a	27.83 b		
			1987			
Beadle	MB	23.43 a	16.57 a	33.13 a	24.37 a	27.27 a
	CP	14.86 a	17.14 a	15.42 a	15.80 a	
	RT	34.84 b	36.55 b	24.51 ab	32.00 a	
	NT	38.28 b	39.98 b	32.56 b	36.95 a	
	Mean	27.85 a	27.56 a	26.43 a		
Worthing	MB	65.12 a	61.70 a	54.27 a	60.36 a	70.35 b
	CP	50.26 a	51.97 a	105.67 c	69.30 ab	
	RT	90.82 b	73.69 b	71.98 ab	78.83 ab	
	NT	68.55 a	82.26 a	67.98 a	72.94 b	
	Mean	68.89 a	67.40 a	74.98 a		

MB- moldboard plow CP- chisel plow
RT- ridge till NT- no-till
CC- conyinuous corn SC- corn after soybeans CS- soybeans
Within a year and soil means with the same letters are not significantly different at .05 level.

Table 43. Tillage and cropping sequence effects on available potassium in the Beadle and Worthing soils.

Soil	Tillage	K (kg ha^{-1}) CC	SC	CS	Tillage mean	Soil mean
			1986			
Beadle	MB	483 a	408 a	400 a	430 a	476 a
	CP	537 a	483 ab	423 a	469 ab	
	RT	451 a	468 ab	460 a	460 ab	
	NT	531 ab	536 b	566 ab	545 b	
	Mean	501 a	466 a	462 a		
Worthing	MB	768 a	801 a	784 a	785 a	715 b
	CP	762 a	751 a	788 a	767 ab	
	RT	620 b	663 a	848 a	686 bc	
	NT	666 ab	765 a	428 c	620 c	
	Mean	704 ab	770 a	668 b		
			1987			
Beadle	MB	428 a	377 a	430 ab	412 a	453 a
	CP	389 a	406 ab	466 ab	420 a	
	RT	488 a	409 a	397 a	431 a	
	NT	488 ab	557 b	597 b	547 a	
	Mean	448 a	437 a	473 a		
Worthing	MB	714 a	703 a	731 a	418 a	651 b
	CP	648 a	725 a	643 a	392 a	
	RT	564 ab	540 b	623 ab	336 a	
	NT	588 a	748 a	740 a	374 a	
	Mean	629 a	679 a	646 a		

MB- moldboard plow CP- chisel plow
RT- ridge till NT- no-till
CC- continuous corn SC- corn after soybeans CS- soybeans
Within a year and soil means with the same letter are not significantly different at .05 level.

Table 44. Available zinc levels under different tillage treatments of the Beadle and Worthing soils.

Soil	Tillage	Zn (kg ha^{-1}) CC	SC	CS	Tillage mean	Soil mean
			1986			
Beadle	MB	4.78 a	1.85 a	3.82 a	4.04 a	4.83 a
	CP	3.90 a	6.44 ab	3.05 a	4.27 a	
	RT	7.83 a	4.82 ab	6.55 a	4.38 a	
	NT	3.60 a	8.71 b	2.67 a	4.67 a	
	Mean	5.03 a	5.45 a	4.03 a		
Worthing	MB	3.08 a	2.64 a	2.79 a	2.85 a	3.08 b
	CP	3.22 a	2.96 a	2.23 a	2.81 a	
	RT	3.24 a	3.38 a	3.58 a	3.39 a	
	NT	3.31 a	2.90 a	3.60 a	3.27 a	
	Mean	3.22 a	2.96 a	3.05 a		

MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till CC- continuous corn SC- corn after soybeans CS- soybeans Within a soil means with the same letter are not significantly different at .05 level.

Table 45. Electrical conductivity measurements in different tillage treatments of the Beadle and Worthing soils.

Soil	Tillage	EC (mmho cm^{-1}) CC	SC	CS	Tillage mean	Soil mean
			1986			
Beadle	MB	0.63 a	0.63 a	0.70 a	0.66 a	0.69 a
	CP	0.70 a	0.67 a	0.77 a	0.71 a	
	RT	0.60 a	0.67 a	0.70 a	0.66 a	
	NT	0.70 a	0.80 a	0.77 a	0.76 a	
	Mean	0.65 a	0.72 a	0.72 a		
Worthing	MB	5.10 a	3.10 b	3.80 bc	4.00 b	3.98 b
	CP	4.20 ab	2.80 b	4.73 c	3.91 b	
	RT	3.63 b	6.13 a	3.83 bc	4.53 b	
	NT	3.40 b	3.87 b	3.37 b	3.54 b	
	Mean	4.08 b	3.98 b	3.84 b		
			1987			
Beadle	MB	0.36 a	0.50 a	0.33 a	0.40 a	0.41 a
	CP	0.47 a	0.53 a	0.67 a	0.56 a	
	RT	0.47 a	0.40 a	0.30 a	0.39 a	
	NT	0.37 a	0.27 a	0.27 a	0.30 a	
	Mean	0.41 a	0.43 a	0.39 a		
Worthing	MB	5.13 a	3.47 c	3.83 c	4.14 b	4.25 b
	CP	4.10 ac	4.50 ab	3.27 bc	3.96 b	
	RT	4.67 a	4.93 a	5.97 a	5.19 b	
	NT	4.06 ab	2.93 bc	4.17 ac	3.72 b	
	Mean	4.49 a	3.96 b	4.31 b		

Within a year and soil means with the same letter are not significantly different at .05 level.
MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till
CC- continuous corn SC- corn after soybeans CS- soybeans

Table 46. Electrical conductivity measurements of Worthing tillage plots

Plot No.	Depth (mm)	EC (mmho/cm) 1986	EC (mmho/cm) 1987	Remarks
1	0-10	18.0	10.7	Wilted plant
	10-50	8.0	7.8	
	50-100	7.5	8.4	
	100-150	6.0	8.3	
	150-200	7.0	7.3	
2	0-10	20.0	11.1	Wilted plant
	10-50	13.4	8.2	
	50-100	9.6	8.1	
	100-150	8.4	8.2	
	150-200	7.9	8.0	
6	0-10	4.0	2.0	Normal plant
	10-50	3.2	1.5	
	50-100	2.4	2.0	
	100-150	2.3	2.1	
	150-200	1.4	2.4	
15	0-10	3.0	1.5	Normal plant
	10-50	2.3	2.8	
	50-100	3.0	3.7	
	100-150	2.6	3.5	
	150-200	1.6	3.6	
25	0-10	5.2	3.5	Normal plant
	10-50	3.5	3.1	
	50-100	3.4	3.2	
	100-150	3.1	3.2	
	150-200	3.0	4.4	
27	0-10	5.0	4.4	Normal plant
	10-50	2.8	3.5	
	50-100	2.2	4.4	
	100-150	2.4	4.7	
	150-200	2.9	5.1	
31	0-10	2.5	14.0	Wilted plant
	10-50	6.0	9.6	
	50-100	7.4	6.7	
	100-150	6.2	7.5	
	150-200	6.2	8.5	

Table 47. Tissue test results of Beadle and Worthing tillage plots.

Tillage	Percent N		Percent P		Percent K		Zn (ppm)	
	CC	SC	CC	SC	CC	SC	CC	SC
					1986			
					Beadle soil			
MB	2.96 a	3.04 a	0.15 a	0.16 a	1.70 a	1.80 a	21.30 a	21.30 a
CP	2.86 a	3.01 a	0.14 a	0.15 a	1.50 b	1.60 b	20.67 a	20.33 a
RT	2.96 a	2.95 a	0.14 a	0.15 a	1.60 ab	1.60 b	23.67 a	24.67 a
NT	3.04 a	2.89 a	0.15 a	0.16 a	1.64 a	1.74 a	24.67 a	23.00 a
					Worthing soil			
MB	2.84 a	2.87 a	0.22 a	0.22 a	1.44 a	1.47 a	23.00 a	22.67 a
CP	2.14 b	2.19 b	0.21 a	0.26 b	1.44 a	1.46 a	17.33 b	18.67 b
RT	2.14 bc	2.52 c	0.24 a	0.24 b	1.40 a	1.46 a	20.67 bc	22.67 ac
NT	2.00 b	2.72 a	0.24 a	0.31 c	1.32 a	1.42 a	18.33 ab	22.33 ab
					1987			
					Beadle soil			
MB	3.25 a	3.17 a	0.24 a	0.24 a	1.66 a	1.66 a	24.00 a	20.33 a
CP	3.01 a	3.06 a	0.20 b	0.22 c	1.48 b	1.50 b	20.67 a	24.67 a
RT	3.18 a	3.06 a	0.26 d	0.26 d	1.58 a	1.60 ab	33.33 b	24.00 a
NT	3.13 a	3.23 a	0.26 d	0.25 ad	1.68 a	1.70 a	22.00 a	23.33 a
					Worthing soil			
MB	3.22 a	3.22 a	0.22 b	0.23 d	1.70 a	1.86 b	35.33 b	32.00 b
CP	2.76 a	2.66 bc	0.20 a	0.20 a	1.56 a	1.68 a	28.67 b	20.67 a
RT	3.01 a	2.43 b	0.24 c	0.25 c	1.58 a	1.70 a	27.00 b	25.67 ab
NT	2.83 a	3.07 a	0.23 bc	0.23 b	1.72 a	1.76 ab	30.67 ab	24.33 a

Table 47. (continued)

Tillage	Ca (%)		Mg (%)		S (%)		Fe (ppm)		Mn (ppm)		Cu (ppm)	
	CC	SC	CC	SC	CC	SC	CC	SC	CC	SC	CC	SC
						1986						
						Beadle soil						
MB	.52a	.52a	.31a	.32a	.16a	.18a	120a	173b	73.7a	70.3a	23.3a	26.7a
CP	.58a	.58a	.36a	.39a	.20a	.21a	120a	120a	76.3a	89.3c	23.3a	24.7a
RT	.52a	.55a	.34a	.36a	.13b	.17ab	117a	123a	65.3b	75.0a	23.0a	24.0a
NT	.54a	.56a	.33a	.35a	.19a	.18a	133a	137ab	66.0b	68.3ab	22.3ab	21.7b
						Worthing soil						
MB	.48a	.55a	.33ac	.26a	.42a	.30b	118a	113ac	64.0a	60.0a	21.0a	24.0a
CP	.53a	.56ab	.26a	.24a	.33bc	.37c	90a	150bc	48.7b	42.0b	18.3ab	18.7b
RT	.51a	.50a	.43b	.31a	.43a	.47a	86a	107a	57.3a	58.7a	16.3a	14.0b
NT	.47a	.62b	.36bc	.30a	.45a	.48a	94a	108a	48.3b	66.7a	17.3ab	17.7b

MB- moldboard plow CP- chisel plcw RT- ridge till NT- notill
CC- continuous corn SC- corn after soybeans
Within a soil means followed by the same letter are not significantly different at .05 level.

APPENDIX D
MULTIVARIATE ANALYSIS OF VARIANCE TABLES

Table 48. Multivariate analysis of tillage effects on surface physical properties of the Beadle and Worthing Soils.

Dependent Variables	F values from Individual ANOVA				MANOVA Test Roy's Maximum Root
	Bd	K-sat	θv	Temp.	F(upperbound)
Source					
T	10.3**	2.5	3.0*	3.0*	11.9
S	1.0	76.9****	186.6****	3.1*	96354.3
S*T	0.5	2.3	2.3	5.0	7.5
S*T*Y	1.1	10.1***	0.1	0.1	9.9

T- tillage   Bd- Bulk density

S- soil   K-sat- saturated hydraulic conductivity

Y- year   θv- surface volumetric moisture

Temp.- surface soil temperature

Table 49. Multivariate analysis of tillage effects on surface chemical properties of Beadle and Worthing soils.

Dependent Variable	F values from individual ANOVA					MANOVA Test Roy's Maximum Root
	pH	O.M.	N	P	K	F(upperbound)
Source						
T	6.3**	0.9	3.8*	2.5	1.0	6.4
S	29.1****	2.0	1.5	58.1****	42.8****	13.4
S*T	3.1*	1.7	0.3	0.1	2.1	2.5
S*T*Y	0.1	0.2	1.9	1.1	0.2	1.6

N- nitrate nitrogen T- tillage

P- Bray's available P S- soil

K- available K Y- year

OM- organic matter

Table 50. Multivariate analysis of tillage effects on corn growth parameters and yield of the Beadle and Worthing soils.

Dependent Variables	F Values from Individual ANOVA				MANOVA Test Roy´s Maximum Root
	PEM	LA	DFS	Yield	F(upperbound)
Source					
T	1.0	1.4	1.3	2.4	8.7
S	16.0	101.0****	208.4****	124.8****	78.5
S*T	0.4	1.9	1.7	0.3	2.6
S*T*Y	0.7	2.3	3.3	1.1	4.6

PEM- Percent emergence T- tillage

LA- Leaf area S- soil

DFS- Days to 50% silking Y- Year

APPENDIX E
PLANT POPULATION DATA AND 1985 YIELD

Table 51. Corn plant population under different tillage treatments in the Beadle and Worthing soils.

Soil	Tillage	1986 CC	1986 SC	1987 CC	1987 SC
		--------Plants ha^{-1} (in 1000)--			
Beadle	MB	60.9 a	60.2 a	63.1 a	64.5 a
	CP	62.3 a	55.9 a	63.1 a	60.2 a
	RT	60.9 a	59.5 a	58.8 a	64.5 a
	NT	57.3 a	61.6 a	60.9 a	65.2 a
Worthing	MB	33.3 c	33.3 c	58.0 ab	56.6 b
	CP	20.8 c	7.9 d	63.8 a	57.3 b
	RT	40.1 c	38.0 c	51.6 b	59.5 b
	NT	38.0 c	31.5 c	61.6 ab	58.8 b

BM- moldboard plow CP- chisel plow
RT- ridge till NT- no-till
CC- continuous corn SC- corn after soybeans

Table 52. Soybean plant population under different tillage treatments in Beadle and Worthing soil.

Soil	Tillage	Plants/ha (in 1000) 1986	1987
Beadle	MB	204.9	256.7
	CP	187.1	278.8
	RT	203.5	282.3
	NT	212.8	255.1
Worthing	MB	177.4	174.1
	CP	153.3	236.4
	RT	174.8	239.3
	NT	167.0	224.3

BM- moldboard plow CP- chisel plow
RT- ridge till NT- no-till
Within a year means are not significantly different at .05 level.

Table 53. Corn and soybean yields for the Beadle and Worthing tillage plots in 1985 with the same conventional tillage in all the plots.

Soil	Tillage	Corn Yield		Scybean Yield
		--------(Mg ha^{-1})------------		
		CC	SC	
Beadle	MB	9.009 ac	8.274 c	2.778 a
	CP	8.068 bd	7.822 bc	2.735 a
	RT	7.604 b	8.108 bc	2.864 a
	NT	8.362 cd	8.404 c	2.983 a
Worthing	MB	7.066 a	6.730 a	2.273 a
	CP	7.176 a	6.804 a	2.096 a
	RT	7.181 a	8.297 b	2.038 a
	NT	7.577 ab	8.297 b	2.536 a

CC- continuous corn plots SC- rotation plots
MB- moldboard plow CP- Chisel Plow in 1986, 1987
RT- Ridge Till in 1986, 1987 NT- no-till in 1986, 1987.
Means with the same letter are not significantly different at .05 level.

APPENDIX F
PRODUCTION COST AND GROSS INCOME

Table 54. Production Cost of corn and soybeans under different tillage practices.

Items	MB	CP	RT	NT
	Cost/ha ($)			
		Corn		
Fertilizer	76.75	76.75	76.75	76.75
Seed	50.59	50.59	50.59	50.59
Herbicide	19.28	19.28	29.31	39.34
Insecticide	22.24	28.91	31.23	33.56
Fuel and oil	24.66	17.25	13.15	9.02
Machine repair	36.60	21.40	19.13	16.83
Interest on capital	51.17	43.34	39.49	35.63
Machine deprec., Taxes and Ins.	49.35	39.86	34.72	29.58
Labor charge	14.21	10.30	7.99	5.68
Total	344.85	307.68	302.36	296.98
		Soybeans		
Fertilifer	-	-	-	-
Seed	23.00	23.00	23.00	23.00
Herbicide	27.65	41.85	52.88	63.90
Insecticide	13.34	20.21	23.45	26.69
Fuel and oil	22.41	14.83	11.91	9.02
Machine repair	32.25	18.93	16.48	14.01
Interest on capital	43.42	34.64	32.15	29.65
Machine deprec., taxes, ins.	42.92	33.16	30.36	27.36
Labor charge	13.02	9.04	7.36	5.68
Total	218.014	195.66	197.59	199.30
Average cost/year for corn-soybean rotation plots	281.43	251.67	249.98	248.14

Table 55. Gross income from the Beadle and Worthing soils.

Tillage	Gross income ($/ha)							
	1986			1987			Average	
	CC	SC	CS	CC	SC	CS	CC	C-SB
				Beadle soil				
MB	432.20	449.32	517.72	592.76	574.95	479.53	512.48	505.38
CP	405.16	457.64	448.73	496.68	543.84	451.42	450.92	475.41
RT	402.17	435.00	458.78	524.98	598.50	488.49	463.58	495.92
NT	415.00	388.22	477.07	490.39	563.53	462.23	452.70	472.91
				Worthing soil				
MB	145.27	156.75	159.57	336.57	434.02	162.16	240.92	228.13
CP	76.40	61.40	44.24	382.34	479.42	148.11	229.37	183.29
RT	113.98	135.51	101.08	401.10	369.11	251.27	257.54	214.24
NT	88.54	147.65	213.57	413.12	430.72	168.49	250.83	240.12

MB-moldboard plow CP-chisel plow RT-ridge till NT-no-till
CC- continuous corn SC- corn after soybeans CS-soybeans
C-SB- corn- soybean rotation
Selling price of corn was $ 1.10/bushel in 1986 and $ 1.40 /bushel in 1987.
Selling price of soybeans was $ 4.37/bushel in 1986 and $ 4.50/bushel in 1987

APPENDIX G
PRECIPITATION EVENTS (1986 AND 1987)

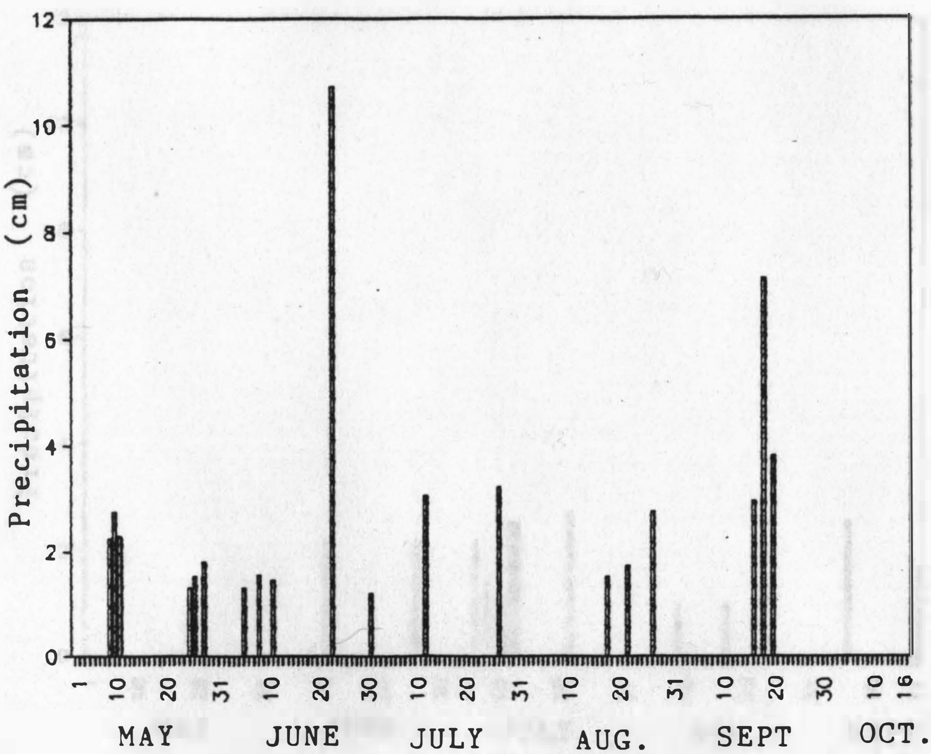

Figure 24. Precipitation events over 1 cm at the research farm, 1986.

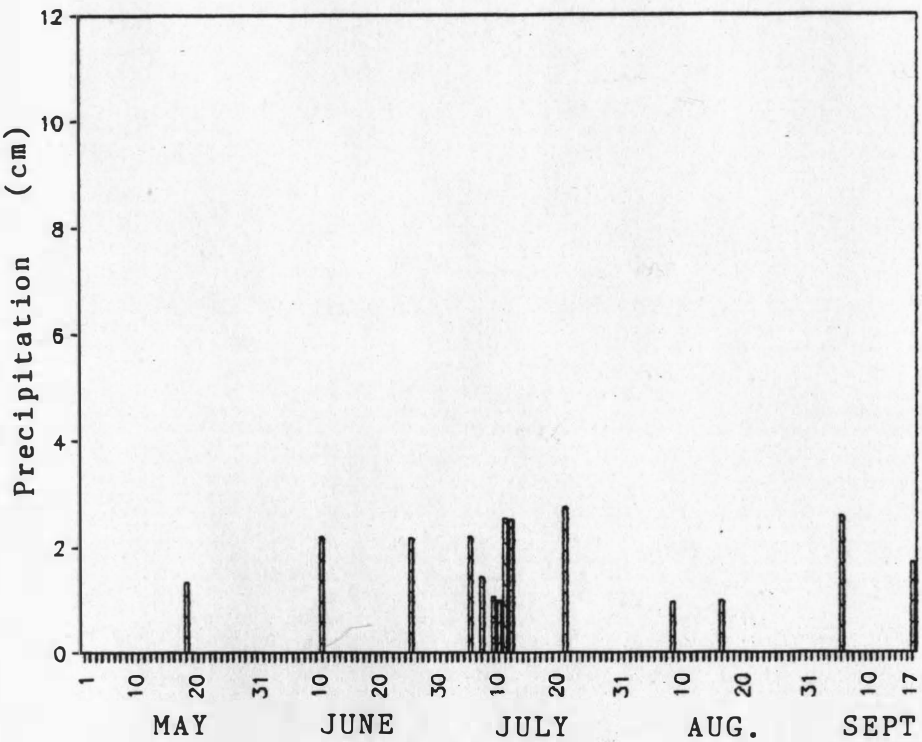

Figure 25. Precipitation events over 1 cm at the research farm, 1987.