

DISSERTATION

EFFECT OF TILLAGE ON SOIL PHYSICAL
PROPERTIES AND CROP PRODUCTION

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY ABDULLAHI ABDURAHMAN ABDI ENTITLED EFFECT OF TILLAGE ON SOIL PHYSICAL PROPERTIES AND CROP PRODUCTION BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION
EFFECT OF TILLAGE ON SOIL PHYSICAL
PROPERTIES AND CROP PRODUCTION

The objective of this study was to determine the effect of two tillage systems--conventional tillage (CT) and reduced tillage (RT)--for a three-year corn-corn-watermelon rotation on: 1) biological production of corn and watermelon, 2) changes in soil physical properties, and 3) effect of tillage on irrigation at the Arkansas Valley Research Center, Rocky Ford, Colorado. Treatments were designed to evaluate tillage systems over the entire duration of the rotation rather than evaluating individual tillage operations or tillage implements.

The results of this study showed neither a benefit nor loss in corn grain-yield under RT when compared to CT. The effect of tillage system on dry matter yield of corn varied with planting method. With flat planting for both CT and RT, yields of total dry matter were higher than CT. When corn was ridge-tilled, the RT system was higher yielding.

Tillage system did influence marketable melon production. The yield of marketable melon over the three years averaged 26% higher for RT. Seed yield was not effected by tillage system in 1985, but a decrease in seed yield was observed in

1986 with RT where the disk was used as the primary tillage tool.

Tillage system also had varied effects upon physical properties of the soil. The RT system resulted in greater aggregate stability, a higher residual soil moisture content, and increased infiltration. In 1986, these benefits may have been counteracted by lower early-season soil temperature and greater soil compaction at the 15-30 in depth. The increased moisture storage resulted in savings of irrigation water, labor and energy--an economic advantage. Lower soil temperatures for the RT system may have contributed to reduced evaporation and reduced runoff--also possible economic and societal benefits. Results of this study indicate that lower soil temperatures may have been the cause for retarded early-season corn growth. The RT system has several beneficial attributes that offer promise for becoming an attractive management system. In terms of immediate benefit to the farmer, greater savings in energy, labor and machinery would be possible under this system. Given proper management and the application of improved cultural practices, i.e. rotation, fertilization, weed control, etc., the farmer may, by using the RT system, produce crop yields equal to or even greater than CT with less dollars, the greatest potential being under rainfall situations.

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CHAPTER I
INTRODUCTION

The need for a viable productive agriculture to feed increasing world population continues to be a major global issue. In 1985, the world was adding 76 million people a year, over 210,000 a day. Some 69 million of the 76 million annual increase occurred in the developing countries (World Bank, 1987).

The contribution of research and technology in alleviating the food problem is reflected by the yield increases brought about by high yielding crop varieties, irrigation, improved farm equipment, fertilization and better tillage practices.

There seems to be a general consensus that continued development of appropriate technologies such as irrigation and fertilizers will continue to impact the efficiency of food and fiber production in the future. However, these advances in short-term technologies can "mask" the effect of erosion on farmland. The development of improved cropland erosion control and moisture conservation technologies that have long-term beneficial effects on sustainable agriculture provides challenges to the farmer and agricultural scientist, and to society as a whole.

When soil is not properly protected with crop residue cover, water and wind erosion of top-soil can be excessively high. This in turn may cause water pollution as well as loss of valuable plant nutrients. Fueled by the growing need to protect cropland, reduced tillage when appropriately developed, has the potential for becoming a worldwide practice where erosion problems are reducing the sustainability of agriculture. Wolman (1985), quoting from various sources, noted an estimated worldwide of cropland loss by erosion of 50 Mha^{1/}. This represented 3.3% of the total cropland in 1975 (1500 Mha) and somewhat smaller percentage of the predicted cropland area in the year 2000 (1800 Mha). A similar proportionate loss is suggested for the productive cropland in the U.S.A. during the same period. It is to be noted that a loss of 50 Mha of cropland over 20 years represents a loss of about 5 ha per minute, or the equivalent of one farm per minute in some parts of the developing world.

Hays (1985) estimates an average annual loss from U.S.'s 167 Mha of cropland of 11.6 Mg^{2/} ha⁻¹ yr⁻¹. He suggests this would be equivalent to 19.4 million dollars in loss of cropland every year as a result of erosion. Further, as noted by Ritchie and Follett (1983), nationally, losses of nitrogen

^{1/}Mha - 10⁶ ha

^{2/}Mg - 10⁶ g - 1 metric ton

(N), phosphorus (P), and potassium (K) via erosion approach \$677 million, \$17 million and \$382 million a year, respectively. These are substantial losses and degradation of the U.S. cropland is likely to continue unless effective conservation tillage systems are adopted.

Studies with reduced tillage in the U.S. have given mixed results. Some reports suggest grain yields increase with reduced tillage systems, whereas others have shown yields are reduced. Most published research to date, however, with regard to reduced tillage, has been on rainfed cropland where evapotranspiration usually exceeds rainfall during much of the growing season. This occurs because of erratic rainfall both in amount and in seasonal distribution. On the other hand, little has been done with reduced tillage under irrigated agriculture.

Interest in reduced tillage on irrigated agriculture is increasing rapidly because problems such as erosion, depleting groundwater and increasing energy costs affect the sustainability of irrigated agriculture. These, coupled with farmers' desires for increased income and efficiency, are the driving forces behind much of the adoption of reduced tillage currently in the U.S. For conservation tillage to be effective, it is imperative that adequate amounts of protective cover be left on the soil surface. The quantity of residue that should be retained on the soil surface for erosion control depends on soil and topographic conditions as

well as on residue type. According to Soil Conservation Service specifications (USDA-SCS, 1988a), at least 30% of the soil surface must be covered with crop residue where soil erosion by water is the major concern. At least 112 kg ha^{-1} of small grain equivalent dry matter is required where soil erosion by wind is the major problem.

Benefits attributed to reduced tillage usually include (1) a reduction in loss of surface soil, (2) soil moisture conservation, (3) reduction in certain production costs as a result of savings in labor and fuel costs, and (4) the potential to increase yield. The advent of herbicides following World War II has eliminated much of the dependence on tillage for weed control and seedbed preparation in row crops. In fact, herbicides may be substituted for tractor power to reduce competition from weeds during the crop season. Tillage management systems that reduce the number of trips made across the field have worked successfully and have resulted in yield stability comparable to conventional tillage systems. It is generally believed that the success of reduced tillage depends largely upon geography, prevailing climatic conditions, soil characteristics and management.

Previous tillage research conducted under irrigation in semiarid southeastern Colorado showed reduced yields of continuous corn in the second and subsequent years when reduced tillage was practiced (Miles, 1982). The findings suggest that reduced tillage used in a crop rotation would be

more successful than when used for continuous corn. Based on these and other observations, a new conservation tillage project was initiated at the Arkansas Valley Research Center in 1985. The approach used in this study was different in that treatments were designed to evaluate "tillage systems" over the entire duration of the rotation rather than evaluating individual tillage operations or tillage implements.

The broad objective of this study was to determine the effect of two tillage systems (conventional and reduced tillage) for a three-year, corn-corn-watermelon rotation on (1) biological production of corn and watermelon and (2) changes in soil physical properties. The usual conventional tillage in the Arkansas Valley consists of primary deep-tillage with a moldboard plow followed by secondary tillage such as disking one or more times, then harrowing. Reduced tillage is a form of tillage system designed to leave at least 30% crop residue on the soil, the objective being to reduce wind and water erosion, to increase moisture conservation, and to improve the sustainability of production agriculture. The specific objectives of this study were to determine the effect of tillage system on:

1. Yield of corn for grain, and on watermelon seed and marketable melon production,
2. Seasonal dry matter accumulation by corn,

3. Soil aggregate formation and size distribution,
and aggregate stability to wind erosion,
4. Soil compaction, soil moisture, and soil temperature,
5. The advance rate of the water front for furrow
irrigation,
6. Infiltration, and
7. The cropping-sequence x tillage interaction on soil
physical properties.

CHAPTER II

LITERATURE REVIEW

Crop production is a complex enterprise in the farming system that cuts across many disciplines. In the past two decades, efforts to conserve soil and water have focused on conservation tillage techniques. Because conservation tillage results in trashy and cloddy soil surface, it affects surface irrigation and machinery performance in field operations such as chemical applications, secondary tillage and planting.

Widespread adoption of conservation technology has not occurred in part because of reluctance on the part of producers to buy or modify equipment, and the lack of an understanding of how to apply the technology to their circumstances. It is well known that crop production practices are location-specific. Cosper (1983) points out that many site-specific tillage studies show significant increases in crop yields when conservation tillage is used on some soils, but on other soils, significant reductions in yields may occur. For still other situations, the method of placement of residue from the previous crop, along with the cropping sequence, determines whether crop yields increase or decrease in comparison with conventional tillage yields.

This review of literature of the biophysical effects of various tillage systems will be discussed under eight sections: (1) tillage definitions, (2) the wind erosion process, (3) conservation tillage cropland in the U.S., (4) effect of tillage on physical properties of the soil, (5) effect of tillage on irrigation, (6) effect of cropping sequence on soil physical properties, (7) effect of tillage on yield and (8) summary.

Tillage Definitions

Textbooks and publications addressing tillage define "conventional tillage" and "conservation tillage" somewhat differently. Conservation tillage terms (all referring to some form of tillage) are common in the literature, for example, minimum tillage, reduced tillage, no-till, mulch tillage, slot plant, and stubble mulch, to name a few. The terms that will be used in this dissertation are "conventional tillage," "reduced tillage," and "ridge-till." No-till also will be defined because reference is made to it from time to time throughout this review.

Conventional tillage is defined herein as a system that utilizes both primary and secondary tillage operations for seedbed preparation. Since the surface soil in conventional tillage systems is free of weeds and crop residue, there is little or no interference from crop residues on movement of machinery performing tillage, chemical application, planting or cultivation.

According to the Conservation Technology Information Center (CTIC, 1987), conventional tillage usually refers to moldboard plowing followed by disking and harrowing. In some areas, moldboard plowing may not be the "conventional" form of tillage.

The moldboard plow has been the traditional primary tillage tool in conventional tillage (Moldenhauer et al., 1983) in the higher precipitation zones (more than 450 mm a year). Its use remains widespread. Newer models of the plow allow turning the furrow up-slope on much steeper slopes than previously thought possible. The chisel plow sometimes is used as a primary tillage tool in the fall in preparation for seeding a spring crop. It goes without saying that in conventional tillage system wind and water erosion can become a serious problem.

Conservation tillage is a broad term used for any crop management system that leaves crop residue on soil surfaces in order to reduce erosion (CTIC, 1987). The type and extent of operations involved vary depending on the specifics of the objectives to be accomplished. Some of the tillage types that fall under conservation tillage category include (1) reduced tillage, (2) no-till, and (3) ridge-till.

Reduced tillage, as the name implies, is a system involving fewer trips over the field and only a partial inversion of the soil. This practice should leave a minimum residue cover of 30% and extends into and beyond planting thus

providing adequate soil protection against wind and water erosion. The objective of reduced tillage is to conserve moisture and reduce soil loss to wind and water erosion. In this writing the terms "reduced tillage" and "minimum tillage" are used interchangeably. The one-way disk became a popular tillage tool for reduced tillage systems (Fenster, 1982) in the late 20's and 30's, replacing the plow for the initial and frequently for the secondary tillage. The chisel plow became popular in the 1950's and 1960's, and subsurface implements (sweeps) became popular in the late 1950's and early 1960's.

Fenster emphasized that equipment for reduced tillage and the sequence of operation varies, depending on the amount of residue present, type of soil, moisture conditions, and weeds present. No one set of tillage tools is best for all conditions. A combination of sweeps, disks, and rodweeders may be needed for some situations. The Conservation Technology Information Center (CTIC, 1983) has developed a glossary for tillage systems and as such, it seems appropriate to use its definitions for no-till and ridge-till.

No-till: a type of conservation tillage in which surface residue is not disturbed. A planter equipped to cut through surface residue prepares a narrow seedbed. Ridge-till: a type of conservation tillage in which a specially designed planter prepares a ridge for the seedbed by scalping the soil surface. Residue is moved to row middles. Ridge-till usually is done on ridges built up by previous year's cultivation. A more

recent definition of ridge-till (including no-till on ridges) is given by the USDA-SCS (1988a) which is as follows: the soil is left undisturbed prior to planting. Approximately one-third of the soil surface is tilled at planting with sweeps or row cleaners. Planting is accomplished on ridges usually 10 to 15 cm higher than the elevation between the rows. Weed control is accomplished with a combination of herbicides and cultivation. Cultivation is used to rebuild ridges.

The Wind Erosion Process

Conditions conducive to wind erosion exist when the soil is loose, dry and finely granulated, the susceptible area is sufficiently large, and the wind is strong and turbulent enough to move soil (Lyles et al., 1985). These conditions often exist in arid and semiarid regions of the world where rainfall is scarce and conservation technology is not practiced to protect soil from erosion hazards. The wind-erosion process involves detachment, transport, sorting, abrasion, avalanching, and deposition of soil particles (USDA-SCS, 1988b). Generally, winds are considered erosive when they reach 20.9 km hr^{-1} at 0.305 m above the ground or 29 km hr^{-1} at a 9.14 m height (USDA-SCS, 1988b).

Wind erosion is dependent directly on the physical attributes of the soil (Chepil and Woodruff, 1963). Some soils are much more resistant to erosion than others. Soil texture is the single most important property long known to effect erodibility of soil by wind. Sandy soils, whose

primary soil particles are less strongly bound together are more susceptible than fine-textured clay soils. Loam soils (medium textured) are most resistant to erosion because of greater stability of their aggregates (Johnson, 1983). Other factors affecting soil's resistance to erosion include organic matter content, structure, CaCO_3 content, and soil moisture. Chepil (1953) conducted studies on the effect of soil texture on erodibility by wind. He reported high erodibility of the fine and very fine sand. The clay and silt fractions were less erodible.

The wind erosion equation (WEQ) is used to predict the wind erosion. It is based on the following equation developed by Woodruff and Siddoway (1965),

$$E = f (I, K, C, L, V);$$

E is the potential average annual soil loss in $\text{Mg ha}^{-1} \text{ yr}^{-1}$, I is soil erodibility, and it is expressed in Mg ha^{-1} ; K is the soil roughness expressed in cm; C is the climatic factor expressed as a percent of Garden City, Kansas "c" factor which is 100; L is the unsheltered distance perpendicular to the prevailing wind direction expressed in m, and V is the quantity, kind, and orientation of vegetation. The later term is expressed in Mg ha^{-1} .

The mathematical relationships among the variables in the wind erosion equation are complicated, but charts and tables have been prepared from which the quantity of erosion (soil loss), as influenced by each of these variables, can be

read at a glance (Chepil, 1962a). Man can either help or hinder soil erosion, depending upon how production factors are managed. The USDA-Soil Conservation Service (1988b) reports some wind erosion always occurs as a natural landforming process, but it has accelerated with human activities as the result of improper use and management of the land. Generally, it is more convenient to prevent wind erosion than trying to tackle it when it occurs. Chepil (1945) proposed two basic methods to control wind erosion. The first of these is to reduce wind velocity near the ground by practices such as the roughening of the surface, the placement of obstructions in the path of the wind, and the retention of undecomposed organic materials above the ground. The second method is to increase the size of soil aggregates by various cropping and tillage practices. In the former method, the object is to reduce the velocity of the wind below that required to initiate soil movement; in the latter it is to increase the minimum velocity required to initiate the movement.

Conservation Tillage Cropland in the U.S.

The 1986 Conservation Technology Information Center (CTIC, 1987) survey, predicted that conservation tillage will be used on 42% of all U.S. cropland farmed by 1990. In 1986, conservation tillage was used on a record 33% of all planted area.

Although full-season corn production dropped by 1.74 million ha for 1986, conservation tillage was used on 41% of that crop. That was up from 39% in 1985. Leading regions in the total conservation tillage were the Corn Belt at 43%, and the Appalachian and Northeast at 40%. Iowa was the leading state in total conservation tillage at 11.3 million ha or 50% of its cropland base. Delaware, with 81%, had the highest percentages of cropland in conservation tillage (CTIC, 1987).

Effect of Tillage on Physical Properties of Soil

Soil Erosion

Intensive agriculture will continue to play a major role in meeting the ever-increasing demand for food and fiber for many years to come. The judicious application of conservation technology to cropland, water and energy resources is needed, however, to maintain high production while still preserving the soil resource base and reducing air and water pollution. Lindstrom et al. (1979), as quoted by Larson (1982), determined the average erosion rate for all cultivated soils in the corn belt when different tillage practices were used. He found that the average erosion rate for conventional tillage (fall moldboard and disc) was $21.5 \text{ Mg ha}^{-1} \text{ yr}^{-1}$; for chisel plow (3.92 Mg ha⁻¹ of corn residue on the soil surface) the average rate was $8.7 \text{ Mg ha}^{-1} \text{ yr}^{-1}$; and for no-tillage (3.9 Mg ha⁻¹ of residue on the soil surface) the average rate was $6.5 \text{ Mg ha}^{-1} \text{ yr}^{-1}$. He further stated that since the average soil

loss tolerance level "T" of Lindstrom et al. (1979) is $9 \text{ Mg ha}^{-1} \text{ yr}^{-1}$, one might conclude that if all corn and soybeans were grown with conservation tillage, chisel plow or no-tillage, erosion could be controlled.

Burwell and Kramer (1983) studied the effects of conventional and conservation tillage for corn on runoff and soil loss from a central Missouri clay-pan soil for 24 consecutive years. They found runoff and soil loss for conventional tillage was 85% and 42% greater, respectively, than for conservation tillage.

Dickey et al. (1983) in Nebraska measured runoff and erosion from furrow irrigation on a 0.5% slope for six tillage treatments. They found soil erosion was higher from chisel, disc, and list tillage systems than from the reduced tillage systems of till-plant, rotary-till and slot-plant. They reported that the chisel system had the highest soil loss, averaging almost $0.2 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ and slot-plant had the lowest, averaging $0.022 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ for an 89% reduction.

Moldenhauer et al. (1983) found an average annual soil loss to water erosion of $1.3 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ with mechanical stubble mulch tillage on 5.4% slope in the Central and Northern Great Plains. They point out that use of no-till fallow practices reduced soil loss 95% relative to conventional tillage.

Dickey et al. (1985) in Nebraska found that moldboard plow systems generally had the greatest soil loss to water

erosion while no-till had the least. Their research was conducted on a silty clay loam soil with a 5% slope and a silt loam soil with 10% slope using rainfall simulation on soybean and corn residues under field conditions.

Soil Aggregation

Soil aggregation is a physical property that affects the functional behavior of the soil with respect to water absorption, aeration and root penetration (Woodruff, 1939). The size distribution of soil aggregates is important because the size of aggregate determines its susceptibility to surface movement (erosion) by wind and water, and because size is important in determining the dimensions of the pore space in cultivated soils (Kemper and Chepil, 1965). Wind is a major natural force disintegrating dry soil particles. Soil erosion by wind forces continues to be a serious problem to Great Plains agricultural productivity. Soil aggregation, both size and stability, has been demonstrated to be a very important variable for evaluating the soil erosion potential (Woodruff and Siddoway, 1965), and improved aggregation is a major factor for controlling wind erosion. Chepil (1943, 1955) concluded that large clods or aggregates with a diameter >0.84 mm were non-erodible by wind, and that there is an inverse relation between the fraction of non-erodible aggregates and wind erosion. Common factors that influence the size, amount and distribution of soil aggregates are type of soil,

cultural practices, moisture gradient in the soil, and type of vegetation.

Armbrust et al. (1982) observed varied influence of tillage on dry soil aggregation in Kansas. They reported that chemically treated plots had more clods >0.84 mm in diameter, and mechanically treated plots had clods with the greatest mechanical stability. They further indicated that clods of the chemical treatment plots were more resistant to overwinter breakdown when snow was heavy and temperatures low because the standing crop residues trapped snow, which protected the aggregates from freeze drying. Beale et al. (1955) working on sandy soil in South Carolina, studied the effect of mulch and clean tillage methods on soil properties over a period of ten years. Mulch-tilled land was prepared for planting corn by disc-harrowing, and by disk-harrowing plus loosening the soil with a spring-tooth tiller. A disk or moldboard plow was used to prepare the turn-plow-treatment. Their results showed that aggregation as a result of mulch tillage was greater than that from moldboard plow treatment from 1945 through 1951.

Unger (1982) in Texas found 75% of the aggregates were >0.84 mm in no-tillage systems which, according to Unger, is the approximate percentage of stable dry aggregate of this size required to hold the average annual soil losses caused by wind erosion to less than the tolerable level of $11.2 \text{ Mg ha}^{-1} \text{ yr}^{-1}$ as given by Woodruff and Siddoway (1965) for a large, bare, smooth, unprotected fields. Unger concluded that the

need for controlling wind erosion by means other than surface cloddiness brought about by normal tillage is apparent.

Rao et al. (1960) evaluated tillage effects with respect to clod-size distribution in clay loam as well as silt loam soils. They found that minimum tillage resulted in clods of 70-100 mm in diameter, and contained more clods in the range from 9.5 to 12 mm than did conventional tillage plots.

Blake and Aldrich (1975) working with corn and potatoes found excessive cultivation reduced both air space and aggregation, although the differences were not always significant.

Mannering et al. (1975) in Indiana compared several conservation tillage practices with conventional tillage with respect to soil aggregation using percentage water stable aggregation as an index of aggregate stability. Their results show an aggregation index for the 0-5 cm depth of 0.77, 0.46 and 0.35 for no-tillage, chisel-plow and conventional-plow, respectively. For the 5-10 cm depth aggregation index values were 0.70, 0.56, and 0.47 for no tillage, chisel-plow and conventional-tillage respectively. This finding shows the negative effects of increased tillage on soil aggregation.

Siddoway (1963) in Idaho suggested the use of the moldboard plow for wind erosion control in the absence of surface vegetation. From tillage tests conducted, Siddoway found that reasonably good wind-erosion control could be

achieved, provided excessive tillage after plowing was avoided.

Research on tillage effects alone on soil cloddiness and dry aggregate stability are limited. Tillage effects are temporary, and climatic factors may play a dominant role in aggregate breakdown on soil surfaces. Black and Siddoway (1979) in Montana reported that soil aggregate deterioration by normal weathering is hastened on bare, unprotected soil compared with soil protected by crop residue. They concluded that a given sequence of tillage operations can thus become counterproductive to soil improvement and protection, thereby intensifying soil degradation with time. In a study in the Central and Northern Great Plains, Black and Power (1965) suggested that fall tillage that flattens crop residues will reduce snow trapping, which in turn reduces soil water storage. Browning et al. (1942) found incorporation of soybean roots and nodules in a soil increased materially the number of larger-sized aggregates.

It is generally believed that cultivation tends to destroy the natural aggregation of the soil by hastening the decomposition of protective organic colloids without supplying fresh organic matter to replace them (Woodruff, 1939). Baver (1949) pointed out that an analysis of the soil from the cultivated fields and from virgin areas in Ohio showed highly significant results, and quoted Bradfield (1938) who reported that the upper 0.91 m of cultivated soil contained 7.3 kg more

solids per 0.03 m^{-3} than the virgin areas. The total porosity of the cultivated soil had declined about 17%. Later investigations by Baver and Farnsworth (1940) showed that the non-capillary porosity (aeration porosity) of the cultivated soil was about 3.5% by volume, whereas that of the same soil in good physical condition was as high as 25%. Fluctuations of soil aggregation may be brought about by climate, tillage operations or other factors that induce either a build-up or breakdown of aggregates in the soil.

Anderson and Browning (1949) measured aggregate size and stability of soil samples taken from tilled and virgin prairie fields in Ames, Iowa. Their findings show that cultivated soils were less aggregated, had considerably less stable aggregates and had lost almost one-third of their original nitrogen in 100 years or less of cultivation and cropping.

Seasonal Fluctuation in Aggregation

Several investigators (Anderson and Bisal, 1969; Anderson and Wenhardt, 1966) have shown that although alternating freezing and thawing increases aggregation, it will vary with texture and soil water content. Chepil (1954) reported the breakdown of aggregates during the winter. He also observed that reaggregation of the smaller size aggregates occurred in the spring, concluding that the wind erosion potential at the soil surface was greater in the spring than in the previous fall. Hinman and Bisal (1968) and Logsdail and Webber (1959) studied the effect of freezing on soil aggregate breakdown and

found that increasing water content increased breakdown. The greatest increase in erodibility from fall to spring occurred in the finest-textured soil, and the least in the coarsest. In a related study, Bisal and Nielson (1964) found that soil aggregates do not necessarily break down over winter. Their finding was further confirmed by the work of Anderson and Wenhardt (1966) who reported that the Wood Mountain clay loam in Canada can be expected to be considerably less erosive in the spring prior to preplanting tillage than they were the previous fall. This implies that soil aggregation occurred over winter.

In areas where the soil surface is bare of snow for extended periods, the exposed layer may freeze-dry, leaving a highly erosive soil at the surface (Hinman & Bisal, 1968). It is therefore advisable to retain an adequate amount of residue cover on the surface to trap snowfall and to protect the soil from the erosive effects of freeze-drying.

Soil Moisture

The effects of reduced tillage in moisture conservation are well understood by farmers, researchers, and extension personnel involved in production agriculture. Research has shown that evaporation losses from reduced tillage is much less than from conventionally-tilled soils (Touchton and Wells, 1985). This is especially true very early in the season until the crop establishes a canopy as a protective cover to help reduce the amount of solar radiation reaching

the soil surface, thereby minimizing the amount of energy available to cause evaporation of soil water. Also, it is evident from the literature that improved surface infiltration is a major factor in maintaining a greater supply of soil moisture under reduced tillage conditions.

Triplett et al. (1968) indicated mulch protection which may be readily available from previous crop residue is necessary to maintain no-tillage corn yields on Wooster silt loam soils of Ohio. They suggest that the beneficial effects of the mulch seem to be associated with increased soil moisture. Smika (1976) working in several Central Great Plains locations noted 2.6 cm more available soil water at the end of 14 months of fallow under mulch conditions than under bare soil. Greater soil moisture storage in chemical fallow than conventional tillage were also indicated by Unger et al. (1971), Wicks and Smika (1973) and Smika and Greb (1978). Moody et al. (1963) found greater moisture and a significantly higher corn yield and greater moisture under mulch conditions. Reduction of evaporation through the season no doubt was an important factor. Blevins et al. (1971) reported decreased evaporation and greater ability for moisture storage under no-tillage systems. The study further indicated the effectiveness of no-tillage corn production on well to moderately well-drained silt loam soils in Kentucky and other regions with similar climatic regimes. Rao et al. (1960) observed that plow-based minimum tillage systems

greatly increased infiltration rates over conventional tillage methods.

In another study, Blevins et al. (1972) noted higher volumetric moisture content under no-tillage conditions in the top 60 cm of soil. They further indicated that tillage system had no effect on soil moisture at a depth greater than 60 cm. Nesmith et al. (1985) reported higher soil moisture in the surface soil with no-till, and they attributed the increased plant available water to the presence of mulch. Mannering et al. (1966), after a five-year study on a sloping, silt loam soil in Indiana, reported minimum tillage for corn substantially increased infiltration. These results were obtained under high intensity, simulated rainfall with rows and tillage parallel to the slope. They point out that infiltration averaged 24% greater on the minimum-tillage treatments than on the conventional treatments. Triplett et al. (1968) found a positive correlation between the quantity of mulch cover and corn yields for no-tilled corn grown in silt loam soils.

Soil Compaction

Soane (1975), as quoted by Hillel (1982), stated that about 90% of the soil surface may be wheel tracked at least once when using conventional tillage to prepare the seedbed for close-growing crops such as cereal grains. There is further trampling of at least 25% during combine harvesting and increasing to as much as 60% where straw is baled and

removed. Keeping tillage passes to a minimum, using (as far as possible) the same wheel tracks, and practicing crop rotation are possible practices that may help alleviate compaction problems.

Bulk density is used as a guide to estimate the degree of soil compaction. The higher the bulk density the greater the soil's resistance to root penetration and moisture movement which in turn lead to reduced seedling emergence and poor crop-growth and yield. Agboola (1981) working on tropical soils in Nigeria pointed out that for four years there was not much change in bulk density (from the initial 1.36 g cm^{-3}) of the soil under the various treatments at 0 to 15 cm and 15 to 30 cm depths, although values were higher for tilled than no-tilled plots and for 15 to 20 cm depth than for 0 to 15 cm. Likewise from a study conducted by Rao et al. (1960), in Illinois, it was shown that, although minimum tillage resulted in lower bulk density, both in the corn row and in the compacted tractor rear wheel track, the difference due to tillage was greater in the compacted wheel tracks. In another study carried out by Shear and Moschler (1969) no significant differences in bulk density were found between tilled and untilled soil at 10 to 12 and 40 to 42 cm depths. Based on these findings they conclude that soil compaction was no greater following several years of no-tillage corn production than when conventional tillage was practiced.

According to the Elanco Products Company (1983), Purdue University researchers found that corn yields were 10 Mg ha^{-1} on non-compacted soil, but only 8.2 Mg ha^{-1} on compacted plots. Ohio workers reported a 30% reduction in corn yields when soil was compacted at the 7.6 to 15.2 cm depth and Illinois scientists reported 60% yield reduction from 10 Mg ha^{-1} to only 6.0 Mg ha^{-1} due to compaction. Blevins et al. (1983) evaluated no-till and conventional tillage systems for corn production in central Kentucky, on a Maury silt loam. They found no difference in bulk density between conventional and no-till treatments on the Maury soil after ten years. However, on somewhat poorly drained silt loam in Western Kentucky, bulk densities in the 0 to 7.5 cm depth of soybean tillage plots were 1.30, 1.37, and 1.37 g cm^{-3} , for chisel-plowing, conventional-tillage, and no-till, respectively. They postulated that the slightly lower bulk density in chisel-plowed treatments may be due to unusually low values obtained when samples were taken from the chisel openings. They were of the opinion that there is little evidence to support the opinion that increases in bulk density under no-till compared with chisel plowing and conventional plowing, as reported by many researchers, are large enough to affect crop yield.

However, Skidmore et al. (1975) reported average bulk densities of 1.7 and 1.3 g cm^{-3} from tilled and pasture fields, respectively, for a Keith silt loam after 60 years of

cultivation. Likewise, Bauer and Black (1981) reported that 25 years after converting grassland to cropland, cultivation to 30.5 cm depth increased bulk densities 7 to 20%, but there was no difference in bulk density between conventional and stubble-mulch management. The higher bulk density for cropped fields was attributed to organic matter depletion. Both the Soil Conservation Society of America (1973) and the United States Department of Agriculture (1977) supported the premise that compaction is greater under reduced tillage than under conventional tillage systems.

Soil Temperature

It is well recognized that surface residues protect soil against erosion and conserve moisture. However, a major adverse effect of surface residue can be the lower soil temperature in the root zone, thus slowing germination and early season crop growth. Griffith et al. (1973) indicated that systems that leave the most surface residue (coulters, rotary, and chisel) had the coolest soil temperatures. Blevins et al. (1971), Burrows, (1963) and Olson and Schoeberl (1970) report lower soil temperatures where corn residues were left on the surface. Moody et al. (1963) noted that the lower temperature under mulch was associated with temporary depression of early season growth. They further illustrated that a substantial increase in growth of mulched over unmulched corn, commencing in late June, was attributed to

improved moisture storage under mulch during the period of high plant water requirement.

Siemens and Oschwald (1978) at Champaign, Illinois, evaluated corn-soybean tillage systems and found no difference between treatments in the mean weekly minimum soil temperatures from late April (8.9°C) to late June (19.4°C). But weekly maximum soil temperatures with the fall-plow treatment averaged from 1.1° to 2.3°C higher than with the conservation tillage treatments during the same period. Furthermore, the fall-plow treatment resulted in corn emergence of one or two days earlier. Corn plants on all plowed plots were generally the tallest throughout the prepollination growth period, and silked two to three days earlier on plowed plots than with conservation tillage treatments. McCalla and Duley (1946) measured soil temperatures in corn plots for several years. They found that heavy mulches, such as 9.0 Mg ha⁻¹, reduced soil temperatures as much as 17.7°C at the 2.5 cm depth in the summer. They further observed that for a period of three or four months following the application of a straw mulch at the rate of 4.5 or 6.7 Mg ha⁻¹, soil temperatures may be lowered as much as 3 to 6°C at the 2.5 cm depth and to 2 to 4°C at the 10.2 cm depth. They state that spring appeared to be the only time when residue cover might reduce soil temperature enough to affect nitrification adversely.

Willis et al. (1957) reported that corn growth increased with soil temperature until the average soil temperature at the 10 cm depth reached about 23 to 24°C. They concluded that the lower soil temperatures created by a mulch tillage system might well be a major reason for the poor early growth and the lower yields of corn that often occur with such systems in the central Iowa region. In an effort to understand the effect of soil temperature on corn growth from mulched and unmulched soils in Iowa, Minnesota, Ohio, and South Carolina, Van Wijk et al. (1959) found stunted early corn growth in the the first three states and no effect of crop residues on early corn in South Carolina.

Effect of Tillage on Irrigation

Water conservation with surface residue has been responsible for marked yield increases, especially in dryland areas of the U.S. Optimizing water use is the goal of many farmers who strive to overcome the variability of infiltration rates in furrow irrigation. In addition to surface residue, the advance rate is influenced by certain soil characteristics such as slope, initial soil moisture, and surface roughness, to mention only a few. One of the most important field data in surface irrigation is the advance rate, which can vary considerably in a given field during the irrigation season (Elliott & Walker, 1982).

Advance Rate

Advance rate is the velocity with which the advancing water front moves in a given furrow. In surface irrigation, a power curve relationship is normally used to describe the advance of the water front. The general form of this function as suggested by Fok and Bishop (1965) is

$$x = pt^r, \quad [2-1]$$

Where x is the advance distance in m, t is the time of advance to x in minutes, and p and r are empirical constants.

Two methods are commonly used to arrive at the constants p and r in the above equation: (1) the two point method of Wilke (1973) resulting in two simultaneous equations

$$x_1 = pt_1^r, \text{ and} \quad [2-2]$$

$$x_2 = pt_2^r, \quad [2-3]$$

where x_1 and x_2 are two advance distances and t_1 and t_2 are the corresponding times to those points, and (2) the regression method.

Arstad and Miller (1978) studied the effect of crop residue on furrow erosion and infiltration on medium-textured soil in Washington State. Disking and till-planting left corn residues in the irrigation furrows. This eliminated soil erosion and increased infiltration rates compared with clean tillage. They concluded that the higher infiltration rates for the reduced tillage probably resulted because corn residue impeded water advance, which in turn increased the wetted perimeter, providing more soil area for infiltration.

Eisenhauer et al. (1982) reported on a two-year tillage study of furrow irrigated corn on a Hastings silt loam in Nebraska. The study included three conventional and three reduced-tillage systems. Their findings show that reduced-tillage systems decreased water advance times by 62% and increased net infiltration by 74%. The advance rates were also 59% faster for the hard furrows than the soft furrows.

Infiltration

Infiltration is the process of water entry into the soil, the rate of this process, relative to the rate of water supply, determines how much water will enter the root zone, and how much, if any will run off (Hillel, 1982). Miller and Aarstad (1971) found the annual addition of 13.4 Mg ha⁻¹ of straw increased infiltration over the control 90% during the first irrigation, 65% during the second and 35% during the third irrigation. Mannering et al. (1966) reported that minimum tillage for corn substantially increased infiltration during a five-year study on sloping, silt loam soil in Indiana. Infiltration averaged 24% greater for minimum tillage than from conventional tillage systems.

Effect of Cropping Sequence on Soil Physical Properties

One of the major factors affecting aggregate size and subsequent erodibility by both wind and water forces is cropping sequence. Researchers have studied aggregate size and stability with corn and soybean in various combinations.

Armbrust et al (1982) reported that continuous corn reduces the amount of soil aggregates >0.84 mm in diameter, dry aggregate stability, and the resistance to overwinter breakdown relative to rotation corn. Wilson and Browning (1945) presented results showing that continuous corn had reduced soil aggregation relative to rotation corn, rotation oats or continuous alfalfa. Similar results were reported by Browning et al. (1942). During the growing season of soybean, aggregation decreased (Strickling, 1951). In terms of erosion losses several investigators (Laflen & Moldenhauer, 1979; Moldenhauer & Wischmeier, 1969) found less soil loss to water erosion after corn than after soybean. In a recent study evaluating the effects of soybean cropping sequences on wet aggregate stability, Fahad et al. (1982) reported greater stability because of larger aggregates for soybean following fallow, than for continuous soybean, using geometric mean diameter as an index. They concluded that roots with a high nitrogen content like soybean lend themselves to rapid decomposition with subsequent reduction in aggregation. Alberts and Wendt (1985) reported results showing no difference in aggregation based on mean-weight diameter values of dry-sieved aggregates between corn and soybean in June, but greater aggregation was observed for corn than soybean in October. In cropping sequences other than corn and soybean it has been observed that forage grasses and grass crops like wheat favor the formation of larger aggregates when grown in

continuous sequence or alternating fallow than when grown in rotation with a legume crop (Wilson & Browning, 1945; Siddoway, 1963). These results indicate the greater effectiveness of grass species in building mechanically-stable, surface-soil aggregates.

Wilson and Browning (1945) found 24% greater aggregation under rotation corn-oats-meadow than under continuous corn when averaged over four years. Armbrust et al. (1982) studied the interaction of continuous monoculture winterwheat, grain sorghum, and soybean with tillage on aggregate size distribution and mechanical stability. Their results showed that aggregates were most stable and least susceptible to overwinter breakdown in the winter wheat plots as compared to sorghum and soybean. Aggregates formed under soybean were observed to be the most susceptible to overwinter breakdown and the least stable.

Laflen and Moldenhauer (1979) measured soil water losses from soybean and corn in a corn-soybean rotation and from sole-cropped corn over a seven-year period in Indiana. They found greater soil losses after soybean than after corn for either the corn-soybean rotation or continuous corn. Erbach (1982) reported that the reduced yield usually associated with continuous corn under conservation tillage systems was not observed for either crop for a corn-soybean rotation. This suggests that corn and soybean can be grown in rotation under conservation tillage systems to control soil erosion without

sacrificing yield of either crop. He noted, however, that following harvest of either corn or soybean, the residue often exceeded 90% ground coverage. Soybean residue tends to be softer and more easily destroyed by tillage operations. In a three-year study, McGregor and Greer (1982) grew corn for grain or silage on erosion plots and small watersheds in Mississippi. They noted that annual soil loss under conventional tillage averaged about 24 and 18 Mg ha⁻¹ for the silage or grain plots, respectively. Annual soil loss rates from the no-till and reduced-till treatments averaged less than 1.5 Mg ha⁻¹. They attributed the reduced erosion to improved soil aggregation resulting from residue cover and increased infiltration associated with the conservation tillage systems.

Mannering and Johnson (1969) found little difference in soil loss during the growing season in Indiana between corn and soybeans with similar row spacings. Siemens and Oschwald (1978) compared seven tillage systems for corn and soybean production in Illinois in terms of erosion control and effects on production. They reported that the amount of residue on the soil surface was almost the same (7.0 Mg ha⁻¹), after harvest for corn and soybeans. After use of the disc-chisel or coulter-chisel, about 84% or 5.9 Mg ha⁻¹ of corn residues remained on the soil surface. After spring tillage and planting, just 2.24 Mg ha⁻¹ remained on the soil surface. The soybean residue was reduced to 0.45 Mg ha⁻¹ after planting with

any of broadcast tillage operations used and 2.24 Mg ha^{-1} with the zero-till treatment. They further pointed out that soil loss caused by simulated rain was substantially lower with conservation tillage systems compared to conventionally tilled plots. Based on these findings, the authors concluded that water erosion is more serious after soybeans than after corn, and erosion is especially severe with fall-tilled, sloping fields.

Fall disk-chisel and similar tillage operations that leave residue or a rough surface are very effective in controlling erosion after corn but are less effective after soybeans. McGregor et al. (1975) compared several no-till cropping systems. Their findings showed that single cropped, no-till soybean produced sufficient residue to control erosion. Mannering et al. (1968) studied soil loss and infiltration from corn, for several rotations on a silt loam soil of 5% slope. They noted that infiltration rates for first and second year corn after a grass-legume meadow were 32 and 26% greater, respectively, than for continuous corn, but the rates for third and fourth year corn after meadow were similar to that of continuous corn. Soil loss from first, second, third and fourth-year corn after meadow were 53, 83, 90, and 97%, respectively, of that from continuous corn. Moldenhauer and Wischmeier (1969) measured the effect of soybeans on the susceptibility of the soil to water erosion. They reported that from 1963 to 1967, average annual soil loss

from soybeans following corn was comparable to that from corn following corn, but soil loss from corn after soybeans was 40% greater. Average annual soil loss from corn after soybeans was 19 Mg ha^{-1} compared to 14 Mg ha^{-1} from each of the other two cropping sequences (losses adjusted for a 91.4 m slope length). Soil loss from corn following soybean was not only greater than that from continuous corn in each year of the test but also greater within the season whenever erosive rains occurred. In another study conducted by Alberts and Wendt (1985) on the effect of soybeans and corn cropping on soil aggregate size and stability, the authors concluded that soybean cropping had no negative effect on the size and stability of aggregates within the tillage zone.

Effect of Tillage on Yield

Tillage system can influence plant growth and yield. Erbach (1982) in a study of tillage for continuous corn and corn-soybean rotations in Ames, Iowa found fall moldboard plowing gave the highest five-year average yield for continuous corn production. Tillage system did not significantly affect yields of either corn or soybean in a corn-soybean rotation. Al-Darby and Lowery (1984) in Wisconsin reported grain yield and total dry matter of corn for a no-till system was comparable to or greater than that for a conventional system corn in spite of growth lag early in the season. Van Doren et al. (1976) compared the relative performance of a wide range of tillage and crop rotations to sustain corn production

on several soils in Ohio. Their findings showed that no-till produced higher yields than conventional tillage on well-drained, sloping soils. They attributed the yield increases to improved moisture storage resulting from the surface mulch and to improved soil structure. On the other hand, when in continuous corn, the no-till system resulted in substantial yield losses for some poorly drained soils. They point out that, for no-till to perform better than conventional tillage, it must be accompanied by crop rotation, desirable plant density and weed control. Shear and Moschler (1969) studied corn on loam soil on the same plots in Virginia for a period of six years, comparing no-tillage, tillage in alternate years, and conventional tillage. Their results showed significantly higher yields of corn with no-till in three of the six years of the study relative to conventional tillage. Alternate-year tillage resulted in significantly higher yields in two successive years than from conventional tillage. Further, there was no benefit from tillage in alternate years as compared with no-tillage. Dry matter yields were higher from no-tillage than conventional tillage for only the first year of the six-year study. In Mississippi, McGregor et al. (1975) found that no-till crop yields of corn were comparable with conventional-till yields. Low yields on some no-till plots indicated that the success of a no-till system depends partially upon timing of herbicide application. Olson and Schoeberl (1970), working in South Dakota, reported yields

from three reduced-tillage systems in a four-year study were at least as good as those from the conventional system. In a three-year study on a permeable prairie soil with a 4% slope in Urbana, Illinois, Van Doran and Stauffer (1943) found 1 Mg ha⁻¹ less corn yield under mulch tillage than with conventional tillage. They concluded that shortage of nitrates under mulch may be a critical factor reducing yields of mulched crops. Jones et al. (1969) found comparable grain yields and plant population between no-till and conventionally tilled plots, but total dry matter production from no-till was significantly lower than that of conventional tillage system. Griffith et al. (1976) compared conventional with conservation tillage and found that chisel and till-plant corn yields were slightly below conventional, while no tillage yields were drastically reduced in the eastern corn belt on soils with poor drainage. In South Carolina, Karlen and Sojka (1985) in a three-year study, found that yields of corn grain with or without supplemental irrigation were lower for the conservation tillage plots than for conventional tillage plots. They concluded that differences in grain yield occurred because lower early season growth for conservation tillage plots could not be rectified later in the season.

Summary

Conservation tillage requires better management practices than conventional tillage to ensure (1) weed control, (2) adequate plant populations, (3) a crop rotation suited to the

climatic-soil environment in which the technology is used and (4) an appropriate irrigation technology for irrigated farming systems.

Weed control still remains a critical factor limiting adoption of conservation tillage technology in the U.S. as well as in other countries. In conservation tillage, the use of conventional or mechanical methods of weed control such as the cultivator was not practical because of surface residues. Consequently, the system must depend mainly on chemical control, particularly for post-emergence weeds. Specific weed control guidelines, chemical and or mechanical, have to be tailored to soil type, tillage system, residue cover, and prevalent weed species (Griffith et al., 1977). When weeds are properly controlled and by judicious selection of the crop rotation, maintenance or even yield increases with conservation tillage are virtually assured.

Yield effects are quite site-specific and the conservation technology requires adjustment for climate, nutrient, soil type, crop rotation and other management practices. One also needs to look at the use of conservation tillage from the farmer's point of view, e.g. (1) relative costs and benefits, (2) short-term vs. long term benefits and (3) better cultural management requirements for conservation tillage. There is need for a thorough socio-economic analysis of conservation tillage to identify both the potential for short-term benefits as well as its effects on a long-term

sustainable agriculture. The farmer can't afford the long-term benefits of conservation tillage technology if the short-term costs are too high. In surface irrigation, the literature emphasizes that reduced tillage systems impede water advance which in turn increases infiltration. In one study, reduced tillage decreased water advance time by 62% and increased infiltration by 74%.

Conservation tillage has potential limitations. In order to achieve success in conservation tillage, certain conditions must be met. Griffith et al (1973) considers that critical factors are weed, insect, and disease control; equipment cost; timeliness of operations; erosion control; above average management; and the agronomic yield potential of the system.

CHAPTER III
MATERIALS AND METHODS

General

This research was initiated in the fall of 1985 and continued through 1987 at Colorado State University's Arkansas Valley Research Center at Rocky Ford, Colorado. The purpose of the study was to evaluate and compare the effect of conventional and reduced tillage systems on yield, crop development and soil physical changes in a three-year, corn-corn-watermelon rotation.

The approach was somewhat different from previous irrigated tillage studies conducted at the Research Center. Treatments were designed to evaluate the two "tillage systems" over the entire duration of a given rotation, rather than to evaluate within-year, individual tillage operations or tillage tools.

The soil in the experimental field is the Rocky Ford series - a deep, well drained, nearly level, silt loam that has a surface layer silted by muddy irrigation water. It is classified as order Entisols, fine-silty, mixed, calcareous, mesic, Ustic Torriorthents (USDA-SCS, 1972). The long-term mean annual precipitation at Rocky Ford is less than 280 mm

(Table 3.1). The mean annual rainfall in 1985, 1986, and 1987 was 321 mm, 329 mm, and 293 mm, respectively. The only lands in the Arkansas Valley that are successfully cropped are those that are irrigated. The experimental field was in alfalfa from 1975-1980, corn in 1981, sorghum in 1982, corn in 1983 and corn-grain sorghum in 1984. Routine soil tests performed during the first year of the study revealed an OM content of 1.4% (Walkley & Black, 1934), a pH (1:1) of 7.9-8.2, (McLean, 1975), an EC (soil) of 0.52 dS m⁻¹ (U.S. Salinity Laboratory Staff, 1954), and a CEC of 21 cmol kg⁻¹ (Chapman, 1965).

Experimental Design

A split-plot randomized block design with four replications was used. The study included two tillage treatments as main plots and year in the crop rotation as subplots. Each replication of 64.0 by 70.1 m (210 x 230 ft) had six plots of 9.14 by 70.1 m (30 x 230 ft). Each plot contained twelve 76-cm rows of corn or eight 114-cm rows of watermelon on 224-cm beds. The plots were separated by 1.5 m wide alleys. The field plot diagram is depicted in Appendix A.

The two tillage system treatments were:

1. Moldboard plow-based conventional tillage (CT) system used for each crop in the rotation.
2. Reduced tillage (RT) where the primary tillage varied, depending on the year of the rotation.

Table 3.1. Long-term monthly average rainfall for Rocky Ford, Colorado for years 1985-1987.

Month	Long Term Average	1985	1986	1987
-----cm-----				
Jan	0.7	2.2	0.3	0.4
Feb	0.6	0.8	0.3	2.6
Mar	1.5	1.7	0.5	1.3
Apr	2.9	5.8	1.7	1.0
May	4.2	7.4	1.0	9.3
Jun	3.2	1.5	5.9	5.5
Jul	4.8	5.3	9.0	2.1
Aug	3.7	1.1	3.8	3.0
Sep	2.6	1.4	5.0	1.5
Oct	1.9	2.3	3.6	0.3
Nov	1.2	2.0	1.6	0.9
Dec	0.6	0.6	0.2	1.4
Total	27.9	32.1	32.9	29.3

Each crop year of the corn-corn-watermelon rotation was represented every year. The crop sequence in this rotation was (1) melon after corn, (2) corn after corn, (3) corn after melon. Thus there were 24 plots - four replications of six treatments.

Field Operations

Appendix B shows the chronological order of the field operations each year. In both CT and RT where primary tillage was used, the primary tillage operations were performed in the fall. Adequate winter and spring precipitation occurred in 1985 and 1987 and eliminated the need for preplant irrigation. However, in 1986, because of limited spring rainfall, the plots required preplant furrow irrigation. The plant residue was not removed from the furrows of the second-year corn RT plots prior to the preplant irrigation. Although the water advance rates were significantly slow, water moved effectively down these residue-covered furrows.

In terms of fertilizer management, all plots received 22.7 kg P₂O₅ ha⁻¹ broadcasted dry in the fall (November) in each of the three years. Preplant applications of aqueous nitrogen solutions were chiseled into the soil each March at rates of 179 and 168 kg N ha⁻¹ in 1985 and 1986, respectively. The nitrogen solution was also a carrier for the preplant herbicides. In 1987, 168 kg N ha⁻¹ was applied again by chisel in March to conventionally-tilled corn plots and first-year

corn in reduced tillage. Ridge-till planted corn (second year corn in reduced tillage) received 161 kg N ha⁻¹. In 1986 and 1987, an additional 112 kg N ha⁻¹ was applied at silking as anhydrous ammonia bubbled into the irrigation water.

Effective weed control in the corn was achieved with split applications of cyanazine (Bladex™)^{1/}; one application applied approximately 21 days preplant with the subsequent application pre-emerge. Weed control for watermelon consisted of preplant application of naptalam (Alanap™) and bensulfide (Prefar™) followed by hand-weeding operations.

Inclement spring weather in 1985 resulted in a late corn planting date of May 28. In 1986 and 1987 corn was planted April 29 and May 5, respectively. The CT corn plots were ridged on 76-cm centers prior to planting. The Buffalo™^{2/} ridge-till planter was used to plant the ridge-till corn for the CT management system, while a conventional double-disk, flex planter was used to plant watermelon of both management systems and the CT corn. All corn row-widths were standard 76-cm rows while watermelon was planted on 224-cm beds, each with two rows per bed.

^{1/}Trade names are used for convenience to the reader and are not intended as an endorsement by Colorado State University.

^{2/}A planter designed to plant corn on ridges usually 10-15 cm higher than the elevation between the rows.

In 1986, the amount of corn residue cover, measured on April after planting was 4.84 Mg Ha^{-1} ($2.52 \text{ Mg Ha}^{-1} \text{ SGe}^{1/}$) for the ridge-till and 2.97 Mg ha^{-1} ($2.0 \text{ Mg ha}^{-1} \text{ SGe}$) for the disk. In 1987 the corn residue after planting on May 5 was 10.15 Mg/ha^{-1} ($5.6 \text{ Mg ha}^{-1} \text{ SGe}$) for the ridge-till and 5.9 Mg ha^{-1} ($2.9 \text{ Mg/ha}^{-1} \text{ SGe}$) for the disk.

Prior to the first irrigation in 1985 a specially-equipped Buffalo cultivator was used to reform the water furrows and non-water furrow ridges of the ridge-till corn for the conservation tillage system. In 1986 and 1987 a standard cultivator with attached furrow openers was used. Sweep cultivators were used for both the CT and RT systems.

Evaluation of Tillage Systems

Conventional (CT) and reduced tillage (RT) systems were evaluated for the corn-corn-watermelon rotation in terms of (1) biological production, (2) changes produced in physical properties of the soil, (3) furrow, water-advance rates and infiltration. Reduced tillage systems are becoming widespread in the Great Plains region. Research on the comparative performance of CT and RT is needed to evaluate the potential for RT management to maintain sustainability of irrigated, row-crop, agricultural systems.

^{1/}Small grain equivalent, based on 25 cm lengths of small grain stalks lying flat on the soil surface arranged in a designated configuration (USDA, Erosion Handbook, 1988).

Evaluation of Biological Production

Dry Matter Accumulation

Dry matter accumulation was determined by sampling of five corn plants at random from a single row on each of the sampling dates given in Table 3.2. The plant material was then air-dried and weighed. Dry matter was expressed as mass per plant. The data were then fitted to Richards function,

$$\ln Y = \ln A - (1/N) (\ln (1 \pm \exp (-K(T - T_0)))) \quad [3-1]$$

where Y is the dependent variable, T (time) is the independent variable, and A, N, T₀ and K are parameters of the Richards function. The parameter A represents the asymptotic maximum, N determines the location of the inflection point and T₀ is an estimate of the time when the curve first rises above zero. The parameter K has no biological significance but can be useful in computing mean relative and mean absolute growth rates (Causton, 1969). This model was first introduced by Richards (1959) for use in plant growth analysis, as a more flexible alternative to functions such as the logistic. Causton (1969) described a computer program to fit the Richards function in 1969. This was expanded by McIntyre et al. (1971) who developed a program based on Causton's 1969 work, the algorithms of which produce what is now known as the Richards I model. The mainframe computer program is written in fortran language and was imported from Australia (McIntyre et al., 1971).

Table 3.2. Dry matter sampling dates - 1986 and 1987.

Sample Number	Year	
	1986	1987
1	5-15	5-27
2	5-27	6-4
3	6-6	6-11
4	6-16	6-18
5	6-20	6-25
6	7-1	7-2
7	7-9	7-9
8	7-17	7-28
9	8-7	8-5
10	8-18	8-14
11	10-17	9-16
12	--	10-7

The Richards I model gives among other things (1) cumulative dry matter on a daily basis, all points of inflection, daily values of the absolute growth rate (first derivative), relative growth rate and the change in rate of the absolute growth rate (second derivative).

The general form of the function and derivatives are shown in Table 3.3. Further, the data were subjected to the analysis of variance using the Statistical Analysis System (SAS).

Corn Plant Population

Final plant population was determined by counting corn plants within the 15 m² (0.014ha) final harvest area. The harvest area consisted of the middle four rows, each 15 m long or (4 rows x 0.76m x 15m = 45.6 m²/plot).

Yield

Corn. The middle four rows, each 15 m long, were hand harvested for grain yield. Ears were counted and shelled by hand. Grain yields were adjusted to 15.5% moisture.

Analysis of variance and mean separation test was performed by using the SAS.

Watermelon. Watermelon yield was expressed as (1) marketable number (i.e., watermelons with a mass of 7 kg or greater), and (2) seed yield. Watermelon fruit counts for marketable number were made each of the two years on

Table 3.3. Application of the Richards function in tillage system studies.

General form:

Cumulative Growth:

$$W = A(1 + e^{-k(T-T_0)})^{-1/N} \quad [3-1]$$

Derivatives and Other Properties:

Cumulative growth:

$$W = A(1 + e^{(kT_0 - kT)})^{-1/N}$$

Instantaneous absolute growth rate (AGR):

$$dw/dT = \frac{+ake^{(kT_0 - kT)}}{n} (1 + e^{(kT_0 - kT)})^{-(1/n+1)} \quad [3-2]$$

Instantaneous relative growth rate (RGR):

$$(1/W) dW/dT = \frac{ke^{(kT_0 - kT)}}{n(1 + e^{(kT_0 - kT)})} \quad [3-3]$$

Change in rate of absolute growth rate $d(\text{AGR})/dT$:

$$d^2W/dT^2 = \frac{+ak^2e^{(kT_0 - kT)}}{n^2(1 + e^{(kT_0 - kT)})^{(1/n+2)}} (e^{(kT_0 - kT)} - n) \quad [3-4]$$

^{1/}Taking ln of equation no. 3-1 and substituting W for Y gives equation 3-1 on page 46.

approximately September 15 from the middle two beds of each plot (i.e., four rows). After the vines died and dropped, the watermelons were mechanically harvested, placed in drums, and moved to a processing plant where seed and pulp were dried. Seed was separated from dried pulp with gravity separators and then weighed. The harvest area consisted of the entire plot (641 m²). Border effects were minimized by 1.50 m-wide alleys plots. Analysis of variance and mean separation test was performed using the SAS package.

Physial Properties of the Soil

Dry Aggregate Size Distribution and Stability

In 1985-86 and 1986-87 between harvest (October) and planting (May), eight soil samples from the 0 to 3 cm depth were collected at random from each plot. A flat, square-cornered, spade was used for this purpose. The samples were placed in wooden trays and brought into the greenhouse for air drying.

Four sampling times were identified as (1) post-harvest, (2) post fall-tillage, (3) winter-tillage, and (4) planting. Approximately 1kg of soil from each sample was sieved to determine the aggregate size distribution using the rotary sieve method developed by Chepil (1962b). The various size fractions were weighed and values recorded after the first sieving. The size fraction representations were <0.42, 0.42-0.84, 0.84-2.0, 2.0-6.4, 6.4-19.2, and >19.2 mm diameter.

The mechanical stability or resistance of soil to breakdown by mechanical forces, was determined by a second sieving of size fractions >0.84 mm. Aggregate size fractions <0.84 are considered erodible, therefore were not included in the second sieving. Mechanical stability as used in this dissertation is equal to W_1/W (100) where W is the weight of aggregates >0.84 mm after first sieving and W_1 is their weight after the second sieving (Mazurak et al., 1953). The percentage of aggregates >0.84 mm ($w/tm(100)$) was calculated from the ratio of the total mass of aggregates >0.84 mm after the first sieving (w) to the total mass of soil (tm). As the rate of wind erosion varies inversely with the proportion of clods >0.84 mm diameter (Chepil, 1958; Chepil & Woodruff, 1959), the percentage of clods >0.84 mm diameter was used as an index of soil stability. Potential erodibility was therefore computed from fractions <0.84 mm using the equation (Armbrust, 1987).

$$Y = a + B \ln x; \quad a = 295.38, \quad B = -66.24 \quad [3-5]$$

where Y is equal to potential soil erodibility in $Mg \text{ ha}^{-1}$, and a and B are regression constants, and x is the aggregate size fraction >0.84 mm diameter.

Geometric mean diameter (GMD) was determined from fraction sizes between 0.42 and 19.2 mm using the following equation of Mazurak (1950),

$$GMD = \exp \left[\frac{\sum_{i=1}^n W_i \log \bar{X}_i}{\sum_{i=1}^n W_i} \right] \quad [3-6]$$

where W_i is the weight of aggregates in a size class with an average diameter x_i , and $\sum_{i=1}^n W_i$ is the total weight of the sample. The geometric mean diameter is used as an index of the aggregate size distribution. A small menu driven computer program was prepared and used to make this equation manageable. All data pertaining aggregate size distribution and stability were subjected to an analysis of variance using the SAS.

Soil Compaction

Core samples for laboratory determination of bulk density were taken from along the rows with steel cylindrical samplers. The cores were 2.065 cm in diameter and 15.24 cm high, and had a volume of 51.05 cm³.

Six core samples were taken from each of four replications for eight corn plots (four CT and four RT) on July 2, and 18 of 1986 at 15.24 and 30.48 cm depths. A third sample consisting of 96 cores (i.e., 12 cores from each replication) were taken on July 24.

In July and August of 1987, samples were again taken from each of the same plots as in 1986. The samples were oven dried at 105° C for 24 hours, weighed, and bulk density of soil was calculated as the mass of dry soil solids divided by its bulk volume.

Soil Moisture

Volumetric soil moisture was determined gravimetrically from core samples taken for bulk density. This was accomplished by multiplying percent gravimetric soil moisture by the bulk density.

Soil Temperature

Daily measurements of soil temperature were taken for both CT and RT between May and mid-August of 1986 and 1987 seasons. Glass thermometers with approximately 2.5 cm penetration probes were installed at random along the rows of two CT and two RT plots.

Soil heat units (SHU), expressed as degree days, were calculated by subtracting a base temperature of 10 C from the daily mean soil temperature.

$$\text{SHU} = (T_x - T_b) \quad [3-7]$$

where:

T_x = the mean daily temperature $(T_{\text{mx}} + T_{\text{min}})/2$

T_b = a base temperature of 10°C

If $T_x < T_b$, the soil heat unit is zero. For example if the daily mean soil temperature is 18°C, SHU for the day is 8 degree-day soil heat units.

A quadratic regression model was also fit to the data for an analysis.

Effect of Tillage on Irrigation

To evaluate the effect of tillage on irrigation, infiltration and the advance rate of the water front in the furrow was determined as follows:

Advance rate: Eight plots were used to evaluate advance for a distance of 61 m. A 60-degree V-notch trapezoidal flume (Robinson & Chamberlain, 1960) was placed upstream and downstream of each furrow. Inflow of water was initiated using a siphon. The time at which water reached the outlet of the upstream flume was recorded. Head readings on each flume were taken immediately after inflow started and recorded with time. Advance time was recorded as water reached each station. The distance between stations was 7.6 m.

The two point method of Wilke (1973) was used to analyse the advance data.

Infiltration: Infiltration was determined by subtracting the outflow volume from the inflow volume and dividing by the land area irrigated per furrow.

CHAPTER IV
RESULTS AND DISCUSSION

Crop Production

Corn Grain Yields

Corn yields on the reduced tillage (RT) compared favorably with conventional tillage (CT) yields. Table 4.1 shows the yield results for each of the three years for corn and the three-year mean. There were no significant differences^{1/} between the two tillage systems in corn yield for any of the three years or for the three-year mean whether corn followed melon or corn. Nor was there a significant year x tillage interaction. Grain yields ranged from 7.5 Mg ha⁻¹ in 1985 to 15.5 and 13.8 Mg ha⁻¹ for 1986 and 1987, respectively. It should be noted that even though 1985 was the first year of the experiment, comparisons of corn yields between tillage systems were the same in 1986 and 1987 as in 1985. The minimal effect of tillage system on corn yield has been observed in other research (Van Doren et al. 1976, and Shear and Moschler, 1969). It should be noted that this three-year study may not have been conducted over a sufficient time

^{1/}Not different by Duncan's multiple range test (MRT) at P=0.05.

Table 4.1. Corn grain yield as influenced by tillage system and crop sequence; corn-corn-watermelon rotation, 1985-1987.

Crop Sequence	Primary Tillage (for seedbed preparation)	Year			Mean
		1985	1986	1987	
-----Mg ha ⁻¹ -----					
1 Corn (after melon)	Plow (CT ₁)	7.38a ^{1,2}	16.2a	13.9a	12.5a
1 Corn (after melon)	Disk (RT ₁)	7.67a	15.2a	13.2a	12.0a
	Mean:	<u>7.5</u>	<u>15.7</u>	<u>13.6</u>	<u>12.3</u>
2 Corn (after corn)	Plow (CT ₂)	7.64a	15.2a	13.6a	12.2a
2 Corn (after corn)	Rid. till (RT ₂) ³	7.31a	15.5a	14.4a	12.4a
	Mean:	<u>7.4</u>	<u>15.4</u>	<u>14.0</u>	<u>12.3</u>

Mean: ⁴	CT	7.5	15.7	13.8	12.3
	RT	7.5	15.4	13.8	12.2

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

²Grain yields corrected to 15.5% moisture content.

³Ridge planted, no primary tillage.

⁴Yearly means of CT and RT are not different at P=0.05.

period to fully develop changes in soil properties that affect yields of corn.

Watermelon Production

Table 4.2 shows the effect of tillage system on marketable melons and seed yield for each of the three years and for the three-year mean. Tillage system had no effect on melon production in 1986. There was, however, a significant increase in marketable number of watermelon with RT in both 1985 and 1987 in which a disk was used for the primary tillage. The RT system yielded 5740 marketable watermelon ha^{-1} as compared to 4290 ha^{-1} produced by CT, an increase of 34%. A 52% increase for RT was obtained for marketable melons in 1987. A similar trend was noted in 1986. When averaged over three-years marketable melons for the RT was 26% above CT (4460 vs 3540 melons ha^{-1}).

Seed yield was not affected by tillage system in 1985, but a decrease in seed yield was observed in 1986 with RT where the disk was used as the primary tillage tool. It was noted that the watermelon vines dropped sooner in the RT system. In addition, there were more diseased melons in this management system. In 1987, significantly lower watermelon seed yield was observed in the CT than in the RT system, an opposite response as in 1986. The effect of tillage system on watermelon seed production varied with year. There was no difference for tillage system in the three-year average (0.21 vs 0.20 Mg ha^{-1} for CT vs RT, respectively).

Table 4.2. Marketable numbers and watermelon seed yield as influenced by tillage system: corn-corn-watermelon rotation, 1985-1987.

Tillage System	Primary Tillage	Marketable Number ¹			Seed Yield ¹		
		1985	1986	1987	1985	1986	1987
		----No. ha ⁻¹ x100----			-----Mg ha ⁻¹ -----		
CT	Plow	42.9b	46.0a	17.4b	0.24a	0.22a	0.17b
RT	Disk	57.4a	50.0a	26.5a	0.22a	0.16b	0.21a

Mean (3 years):		CT	35.4b		CT	0.21a	
		RT	44.6a		RT	0.20a	

¹Average values within a column followed by same letter are not different by Duncan's Multiple Range Test (P=0.05).

Crop Development Patterns

Figures 4.1 to 4.3 show total dry matter accumulation patterns per plant for each of the tillage systems for 1986. Any point on the curves in Figure 4.1 gives the dry matter accumulated to that date (g plant^{-1}). The slope of the line at that point (dy/dx) is the absolute growth rate (AGR) in g plant^{-1} shown in Figure 4.2. The maximum AGR shown in Figure 4.2 occurs at the inflection point of the accumulation growth curve shown in Figure 4.1. For example, on day 59 when the maximum growth rate of $10 \text{ g plant}^{-1} \text{ day}^{-1}$ was attained for CT, the total dry matter accumulated was 146 g plant^{-1} (Figures 4.1 and 4.2).

The rate of change in growth rate is the second derivative of the growth curve (d^2y/dx^2). As the AGR increased (Figure 4.2), its rate of change (Figure 4.3) was positive until the first inflection point was reached. Then the rate of change decreased and became zero when the AGR maximized (Figure 4.3). After the AGR reached a maximum ($d^2y/dx^2=0$), its rate of change became negative, and decreased to a minimum at the second inflection point on the right side of the AGR curve. Then the rate of change in AGR increased (negative values decreased) to zero when plant growth ceased. Figures 4.4, 4.5 and 4.6 show the dry matter accumulation and growth rate patterns for 1987.

The pattern of dry matter accumulation was similar for both first and second year corn for each of the tillage

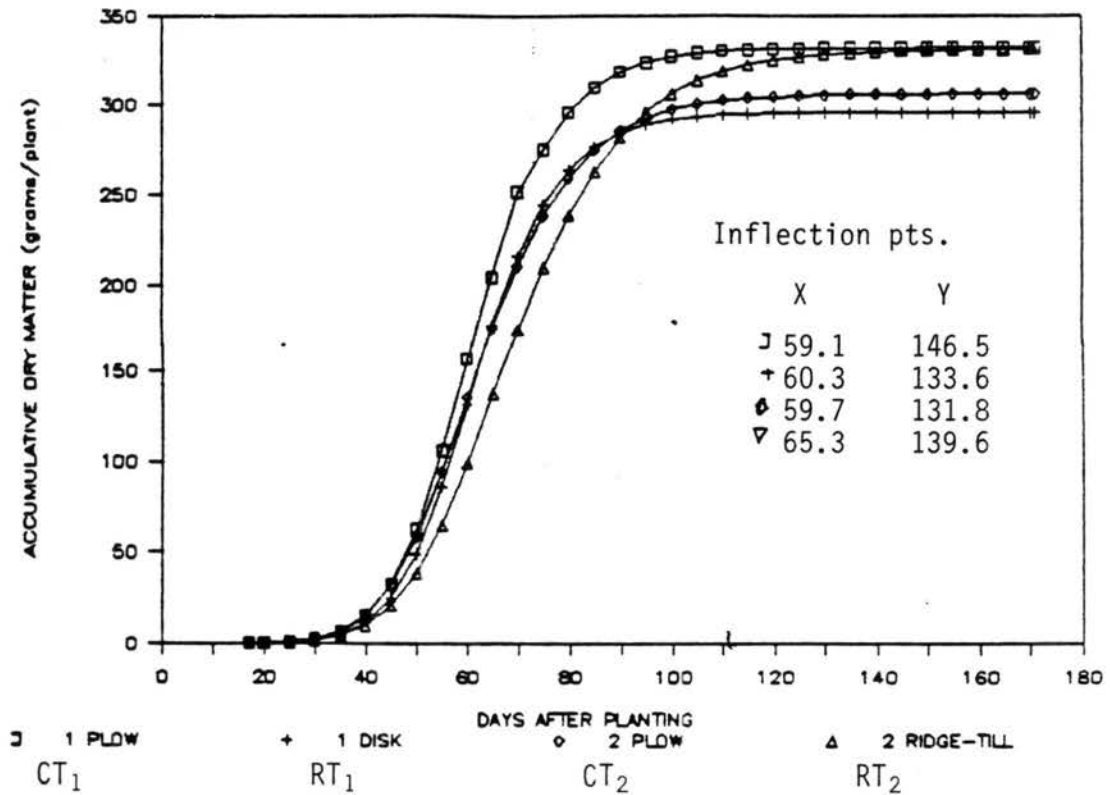


Figure 4.1. Seasonal accumulation of total dry matter for first (CT₁ and RT₁) and second year (CT₂ and RT₂) corn as affected by tillage system, 1986.

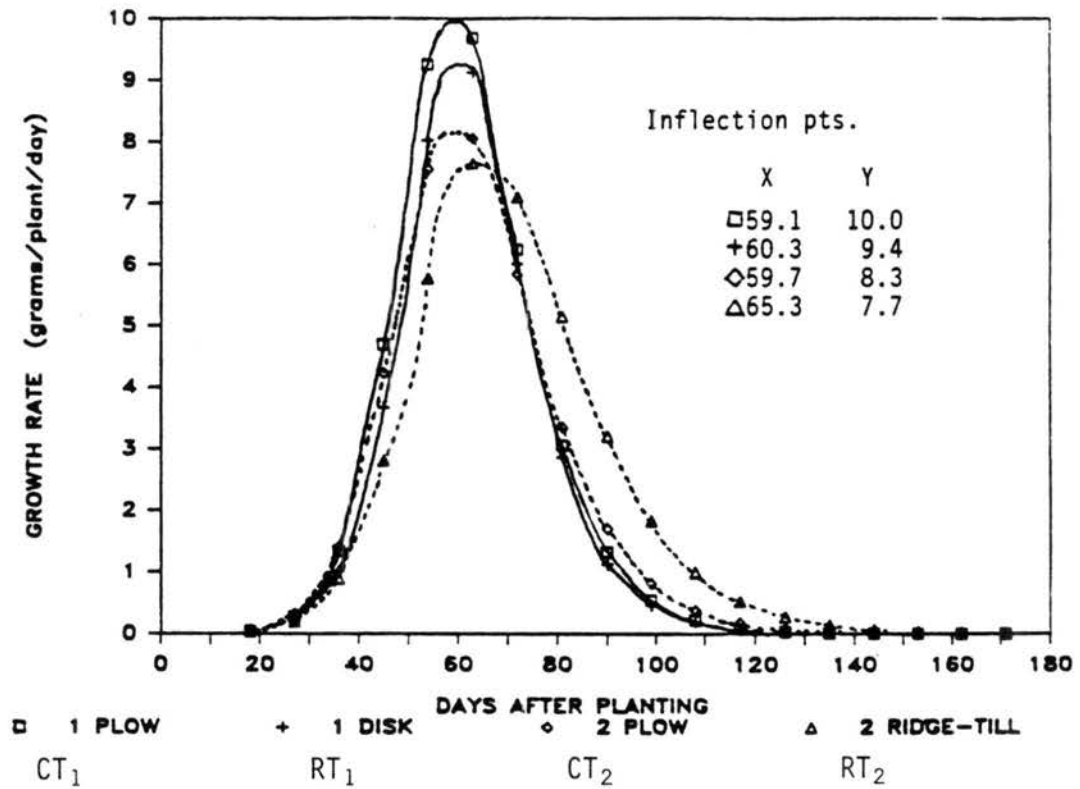


Figure 4.2. Seasonal absolute growth rate (AGR) of total dry matter for first (CT₁ and RT₁) and second year (CT₂ and RT₂) corn as affected by tillage system, 1986.

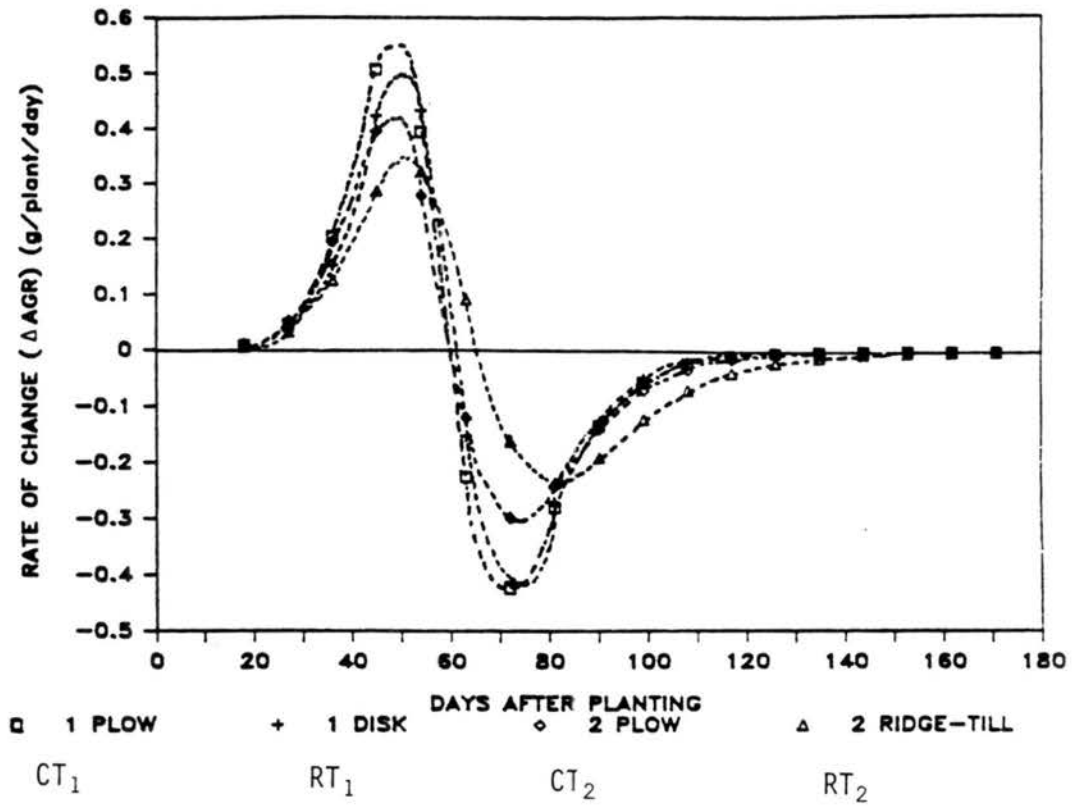


Figure 4.3. Seasonal rate of change in absolute growth rate (AGR) for first (CT₁ and RT₁) and second year (CT₂ and RT₂) corn as affected by tillage system, 1986.

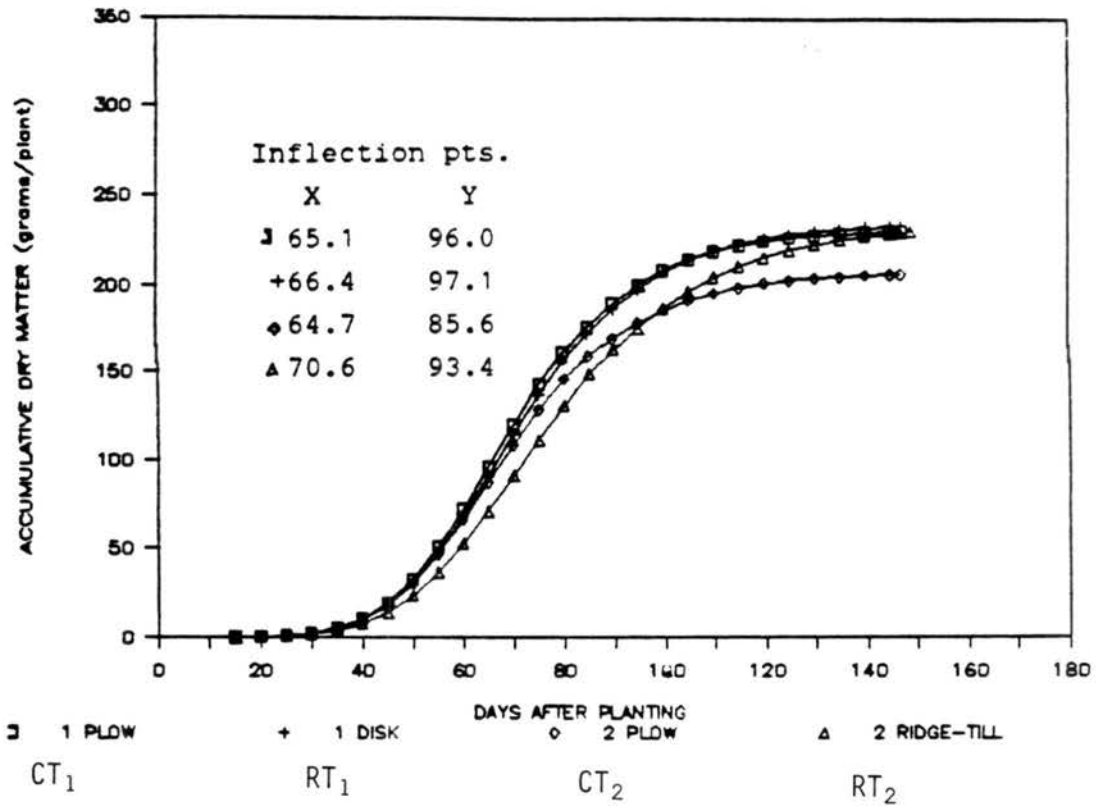


Figure 4.4. Seasonal accumulation of total dry matter for first (CT₁ and RT₁) and second year (CT₂ and RT₂) corn as affected by tillage system, 1987.

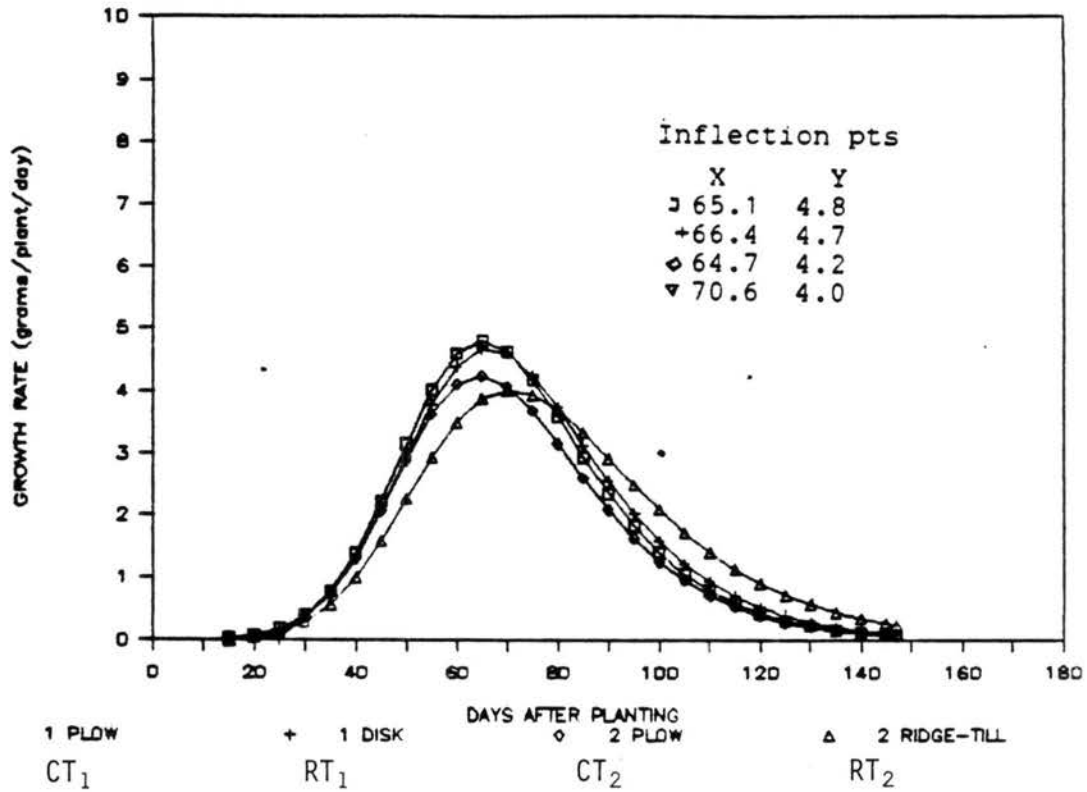


Figure 4.5. Seasonal absolute growth rate (AGR) of total dry matter for first (CT₁ and RT₁) and second year (CT₂ and RT₂) corn as affected by tillage system, 1987.

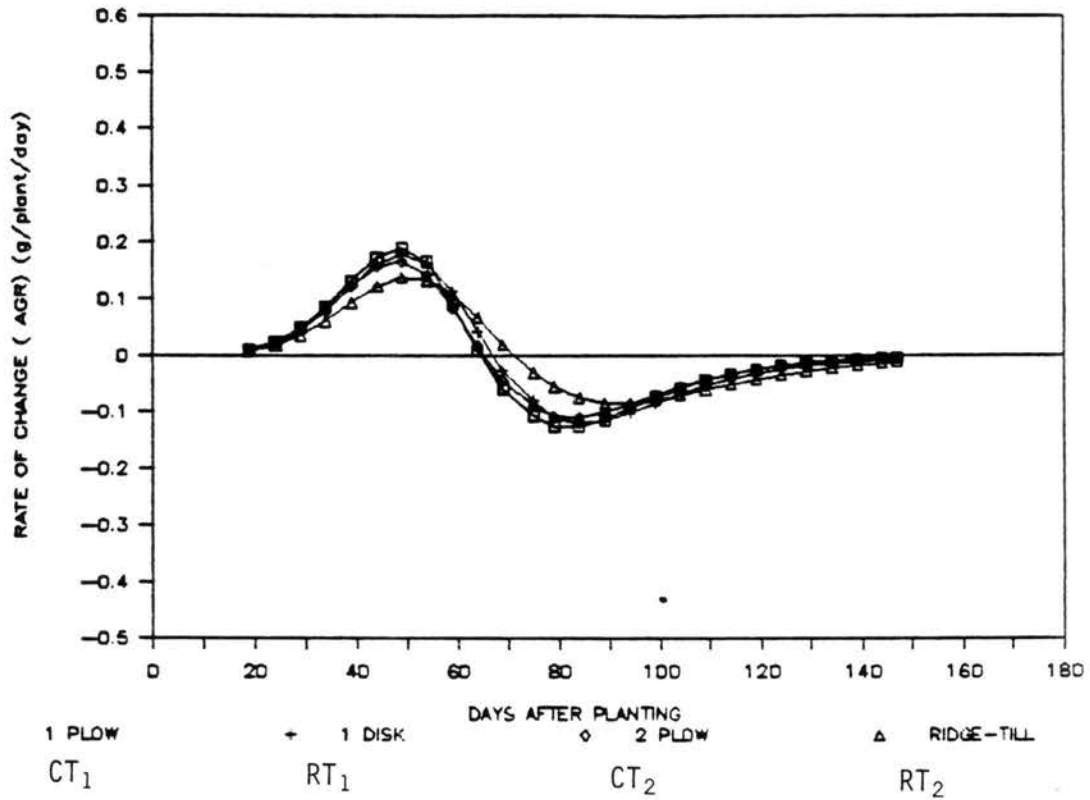


Figure 4.6. Seasonal rate of change in absolute growth rate (AGR) for first (CT₁ and RT₁) and second year (CT₂ and RT₂) corn as affected by tillage system, 1987.

systems. For both years corn grown in the RT system developed at a slower rate through 70 days than that in the CT system (Table 4.3). Not only did the maximum AGR occur later with RT tillage, but the maximum rate was lower (Figures 4.1 and 4.4). Conversely, after 90 days, corn under RT generally showed the faster AGR (Table 4.4). From Table 4.3, it can be seen for 1986 and 1987 that on both the 59th and 70th day after planting, the accumulated dry matter for the CT treatments was greater than that accumulated by RT treatments. Also for each year, conventional tillage (plow) of first year corn accumulated the most dry matter and RT of second year (ridge-till) the least. There was little difference between RT (disk) of first year corn and CT (plow) of second year corn. It is to be noted that the ridge-till treatment was the lowest on day 70 after planting, but it surpassed the CT treatment by day 140, about 20 days after the CT treatment had ceased growth.

Final total dry matter production, calculated in Mg ha^{-1} is summarized in Table 4.5. When averaged over the two years 1986-1987, total dry matter production was about the same for the two tillage systems (34.6 vs 35.3 Mg ha^{-1}). There was, however, a significant tillage by corn-sequence-year interaction for both 1986 and 1987 and for the two-year mean. Total dry matter production was greater for the CT system for first-year corn (37.3 vs 33.5 Mg ha^{-1}), but for second-year corn, production was greater for the RT system (37.0 vs 31.9

Table 4.3. Calculated dry matter accumulation after 59 and 70 days for first and second year corn, 1986 and 1987.

Day	Crop Sequence	Primary Tillage (for seedbed preparation)	Year	
			1986	1987
			-----g/plant ¹ -----	
59	1st year corn	CT (plow)	145.7	67.6
	1st year corn	RT (disk)	121.8	63.5
	2nd year corn	CT (plow)	126.4	62.0
	2nd year corn	RT (ridge-till)	91.6	49.0
70	1st year corn	CT (plow)	245.2	119.4
	1st year corn	RT (disk)	215.8	113.8
	2nd year corn	CT (plow)	210.5	107.9
	2nd year corn	RT (ridge-till)	174.7	90.8

¹Not significant at P=0.05 for the tillage x crop interaction for 63 and 71, and 57 and 76 days after planting in 1986 and 1987, respectively.

Table 4.4. Calculated absolute growth rate on days 59, 70 and 90 for first and second year corn, 1986 and 1987.

Day	Crop Sequence	Primary Tillage (for seedbed preparation)	Year	
			1986	1987
----g/plant/day ¹ ----				
59	1st year corn	CT (plow)	10.2	4.5
	1st year corn	RT (disk)	9.3	4.3
	2nd year corn	CT (plow)	8.3	4.0
	2nd year corn	RT (ridge-till)	7.1	3.4
70	1st year corn	CT (plow)	7.1	4.6
	1st year corn	RT (disk)	6.8	4.6
	2nd year corn	CT (plow)	6.4	4.1
	2nd year corn	RT (ridge-till)	7.4	4.0
90	1st year corn	CT (plow)	1.3	2.3
	1st year corn	RT (disk)	1.2	2.5
	2nd year corn	CT (plow)	1.7	2.1
	2nd year corn	RT (ridge-till)	3.2	2.9

¹Significant F test for the tillage x crop sequence interaction for 93 days after planting in 1987.

Table 4.5. Total dry matter production of corn at final harvest as influenced by tillage system and crop sequences, 1986-1987.

Crop Sequence	Tillage	Year		
		1986	1987	Average
-----Mg ha ⁻¹ -----				
1st year corn	CT (plow)	44.6a ¹	29.9ab	37.3a
1st year corn	RT (disk)	38.8a	28.1b	33.5ab
2nd year corn	CT (plow)	38.0a	25.7b	31.9b
2nd year corn	RT (disk)	39.9a	34.0a	37.0a

Mean:	CT	41.3	27.8	34.6
	RT	39.4	31.1	35.3

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Mg ha⁻¹). That ridge-till seedbed preparation was used for the RT system for second-year corn may have been the factor that gave the late-season spurt in growth (Figures 4.1 and 4.4) and surpassed the CT system for the final harvest.

This study demonstrates how the Richards model of the seasonal growth pattern can be used to explain final harvest yields. Based on these results, when early growth is the production goal, such as seasonal serial harvesting for mid-season animal feed, CT would be the better practice because of more rapid early growth. Conversely, where the production goal is final dry matter or grain, the RT system with ridge-till would be the recommended practice.

Physiologically, the second derivative of Richards model also identified corn silking dates for the two tillage x crop sequence treatments both in 1986 and 1987. The minimum value for the second derivative is the second inflection point on the AGR curve. The date at which the inflection occurred was either the same day (four comparisons) or within one day (four comparisons) of the recorded field observations of silking (Table 4.6). To this author's knowledge, the physiological significance of the minimum values shown by the second derivative has not been reported in the literature.

Total dry matter production and grain yields varied considerably between years. Average dry matter yields for 1987 were 48% lower than 1986 and grain yield 12% lower. The differences can be attributed primarily to a 12 to 13 day

Table 4.6. Silking date observations for corn in relation to inflection dates of the AGR curves, 1986-1987.

Year	Crop Sequence	Tillage System	Observed Silking Date	Date of Change in Growth Rate ¹	
				Days After Planting	Calendar Date
1986	Corn (after melon)	Plow (CT)	7-7	71	7-7
	Corn (after melon)	Disk (RT)	7-7	72	7-8
	Corn (after corn)	Plow (CT)	7-10	75	7-11
	Corn (after corn)	None (RT)	7-17	82	7-18

1987	Corn (after melon)	Plow (CT)	7-21	82	7-21
	Corn (after melon)	Disk (RT)	7-21	82	7-21
	Corn (after corn)	Plow (CT)	7-21	82	7-21
	Corn (after corn)	None (RT)	7-28	90	7-29

¹Days after planting to the second inflection point on the AGR curve.

delay in planting in 1987 relative to 1986 because of a wet spring. There was a hail storm on May 20 in 1987, but it caused only minor crop damage.

Corn Plant Population

Although tillage influenced total dry matter production in 1986 (Table 4.5), final plant population was not affected by tillage in the three years of the study (Table 4.7). It was observed that corn plants in the CT plots generally were taller than those in RT plots. The reduced height was more evident in 1987 than in 1986 or in 1985, and also more pronounced in the ridge-tilled corn plots than in the disked plots for the RT system.

Corn Ear-Leaf Nitrogen Contents

At silking a nitrogen deficiency was observed in the ridge-till corn. Total ear-leaf nitrogen contents were determined. The results revealed a significantly lower total nitrogen content in the ridge-till corn than in the other treatments (Table 4.8). This suggests that the ridge-till method was not as efficient in nitrogen utilization since all treatments received the same quantity of nitrogen fertilizer. There were no differences in grain nitrogen between the two tillage systems, which suggest that an additional quantity of nitrogen applied during the reproductive period alleviated the problem.

Table 4.7. Corn plant population as influenced by tillage system and crop sequence; corn-corn-watermelon rotation, 1985-1987.

Rotation Year and Crop	Primary Tillage (for seedbed preparation)	Year		
		1985	1986	1987
-----Plants ha ⁻¹ x100-----				
1 Corn (after melon)	Plow (CT)	55.7a ¹	79.7a	82.6a
1 Corn (after melon)	Disk (RT)	57.3a	74.9a	79.4a
Mean:		<u>56.5</u>	<u>77.3</u>	<u>81.0</u>
2 Corn (after corn)	Plow (CT)	55.1a	74.5a	79.3a
2 Corn (after corn)	None (RT) ²	53.7a	74.3a	86.9a
Mean:		<u>54.4</u>	<u>74.4</u>	<u>83.1</u>

Mean:*	CT	55.4	77.1	81.0
	RT	55.5	74.6	83.2

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

²Ridge-till planted.

*There were no differences between CT and RT yearly means at P=0.05.

Table 4.8. Total corn ear-leaf nitrogen at silking and grain nitrogen contents at harvest for each tillage system; corn-corn-watermelon rotation, 1986-1987.

Year of Rotation	Primary Tillage (for seedbed preparation)	Ear Leaf Nitrogen		Grain Nitrogen	
		1986	1987	1986	1987
-----%-----					
1 Corn (after melon)	Plow (CT)	2.84a ¹	2.64a	1.28a	1.30ab
1 Corn (after melon)	Disk (RT)	2.70b	2.45b	1.34a	1.26b
Mean:		<u>2.77</u>	<u>2.55</u>	<u>1.31</u>	<u>1.28</u>
2 Corn (after corn)	Plow (CT)	2.81ab	2.56ab	1.31a	1.35a
2 Corn (after corn)	None (RT) ²	2.35c	2.43b	1.29a	1.26b
Mean:		<u>2.58</u>	<u>2.50</u>	<u>1.30</u>	<u>1.31</u>

Mean:	CT	2.83*	2.60*	1.30	1.33
	RT	2.53	2.44	1.32	1.26
Critical Level:		2.0 - 2.5		1.25 - 1.50	

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

²Ridge-till planted without primary tillage.

*Differ from RT yearly mean at P=0.05.

Summary of Crop Productivity

When the two rotation years for corn were averaged, both grain (Table 4.1) and total dry matter production (Table 4.5) were similar for the two tillage systems. There was, however, a significant tillage-system x rotation-year interaction for total dry matter. The interaction in Figure 4.7 shows a higher dry matter for first-year corn for CT, but higher dry matter for RT for second year corn. As previously noted, the ridge-till planting method may have been an important factor resulting in the higher yields for RT total dry matter. The same interaction for corn grain was not significant although there was the same trend. Thus in concurrences with the published literature, crop production using RT may be superior to, equal to or less than that attained with CT. The net effect will depend upon factors such as the site-specific physical environment, the type of system being compared, crop species, and crop sequence, plant part harvested and time of harvest. Nor did tillage system had significant effect on final plant population of corn, either following watermelon or corn. The comparable corn plant densities and resultant grain yield and dry matter production for RT and CT reflect the potential for the RT system for wider application into the technology of low input, sustainable agriculture.

The results also indicate reduced nitrogen uptake for the ridge-till system as evidenced by the lower nitrogen content in the ear-leaf at silking. A possible factor affecting the

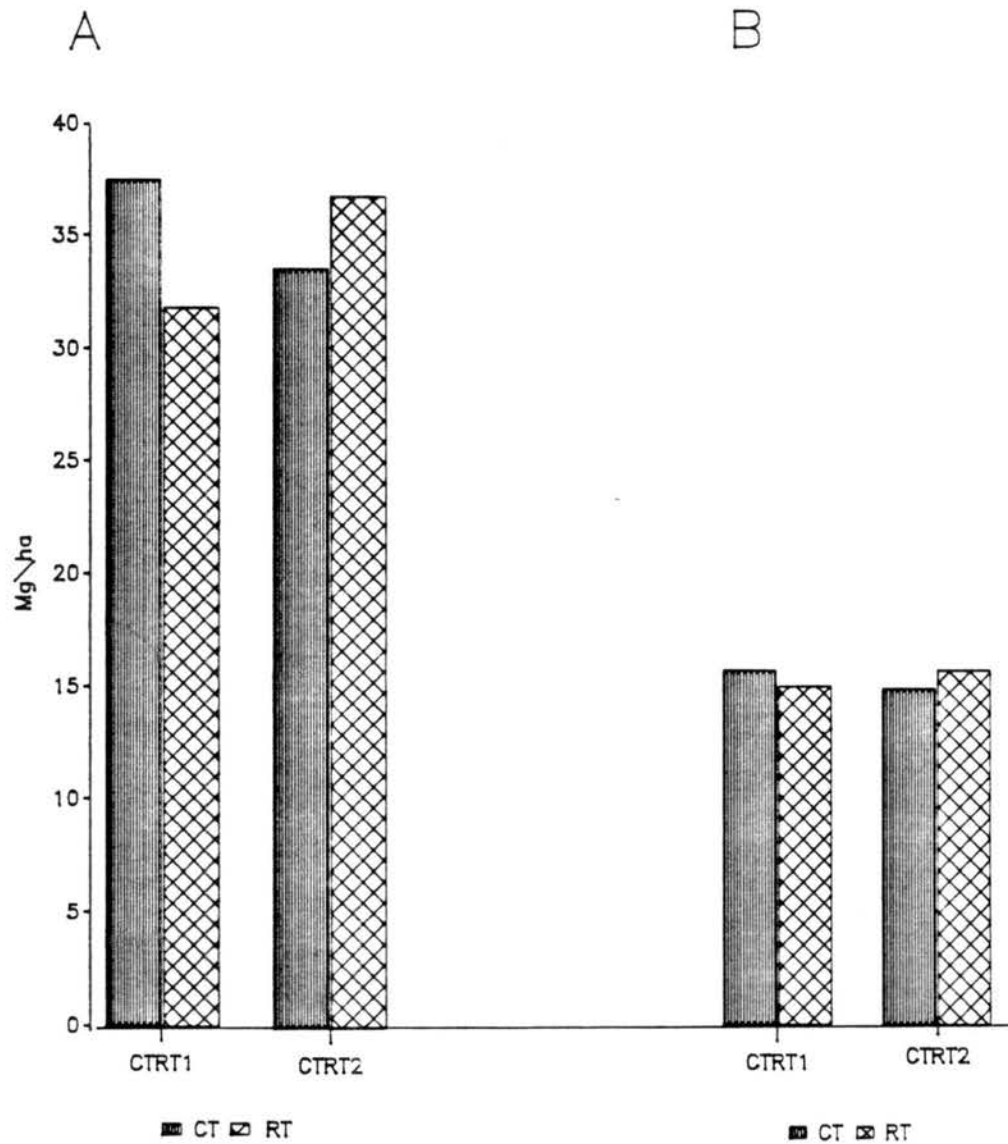


Figure 4.7. The effect of tillage system and year of rotation on total dry matter and grain yield, 1986-1987 average. Subscripts 1 and 2 refer to first and second year corn, respectively.

nitrogen uptake might well be its tie-up in plant residues in the surface soil. Often, the RT system has been found to cause reduced NO_3 -nitrogen in the rooting zone (Moody et al, 1952 and, Dowdell and Cannell, 1975).

In 1985 and 1987, RT gave a significant increase in the marketable number of watermelon. There were no differences for tillage system in 1986, although the trend indicated an increase. In 1985, watermelon seed yields were not affected by tillage, but the 1986 seed yields were lower where reduced tillage was used. This was attributed to a greater number of diseased watermelon. The 1987 watermelon seed yields were greater with reduced tillage.

Effect of Tillage on Physical Properties of the Soil

Soil Aggregation

Aggregate size. Dry aggregate size >0.84 mm in the 0-3 cm depth was not affected by tillage system (Table 4.9) in either 1986 or 1987, but it was affected both by sampling date (Table 4.10), and cropping sequence (Table 4.11). There was also an interaction between sampling date, tillage and crop sequence. Duncan's multiple range test at the 0.05 level identified differences in aggregate size due to sampling date (Table 4.10). In 1986, the post-fall sample had the most aggregates >0.84 mm. The winter sample had the lowest aggregation and the planting samples were intermediate. Again in 1987, the post-harvest and fall samplings had more

Table 4.9. Effect of tillage system on percentage of >0.84 mm diameter aggregates in the 0-3 cm depth, 1986 and 1987.

Tillage System	Year	
	1986	1987
	-----%-----	
RT	58.0a ¹	61.6a
CT	56.9a	60.6a

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Table 4.10. Effect of sampling date on percentage of >0.84 mm diameter aggregates in the 0-3 cm depth, 1986 and 1987.

Sample ID	Sampling Date	Year	
		1986	1987
		-----%-----	
Post Harvest	Nov:25-85;26-86	56.8b ¹	64.4a
Post Fall	Dec:24-85;25-86	67.6a	63.2a
Winter	Feb:17-86;19-87	51.8c	58.5b
Planting	Apr:29-86;18-87	53.5bc	58.5b

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Table 4.11. Effect of cropping sequence on percentage of >0.84 mm diameter aggregates in the 0-3 cm depth, 1986 and 1987.

Crop Sequence	Year	
	1986	1987
	-----%-----	
Corn after watermelon	62.2a ¹	63.2a
Corn after corn	52.9c	58.8b
Watermelon after corn	57.3b	61.3a

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

aggregates >0.84 mm than the winter or planting samplings. Chepil (1954) reported that the breakdown of coarse aggregates during the winter is apparently due to expansion of ice crystals within the aggregates. The sampling-date effect may be attributed to several possible causes, for example, cropping sequence, season of the year, and/or soil moisture condition when samples were taken.

The cropping sequence effect in 1986 (Table 4.11) shows that there were fewer aggregates >0.84 mm in the continuous corn plots (corn after corn) than for watermelon after corn or corn after watermelon. In 1987, continuous corn plots again had fewer aggregates >0.84 mm than corn after watermelon or watermelon after corn. There was no difference in 1987 between corn after watermelon and watermelon after corn.

The effect of tillage system and cropping sequence on aggregate size distribution relative to primary particle size

distribution is shown in Figures 4.8 through 4.11. The area between the primary particle size distribution curve and the curve for a given management system as shown in Figure 4.8 indicates the degree of aggregation for that system. The greater the area between the two curves, the greater the aggregation (Fahad et al., 1982). When comparing two management systems, the system shown by the lower curve is more aggregated.

Table 4.12 shows the ranking of amount of aggregation for the two management systems. The average aggregation for the RT system ranked 14% and 24% higher than CT system for 1986 and 1987, respectively.

Geometric mean diameter of aggregates. To further evaluate the effect of cropping sequence on soil aggregation, the geometric mean diameter (GMD) was calculated from size distributions of soil aggregates to 19.2 mm. Although there was no tillage effect on GMD either year (Table 4.13), there were differences in GMD at the 0.05 probability level due to cropping sequence (Table 4.14). The trend was similar to that for aggregate size >0.84 mm discussed earlier. The GMD was larger for situations where there were more aggregates >0.84 mm diameter. There was an exception in 1987 where continuous corn plots were comparable to the watermelon after corn sequence. The smaller GMD associated with continuous corn plots is indicative of less aggregation for continuous corn.

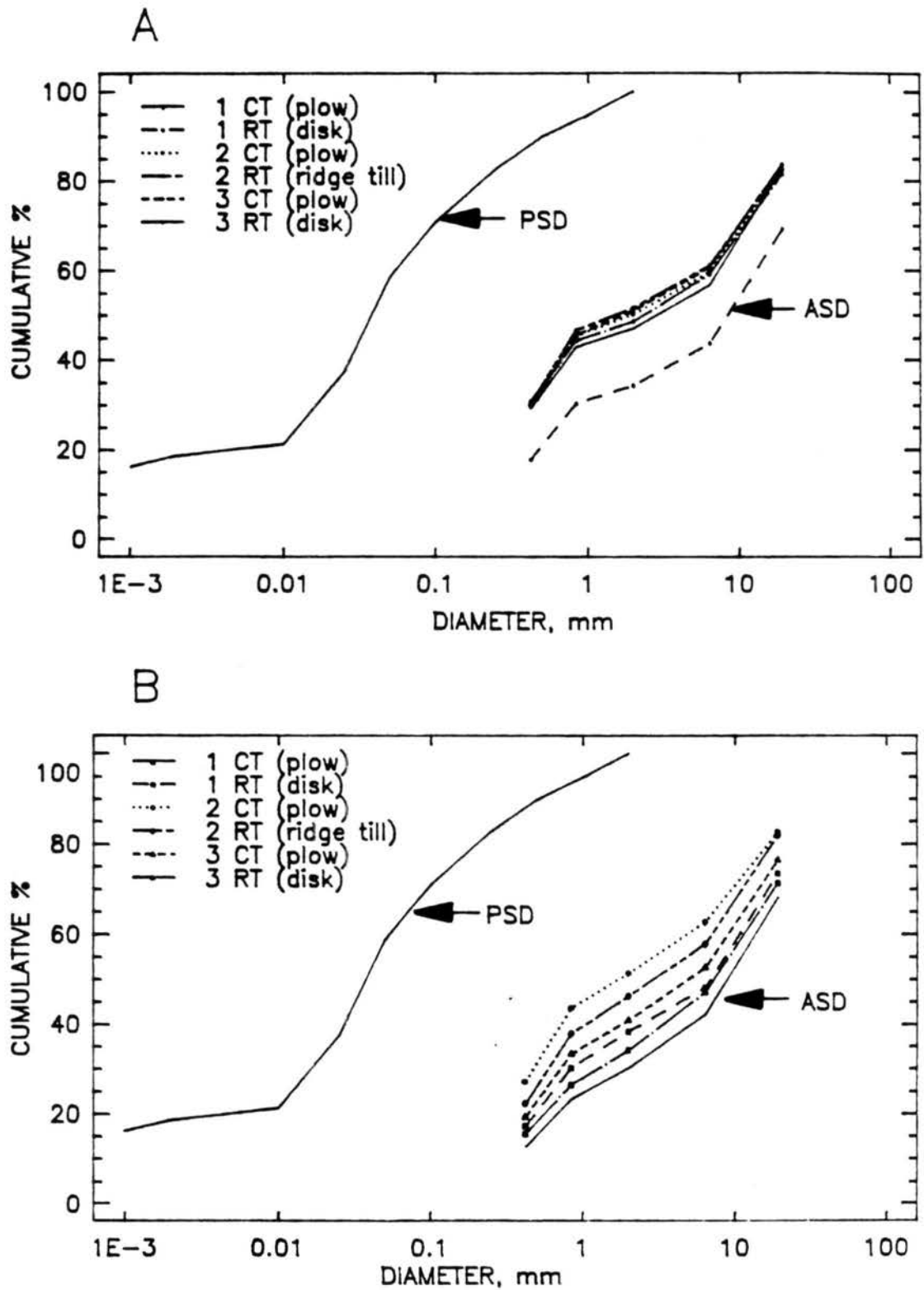


Figure 4.8. Effect of tillage system and cropping sequence on particle size distribution (PPS) and on aggregate size distribution (ASD) for a) post harvest, 1986 and b) post fall, 1986.

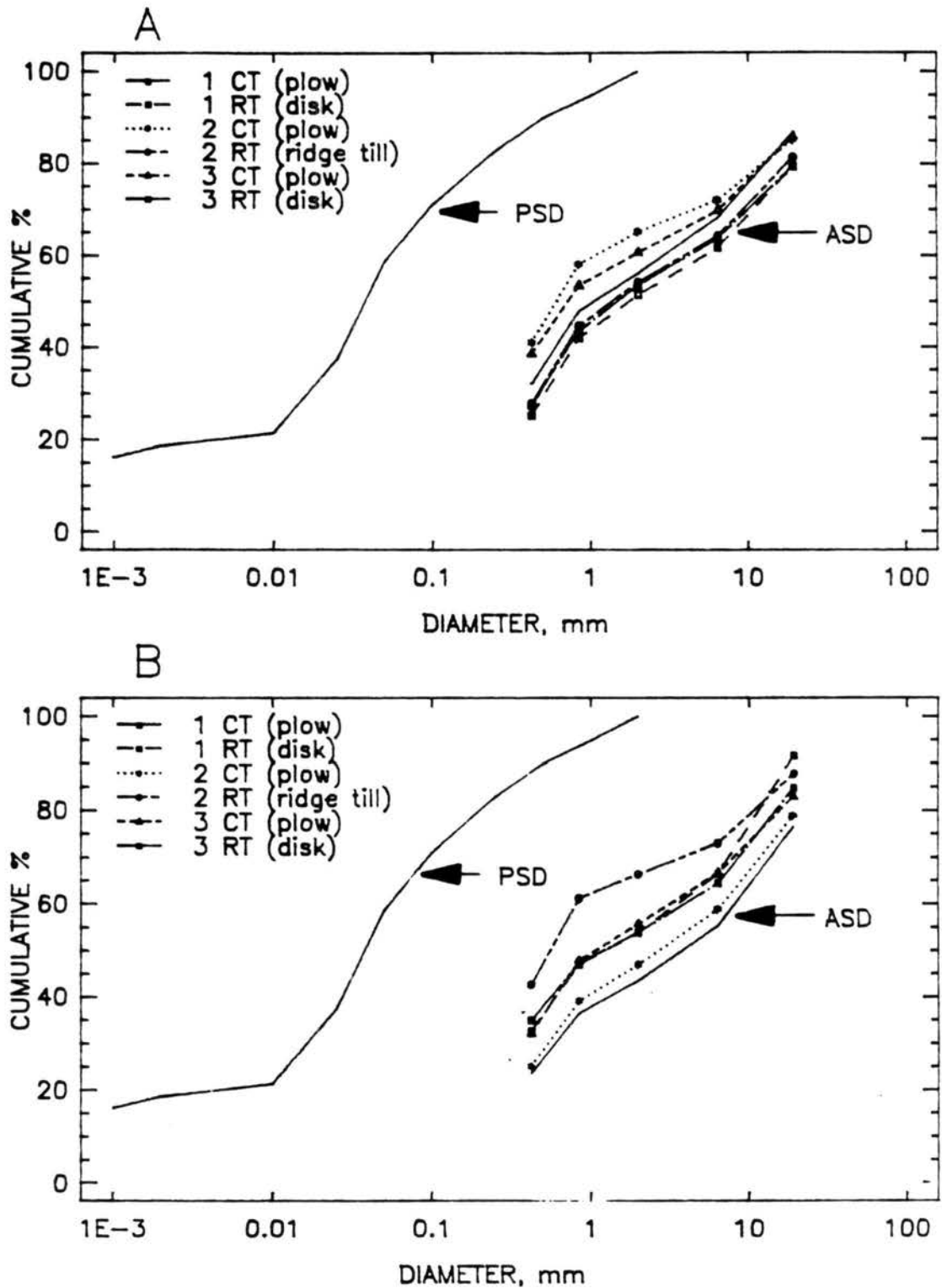


Figure 4.9. Effect of tillage system and cropping sequence on particle size distribution (PPS) and on aggregate size distribution (ASD) for a) winter, 1986 and b) planting, 1986.

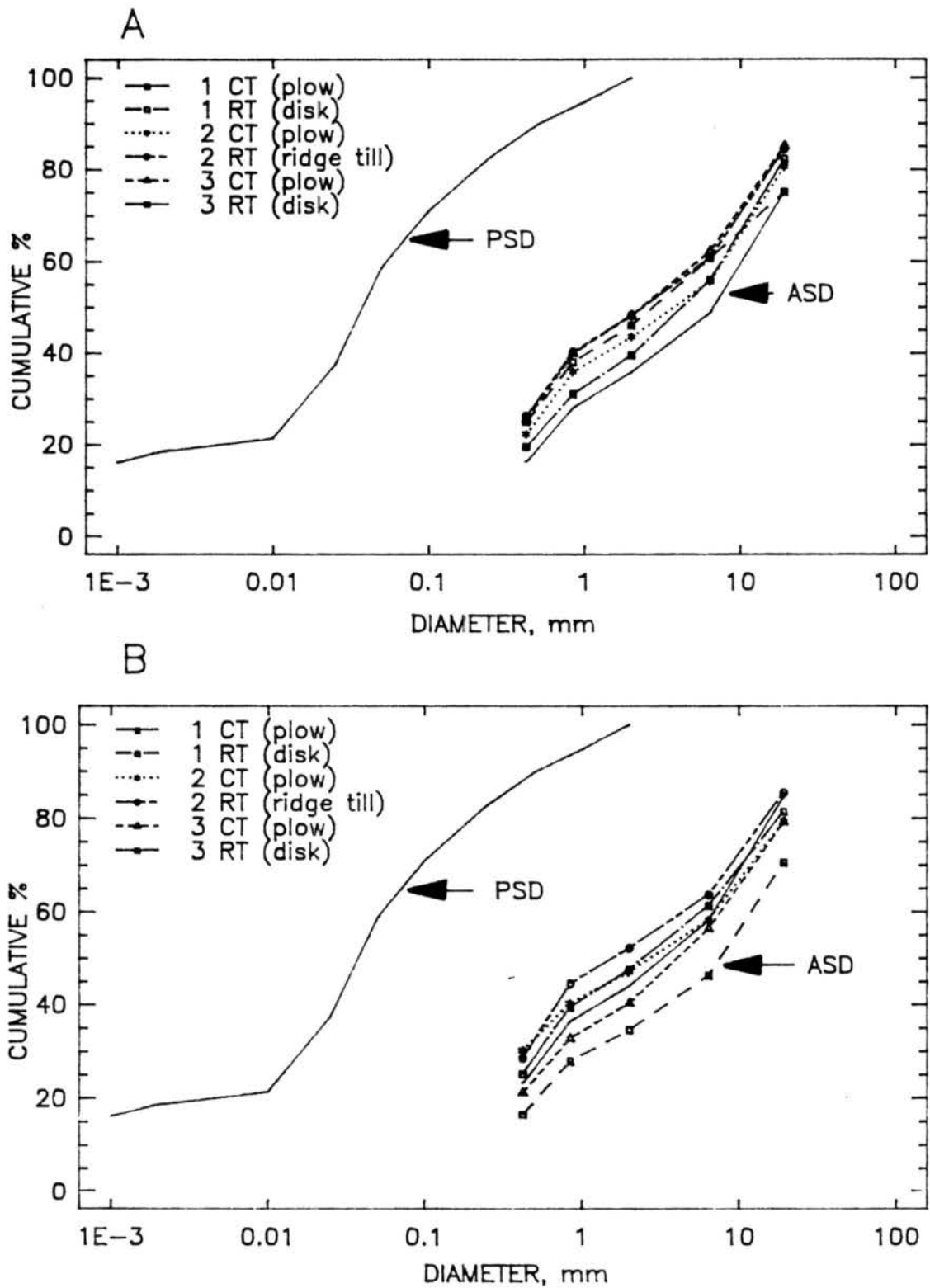


Figure 4.10. Effect of tillage system and cropping sequence on particle size distribution (PPS) and on aggregate size distribution (ASD) for a) post harvest, 1987 and b) post fall, 1987.

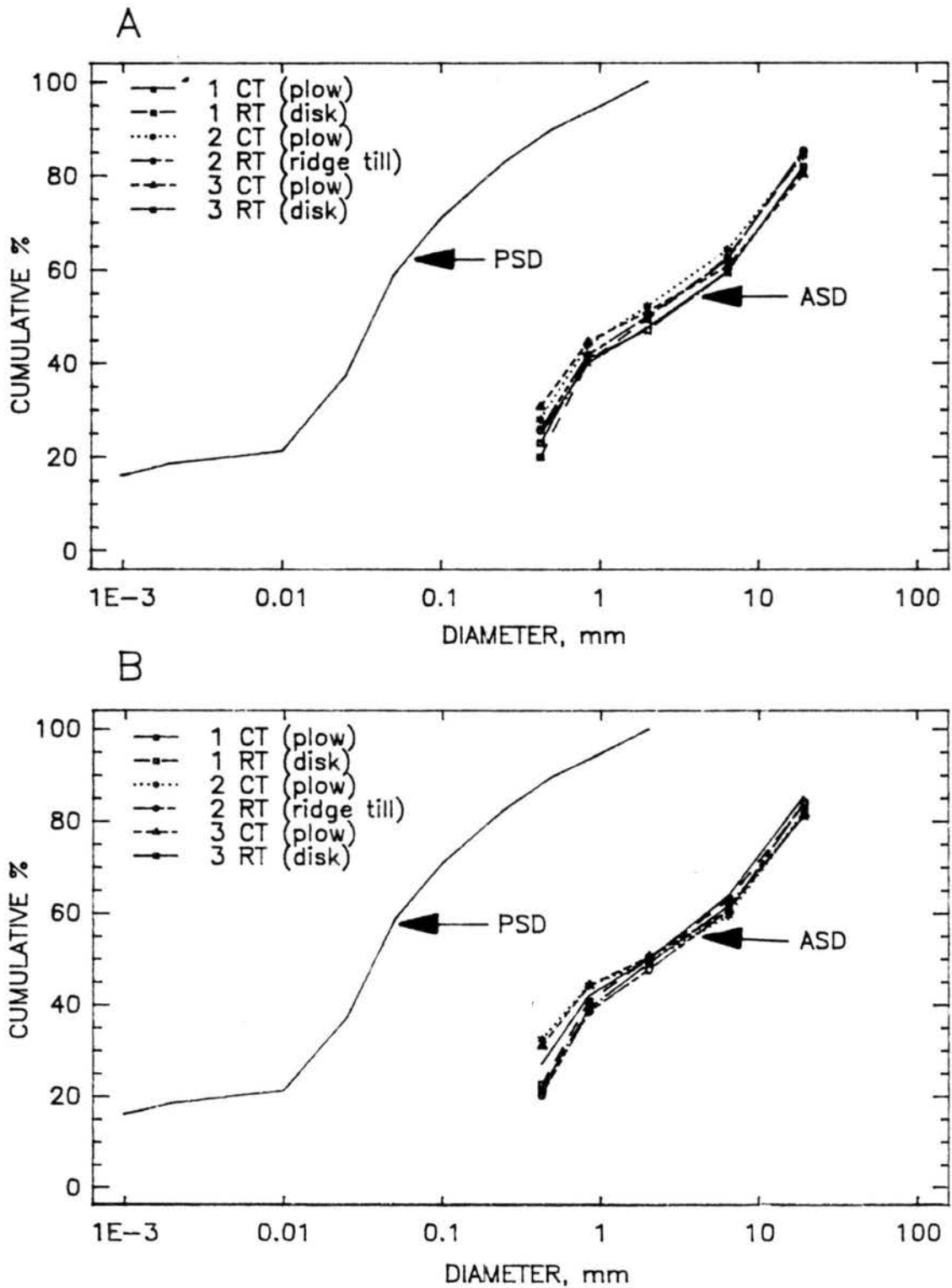


Figure 4.11. Effect of tillage system and cropping sequence on particle size distribution (PPS) and on aggregate size distribution (ASD) for a) winter, 1987 and b) planting, 1987.

Table 4.12. Effect of the tillage and cropping sequence on aggregate size distribution relative to primary particle size distribution.

Sampling Date	Tillage x cropping sequence: 1986					
	CT (plow)	RT (disk)	CT (plow)	RT (r.t.)	CT (plow)	RT (disk)
-----Ranking, 1986-----						
Nov-85	2	1	4	6	5	3
Dec-85	1	3	6	5	4	2
Feb-86	4	1	6	3	5	2
Apr-86	1	4	2	6	5	3
-----Ranking, 1987-----						
Nov-86	1	4	3	5	6	2
Dec-86	3	1	4	6	2	5
Feb-87	2	3	6	4	5	1
May-87	6	3	4	1	5	2

Ranking:						
1986:	CT average = 3.75					
	RT average = 3.25		difference 14%			
1987:	CT average = 3.92					
	RT average = 3.08		difference 24%			

¹A score of 1 to 6 was used for ranking above treatments, 1 being the highest and 6 the lowest aggregation. For example for Nov-85, CT (plow) is ranked 2, RT (disk) is 1, CT (plow) is 4, etc.

Table 4.13. Geometric mean diameter of aggregates as affected by tillage, 1986 and 1987.

Tillage	Year	
	1986	1987
	-----mm-----	
Reduced tillage (RT)	1.4a ¹	1.6a
Conventional tillage (CT)	1.4a	1.5a

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Table 4.14. Geometric mean diameter of aggregates as affected by crop sequence, 1986 and 1987.

Crop Sequence	Year	
	1986	1987
	-----mm-----	
Corn after watermelon	1.6a ¹	1.7a
Corn after corn	1.2a	1.5b
Watermelon after corn	1.4b	1.5b

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Geometric mean diameter as affected by sampling date is presented in Table 4.15. As with the aggregate size (Table 4.10), aggregation as shown by GMD was greater in fall than in winter. The relationship between the GMD and percentage aggregates >0.84 mm are shown in Figure 4.12. The correlation coefficient as determined by the regression line is significant indicating that the fraction of aggregates >0.84 mm is highly related to GMD.

Table 4.15. Geometric mean diameter of aggregates as affected sampling date, 1986 and 1987.

Sample ID	Sampling Date	Year	
		1986	1987
		-----%-----	
Post Harvest	Nov:25-85;26-86	1.4b ¹	1.8a
Post Fall	Dec:24-85;25-86	1.9a	1.6b
Winter	Feb:17-86;19-87	1.0c	1.4c
Planting	Apr:29-86;18-87	1.1c	1.4c

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

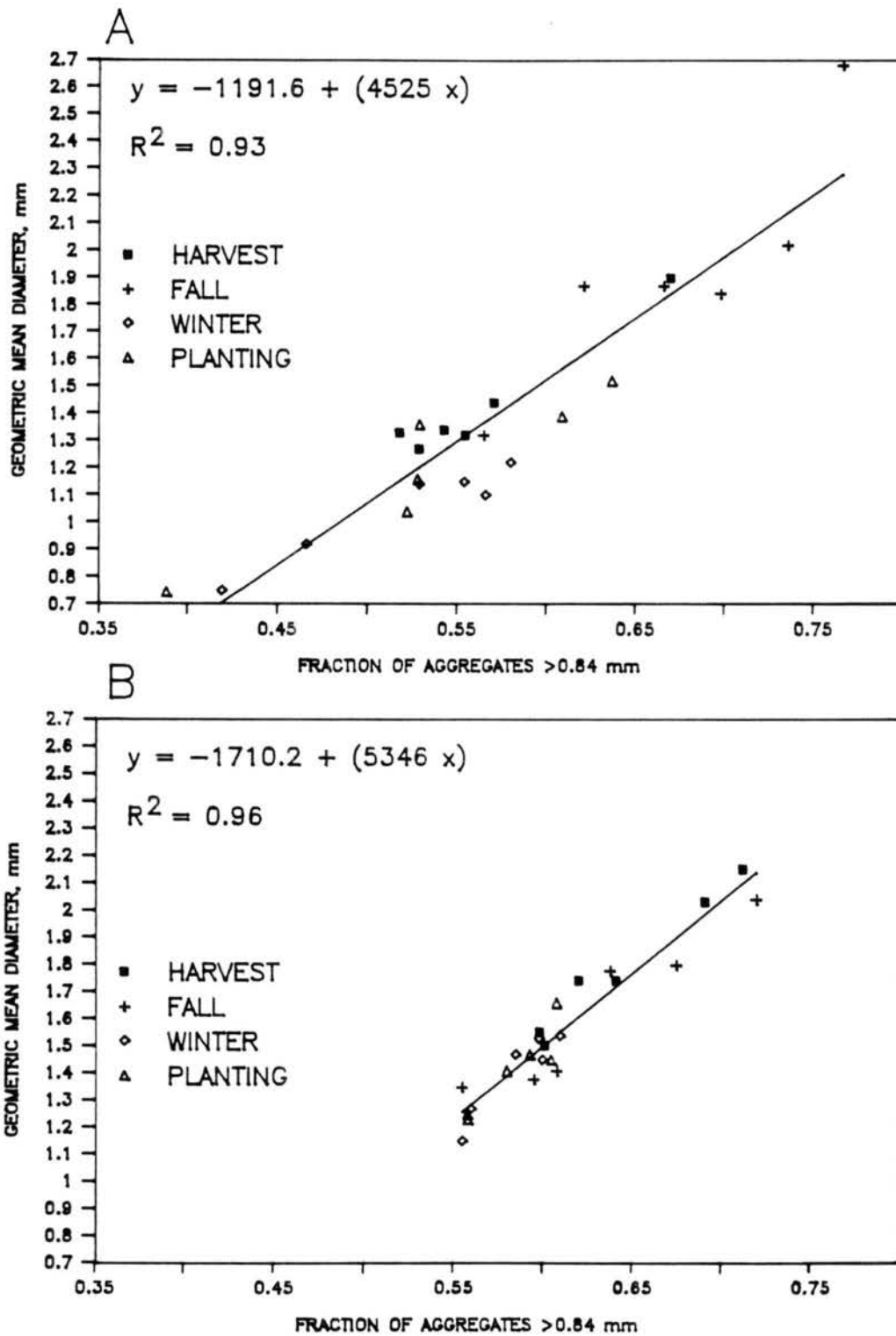


Figure 4.12. Regression of the fraction of aggregates >0.84 mm on geometric mean diameter for sampling date data for a) 1986 and b) 1987.

Erodibility. The erodibility of the dry aggregates was evaluated from the percentage of aggregates >0.84 mm, a method proposed by Siddoway (1963) who found that the potential for soil loss by wind erosion varied inversely with the proportion of clods >0.84 mm in diameter. Erodibility, (Y) was calculated using the equation (USDA-Wind Erosion Lab, 1987) $Y = a + b \ln x$; where Y is the potential soil loss in $\text{Mg ha}^{-1} \text{ yr}^{-1}$; $a = 295.38$; $b = -66.24$ and x is size fraction >0.84 mm diameter. Erodibility was greater for both winter and planting samplings (Table 4.16) than for the post harvest and post fall samplings. The calculation of erodibility using the above equation gave results consistent with aggregate stability based on a simple percentage of aggregates >0.84 mm for both years.

Table 4.16. Potential soil loss (erodibility) as affected by sampling date, 1986 and 1987.

Sample ID	Sampling Date	Year	
		1986	1987
		----- $\text{Mg ha}^{-1} \text{ yr}^{-1}$ -----	
Post Harvest	Nov:25-85;26-86	28.7b ¹	44.6b
Post Fall	Dec:24-85;25-86	17.1c	45.7b
Winter	Feb:17-86;19-87	35.0a	58.5a
Planting	Apr:29-86;18-87	32.8ab	58.5a

¹Average values within a column followed by same letter are not different by Duncan's multiple range test ($P=0.05$).

Chepil (1954) reported that aggregates break down during the winter. Although reaggregation of the smaller size aggregates occurs in the spring, Chepil concluded that the wind erosion potential at the soil surface was greater in the spring than in the previous fall. Hinman and Bisal (1968) and Logsdail and Webber (1959) studied the effect of freezing on soil aggregate-breakdown and found that bare soil when exposed without snow cover was highly erosive in the spring.

The effect of cropping sequence on erodibility (Table 4.17) shows that erodibility is greatest for the corn-corn crop sequence, again consistent with the measurement of aggregates >0.84 mm. There were no differences in erodibility due to tillage system for either of the two years (Table 4.18) of the study.

Table 4.17. Potential soil loss (erodibility) as affected by crop sequence, 1986 and 1987.

Crop Sequence	Year	
	1986	1987
	-----Mg ha ⁻¹ yr ⁻¹ -----	
Corn after watermelon	22.5c ¹	47.0b
Corn after corn	34.1b	56.7a
Watermelon after corn	28.5b	51.7ab

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Table 4.18. Soil loss potential (erodibility) as affected by tillage, 1986 and 1987.

Tillage	Year	
	1986	1987
	-----Mg ha ⁻¹ -----	
Reduced tillage (RT)	25.7a ¹	53.5a
Conventional tillage (CT)	31.1a	50.0a

¹Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Mechanical stability. Mechanical stability of dry aggregates was determined as the percentage of >0.84 mm aggregates remaining after a second sieving of size fraction >0.84 mm. Since aggregate-size fractions <0.84 mm are considered erodible (Chepil, 1962b), this size was not included in the second sieving. Mechanical stability of dry aggregates was greater in fall of 1986-87 than the following winter (Table 4.19), but in 1985-86 the mechanical stability was highest at planting, the post-fall sample was next in stability with the post-harvest lowest stability.

Tillage effect on mechanical stability of soil aggregates was consistent. Both in 1986 and 1987, RT was significantly more stable than CT (Table 4.20). The effect of cropping sequence on dry aggregate mechanical stability over the two years is shown in Table 4.21. Aggregate mechanical stability was less both years for the corn-corn sequence. The result was similar to the GMD measurements (Table 4.14) for the

various cropping sequence treatments. Since the beneficial effect of soil organic matter on soil is well known (Van Doren, 1976), the increase in mechanical stability for RT probably is associated with the increase in crop residues in the 0-3 cm depth. This would increase the microbial activity and soil aggregation. Broader (1984) found no-tillage surface soils (0-7.5 cm) were wetter, higher in organic matter, and more compact than conventionally-tilled soils. Further, Moody et al., (1952) reported the 0-7.5 cm layer of soil under mulch was more aggregated, and was higher in both percentage organic matter and total nitrogen than conventionally-tilled (plowed) soils.

Table 4.19. Mechanical stability of >0.84 mm aggregates as affected by sampling date, 1986 and 1987.

Sample ID	Sampling Date	Year	
		1986	1987
		-----% ¹ -----	
Post Harvest	Nov:25-85;26-86	71.1c ²	82.7a
Post Fall	Dec:24-85;25-86	81.9ab	85.3a
Winter	Feb:17-86;19-87	79.6b	78.8b
Planting	Apr:29-86;18-87	84.2a	79.0b

¹Percentage of the >0.84 mm aggregates remaining after second sieving.

²Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Table 4.20. Mechanical stability of >0.84 mm aggregates as affected by tillage, 1986 and 1987.

Tillage	Year	
	1986	1987
	-----% ¹ -----	
Reduced tillage (RT)	80.9a ²	83.4a
Conventional tillage (CT)	77.6b	79.5b

¹Percentage of the >0.84 mm aggregate remaining after second sieving.

²Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Table 4.21. Mechanical stability of >0.84 mm aggregates as affected by crop sequence, 1986 and 1987.

Crop Sequence	Year	
	1986	1987
	-----% ¹ -----	
Corn after watermelon	83.1a ²	83.8a
Corn after corn	74.8b	77.5b
Watermelon after corn	79.8a	82.9a

¹Percentage of the >0.84 mm aggregate remaining after second sieving.

²Average values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

Soil Moisture

Volumetric soil moisture was determined for the 0-15 and 15-30 cm depth for 1986 and 1987 for the two tillage systems (Table 4.22). Volumetric soil moisture was consistently higher for the RT system for each soil depth for both years and for the total in 30 cm. The averages for the 30 cm depths were 23.8 vs 19.9% in 1986 and 26.3 vs 21.4% in 1987, for the RT and CT systems, respectively. There was no appreciable difference in soil moisture with depth for CT for either year, but with RT, volumetric soil moisture was higher in the 15-30 cm than in the 0-15 cm depth in 1986 but was the reverse in 1987. The higher volumetric moisture content for both depths for RT reflects the beneficial effect of this system in reducing evaporation and enhancing crop water-use efficiency due to surface residue cover.

The tillage x sampling date effect on volumetric soil moisture is given in Table 4.23. Soil moisture was consistently higher for RT than for CT system for each sampling date for both years of the study. Average precipitation received during June and July amounted to 5.9 and 3.0 cm for 1986 and 1987, respectively. Total rainfall for the year 1986 was 33 cm as compared to 29 cm for 1987. In 1986, the CT system received five irrigations (including a germination irrigation) as compared to four for RT. In 1987, RT received one less irrigation than CT which received four irrigations. This explains how RT production systems

use both its on-season and off-season moisture conserving advantage to meet crop water requirements throughout the growing season.

The one irrigation saved by the RT each year suggests lower energy and power requirements than for CT.

Table 4.22. The effect of tillage and sample depth on soil moisture, 1986-1987.

Tillage	Depth	Year		
		1986	1987	
-----cm H ₂ O-----				
Conventional (CT)	0-15 cm	20.1c ¹	20.7c	
	15-30 cm	19.7c	22.1c	
Reduced (RT)	0-15 cm	22.9b	27.4a	
	15-30 cm	24.7a	25.2b	

Mean:	CT	0-30 cm	19.9	21.4
	RT	0-30 cm	23.8*	26.3*

Mean:		0-15 cm	21.5	24.1
		15-30 cm	22.2	23.7

¹Average values within a column followed by same letter are not different by Duncan's Multiple Range Test (P=0.05).

Each value is an average of four replications.

*Greater than CT at P = 0.05.

Table 4.23. The effect of tillage and sampling date on soil moisture content, 1986-1987.

Sampling Date	Tillage	Year	
		1986	1987
-----cm H ₂ O-----			
1 Jul-2-86;21-87	(CT)	18.9d ¹	20.4d
	(RT)	19.7c	28.0a
2 Jul-18-86;Aug-6-87	(CT)	22.9b	20.3d
	(RT)	24.7a	25.9b
2 Jul-24-86;Aug-11-87	(CT)	20.5c	22.5c
	(RT)	24.5a	25.7b

Mean:	CT	20.8	21.1
	RT	23.0*	26.5*

Mean:	Jul-2-86;21-87	19.3	24.2
	Jul-18-86;Aug-6-87	23.8	23.1
	Jul-24-86;Aug-11-87	22.5	24.1

¹Average values within a column followed by same letter are not different by Duncan's Multiple Range Test (P=0.05). Each value is an average of four replications.

*Greater than CT at P = 0.05.

Soil Compaction

The effect of tillage on soil compaction in the 0-15 and 15-30 cm depth, as determined by bulk density, is shown on Table 4.24. The results show an increase in bulk density for the RT at the 15-30 cm depth in 1986, but there was no tillage effect at either depth in 1987. When averaged over tillage system, depth had no effect on bulk density. There was a depth by tillage interaction in 1986 because of a higher bulk density at the 15-30 cm depth for RT but no effect of tillage system for bulk density of the 0-15 cm depth.

Table 4.24. The effect of tillage and depth on bulk density, 1986-1987.

Tillage	Depth	Year	
		1986	1987
		-----g cm ⁻³ -----	
Conventional (CT)	0-15 cm	1.30b ¹	1.30a
	15-30 cm	1.20c	1.30a
Reduced (RT)	0-15 cm	1.30b	1.30a
	15-30 cm	1.40a	1.30a
Mean:	CT	1.25	1.30
	RT	1.35*	1.30
Mean:	0-15 cm	1.30	1.30
	15-30 cm	1.30	1.30

¹Average values within a column followed by same letter are not different by Duncan's Multiple Range Test (P=0.05).

Each value is an average of four replications.

*Greater than CT at P = 0.05.

Results of the interaction effect of tillage and sampling date are reported in Table 4.25. In 1986, the bulk density of RT was greater than CT for each sampling date. In 1987, bulk density for the RT system was larger only for sampling two.

Table 4.25. The effect of tillage and sampling date on bulk density, 1986-1987.

Sampling Date	Tillage	Year	
		1986	1987
-----g cm ⁻³ -----			
1 Jul-2-86;21-87	(CT)	1.40b ¹	1.30a
	(RT)	1.50a	1.30a
2 Jul-18-86;Aug-6-87	(CT)	1.20c	1.20c
	(RT)	1.30b	1.30b
2 Jul-24-86;Aug-11-87	(CT)	1.20c	1.20c
	(RT)	1.30b	1.20c
Mean:	CT	1.26	1.23
	RT	1.36*	1.26
Mean:	Jul-2-86;21-87	1.45	1.30
	Jul-18-86;Aug-6-87	1.25	1.25
	Jul-24-86;Aug-11-87	1.25	1.20

¹Average values within a column followed by same letter are not different by Duncan's Multiple Range Test (P=0.05). Each value is an average of four replications.

*Greater than CT at P = 0.05.

As noted above, RT had greater bulk density at the 15-30 cm depth than CT in 1986. This is in agreement with research reported in the literature. Soil bulk densities remained persistently higher in Ontario for soils on which zero tillage was practiced for continuous corn than on soils which are conventionally tilled (Kay et al., 1985 and Vyn et al, 1982). Miles (1982) at the Arkansas Valley Research Center, suspected that RT for continuous corn production caused an increase in soil compaction. Warkentin (1971) measured lower bulk densities at the 20 cm depth in subsoiled fields than in fields not subsoiled regardless of tillage type. In the present study the higher bulk density at the 15-30 cm depth for RT in 1986 may be attributed to the elimination of plowing. The lower bulk density for the 15-30 cm depth in conventionally tilled soils, although temporary in nature, may be attributed to a loosening effect of plowing within the plow layer. In reduced tillage, since little subsurface soil disturbance is involved, it is possible that changes in subsoil compaction occur gradually and increases with time indicating the need for long-term experiments. Compacted soils generally have negative effects on root growth and water movement. In this study, the increase in soil compaction, as determined by bulk density, showed no effect on crop yield despite differences related to tillage, depth, and sampling date.

Soil Temperature

Soil temperature at the 2.5 cm was recorded from May to July for 45 and 41 days for 1986 and 1987, respectively. During this period, mean daily temperatures averaged 1.1°C higher for the 1986 season and 0.3°C higher for 1987 for conventional than for reduced tillage. A regression model of the form $y = b_0 + b_1 \text{ Day} + b_2 \text{ Day}^2$ was fitted to the data where y is predicted temperature, b_0 is the intercept and b_1 and b_2 are respectively the linear and quadratic effects of the advance in days (Figure 4.13). The data show that the soil temperature for CT at the 2.5 cm was consistently higher than RT over time since neither the interaction between day and tillage system nor between Day^2 and tillage system were significant.

The data show that crop residues were quite effective in maintaining a lower soil temperature level each year for reduced tillage for the period May through July. Beyond this period although data collection was discontinued, crop growth observations and dry matter yields showed a gradual increase in corn growth, possibly as the result of an increase in soil temperature for RT.

The effect of crop residue on soil temperature can also be expressed in soil heat units (SHU). Soil heat units for the CT and RT systems were calculated for a 10°C base. For example, the mean soil temperature for RT on day 40 in 1986

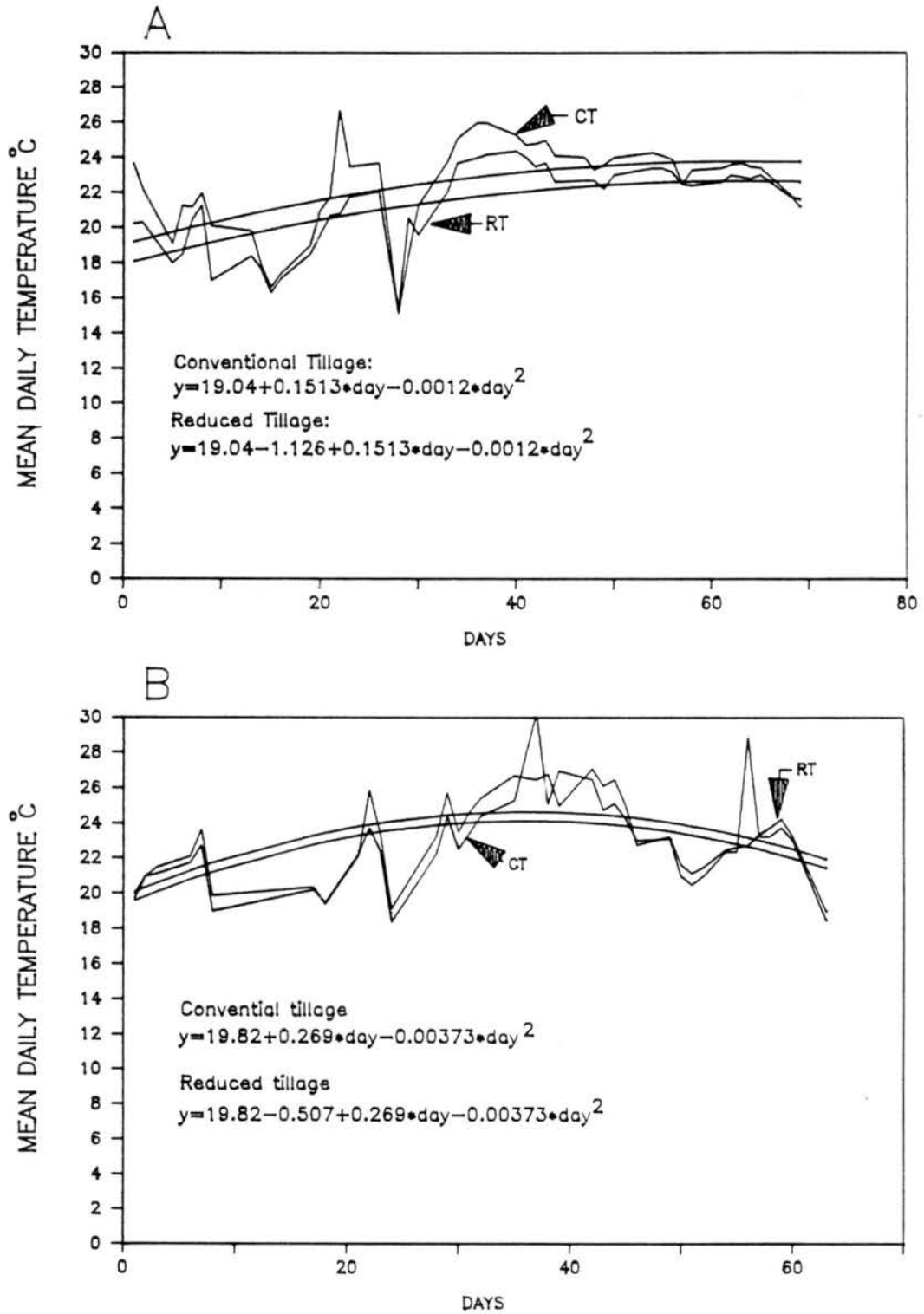


Figure 4.13. The effect of tillage system on seasonal soil temperatures at the 2.5 cm depth for a) 1986 and b) 1987.

was 24°C, the SHU for that day were 14. Daily SHU were calculated from May to mid-July, periods of 45 and 41 days for 1986 and 1987, respectively, then summed. The accumulated SHU were 521 and 470 in 1986 and 503 and 491 in 1987 for the CT and RT systems, respectively. Thus, there were 51 more SHU for CT than RT in 1986 and 12 more in 1987.

Radiation reaching the plant and soil surface in its effect on soil temperature, influences plant transpiration and evaporation (Bennett, 1977). Since RT leaves crop residues on the surface that act as a blanket, less solar radiation reaches the surface, and the soil warms more slowly. Thus RT results in a lower soil temperature than CT. Several researchers had reported lower soil temperatures where RT is practiced (Bennett, 1977; Olson et al., 1970 and Moody et al., 1963). Burrows (1963), after studying different rates of mulching in Iowa, concluded that lower soil temperatures under RT was a factor in reducing growth of corn.

RT decreased total dry matter yields of corn (Table 4.5) below conventional tillage in 1986, but tillage system had little effect on total dry matter production in 1987 or on grain yield of corn for either year. The difference in corn dry matter production in 1986 may be attributed to the germination irrigation given to CT which may have given this treatment added efficiency for nitrogen uptake. The lesser SHU accumulated by RT also may have contributed to the lower dry matter yield.

Effect of Tillage on Irrigation

The effect of tillage on irrigation was evaluated from 1) advance rate and 2) infiltration measurements for CT and RT for 1986 and 1987. The field plots were irrigated five times in 1986 including a germination irrigation and four times in 1987, but discussion will be limited to two irrigations for each year. These are irrigations two and three for 1986 and one and two for 1987 because more complete records are available. Irrigation data collected included inflow and outflow volumes, and the rate of water advance.

Advance Rate

The objective of studying furrow water advance was to determine the effect of tillage on the rate the advancing water front moves down the irrigated furrow. It is generally accepted that the amount of water that infiltrates into the root zone depends mainly on the opportunity time that is the length of time the advancing water stays on the soil surface. This implies, that the slower the water moves, the greater the infiltration and vice-versa. By measuring inflow and outflow, it is possible to estimate the infiltrated volume and the volume of tailwater runoff. As recession time was short, no attempt was made to measure it. Recession time may be important only where slopes are less than 0.05% (Jensen, 1980). In this study, advance rate was described using a power curve relationship in the form of:

$$X = pt^r \quad [4-1]$$

where x is advance distance in m at time t in minutes, and p and r are fitting constants. In order to determine the constants p and r of the above equation, the two point method (Wilke, 1973) was used. The two point method is a field method, is less tedious and requires only a hand-held programmable calculator. This method yields nearly as good a function as the non-linear regression does for predicting advance distance by utilizing the following equations:

$$r = \frac{\ln(0.5)}{\ln\left(\frac{t_L/2}{t_L}\right)} \quad [4-2]$$

$$P = \frac{L}{t_L r} \quad [4-3]$$

where L is the length of field to be irrigated, and $t_L/2$ and t_L are the advance time to the mid and end of the irrigated field, respectively.

Data for the advance time-advance distance relationships for CT and RT shown in Figures 4.14 and 4.15 were fitted to the advance rate power curve equation using the two-point method. A statistical analysis of the data is given in Table 4.26.

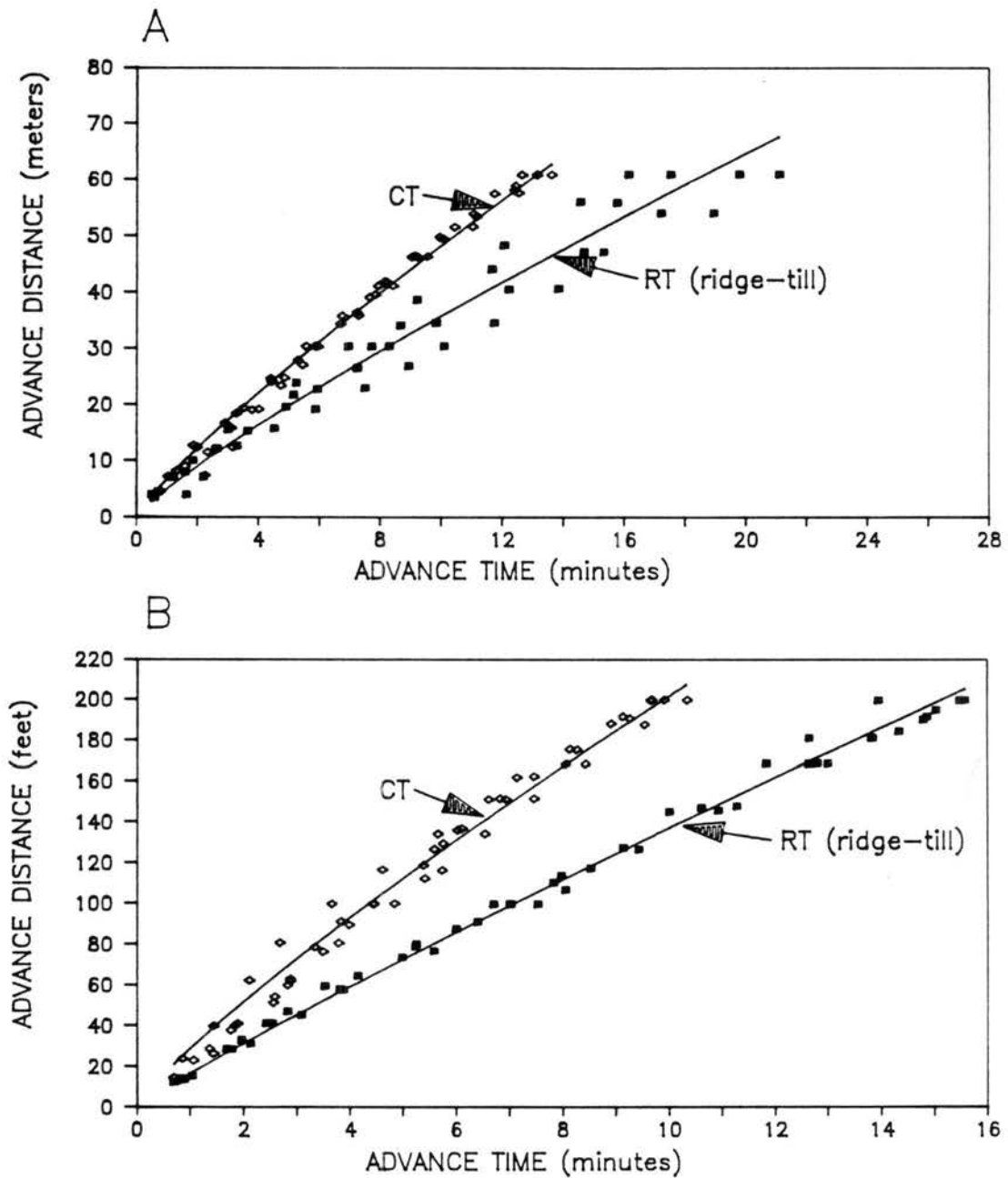


Figure 4.14. The effect of tillage system on the advance-time/advance-distance relationship: a) second irrigation, 7/14/86, and b) third irrigation, 7/31/86.

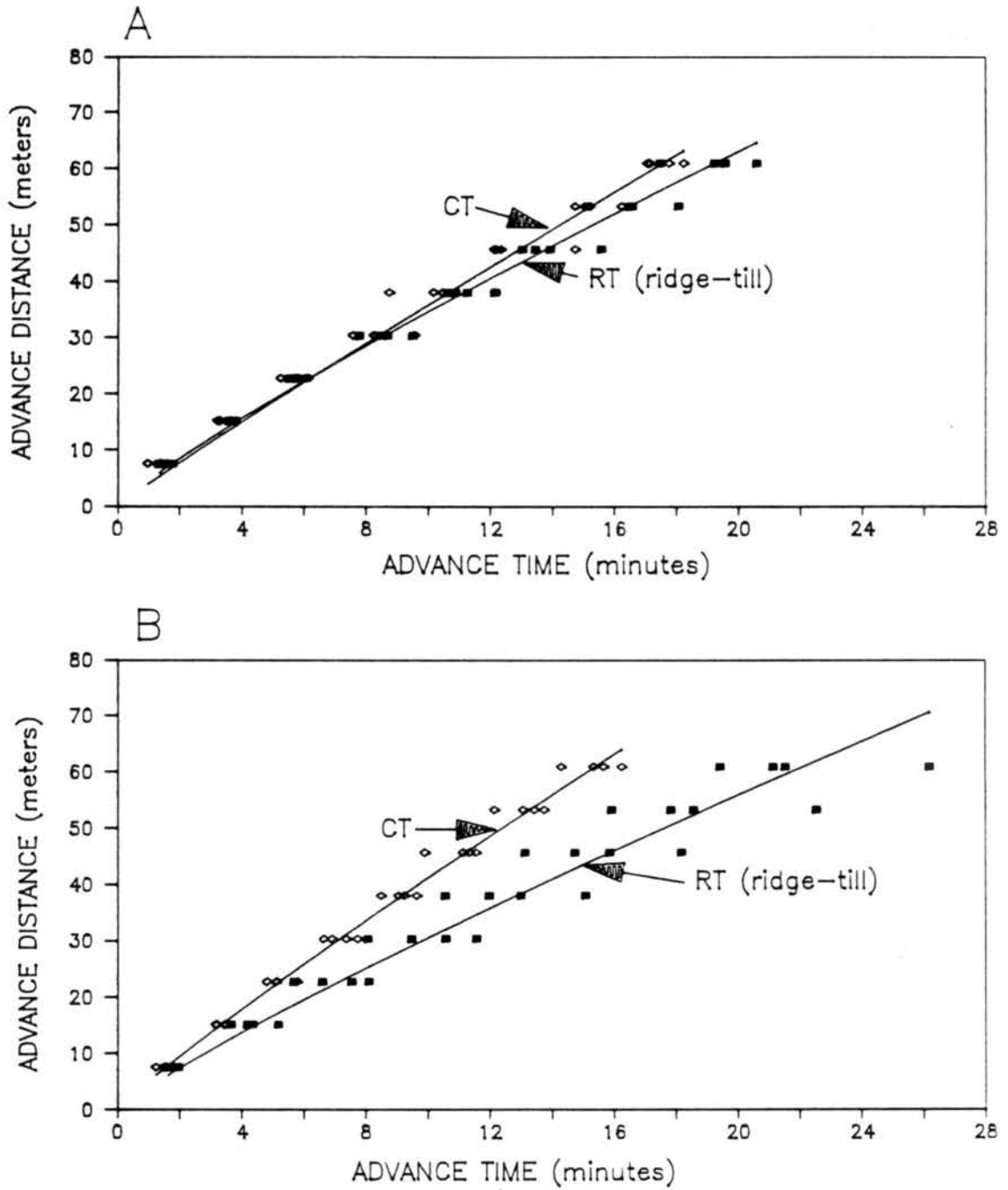


Figure 4.15. The effect of tillage system on the advance-time/advance-distance relationship: a) first irrigation, 7/16/87, and b) second irrigation, 7/30/87.

Table 4.26. Analysis of irrigation advance times, 1986 and 1987.

1986			1987		
Irrigation	Tillage	Advance Minutes ^{1,2}	Irrigation	Tillage	Advance Minutes ^{1,2}
2 (7/14/86)	CT	13.2bc	1 (7/16/86)	CT	17.6ab
	RT	18.6a		RT	19.2b
3 (7/31/86)	CT	9.9c	2 (7/30/87)	CT	13.9b
	RT	14.7ab		RT	22.1a

Mean	CT	11.6			15.8
	RT	16.7*			20.7*

¹Time to advance 61 m; each value is average of two replications.

²Values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

*Greater than CT at P=0.05.

From the table and figures, it is evident that in general RT data is more scattered than CT data because of relatively longer advance times and a more variable furrow conditions. The longer advance times associated with RT are attributed primarily to greater roughness of the irrigated furrows and also possibly to an increase in infiltration rate because of the surface residue. Advance times were almost always longer for first irrigation than for later irrigations each year. Eisenhauer et al. (1982) attributed this phenomena to the smoothing and surface sealing of the furrows that take place during the first irrigation, thus reducing advance times for subsequent irrigations. Some of the loose residue may also be transported off the field during the first irrigation.

Infiltration

Infiltration was calculated by subtracting the outflow volume from the inflow volume and dividing by the land area irrigated per furrow. Table 4.27 shows infiltration data for two irrigations each for 1986 and 1987.

Infiltration was consistently higher for RT than CT for second and third irrigations in 1986 and the first two irrigations in 1987. There was a 65% average increase in infiltration depth for the four irrigations for RT. After any given irrigation, infiltration depths for subsequent irrigations were always less except in 1986 where irrigation two and three were not different for CT but were different for RT.

Table 4.27. Analysis of net infiltration depth, 1986 and 1987.

1986			1987		
Irrigation	Tillage	Depth Min ^{1,2}	Irrigation	Tillage	Depth Min ^{1,2}
2 (7/14/86)	CT	146c	1 (7/16/86)	CT	152c
	RT	236a		RT	277a
3 (7/31/86)	CT	134c	2 (7/30/87)	CT	126d
	RT	193b		RT	221b

Mean	CT	140			139
	RT	200*			249*

¹Time to advance 61 m; each value is average of two replications.

²Values within a column followed by same letter are not different by Duncan's multiple range test (P=0.05).

*Greater than CT at P=0.05.

The slow advance caused by surface residues allowed greater infiltration to take place under RT than under CT. Williams and Doneen (1960) found greater infiltration under furrow irrigation by incorporation of crop residues. Eisenhauer et al. (1982) have shown that RT systems when compared with CT, increased net infiltration by 74%, and Miller and Aarstad (1971) found that an annual addition of 1.34 mg ha⁻¹ of straw increased infiltration over the control about 90% during the first irrigation, 65% during the second, and 35% during the third irrigation. Aarstad and Miller (1978) reported corn residues in the furrow increased infiltration rates compared to CT. They attributed such increase to slow water advance which, according to the authors, increased the wetted perimeter providing more soil area for infiltration. Duley and Russel (1939) found that surface residues reduced the sealing of the soil surface layer, thus maintaining a higher infiltration.

The results of this study and the literature cited emphasize the importance of residues in increasing the soil's capacity to absorb water into the profile and consequently reduce run-off. As infiltrability of soil increases, the risk of top-soil erosion is reduced. As noted by Mannering and Meyer, (1963) a mulch dissipates the rain drop energy or in case of irrigation slows water-flow velocity down the furrow, reduces surface sealing and because infiltration is greater, reduces erosion. The results also show that infiltration is

almost always higher for the first irrigation than for subsequent irrigations as surface residues lose their effectiveness as the season progresses.

Discussion and Conclusions

Soil type, climate condition, agronomic and management practices will affect the performance of CT and RT systems in different ways. In this study, tillage system had little effect on grain yield of corn, but RT had greater marketable watermelon yields than CT. Total dry matter production varied with the tillage system. Where both systems used flat planting, the CT system produced more dry matter. When the RT system used ridge-till planting, total dry matter production was greater for the RT system.

Tillage system also had varied effects on physical properties of the soil. The RT system resulted in greater aggregate stability, a higher residual soil moisture content, and increased infiltration. In 1986, these benefits may have been counteracted by lower early-season soil temperature and greater soil compaction at the 15-30 in depth. The increased moisture storage resulted in savings of irrigation water, labor and energy--an economic advantage. Lower soil temperatures for the RT system may have contributed to reduced evaporation and reduced runoff--also possible economic and societal benefits. Results of this study indicate that lower soil temperatures may have been the cause for retarded early-season corn growth.

Although there was no difference for tillage systems in erodibility and percentage aggregates >0.84 mm in diameter, there was a definite trend for increased aggregation with the RT system.

The effect of continuous cropping of corn on aggregation suggest that crop rotation must be an essential component in conservation farming in order to maximize crop productivity and minimize soil loss due to wind and water erosion. The continuous corn plots had fewest aggregates >0.84 mm in diameter, the average geometric mean diameter (GMD) of the aggregates was lowest, the mechanical stability was lowest and the potential in loss to erosion was highest.

Based on the above discussion and the review of literature, we can conclude:

1. Although the short-term crop productivity of the two tillage systems were nearly the same, RT may have the distinct long-term advantages of protecting agricultural land from wind and water erosion, thus increasing the sustainability of crop production.
2. From the farmer's point of view and for the short-term, he/she should respond to the better economic output when analyzed in terms of costs of production, i.e., chemicals, labor, energy. Because of the risks involved, the farmer generally is less interested in long-term benefits unless there is the high probability

that current income can be increased through improved yield per hectare.

Over the long-term, RT would appear advantageous but can't be shown here. The reduced soil and nutrient loss when following a RT system and the resultant prevention of air and water pollution are important advantages that need to be recognized.

3. From society's point of view, RT offers greater promise over the long-term. Society is interested in the promotion and development of RT because of the long-term benefits outlined under item 2 above.

If the farmer is to implement a RT program, however, he/she must be given the incentives and/or the tools (educational, management, loans) that will help to do a better job as a farm manager and to minimize risks involved in developing the new system.

Additional research on conservation tillage in Southeastern Colorado should be directed to: 1) determining the amount of residues required to maintain crop productivity under southeastern Colorado's climatic environment and the site-specific agronomic and management practices, 2) corn germination, plant densities and corn development as effected by soil temperature and mulch as used for RT, 3) weed control and timing of herbicide application under conservation tillage, and 4) ridge-till planting of corn for RT.

CHAPTER V

SUMMARY

The objective of this study was to determine the effect of two tillage systems--conventional tillage (CT) and reduced tillage (RT)--for a three-year corn-corn-watermelon rotation on: 1) biological production of corn and watermelon, 2) changes in soil physical properties, and 3) effect of tillage on irrigation at the Arkansas Valley Research Center (AVARC), Rocky Ford, Colorado. The approach used in this study was different from previous tillage research conducted under irrigation in semi-arid southeastern Colorado. Treatments were designed to evaluate tillage systems over the entire duration of the rotation rather than evaluating individual tillage operations or tillage implements.

The results of this study showed neither a benefit nor loss in corn grain-yield under RT when compared to CT. The effect of tillage system on dry matter yield of corn varied with planting method. With flat planting for both CT and RT, yields of total dry matter were higher with CT. When corn was ridge-tilled, the RT system was higher yielding.

Tillage system did influence marketable melon production. The yield of marketable melon over the three years averaged 26% higher for RT. Seed yield was not effected by tillage

system in 1985, but a decrease in seed yield was observed in 1986 with RT where the disk was used as the primary tillage tool.

Soil physical properties evaluated included 1) aggregate size distribution, 2) geometric mean diameter (GMD) of aggregates, 3) erodibility, 4) mechanical stability, 5) soil moisture, 6) soil compaction, and 7) soil temperature.

The GMD and mechanical stability of soil aggregates >0.84 mm were greater and erodibility of the aggregates was reduced in soil from the RT system. More residual soil moisture was stored with RT, but surface soil temperatures were 0.3 to 1.1°C lower. Soil compaction in the 15-30 cm soil depth was greater for the RT system. Tillage systems (CT vs RT) had little effect on total soil aggregates >0.84 mm diameter.

Soils in the corn-corn plots were less well aggregated and had considerably more erodible aggregates than those found in the corn after melon or watermelon after corn cropping sequence. Mechanical stability of aggregates from the corn-corn rotation was less than those from either corn after melon or melon after corn.

Soil aggregation was highest in the fall and lowest in the winter for both 1986 and 1987. Aggregate erodibility was greater for samples taken during the winter than for those taken in the fall.

The increase in aggregate diameter with time shown by this study was associated mainly with cropping sequence,

season effect and cultural management practices. The immediate beneficial effects of surface residue on soil aggregation was not apparent from the GMD calculations. From the above discussion, it is concluded that RT will be more successful when combined with rotation of crops.

Water advance in the furrow was slower for RT than CT. The longer advance times associated with RT are attributed primarily to greater roughness of the irrigated furrows, and also possibly to an increase in infiltration rate because of surface residues. Infiltration was consistently higher for RT than CT and for first irrigations than for subsequent irrigations. The slow water advance caused by surface residues allowed greater infiltration to take place under RT than under CT.

In the relatively short-term of this study, it was found that RT has several beneficial attributes that offer promise for becoming an attractive management system. In terms of immediate benefit to the farmer, greater savings in energy, labor and machinery would be possible under this system. Given proper management and the application of improved cultural practices, i.e. rotation, fertilization, weed control, etc., the farmer may, by using the RT system, produce crop yields equal to or even greater than CT with less dollars, certainly greater yields in dry seasons.

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APPENDICES

APPENDIX A

FIELD PLOT DESIGN, ROCKY FORD, COLORADO

I				III					
⋮	1	2	3	3	2	1	2	1	3
1985	Corn	Corn	Melon	Melon	Corn	Corn	Corn	Corn	Melon
	2	3	1	1	3	2	3	2	1
1986	Corn	Melon	Corn	Corn	Melon	Corn	Corn	Melon	Corn
	3	1	2	2	1	3	2	1	3
1987	Melon	Corn	Corn	Corn	Corn	Melon	Corn	Melon	Corn
		A			B			A	

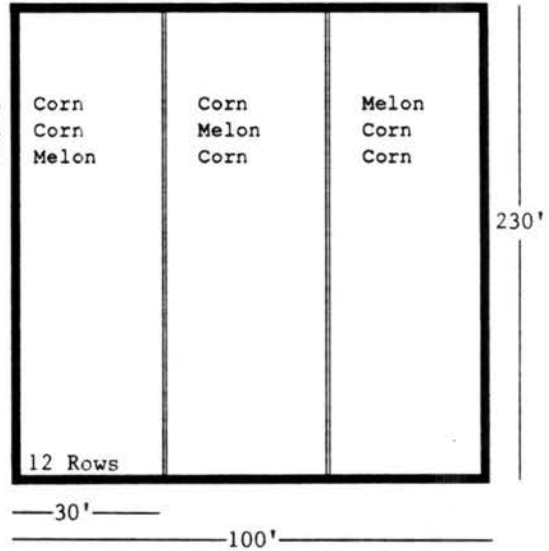
II				IV					
⋮	2	1	3	2	3	1	1	2	3
1985	Corn	Corn	Melon	Corn	Melon	Corn	Corn	Corn	Melon
	3	2	1	3	1	2	2	3	1
1986	Melon	Corn	Corn	Melon	Corn	Corn	Corn	Melon	Corn
	1	3	2	1	2	3	3	1	3
1987	Corn	Melon	Corn	Corn	Corn	Melon	Melon	Corn	Melon
		B			A			A	

- A. Conventional Tillage System
- B. Reduced Tillage System

Conventional Reduced

- 1 Corn ----->
 - Plow Ridge-Till
 - Disk
 - Ridge
- 2 Corn ----->
 - Plow Disk
 - Disk
- 3 Melon ----->
 - Plow Plow
 - Disk Disk
 - Ridge Ridge

1985	Corn	Corn	Melon
1986	Corn	Melon	Corn
1987	Melon	Corn	Corn



APPENDIX B

SEQUENCE OF FIELD OPERATIONS EACH YEAR
AFTER ROTATION IS ESTABLISHED

Rotation Year and Crop	Time	Conventional (Moldboard Plow)	Conservation (Disk)
Corn #1	Fall	Chop stalks	Chop stalks
	Fall	Disk (Fall)	Disk
	Fall	Plow	--
	Spring	Disk (Spring)	Disk
	Spring	Cultipacker	--
	Spring	Ridge or bed	Ridge or bed
	Early Spring	--	Spray (*)
	Preplant	--	Spray (*)
	Spring	Plant	Plant
	Spring	Cultivate	Cultivate
	Summer	Cultivate	Cultivate
	Spring	Bladex	--
	Fall	Harvest	Harvest
Corn #2	Fall	Chop Stalks	Chop Stalks
	Fall	Disk (Fall)	--
	Fall	Plow	--
	Spring	Disk (Spring)	--
	Spring	Cultipacker	--
	Spring	Ridge or bed	--
	Early Spring	--	Spray (*)
	Preplant	--	Spray (*)
	Spring	Plant	Plant
	Spring	Cultivate	Cultivate
	Summer	Cultivate	Cultivate
	Spring	Bladex	--
	Fall (Oct)	Harvest	Harvest
Water- melon #3	Fall	Chop Stalks	Chop Stalks
	Fall	Disk (Fall)	Disk (Fall)
	Fall	Plow	--
	Spring	Disk (Spring)	Disk (Spring)
	Spring	--	Disk (Spring)
	Spring	Cultipacker (2)	--
	Spring	Float	--
	Preplant	Naptalam, Bensulfide	Naptalam, Bensulfide
	Spring	Plant	Plant
	Summer	Cultivate (4)	Cultivate
Fall	Harvest	Harvest	

* = Bladex, Naptalam, Bensulfide

APPENDIX C

FIELD DATA, 1985-1987

Table C.1. Corn and watermelon yields, 1985.

Case No.	Variables														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	2	1	2	Corn	Conservation	8203.5	50.0	31.5	7205.4	144.1	27.443				2
2	2	2	1	Corn	Conservation	9264.0	50.5	29.6	8256.1	163.5	25.410				1
3	2	4	2	Corn	Conventional	7303.5	51.0	30.8	6449.2	126.5	22.651				4
4	2	6	1	Corn	Conventional	7695.5	51.5	29.7	6853.0	133.1	23.232				3
5	4	7	1	Corn	Conservation	7667.0	51.0	27.6	6940.0	136.1	23.377				1
6	4	8	2	Corn	Conservation	7013.0	49.5	31.1	6178.5	124.8	20.183				2
7	4	11	2	Corn	Conventional	8305.5	50.5	26.7	7571.3	149.9	22.796				4
8	4	12	1	Corn	Conventional	7202.0	51.5	27.8	6508.8	126.4	22.216				3
9	1	13	1	Corn	Conventional	7115.0	49.0	30.3	6306.8	128.7	22.216				3
10	1	14	2	Corn	Conventional	6897.0	51.0	30.6	6099.6	119.6	19.892				4
11	1	17	2	Corn	Conservation	6331.0	49.0	30.6	5599.0	114.3	19.166				2
12	1	18	1	Corn	Conservation	6984.5	50.5	31.5	6134.7	121.5	21.054				1
13	3	20	2	Corn	Conservation	7971.5	49.5	29.5	7111.4	143.7	22.361				2
14	3	21	1	Corn	Conservation	6882.5	50.0	31.3	6054.3	121.1	20.909				1
15	3	22	2	Corn	Conventional	8076.0	50.0	30.0	7175.2	143.5	23.958				4
16	3	23	1	Corn	Conventional	7480.5	50.0	29.4	6677.0	133.5	22.506				3
17	2	3	3	Watermelon	Conservation							2092.0	213.0		1
18	2	5	3	Watermelon	Conventional							1336.0	218.0		2
19	4	9	3	Watermelon	Conservation							2685.0	200.0		1
20	4	10	3	Watermelon	Conventional							2427.0	205.0		2
21	1	15	3	Watermelon	Conventional							1691.0	248.0		2
22	1	16	3	Watermelon	Conservation							2453.0	256.0		1
23	3	19	3	Watermelon	Conservation							2072.0	208.0		1
24	3	24	3	Watermelon	Conventional							1489.0	199.0		2

List of Variables:

- | | | | |
|---|-------------------------------------|----|--|
| 1 | Replication Number | 8 | Percent Grain Moisture |
| 2 | Plot Number | 9 | Adjusted Corn Yield to 15.5% Moisture (pounds/acre) |
| 3 | Year of Rotation | 10 | Adjusted Corn Yield to 15.5% Moisture (bushels/acre) |
| 4 | Crop | 11 | Plant Population (plants/acre - in thousands) |
| 5 | Tillage System | 12 | Watermelon Yield (marketable number/acre) |
| 6 | Unadjusted Corn Yield (pounds/acre) | 13 | Watermelon Yield (seed yield/acre - pounds) |
| 7 | Test Weight (pounds/bushel) | 14 | Tillage System Identification |

Table C.2. Corn and watermelon yields, 1986.

Case No.	Case				Variables												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	2	2	2	Conservation	2-Yr Corn	0.8524	15037.9	21.2	14330.7	238.8	28401	0.5046	1.31				1.00
2	3	2	1	Conservation	1-Yr Corn	0.8630	14751.2	20.0	14198.0	236.6	31189	0.4552	1.30				1.00
3	5	2	3	Conventional	1-Yr Corn	0.8655	15578.1	21.2	14845.5	247.4	32757	0.4532	1.25				1.00
4	6	2	4	Conventional	2-Yr Corn	0.8569	13489.8	20.0	12983.9	216.4	27356	0.4746	1.33				1.00
5	7	4	2	Conservation	2-Yr Corn	0.8551	14020.2	20.6	13427.3	223.8	29447	0.4560	1.38				1.00
6	9	4	1	Conservation	1-Yr Corn	0.8561	13246.0	20.0	12749.3	212.5	30492	0.4181	1.33				1.00
7	10	4	3	Conventional	1-Yr Corn	0.8660	15111.8	19.2	14642.7	244.0	33454	0.4181	1.30				1.00
8	12	4	4	Conventional	2-Yr Corn	0.8572	13061.4	18.6	12720.0	212.0	30666	0.4148	1.36				1.00
9	13	1	4	Conventional	2-Yr Corn	0.8546	15225.6	19.4	14728.3	245.5	31712	0.4644	1.28				1.00
10	15	1	3	Conventional	1-Yr Corn	0.8451	14864.9	19.6	14355.3	239.3	32931	0.4359	1.30				1.00
11	16	1	1	Conservation	1-Yr Corn	0.8622	15255.8	19.2	14782.3	246.4	32409	0.4561	1.39				1.00
12	18	1	2	Conservation	2-Yr Corn	0.8391	14423.1	20.8	13790.3	229.8	31537	0.4373	1.22				1.00
13	19	3	1	Conservation	1-Yr Corn	0.8631	12940.8	19.2	12539.1	209.0	27356	0.4584	1.33				1.00
14	21	3	2	Conservation	2-Yr Corn	0.8495	14587.1	21.0	13924.1	232.1	31015	0.4489	1.26				1.00
15	23	3	4	Conventional	2-Yr Corn	0.8680	14367.8	18.6	13992.3	233.2	31015	0.4511	1.28				1.00
16	24	3	3	Conventional	1-Yr Corn	0.8647	14275.5	18.8	13879.0	231.3	29969	0.4631	1.25				1.00
17	1	2	1	Conservation	3-Yr Melon				115.5	1.9		-.0001		1989	134.97	1533	0.77
18	4	2	2	Conventional	3-Yr Melon				115.5	1.9		-.0001		2144	185.86	953	0.44
19	8	4	1	Conservation	3-Yr Melon				115.5	1.9		-.0001		2273	158.65	1104	0.49
20	11	4	2	Conventional	3-Yr Melon				115.5	1.9		-.0001		1989	197.66	1148	0.58
21	14	1	2	Conventional	3-Yr Melon				115.5	1.9		-.0001		1911	215.46	1016	0.53
22	17	1	1	Conservation	3-Yr Melon				115.5	1.9		-.0001		1989	156.25	1003	0.50
23	20	3	1	Conservation	3-Yr Melon				115.5	1.9		-.0001		1860	149.96	1275	0.69
24	22	3	2	Conventional	3-Yr Melon				115.5	1.9		-.0001		1498	173.99	991	0.66

List of Variables:

- | | | | |
|---|--------------------------------|----|---|
| 1 | Plot Number | 9 | Adjusted Grain Yield at 15.5% Moisture (pounds/acre) |
| 2 | Replication Number | 10 | Adjusted Grain Yield at 15.5% Moisture (bushels/acre) |
| 3 | Tillage System Number | 11 | Final Corn Plant Population (plants/acre) |
| 4 | Tillage System Designation | 12 | Corn Grain Yield/Plant (pounds/plant) |
| 5 | Year of Rotation | 13 | Corn Grain Nitrogen Content |
| 6 | Shelling Percentage | 14 | Watermelon Yield (marketable number/acre) |
| 7 | Unadjusted yield (pounds/acre) | 15 | Watermelon Seed Yield (pounds/acre) |
| 8 | Grain Moisture Percentage | 16 | Diseased Watermelon Counts (number/acre) |
| | | 17 | Ratio of Diseased Watermelon to Marketable Number |

Table C.3. Corn and watermelon yields, 1987.

Case No.				Variables												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	2	1	Conservation	1-Yr Corn	2.49	33106	12323.0	20.0	11860.9	0.6634	245.20	17880.16	7.4		
2	3	2	2	Conservation	2-Yr Corn	2.41	39030	14733.0	22.5	13891.1	0.7636	211.60	18191.07	7.8		
3	4	2	3	Conventional	1-Yr Corn	2.49	33803	10280.3	22.9	9661.3	0.4095	316.90	23595.09	8.3		
4	5	2	4	Conventional	2-Yr Corn	2.63	31363	11581.7	21.1	11046.1	0.5754	277.90	19197.75	8.9		
5	8	4	1	Conservation	1-Yr Corn	2.35	32409	11373.4	20.7	10883.4	0.4866	313.30	22365.06	8.1		
6	9	4	2	Conservation	2-Yr Corn	2.44	33106	13126.5	20.3	12602.8	0.5130	336.90	24566.98	7.8		
7	10	4	4	Conventional	2-Yr Corn	2.59	33803	13285.7	21.1	12671.3	0.6645	256.10	19068.17	8.3		
8	11	4	3	Conventional	1-Yr Corn	2.74	32409	13588.8	21.8	12885.9	0.5387	335.10	23921.27	8.5		
9	14	1	3	Conventional	1-Yr Corn	2.59	34151	15620.7	20.9	14923.0	0.6642	298.70	22468.95	7.8		
10	15	1	4	Conventional	2-Yr Corn	2.56	32409	13082.5	21.7	12416.0	0.7119	244.30	17439.47	8.3		
11	16	1	2	Conservation	2-Yr Corn	2.44	32409	13916.6	24.3	12936.6	0.5957	304.20	21715.46	8.0		
12	17	1	1	Conservation	1-Yr Corn	2.35	29969	13348.4	21.9	12647.6	0.6965	275.10	18159.63	8.2		
13	19	3	2	Conservation	2-Yr Corn	2.41	36242	12922.9	24.0	12037.1	0.5173	291.50	23269.92	8.0		
14	20	3	1	Conservation	1-Yr Corn	2.61	33106	12581.2	22.0	11910.9	0.6290	259.70	18937.51	7.9		
15	22	3	3	Conventional	1-Yr Corn	2.74	33454	13149.7	23.9	12258.2	0.6735	247.00	18200.74	7.9		
16	24	3	4	Conventional	2-Yr Corn	2.46	31015	13125.5	22.5	12375.5	0.7281	248.00	16996.77	8.3		
17	2	2	5	Conservation	Melon										183.1	1265.5
18	6	2	6	Conventional	Melon										157.8	749.0
19	7	4	5	Conservation	Melon										164.1	1136.3
20	12	4	6	Conventional	Melon										126.3	387.4
21	13	1	6	Conventional	Melon										170.5	929.7
22	18	1	5	Conservation	Melon										189.4	903.9
23	21	3	5	Conservation	Melon										195.7	981.4
24	23	3	6	Conventional	Melon										157.8	749.0

List of Variables:

- | | |
|---|---|
| 1 Plot Number | 9 Grain Moisture Content (percent) |
| 2 Replication Number | 10 Corrected Grain Yield (pounds/acre) |
| 3 Tillage System Number | 11 Corn Harvest Index(pounds grain/pounds total dry matter) |
| 4 Tillage System Designation | 12 Final Total Dry Matter (grams/plant) |
| 5 Year of Rotation | 13 Above Ground Dry Matter (pounds/acre) |
| 6 Ear-Leaf Nitrogen | 14 Corn Grain Protein Content (percent) |
| 7 Plant Populatio (plants/acre) | 15 Watermelon Seed Yield (pounds/acre) |
| 8 Unadjusted Corn Grain Yield (pounds/acre) | 16 Marketable Numbers of Watermelon (number/acre) |

Table C.4. Corn total seasonal dry matter accumulation,¹ 1986 and 1987.

Sam	Till	Corn	Rep ²	1986	1987	Sam	Till	Corn	Rep	1986	1987
---g/5 plants---						---g/5 plants---					
1	1	1	1	1.00	0.62	3	2	2	2	36.71	12.69
1	1	1	1	.99	1.09	3	2	2	3	29.97	10.30
1	1	1	3	.70	1.00	3	2	2	4	49.80	10.08
1	1	1	4	.79	.96	4	1	1	1	314.67	28.99
1	1	2	1	.99	.69	4	1	1	2	362.28	41.46
1	1	2	2	1.22	.58	4	1	1	3	216.48	14.32
1	1	2	3	.72	1.05	4	1	1	4	397.29	29.63
1	1	2	4	.80	.93	4	1	2	2	245.55	18.17
1	2	1	1	.83	.72	4	1	2	2	283.64	24.22
1	2	1	2	.99	.87	4	1	2	3	348.18	22.43
1	2	1	3	.58	1.00	4	1	2	4	197.32	34.32
1	2	1	4	.68	.71	4	2	1	1	112.00	17.29
1	2	2	1	.43	.99	4	2	1	2	265.36	23.47
1	2	2	2	.72	.50	4	2	1	3	107.51	24.45
1	2	2	3	.67	.89	4	2	1	4	97.44	17.13
1	2	2	4	.48	.70	4	2	2	1	214.60	26.81
2	1	1	1	7.57	1.73	4	2	2	2	207.57	32.57
2	1	1	2	6.34	1.67	4	2	2	3	213.12	26.18
2	1	1	3	3.23	1.32	4	2	2	4	184.91	28.62
2	1	1	4	5.15	1.68	5	1	1	1	461.00	87.76
2	1	2	1	6.52	.85	5	1	1	2	478.00	96.26
2	1	2	2	9.84	1.42	5	1	1	3	232.00	45.00
2	1	2	3	8.00	1.16	5	1	1	4	347.00	107.46
2	1	2	4	8.15	1.78	5	1	2	1	436.00	77.25
2	2	1	1	6.50	1.94	5	1	2	2	336.00	78.30
2	2	1	2	6.71	1.26	5	1	2	3	340.00	75.18
2	2	1	3	6.68	1.76	5	2	1	1	307.00	61.01
2	2	1	4	2.47	1.48	5	2	1	1	445.00	64.06
2	2	2	1	5.22	2.33	5	2	1	2	481.00	87.06
2	2	2	2	4.01	2.87	5	2	1	3	314.00	63.59
2	2	2	3	5.22	2.39	5	2	1	4	326.00	83.72
2	2	2	4	4.08	1.28	5	2	2	1	207.00	62.02
3	1	1	1	74.02	6.75	5	2	2	2	292.00	70.08
3	1	1	2	38.80	8.58	5	2	2	3	254.00	58.18
3	1	1	3	59.85	17.37	5	2	2	4	238.00	66.33
3	1	1	4	71.06	7.07	6	1	1	1	858.00	298.62
3	1	2	1	56.90	10.03	6	1	1	2	902.00	295.52
3	1	2	2	84.68	10.33	6	1	1	3	786.00	174.52
3	1	2	3	48.94	15.81	6	1	1	4	964.00	221.82
3	1	2	4	55.87	13.42	6	1	2	1	985.00	221.52
3	2	1	1	56.01	9.35	6	1	2	2	910.00	381.02
3	2	1	2	82.30	16.29	6	1	2	3	936.00	185.72
3	2	1	3	56.34	17.96	6	1	2	4	523.00	228.12
3	2	1	4	10.67	12.02	6	2	1	1	890.00	161.02
3	2	2	1	26.75	7.74	6	2	1	2	946.00	282.32

Table C.4 (Cont'd).

Sam	Till	Corn	Rep ²	1986	1987	Sam	Till	Corn	Rep	1986	1987
---g/5 plants---						---g/5 plants---					
6	2	1	3	826.00	155.52	9	1	2	4	1040.00	503.90
6	2	1	4	531.00	296.02	9	2	1	1	1357.00	685.50
6	2	2	1	690.00	268.12	9	2	1	2	1501.00	576.60
6	2	2	2	736.00	190.62	9	2	1	3	1103.00	703.70
6	2	2	3	459.00	155.70	9	2	1	4	1200.00	790.00
6	2	2	4	505.00	295.52	9	2	2	1	1370.00	599.30
7	1	1	1	921.00	421.23	9	2	2	2	1361.00	581.10
7	1	1	2	1038.00	342.34	9	2	2	3	1364.00	99.90
7	1	1	3	1043.00	206.61	9	2	2	4	1483.00	617.40
7	1	1	4	1065.00	377.20	10	1	1	1	1627.00	794.50
7	1	2	1	935.00	285.93	10	1	1	2	1463.00	858.10
7	1	2	2	926.00	364.29	10	1	1	3	1556.00	880.80
7	1	2	3	955.00	288.47	10	1	1	4	1527.00	653.80
7	1	2	4	927.00	274.27	10	1	2	1	1562.00	903.90
7	2	1	1	1139.00	283.62	10	1	2	2	1486.00	730.90
7	2	1	2	1067.00	384.83	10	1	2	3	1362.00	758.20
7	2	1	3	1279.00	285.01	10	1	2	4	1224.00	676.50
7	2	1	4	807.00	285.39	10	2	1	1	1047.00	917.10
7	2	2	1	877.00	236.20	10	2	1	2	1281.00	1076.00
7	2	2	2	724.00	423.08	10	2	1	3	1142.00	790.00
7	2	2	3	1010.00	194.20	10	2	1	4	1462.00	726.40
7	2	2	4	937.00	281.87	10	2	2	1	1671.00	703.70
8	1	1	1	1371.00	498.95	10	2	2	2	1453.00	1035.10
8	1	1	2	1442.00	485.70	10	2	2	3	1420.00	763.30
8	1	1	3	1251.00	460.00	10	2	2	4	1582.00	908.00
8	1	1	4	1588.00	453.58	11	1	1	1	2060.00	1303.00
8	1	2	1	1543.00	498.95	11	1	1	2	2656.00	1525.45
8	1	2	2	1192.00	453.59	11	1	1	3	2683.00	1357.45
8	1	2	3	1247.00	277.98	11	1	1	4	1976.00	1652.55
8	1	2	4	801.00	498.98	11	1	2	1	1987.00	1439.20
8	2	1	1	1233.00	498.00	11	1	2	2	1950.00	1266.65
8	2	1	2	1548.00	524.00	11	1	2	3	2121.00	1203.10
8	2	1	3	1079.00	498.00	11	1	2	4	1914.00	1257.60
8	2	1	4	1082.00	572.40	11	2	1	1	2019.00	1343.85
8	2	2	1	736.00	453.59	11	2	1	2	2376.00	1407.40
8	2	2	2	1314.00	483.80	11	2	1	3	2341.00	1180.40
8	2	2	3	742.00	408.90	11	2	1	4	1691.00	1466.40
8	2	2	4	894.00	423.80	11	2	2	1	2434.00	749.10
9	1	1	1	1596.00	690.10	11	2	2	2	2049.00	1389.25
9	1	1	2	1529.00	576.60	11	2	2	3	2077.00	1262.10
9	1	1	3	1303.00	653.80	11	2	2	4	2099.00	1312.05
9	1	1	4	1465.00	799.00	12	1	1	1		1493.65
9	1	2	1	1419.00	505.90	12	1	1	2		1584.45
9	1	2	2	1282.00	803.60	12	1	1	3		1234.90
9	1	2	3	1402.00	549.30	12	1	1	4		1675.25

Table C.4 (Cont'd).

Sam	Till	Corn	Rep ²	1986	1987	Sam	Till	Corn	Rep	1986	1987
---g/5 plants---						---g/5 plants---					
12	1	2	1		1221.25	12	2	1	3		1298.45
12	1	2	2		1389.25	12	2	1	4		1566.30
12	1	2	3		1243.95	12	2	2	1		1520.90
12	1	2	4		1280.30	12	2	2	2		1057.80
12	2	1	1		1375.60	12	2	2	3		1457.35
12	2	1	2		1225.80	12	2	2	4		1684.35

¹To run Richards function use 1) g/plant and 2) average of the four replications.

²Sample, Tillage, Replication

Table C.5. Aggregate analysis.

Sam	Till	CS	Rep ¹	1985-1986				1986-1987			
				Agg ₁	Agg ₂	Erod	GMD ²	Agg ₁	Agg ₂	Erod	GMD
1	1	1	1	56.5	84.6	28.15	1.53	.710	.831	13.02	2.42
1	1	1	2	52.1	74.1	33.52	1.28	.729	.859	11.27	2.06
1	1	1	3	66.9	82.7	16.96	1.58	.778	.845	6.96	2.55
1	1	1	4	52.7	79.0	32.76	1.38	.630	.750	20.94	1.58
1	2	1	1	69.1	88.1	14.82	1.87	.598	.830	24.39	1.57
1	2	1	2	69.5	89.8	14.43	1.87	.658	.846	18.05	1.83
1	2	1	3	69.6	92.6	14.34	1.98	.546	.792	30.42	1.42
1	2	1	4	59.6	89.4	24.61	1.87	.678	.826	16.07	2.14
1	1	2	1	39.0	72.5	52.71	.83	.677	.799	16.17	1.96
1	1	2	2	59.3	84.7	24.95	1.18	.600	.749	24.17	1.47
1	1	2	3	55.3	82.4	29.57	1.37	.698	.817	14.15	2.07
1	1	2	4	63.7	85.9	20.21	1.94	.588	.800	25.51	1.45
1	2	2	1	60.6	85.6	23.51	1.28	.681	.848	15.78	2.05
1	2	2	2	45.8	73.6	42.06	.95	.488	.682	37.86	1.12
1	2	2	3	46.8	86.5	40.63	1.16	.655	.791	18.36	1.76
1	2	2	4	58.3	82.1	26.07	1.68	.569	.758	27.68	1.25
1	1	3	1	48.3	71.9	38.54	1.02	.608	.875	23.29	1.38
1	1	3	2	43.7	76.4	45.17	1.00	.584	.852	25.96	1.58
1	1	3	3	68.1	84.8	15.78	1.84	.587	.871	25.62	1.51
1	1	3	4	57.1	81.5	27.45	1.51	.625	.863	21.47	1.54
1	2	3	1	59.1	72.8	25.17	1.53	.657	.863	18.16	1.84
1	2	3	2	61.9	82.6	22.11	1.41	.694	.901	14.53	2.10
1	2	3	3	61.0	84.9	23.08	1.55	.725	.906	11.64	2.17
1	2	3	4	40.0	70.4	51.03	.80	.685	.900	15.39	2.00
2	1	1	1	69.1	82.9	14.82	1.90	.610	.860	23.37	1.72
2	1	1	2	77.1	85.4	7.56	2.89	.700	.850	14.36	2.02
2	1	1	3	81.1	82.4	4.21	2.98	.610	.860	22.61	1.51
2	1	1	4	79.6	89.0	5.45	2.95	.630	.870	21.08	1.87
2	2	1	1	70.0	84.0	13.96	1.83	.750	.930	9.39	2.25
2	2	1	2	72.0	88.9	12.09	1.96	.720	.920	12.09	1.84
2	2	1	3	71.8	87.9	12.28	2.03	.730	.910	11.06	2.11
2	2	1	4	65.3	83.0	18.56	1.53	.680	.870	15.45	1.96
2	1	2	1	65.7	83.6	18.16	1.46	.690	.910	14.57	1.65
2	1	2	2	56.1	79.3	28.62	1.24	.550	.750	30.14	1.06
2	1	2	3	41.4	64.1	48.73	1.58	.520	.760	33.32	1.10
2	1	2	4	62.8	81.7	21.49	.98	.620	.750	21.63	1.72
2	2	2	1	45.9	67.6	41.92	1.07	.570	.840	27.09	1.44
2	2	2	2	71.7	83.2	12.37	2.68	.590	.870	25.14	1.60
2	2	2	3	72.8	84.8	11.36	2.08	.440	.630	25.02	.84
2	2	2	4	58.1	71.3	26.30	1.64	.620	.850	22.50	1.51
2	1	3	1	71.7	87.9	12.37	2.02	.670	.920	16.53	1.87
2	1	3	2	59.6	76.6	24.61	1.74	.60	.900	24.70	1.55
2	1	3	3	65.0	83.0	18.87	1.63	.730	.930	11.50	2.01
2	1	3	4	70.2	80.3	13.77	2.09	.700	.920	14.39	1.75

Table C.5 (Cont'd).

Sam	Till	CS	Rep ¹	1985-1986				1986-1987			
				Agg ₁	Agg ₂	Erod	GMD ²	Agg ₁	Agg ₂	Erod	GMD
2	2	3	1	64.9	78.9	18.97	1.56	.630	.820	21.31	1.55
2	2	3	2	73.7	90.2	10.55	1.56	.580	.910	26.64	1.29
2	2	3	3	72.0	88.1	12.18	2.02	.610	.920	23.01	1.33
2	2	3	4	83.8	88.2	2.04	3.09	.610	.900	23.39	1.48
3	1	1	1	51.9	84.5	27.11	1.16	.590	.820	25.33	1.45
3	1	1	2	45.4	81.7	31.27	.91	.640	.820	19.61	1.44
3	1	1	3	59.4	85.8	22.00	1.35	.580	.810	26.49	1.41
3	1	1	4	52.4	82.6	25.62	1.14	.590	.780	25.30	1.48
3	2	1	1	57.4	75.6	33.78	1.26	.610	.830	23.18	1.62
3	2	1	2	53.9	85.8	42.64	1.17	.540	.810	30.85	1.29
3	2	1	3	62.0	86.9	24.84	1.26	.630	.870	20.92	1.64
3	2	1	4	58.7	85.0	33.14	1.21	.610	.760	23.41	1.55
3	1	2	1	26.7	55.5	35.98	.60	.630	.830	20.53	1.30
3	1	2	2	48.5	72.7	30.18	.76	.580	.800	26.20	1.42
3	1	2	3	42.8	54.6	24.61	.81	.520	.660	33.77	1.16
3	1	2	4	49.4	79.6	27.57	.86	.510	.770	35.43	1.19
3	2	2	1	50.2	78.3	77.80	1.09	.630	.830	20.88	1.72
3	2	2	2	54.8	84.4	38.27	1.18	.590	.810	25.75	1.60
3	2	2	3	59.6	80.9	46.55	1.17	.620	.870	22.17	1.46
3	2	2	4	57.0	89.6	37.04	1.14	.500	.760	36.87	1.11
3	1	3	1	32.1	70.8	31.27	.64	.550	.760	29.87	1.08
3	1	3	2	55.0	81.4	25.62	1.12	.530	.740	32.70	1.04
3	1	3	3	51.5	78.0	32.89	.97	.570	.780	27.53	1.27
3	1	3	4	47.9	80.7	22.75	.95	.570	.830	27.80	1.23
3	2	3	1	53.9	80.9	65.60	1.04	.670	.800	16.49	1.98
3	2	3	2	58.7	85.9	29.93	1.26	.600	.800	24.39	1.30
3	2	3	3	52.6	80.7	34.29	1.12	.560	.770	28.56	1.32
3	2	3	4	61.3	84.1	39.09	.99	.610	.860	23.32	1.57
4	1	1	1	63.8	88.3	20.10	1.04	.610	.860	23.18	1.62
4	1	1	2	59.2	87.9	25.06	1.26	.510	.840	35.43	1.19
4	1	1	3	72.3	91.9	11.82	1.12	.580	.810	26.49	1.40
4	1	1	4	59.2	90.0	25.06	1.32	.620	.800	21.78	1.43
4	2	1	1	49.6	85.7	36.78	1.25	.630	.840	20.92	1.64
4	2	1	2	53.8	85.9	31.39	1.36	.570	.830	27.80	1.23
4	2	1	3	58.9	86.7	25.40	1.60	.540	.830	30.88	1.28
4	2	1	4	49.4	84.5	37.05	1.21	.630	.830	20.88	1.72
4	1	2	1	65.9	90.6	17.96	1.43	.550	.630	29.96	1.08
4	1	2	2	60.4	89.2	23.73	1.32	.590	.780	25.30	1.48
4	1	2	3	64.1	89.9	19.79	1.59	.570	.780	27.53	1.27
4	1	2	4	53.2	84.8	32.14	1.23	.520	.640	33.77	1.16
4	2	2	1	42.4	69.1	47.17	.81	.590	.820	25.33	1.45
4	2	2	2	36.3	62.6	57.46	.74	.590	.810	25.75	1.60
4	2	2	3	38.5	53.5	53.56	.78	.610	.860	23.32	1.57
4	2	2	4	38.1	66.4	54.25	.65	.670	.810	16.43	2.02

Table C.5 (Cont'd).

Sam	Till	CS	Rep ¹	1985-1986				1986-1987			
				Agg ₁	Agg ₂	Erod	GMD ²	Agg ₁	Agg ₂	Erod	GMD
4	1	3	1	51.9	88.1	33.78	.99	.560	.770	28.51	1.33
4	1	3	2	58.9	90.7	25.40	1.17	.500	.760	36.84	1.11
4	1	3	3	48.9	88.6	37.72	1.05	.640	.820	19.61	1.45
4	1	3	4	49.0	90.0	37.59	.95	.530	.740	32.70	1.04
4	2	3	1	40.5	86.0	50.21	.87	.620	.870	22.16	1.46
4	2	3	2	57.6	92.3	26.87	1.04	.580	.800	26.20	1.42
4	2	3	3	63.2	65.0	20.73	1.66	.590	.810	24.84	1.60
4	2	3	4	50.0	89.3	36.25	1.07	.630	.830	20.53	1.31

¹Sample, Tillage, Replication

²Agg₁ is >0.84 mm aggregates in %, Agg₂ is aggregate stability in %, Erod is potential erodibility in Mg ha⁻¹yr⁻¹, and GMD is geometric mean diameter in mm.

Table C.6. Aggregate and particle size distributions, 1985-1986.

Sample	FS ²	ASD ¹						PSD ³
		CT ₁	RT ₁	CT ₂	RT ₂	CT ₃	RT ₃	
1	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	29.2	17.7	29.9	30.2	29.6	30.8	
	0.500							89.86
	0.840	43.0	30.4	45.6	46.8	45.7	44.5	
	1.000							94.73
	2.000	47.2	34.4	50.4	51.7	51.1	48.8	100.00
	6.400	56.9	43.9	59.8	61.2	60.8	59.3	
19.200	82.8	69.2	82.5	83.6	83.5	81.5		
2	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	12.7	17.3	27.2	22.3	19.3	15.5	
	0.500							89.86
	0.840	23.3	30.3	43.6	37.9	33.4	26.5	
	1.000							94.73
	2.000	30.2	38.3	51.4	46.3	40.9	34.2	100.00
	6.400	42.1	48.1	62.8	57.9	52.7	47.2	
19.200	68.2	73.5	82.7	82.0	76.5	71.4		
3	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	31.9	25.0	40.9	27.6	38.4	27.1	
	0.500							89.86
	0.840	47.8	42.0	58.1	44.6	53.4	43.4	
	1.000							94.73
	2.000	56.1	51.4	65.1	54.1	60.6	53.4	100.00
	6.400	68.1	61.6	72.0	64.1	69.7	63.6	
19.200	86.6	79.3	85.2	81.3	85.9	79.3		

Table C.6 (Cont'd).

Sample	FS ²	ASD ¹						PSD ³
		CT ₁	RT ₁	CT ₂	RT ₂	CT ₃	RT ₃	
4	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	23.5	32.6	25.0	42.6	32.0	34.9	
	0.500							89.86
	0.840	36.4	47.0	39.1	61.2	47.8	47.2	
	1.000							94.73
	2.000	43.5	53.8	47.0	66.4	55.7	53.9	100.00
	6.400	55.3	66.5	58.9	73.0	66.7	64.5	
	19.200	76.5	91.6	78.9	87.8	83.0	84.8	

¹Aggregate Size Distribution in cum. %

²Fraction Size in mm

³Particle Size Distribution in cum. %

Table C.7. Aggregate and particle size distributions, 1986-1987.

Sample	FS ²	ASD ¹						PSD ³
		CT ₁	RT ₁	CT ₂	RT ₂	CT ₃	RT ₃	
1	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	16.2	24.9	22.2	26.2	25.4	19.4	
	0.500							89.86
	0.840	28.0	38.0	35.9	40.2	39.9	31.0	
	1.000							94.73
	2.000	35.8	46.0	43.5	48.2	48.2	39.5	100.00
	6.400	48.7	60.7	55.7	60.8	62.2	55.9	
19.200	75.0	75.0	80.5	84.4	85.0	82.2		
2	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	23.1	16.5	30.2	28.5	21.1	25.1	
	0.500							89.86
	0.840	36.4	27.9	40.3	44.6	32.8	39.5	
	1.000							94.73
	2.000	44.0	34.6	47.1	52.3	40.4	47.6	100.00
	6.400	58.1	46.3	58.3	63.7	56.4	61.3	
19.200	84.6	70.6	79.4	85.5	79.2	81.4		
3	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	24.9	20.0	28.0	25.8	30.7	23.0	
	0.500							89.86
	0.840	40.0	40.3	44.0	41.8	44.6	41.1	
	1.000							94.73
	2.000	47.7	49.5	52.3	50.0	51.1	47.1	100.00
	6.400	59.6	62.6	64.3	62.1	60.7	59.5	
19.200	81.6	84.5	84.2	85.2	80.2	81.8		

Table C.7 (Cont'd).

Sample	FS ²	ASD ¹						PSD ³
		CT ₁	RT ₁	CT ₂	RT ₂	CT ₃	RT ₃	
4	0.001							16.00
	0.002							18.60
	0.010							21.33
	0.025							37.33
	0.050							58.74
	0.100							71.00
	0.250							82.77
	0.420	27.0	22.5	32.4	20.2	30.9	21.5	
	0.500							89.86
	0.840	42.1	40.8	44.3	38.6	44.3	39.3	
	1.000							94.73
	2.000	50.1	50.2	49.7	47.7	50.5	49.1	100.00
	6.400	63.8	62.9	59.5	60.6	60.6	61.6	
	19.200	85.5	83.8	82.2	84.2	81.6	81.2	

¹Aggregate Size Distribution in cum. %

²Fraction Size in mm

³Particle Size Distribution in cum. %

Table C.8. Soil moisture, bulk density, 1986-1987.

Sam	Till	CS	Rep ¹	1986		1987	
				Moisture ²	Bulk Density ³	Moisture	Bulk Density
1	1	1	1	18.91	1.37	17.80	1.34
1	1	1	2	17.63	1.41	18.10	1.29
1	1	1	3	16.70	1.21	18.10	1.29
1	1	1	4	20.70	1.50	21.90	1.25
1	1	2	1	21.90	1.46	18.40	1.25
1	1	2	2	18.10	1.25	20.00	1.29
1	1	2	3	18.76	1.21	25.10	1.32
1	1	2	4	18.61	1.41	24.00	1.22
1	2	1	1	23.87	1.55	29.90	1.34
1	2	1	2	24.20	1.44	29.70	1.33
1	2	1	3	25.00	1.47	32.00	1.41
1	2	1	4	23.64	1.45	25.20	1.39
1	2	2	1	22.11	1.34	30.00	1.32
1	2	2	2	20.40	1.36	25.60	1.30
1	2	2	3	22.44	1.36	26.80	1.27
1	2	2	4	26.73	1.65	24.80	1.29
2	1	1	1	16.29	1.30	21.10	1.27
2	1	1	2	21.98	1.33	20.40	1.22
2	1	1	3	18.96	1.31	20.30	1.23
2	1	1	4	21.20	1.23	20.10	1.24
2	1	2	1	20.72	1.20	17.80	1.23
2	1	2	2	20.76	1.20	21.00	1.29
2	1	2	3	20.16	1.20	19.60	1.25
2	1	2	4	17.63	1.10	22.20	1.20
2	2	1	1	21.03	1.23	25.10	1.23
2	2	1	2	19.63	1.30	26.60	1.26
2	2	1	3	20.11	1.13	31.00	1.32
2	2	1	4	18.98	1.13	26.90	1.25
2	2	2	1	27.17	1.43	24.00	1.25
2	2	2	2	23.66	1.30	24.50	1.28
2	2	2	3	26.78	1.53	25.20	1.28
2	2	2	4	24.55	1.47	24.10	1.29
3	1	1	1	19.05	1.27	19.60	1.25
3	1	1	2	21.40	1.23	19.60	1.25
3	1	1	3	21.38	1.28	20.70	1.22
3	1	1	4	22.12	1.40	21.00	1.26
3	1	2	1	20.21	1.17	23.20	1.24
3	1	2	2	20.21	1.10	22.40	1.24
3	1	2	3	19.80	1.10	22.60	1.27
3	1	2	4	20.00	1.17	22.90	1.24
3	1	1	1	22.40	1.40	22.00	1.26
3	1	1	2	18.85	1.30	22.90	1.23
3	1	1	3	22.61	1.27	23.10	1.26
3	1	1	4	21.50	1.20	25.10	1.24
3	1	2	1	19.92	1.20	23.80	1.25

Table C.8 (Cont'd).

Sam	Till	CS	Rep ¹	1986		1987	
				Moisture ²	Bulk Density ³	Moisture	Bulk Density
3	1	2	2	19.67	1.15	23.30	1.23
3	1	2	3	18.15	1.10	23.20	1.26
3	1	2	4	21.01	1.10	23.90	1.23
3	2	1	1	24.18	1.30	24.50	1.21
3	2	1	2	23.62	1.27	24.80	1.23
3	2	1	3	23.92	1.30	24.60	1.26
3	2	1	4	24.00	1.23	25.00	1.20
3	2	2	1	27.62	1.40	23.80	1.24
3	2	2	2	26.03	1.43	24.10	1.23
3	2	2	3	24.00	1.50	23.90	1.24
3	2	2	4	26.61	1.47	24.70	1.21
3	2	1	1	24.11	1.23	28.30	1.21
3	2	1	2	24.11	1.23	27.80	1.25
3	2	1	3	23.62	1.23	38.40	1.22
3	2	1	4	22.88	1.23	29.00	1.24
3	2	2	1	27.00	1.43	24.80	1.21
3	2	2	2	24.88	1.43	25.00	1.23
3	2	2	3	23.71	1.33	25.50	1.21
3	2	2	4	21.45	1.30	26.80	1.22

¹Sample, Tillage, Replication

²Soil moisture is in cm.

³Bulk density is in g cm⁻³.

Table C.9. Soil temperatures, 1986.¹

Day	Conventional Tillage			Conservation Tillage		
	Obs Mean	SHU	Cum SHU	Obs Mean	SHU	Cum SHU
1	23.7	13.7	13.7	20.2	12.2	12.2
2	22.2	12.2	25.9	20.3	10.3	25.5
5	19.1	9.1	35.0	18.0	8.0	30.5
6	21.3	11.3	46.3	18.5	8.5	39.0
7	21.2	11.2	57.5	20.5	10.5	49.5
8	22.0	12.0	69.5	21.3	11.5	61.0
9	20.1	10.1	79.6	17.0	7.5	68.5
13	19.8	9.8	89.4	18.4	8.4	76.9
14	17.9	7.8	97.2	17.7	7.7	84.6
15	16.6	6.6	103.8	16.3	6.3	90.9
16	17.4	7.4	111.2	17.1	7.1	98.0
19	19.0	9.0	120.2	18.5	8.5	106.5
20	21.0	11.0	131.2	19.6	9.6	116.1
21	21.8	11.8	143.0	20.7	10.7	126.8
22	26.7	16.7	159.7	20.8	10.8	137.6
23	23.5	13.5	173.2	21.8	11.8	149.4
26	23.7	13.7	186.9	22.1	12.1	161.5
27	19.5	9.5	196.4	18.4	8.4	169.9
28	15.1	5.1	201.5	15.3	5.3	175.2
29	18.5	8.5	210.0	20.6	10.6	185.8
30	21.3	11.3	221.3	19.6	9.6	195.4
33	23.8	13.8	235.1	22.1	12.1	207.5
34	25.1	15.1	250.2	23.7	13.7	221.2
36	26.0	16.0	266.2	24.0	14.0	235.2
37	26.0	16.0	282.2	24.2	14.2	249.4
40	25.3	15.3	297.5	24.4	14.4	263.8
41	24.7	14.7	312.2	24.0	14.0	277.9
42	24.8	14.8	327.0	23.5	13.5	291.3
43	25.0	15.0	342.0	23.7	13.7	305.0
44	24.1	14.1	356.1	22.6	12.6	317.6
47	24.0	14.0	370.1	22.7	12.7	330.3
48	23.3	13.3	383.4	22.7	12.7	343.0
49	23.6	13.6	397.0	22.2	12.2	355.2
50	24.0	14.0	411.0	23.0	13.0	368.2
54	24.3	14.3	425.3	23.4	13.4	381.6
55	24.1	14.1	439.4	23.4	13.4	395.0
56	23.9	13.9	453.3	23.2	13.2	408.2
57	22.5	12.5	465.8	22.5	12.5	420.7
58	23.3	13.3	479.1	22.4	12.4	433.1
61	23.4	13.4	492.5	22.6	12.6	445.7
62	23.6	13.6	506.1	23.0	13.0	458.7
63	23.7	13.7	519.8	22.9	12.9	471.6
64	23.5	13.5	533.3	22.8	12.8	484.4
65	23.4	13.4	546.7	23.0	13.0	497.4
68	21.9	11.9	558.6	21.8	11.8	509.2
69	21.2	11.2	569.8	21.6	11.6	520.8

¹Observed daily mean temperature in °C, soil heat unit in degree days, cumulative SHU. Each value is an average of three replications.

Table C.10. Soil temperatures, 1987.¹

Day	Conventional Tillage			Conservation Tillage		
	Obs Mean	SHU	Cum SHU	Obs Mean	SHU	Cum SHU
1	20.0	10.0	10.0	19.8	9.8	9.8
2	21.0	11.0	21.0	21.0	11.0	20.8
3	21.5	11.5	32.5	21.1	11.1	31.9
6	22.1	12.1	44.6	21.8	11.8	43.6
7	23.6	13.6	58.2	22.8	12.8	56.4
8	19.9	9.9	68.1	19.0	9.0	65.4
17	20.4	10.4	78.5	20.3	10.3	75.6
18	19.4	9.4	87.9	19.5	9.5	85.1
21	22.1	12.1	100.0	22.3	12.3	97.4
22	25.9	15.9	115.8	23.8	13.8	111.1
23	23.4	13.4	129.2	22.4	12.4	123.5
24	19.1	9.1	138.4	18.4	8.4	132.0
28	23.3	13.3	151.6	22.3	12.3	144.1
29	25.8	15.8	167.4	24.4	14.4	158.5
30	23.5	13.5	180.9	22.5	12.5	171.0
31	24.7	14.7	195.5	23.5	13.5	184.5
32	25.5	15.5	211.0	24.4	14.4	199.0
35	26.8	16.8	227.8	25.3	15.3	214.3
37	26.5	16.5	244.3	30.4	20.4	234.7
38	26.8	16.8	261.1	25.1	15.1	249.8
39	25.0	15.0	276.1	27.0	17.0	266.8
42	27.1	17.1	293.2	26.5	17.0	283.3
43	26.1	16.1	309.3	24.8	14.8	298.0
44	26.5	16.5	325.8	25.1	15.1	313.1
45	25.0	15.0	340.8	24.3	14.3	327.4
46	22.8	12.8	353.6	23.0	13.0	340.4
49	23.3	13.3	366.8	23.1	13.1	353.5
50	21.6	11.6	378.5	21.0	11.0	364.5
51	21.1	11.1	389.6	20.5	10.5	375.0
52	21.5	11.5	401.1	21.0	11.0	386.0
54	22.5	12.5	413.6	22.4	12.4	398.4
55	22.6	12.6	426.2	22.4	12.4	410.8
56	22.8	12.8	439.0	28.9	18.9	429.7
57	23.4	13.4	452.4	23.3	13.3	442.9
58	23.8	13.8	466.1	23.3	13.3	456.2
59	24.3	14.3	480.4	23.8	13.8	470.0
60	23.3	13.3	493.6	23.0	13.0	483.0
63	19.0	9.0	502.6	18.5	8.5	491.4

¹Observed daily mean temperature in °C, soil heat unit in degree days, cumulative SHU. Each value is a single observation (no replications).

Table C.11. Net infiltration, 1986 and 1987.

Till	IR	Rep ¹	1986	Till	IR	Rep	1987
			-mm--				-mm--
1	2	1	148.5	1	1	1	150.0
1	2	2	142.0	1	1	2	153.0
2	2	1	244.0	2	1	1	283.0
2	2	2	228.0	2	1	2	270.0
1	3	1	144.0	1	2	1	127.0
1	3	2	123.5	1	2	2	124.0
2	3	1	195.5	2	2	1	223.0
2	3	2	191.5	2	2	2	219.0

¹Tillage, irrigation and replication numbers.

Table C.12. Irrigation advance times, 1986 and 1987.

Till	IR	Rep ¹	1986	Till	IR	Rep	1987
			-min-				-min-
1	2	1	13.3	1	1	1	17.7
1	2	2	13.1	1	1	2	17.4
2	2	1	16.8	2	1	1	19.4
2	2	2	20.4	2	1	2	19.0
1	3	1	9.8	1	2	1	15.5
1	3	2	10.0	1	2	2	12.3
2	3	1	14.5	2	2	1	20.3
2	3	2	14.8	2	3	3	23.9

¹Tillage, irrigation and replication numbers.

Table C.13. Ear-leaf nitrogen, 1986.

Case No.	Variables				
	1	2	3	4	
1	1	1	1		2.87
2	2	1	1		2.92
3	3	1	1		2.79
4	4	1	1		2.76
5	1	1	2		2.79
6	2	1	2		2.82
7	3	1	2		2.84
8	4	1	2		2.79
9	1	2	1		2.79
10	2	2	1		2.69
11	3	2	1		2.76
12	4	2	1		2.55
13	1	2	2		2.53
14	2	2	2		2.29
15	3	2	2		2.43
16	4	2	2		2.14

List of Variables:

- 1 - Replication Number
- 2 - Tillage Management Treatment
- 3 - Year of the Rotation
- 4 - Corn-Ear Leaf Nitrogen Content

APPENDIX D
ANALYSIS OF VARIANCE

Table D.1. Analysis of variance for corn and watermelon production, 1985-1987.

Source of Variation	1985-1987			1985 & 1987			1985-1987			1985-1987		
	Corn Grain Yield			Corn Total Dry Matter			Marketable Melon No.			Mean Seed Yield		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Total	47			31			23			23		
Tillage x Crop Sequence	3	584425.70	0.74	3	151256.00	3.98*	1	806667.67	16.59*	1	8909.08	0.16
Replication (year)	11	45676.00	57.56*	7	636511.82	16.77*	11	702483.05	14.45*	11	1659.40	3.02*
Residual	33	79352.00	--	21	37963.00	--	11	48609.43	--	11	549.83	--

* Significant at P=0.05.

Table D.2. Aggregate analysis, 1985-1986 and 1986-1987.

Source of Variation	df	1985-1986								1986-1987							
		Agg ₁		Agg ₂		Erod		GMD		Agg ₁		Agg ₂		Erod		GMD	
		MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Total	95																
Sample	3	11.98	20.30*	7.90	17.50*	1518.41	16.01*	3.83	35.42*	0.0230	8.95*	0.0210	8.08*	285.95	10.50*	0.82	12.15*
CS	2	6.95	11.80*	5.62	12.50*	1076.46	11.35*	1.12	10.37*	0.0160	6.04*	0.0350	13.71*	142.60	5.24*	0.49	7.30*
Rep	3	1.36	2.30	0.77	1.70	227.47	2.40	0.28	2.57	0.0043	1.65	0.0019	0.74	61.43	2.26	0.10	1.52
Till	1	0.26	0.44	2.65	5.90*	720.84	7.60*	0.05	0.50	0.0026	1.01	0.0150	5.89*	60.39	2.22	0.21	3.11
Till x Rep	3	0.20	0.34	0.16	0.36	98.33	1.04	0.02	0.21	0.0017	0.66	0.0004	0.16	9.39	0.34	0.05	0.69
Till x CS	2	0.81	1.37	2.47	5.50*	208.39	2.20	0.04	0.43	0.0026	0.99	0.0011	0.43	27.35	1.00	0.07	1.08
Till x CS x Rep	12	0.39	0.66	0.37	0.82	68.54	0.72	0.03	0.25	0.0018	0.72	0.0014	0.59	27.87	1.02	0.02	0.31
Sample x Till	3	4.39	7.44*	2.60	5.80*	566.35	5.97*	0.14	1.29	0.0041	1.60	0.0040	1.57	45.32	1.66	0.14	2.11
Sample x CS	6	0.43	0.73	0.55	1.20	42.00	0.44	0.11	0.99	0.0041	1.58	0.0067	2.62*	26.99	0.99	0.12	1.82
Sample x Till x CS	6	1.32	2.23	0.35	0.78	171.22	1.81	0.54	5.04*	0.0101	3.93*	0.0035	1.35	103.00	3.78*	0.24	3.60*
Residual	54	0.59	--	0.45	--	94.80	--	0.11	--	0.0026	--	0.0026	--	27.22	--	0.067	--

* Significant at P=0.05.

Table D.3. Volumetric soil moisture and bulk density, 1986 and 1987.

Source of Variation	df	1986				1987			
		Vol. Moist. Content		Bulk Density		Vol. Moist. Content		Bulk Density	
		cm H ₂ O		g cm ⁻³		cm H ₂ O		g cm ⁻³	
		MS	F	MS	F	MS	F	MS	F
Total	95								
Sample	2	12.95	5.67*	0.09900	18.46*	5.22	1.95	0.02700	44.03*
Depth	1	12.00	5.26*	0.00033	0.06	2.01	0.75	0.00310	5.05*
Rep	3	1.52	0.67	0.00800	1.46	5.91	2.21	0.00140	2.36
Till	1	216.32	94.78*	0.14200	26.39*	394.77	147.78*	0.00550	9.11*
Till x Rep	3	1.69	0.74	0.00430	0.81	8.92	3.34*	0.00140	2.24
Till x Depth	1	14.05	6.16*	0.17400	32.22*	40.51	15.16*	0.00081	1.34
Sample x Depth	2	13.14	5.76*	0.10800	2.01	5.28	1.98	0.00350	5.85*
Sample x Till x Depth	2	14.60	6.40*	0.04300	8.05*	0.97	0.34	0.00100	1.65
Sample x Till	2	2.62	1.15	0.00170	0.32	21.40	8.01*	0.00750	12.38*
Sample x Till x Rep	12	3.33	1.46	0.00790	1.42	4.50	1.69	0.00059	0.97
Residual	34	2.28	--	0.00540	--	2.67	--	0.00061	--

* Significant at P=0.05.

Table D.4. Irrigation advance times and net infiltration, 1986 and 1987.

Source of Variation	Advance Times (minutes)						Net Infiltration (mm)					
	1986			1987			1986			1987		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Total	7			7			7			7		
Tillage x Irrigation	3	26.00	16.73*	3	23.410	6.00	3	4410.61	141.00*	3	9355.468	429.35*
Replication	1	1.90	1.22	1	0.011	0.00	1	270.28	8.64	1	36.120	1.66
Residual	3	1.55	--	3	3.900	--	3	31.28	--	3	21.790	--

* Significant at P=0.05.