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The influence of conservation tillage on edaphtic properties of a typic dystrochrept in Massachusetts /

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THE INFLUENCE OF CONSERVATION TILLAGE ON EDAPHTIC PROPERTIES OF A TYPIC DYSTROCHREPT IN MASSACHUSETTS

A Thesis Presented

by

Peter Forbes Waldron

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This study was not without its moments of exasperation or feeling that "the engine of the world had stopped"; even so, Rick Staples and friends always managed to get it going. Sometimes it took as long as six months.

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The thesis is dedicated to the following thought:

"This", he said, handling it, "is a stone, and with a certain length of time it will perhaps be soil and from the soil it will become plant, animal or man."

H.H.

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CHAPTER I

INTRODUCTION

1.1 Statement of Problem

During the 19th century, the prevailing European concept of soil tillage was that it improved soil fertility, and that increased tillage resulted in better growing conditions (Kuipers 1975). Even in the first half of this century, these ideas governed agricultural production with emphasis on soil structure improvement, while appropriate weed control received only secondary attention (Kuipers 1963).

Immigration of Europeans into the United States led to import of European farm technology without much thought about its applicability or usefulness in this country. The disastrous results of this approach are evident from the dust bowl days in the early 1930's, and since that time efforts have been made to curb erosion by means of reducing tillage. Even today, the principal reason for conservation tillage is that it limits the loss of fertile top soil from intensively cropped lands. Frequently cited additional benefits of conservation tillage include savings in soil water losses through decreased evaporation, use of less energy to produce crops, and increased crop yields under certain conditions.

A conservation tillage system is one in which plant residue or rough soil surface is used to reduce loss of soil or water compared to unridged or clear tillage (SCSA 1976). Application of such tillage systems in the New England area has been rather limited when compared to other production regions. Christensen and Norris (1983) reported that the Corn Belt, the Northern Plains, Appalachia, and the Mountain States had more than 30% cropland in minimum tillage during 1981. Estimated cropland under no-till management in Massachusetts in 1981 was 600 hectares (2.9% of conventional tillage) and an estimated 3000 hectares (14.3% of conventional tillage) were cropped using minimum tillage (Lessiter 1982). One of the reasons for the slow acceptance of conservation tillage is the lack of research data pertaining to problems specific to the New England region. Climate, soils, and the socio-economic infrastructure are some factors which need to be addressed to evaluate the potential of conservation tillage in this area. The beneficial effect of this tillage system on erosion control is beyond questioning, but the acceptance by the farmer depends to a large extent on whether or not this system results in larger financial returns than the use of conventional tillage methods. Before economic benefits can be weighed against liabilities, it is necessary to evaluate the various conservation tillage systems under typical New England conditions, rather than the unilateral application of data generated elsewhere on different soils, with other crops and under dissimilar climatic conditions.

The purpose of this study is to: (i) compare differences in yield of three conservation tillage practices versus conventional tillage; (ii) examine the influence of the tillage treatments on selected soil properties; (iii) relate differences in these soil properties to plant growth using vegetative and root growth measurements; and (iv) evaluate methods of pre-tillage soil management that may ameliorate problems associated with conservation tillage practices during the first years of application.

1.2 Literature Review

Historical Perspective

In the early 1930's the Department of the Interior responded to the soil erosion problems, by founding the Soil Erosion Service, which, in 1935, became the Soil Conservation Service under the USDA (Rasmussen 1982). At that time, the concept of reducing or minimizing tillage seems to have been expressed by taking intensively worked, marginal cropland out of production. In 1936, farmers were offered payments for shifting cropland from soil depleting crops into soil conserving crops (Rasmussen 1982). It had been known that the adverse effects of tilling the soil could be controlled through crop rotation, planting legumes and contour plowing (Cochrane 1979). Cultivation, however, had yet to be explained in view of the physical behavior of the soil in relation to plant growth. In addition, the economics of the period did not always assure application of the available knowledge.

With the exception of the steel plow share, developed in 1834, there had been no effective advance in the design of the moldboard plow up to the 1900's (Cochrane 1979). Because of an incorrect interpretation of the effect of tillage on the soil, the practice of multiple cultivations to pulverize the soil was made popular (Pereira 1975). Kuipers (1970) reported that the general idea was that if tillage makes the soil fertile, it therefore cannot be overdone.

The knowledge base on which a modern agriculture would later develop was just beginning to take shape by the turn of the century. The discovery of soil relationships and soil properties to fulfill the scientific age of agriculture was not to occur until after 1933 (Cochrane 1979). By this time, tillage research was under way at Rothamsted, England to evaluate the effects of tillage on soil structure (Pereira 1975). In the United States, the real start of tillage research began in 1937 at the Ohio Agricultural Experiment Station (Page and Willard 1949). The objective of this work was to find which soil conditions could best promote corn production. In these experiments, yields were measured as the only indicator of the value of a tillage treatment.

Reduced-tillage experiments in the Northeast coincided with the publishing of "Plowman's Folly" in 1943 (Faulkner 1943). At the Cornell University Agricultural Experiment Station, modified plowing and disking were substituted for the moldboard plow (Free 1953). Corn yields under these procedures were two-thirds of those obtained with conventional seedbed preparation.

Tillage experiments focused on yield produce information that is only of importance in fairly small regions and under the environmental conditions prevailing at the time of the experiment. Many researchers, realizing the limitations of conventional cultivation experiments, turned their attention to the problem of measuring soil properties. A great deal of data was generated in defining and measuring soil physical properties, which were often only indirectly related to the root environment (Kuipers 1963). Hawkins and Brown (1963) stated the need to concentrate tillage research on measurable physical properties of the soil that are of importance to plant growth. Four principal soil physical factors that affect plant growth were formulated by Fontaine (1958) as: soil temperature, soil moisture, soil air, and the resistance of soil to root/shoot growth.

Soil Temperature

Larson (1964) showed that tillage influences the soil temperature by changes in soil density, amount of mulch cover, and microrelief differences. Several studies have found conservation till-age systems to be associated with lower midafternoon soil temperatures (at the 5 cm depth) during the early part of the growing season (Domby and Khonke 1955, Soane and Pidgeon 1975, and Mock and Erback 1977).

Walker (1969), in a laboratory study, showed that a difference of only one degree in the soil temperature range from 12 - 45°C, induced changes in the growth and nutritional behavior of corn seedlings amounting to as much as 30 - 40%/°C. Soil temperature can easily influence the behavior of the corn seedling due to the fact that the growing point (apical meristem) is below the soil surface for the first four to six weeks of plant growth (Duncan 1976). As the season progresses, differences in soil temperature due to the tillage operations have been found to decrease as the crop canopy develops and straw or corn stubble decompose (Gauer *et al*. 1982).

While conservation tillage lowers soil temperature during some part of the growing season, Hay (1977) showed that in the winter months, no-till plots had less temperature variation than conventional tillage. Hay suggested the insulating effects of the stubble mulch residue as a possible explanation.

Soil Moisture

Fluker (1958) stated that soil moisture influences radiation, evaporation, specific heat, thermal conductivity, diffusivity, and heat capacity of the soil. Soil moisture is normally lost from the plant root zone by evaporation from the soil surface, runoff as surface water, transpiration by the growing plant and percolation to depths beyond the normal root zone. Conservation tillage practices have been reported to conserve or increase soil water content and thereby influence plant growth.

Belevins *et al*. (1971) reported that no-till plots on a silt loam in Lexington, Kentucky had higher volumetric moisture contents than conventional tillage to a depth of 60 cm during most of the growing season. Seasonal differences were also reported by Shanholtz and Lillard (1969) who found a greater gravimetric moisture content in the first 15 cm of no-till plots early in the Virginia growing season when compared to conventional tillage. As the season progressed, it was suggested that differences gradually decreased because of demands made by increased plant growth.

In-situ matric suction was evaluated by Taylor *et al*. (1980) in various tillage treatments using Jet-Fill tensiometers. Allmaras and

Nelson (1971) used tensiometers with mercury manometers to measure matric potential under combinations of tillage and straw mulch strips. Comparisons from the different treatments, after tillage, showed a non-uniform soil environment in the direction perpendicular to the row. The bare tilled soil had the highest nonuniformity and lowest matric potential throughout the growing season. Gantzer and Blake (1978) described this nonuniformity of the tillage row by measuring the hydraulic properties of the soil.

Hydraulic properties are determined in part by the size and geometry of a soil pore system. Klute (1982) reports that relatively few studies of different tillage systems by the use of hydraulic conductivity measurements have been made. Those studies that have used hydraulic conductivity have usually been confined to differences between no-till and conventional tillage.

Mielke and Wilhelm (1981) showed that the greatest hydraulic conductivity was found in the surface 76 mm of a sod treatment, intermediate for the chemical and subtilled treatments and least for the plowed. If samples for hydraulic conductivity include earthworm channels it is easy to see how conductivity can be higher in no-till plots. When earthworm channels are not included in samples, no-till plots will have the lowest hydraulic conductivity (Allmaras et al. 1982, and Ehlers 1976, 1977).

Surface characteristics such as roughness and macro pore system govern the entry of water into the soil during high rainfall rates

(Edwards 1982). Mielke and Wilhelm (1981) determined the rate of infiltration into the soil by the double cylinder method. The hourly rate and total amount of infiltration for the subtilled and chemical treatments were more than double the values for the plowed treatments.

Triplett and Van Doren (1968) compared the effect different residues had on water infiltration in no-till plots. Rates for the 80% residue treatment exceeded plowing, no-tillage bare and no-tillage with 40% residue. This occurred even though the no-till and double residue treatments had as great or greater bulk density and as low or lower air filled porosity, near the soil surface, as the other treatments. Vertical earthworm channels were not looked at in this study.

Bouma et al. (1982) described three different types of steady infiltration rates associated with individual worm channels. Excavation of stained, gypsum-filled channels, following an infiltration run, showed that rates were associated with the following conditions: (i) low steady rates of about 20 cm^3/min were measured in channels in which the earthworm was still present within 50 cm below the surface of infiltration; (ii) higher rates of about 140 cm^3/min were measured in long, more or less vertical channels which extended to a maximum depth of 1.5 m below surface; (iii) high rates of 400 cm^3/min were measured in channels which ended within 50 cm below the surface infiltration, in highly porous mole burrows.

The infiltrability of worm channels in untilled soil was computed by Ehlers (1975) as more than 1000 $cm^3/m^2/min$, although the volume of the channels amounted to 0.2% of the area sampled. Many researchers have reported increases in earthworm populations under no-tillage to as high as 2 to 4 times of those found in conventionally tilled plots (Hopp 1949, Barly 1961, Soane and Pidgeon 1975, Ehlers 1975, Gantzer and Blake 1978, and Edwards and Lofty 1982).

The current tendency toward reducing seedbed preparation and mid-season cultivation indicates the importance of maintaining and encouraging practices that favor the buildup of earthworm activity (Edwards 1980). In the absence of earthworm channels, reductions in the infiltration rate often are a function of the hydraulic resistance of the soil crust.

Frost Heave Action

The combined effects of moisture and low temperature may produce frost heaves. Frost heaving in the soil is related to (i) size and percent of soil pores, (ii) particle size distribution, (iii) water content, (iv) rate of cooling, (v) depth of freezing, (vi) direction of cooling, and (vii) external pressures (Taber 1930). Tillage can drastically change most of the soil factors influencing frost action with the exception of the non-variable soil properties such as particle size. Conservation tillage practices are known to effectively alter many of the negative soil characteristics associated with conventional tillage.

Research concerning frost heaving in agricultural soils has concentrated predominently on the effect heaving may have on the overwintering of forage and cereal crops. While there is limited data available that links frost heaving to tillage practice, frost heave studies conducted under forage crops show some interesting relationships when compared to row crops.

Portz (1967) found that in Illinois, destructive frost heaving as measured by the movement of wood dowels, occurred most frequently under conditions of high rainfall on moderately poorly drained soils with temperatures fluctuating around the freezing point. A linear increase in frost heaving with increased precipitation was indicated for the period of 1913 to 1962. However, a rather low correlation coefficient of 0.36 indicates that antecedent precipitation does not account for all the variability. It is suggested by Holmes and Robertson (1960) that alternate freezing and thawing favor frost heaving in field plots mainly because water accumulates near the surface under these conditions which in turn provides more nearly optimum conditions for soil frost heaving to take place.

Heaving differences in forage stands and in bare ground was compared by Decker and Ronningen (1957) in a silt loam soil. Conclusions were that the heaving of pointed wooden dowels were negligible on all areas except those deprived of vegetation. Variation in heaving associated with differences in dowel diameter (.63 cm, .95 cm, and 2.54 cm) was not found to be significant.

A heavometer was used by Holmes and Robertson (1960) to measure soil heaving in alfalfa plots. Heaving was reported to occur mainly during two periods in December and March. Both examples were marked by negligible snow cover and widely fluctuating air temperatures.

The literature that does report the effect freezing may have on the tilled soil and row crops discusses only indirect measurements of frost action by the determination of soil temperature, resistance readings, and soil structure changes.

Bay et al (1952) measured the depth of frost penetration by resistance readings and noted the influence of cover crops in reducing the rate of soil freezing and thawing. Stubble mulch on uncultivated soil was found by Hay (1977) to insulate the surface layers from extreme temperature fluctuations resulting in less soil freezing than cultivated soil and fewer hours above 5°C.

Under continuous corn, soil structure change was reported by Slater and Hopp (1951) to be confined almost solely to the winter months. The greatest and most rapid change in surface soil structure, other than those produced during tillage, were found by Domby and Kohnke (1955) to be the result of alternate freezing and thawing of certain soils while wet.

Effects of Soil Compaction

Swanson and Jacobson (1956) noted compaction zones that are related to the soil surface, soil depth, treatment, and horizontal or vertical position in the plow layer. Soil crusts are examples of horizontal compaction zones. The vertical compaction zones are represented by the area between rows travelled over and compacted by tractor wheels during cultivation.

The formation of surface crusts by heavy rain is a common occurrence, particularly on soils which have been intensively cultivated

(McIntyre 1958). Morphological observations by Falayi and Bouma (1975) showed the processes of wash-in and deposition rather than compaction had been active in crust formation. Evans and Buol (1968) studied the sequence of events leading to crust formation under field conditions. These steps were found to be: (i) breakdown of soil aggregates by slaking on rain drop impact; (ii) movement of fine particles into the upper few centimeters of soil and deposition in pores; (iii) compaction of the soil surface to form a thin film on the surface which resists further entry of water and movement of fine particles into soil pores; (iv) deposition of fine particles on the surface from suspension. Pagliai et al. (1983), reporting on surface crust formation under no-till and conventional tillage, found the crusts of the tilled plots to be formed by several layers of horizontally oriented plate-like particles. Soil crusts were much less developed in samples taken from the surface of the no-till plots. Thin sections of the no-till surface showed that layers of oriented particles were absent and pores were present in the surface layer.

Seedling emergence was found by Parker and Taylor (1964), as measured with a penetrometer, to be affected by soil strength, moisture tension and soil temperature. In a field study comparing measurements using the penetrometer and the vane shear strength procedure, Taylor and Burnet (1964) showed results to have a 0.97 correlation coefficient.

Effects of compaction in the plow layer can be described by pulverizing dry aggregates, compressing and deforming moist aggregates and by pushing individual soil particles closer together, all resulting in reduced porosity (Voorhees and Lindstrom 1982). Kuipers and Van Ouwerkerk (1963) used a relief meter to measure that point when seedbed preparation reduced the porosity from favorable to a critical low level. Gantzer and Blake (1978) reported that the total porosity of surface samples taken under no-tillage was lower throughout the growing season when compared to conventional tillage. In a similar experiment, Phillips and Kirkham (1962) showed no difference in soil air or percent of carbon dioxide due to compaction, but differences in air permeability were associated with tillage operations.

Compaction is often referred to as an alteration in soil density. However, since bulk density is so strongly influenced by soil texture, the two must be correlated for useful interpretation of bulk density data. A six-year study on a Le Sueur clay loam in south central Minnesota found the bulk density in no-till plots to be greater than conventional tilled sites in the spring and fall (Gantzer and Blake 1978). Significant differences in bulk density were found by Byers and Webber (1957) on a Burford loam, when the mean values for bulk density for all tillage treatments were compared. After a five-year study period, the same authors found no significant difference in soil aggregation, bulk density, or porosity between the no-till and plowed treatments.

Bulk density measurements exhibit both spatial and temporal variabliity (Cassel 1982). This spatial variability, according to Cassel, results from vertical and lateral changes in soil properties such as texture, structure, organic matter content, and from the effects of past soil management. For this reason, measurements of bulk density may not always provide a good indication of the effects of compaction on plant growth.

When bulk density was compared with changes in mechanical impedence, the bulk density values were found to increase 20% or less, and differences due to tractor traffic were not significant below a depth of 15 cm (Voorhees and Lindstrom 1982). The corresponding increase of cone resistance was up to 400%, and in one year the differences due to traffic was significant to a depth of 60 cm.

Van Ouwerkerk and Boone (1970) used moisture retention curves to show that for any given level of compaction, a variety of different soil geometric structures can be present. Dexter (1976) developed an early technique for quantifying the geometric structure of tilth by measuring the distribution of angles of incidence between voids and aggregates. This method, which used paraffin as a saturating medium allows only calculations of the macropores.

At present, there are many techniques available to study changes in macro and micro structure of soil types. For example, Pagliai *et al*. (1983) used electro-optical image analysis for pore size distribution and orientation patterns between conventional and no-tilled plots. Fabric analysis has also been used to demonstrate the relationship between the type of stress applied and the structural response (Ismail 1975, Murphy *et al*. 1977). However, these morphological procedures are tedious and time consuming which makes immediate field application virtually impossible.

To a large extent, research studying the soil tillage system interaction has concentrated on differences between two extremes, namely, conventional tillage and no-tillage. Expanded knowledge about reduced and minimum tillage systems should be valuable as well. In some studies, corn yields on no-till plots have showed an increase over conventional tillage despite colder soil tempeatures, higher compaction, higher moisture contents, and a more homogenous pore distribution (Van Ouwerkerk and Boone 1970). This seems to indicate that the assessment of the soil physical condition in relation to plant growth needs to be extended to a wider range of tillage treatments.

Nutrient Availability

In conservation tillage treatments, nutrients in the soil that are slowly mobile, such as phosphate and potassium tend to be concentrated in surface layers. Shear and Moschler (1969) found accumulations of available potassium in the upper 5 cm of no-till soil to be 76% higher than that found in conventional tilled soil. Higher concentrations of phosphate and potassium were found by Triplett and Van Doren (1968) at the surface of no-tilled plots; but, no difference in surface concentration was found at tasseling when compared to conventional tillage.

When direct drilling of small grains is initiated, the nitrogen requirement has been found to be much higher than for conventional tillage (Russell *et al*. 1975). Belevins *et al*. (1977) showed that the distribution of nitrogen generally followed that of organic carbon, and that organic matter under no-till was less humified. Belevins *et al*.

(1983) found that the organic carbon level on no-till plots was twice as high as in conventional tillage with no significant difference below a depth of 5 cm.

Higher rates of soil nitrogen loss have been observed in no-till with corn due to leaching, denitrification, increased soil water, and increased biopores (Mengel et al. 1982). Increased denitrifying activity was found to be significantly correlated with the increased soil moisture of no-till plots (Rice and Smith 1982). These studies concluded that enchanced denitrification may account for lower soil nitrate concentrations and therefore higher nitrogen fertilizer needs for no-till corn.

Any tillage operation which will improve the permeability of the soil and allow increased root proliferation will improve the supply and utilization of nutrients because of the enchanced possibility for mass flow, diffusion , and root extension (Sumner and Boswell 1981).

Plant Growth

The pattern of root distribution in the soil determines the zone at which water and nutrients are made available to plants (Chaud 1974). Roots growing near the surface under no-till and reduced tillage are reported by Sumner and Boswell (1981) to be capable of freely supplying the nutrient needs of the corn plant as long as moisture conditions are favorable. Barber (1971) noted that even though the root mass was less under no-till corn the root growth obtained was sufficient to support normal growth and yield.

In laboratory studies, Russell and Goss (1974) found that the vertical movement of roots could be reduced by impedence but that there was sufficient opportunity for lateral development so that neither the dry weight of the root system or its ability to absorb nutrients from the restricted rooting zone was affected. Under mulched plots, Chaudhary and Prihar (1974) noted lateral root development that was associated with improved early growth and grain yields of corn.

Most of the tillage effort is devoted toward the production of a good seedbed and less effort is directed at producing a good rooting environment. One of the reasons that root bed preparation is usually not considered part of the tillage operation is that the root systems change throughout the growth of the corn plant (Trouse 1971). Hanway (1963) described ten stages of corn growth that were associated with significant increases in vegetative dry matter accumulation. Boekel (1963) suggested that the different growth stages of a corn plant would mean different demands on the soil by a changing root system. Root development occurring at a given location in the soil, and whether or not this was associated with stages in above ground growth, was studied by Foth (1962). Using conventional tillage, Foth described the following five stages of corn root growth associated with vegetative changes: (i) vegetative top growth and downward-diagonal root growth; (ii) continued vegetative growth, root "filling" in the upper soil layers, and appearance of the brace roots; (iii) rapid stem elongation, emergence of tassel, silking and pollination, accompanied by pronounced extension, and growth of roots vertically into the deeper soil layers and the continued development of brace roots; (iv) development of the ear to the early milk stage and completion of brace root growth; (v) maturation of seed and no significant growth of the root system.

CHAPTER II

MATERIALS AND METHODS

2.1. Experimental Parameters

Tillage research began in 1981 at the University of Massachusetts Experimental Farm in South Deerfield, on an Agawam silt loam variant (Typic Dystrochrept, coarse-loamy, mixed, mesic) with a 2 - 3% slope. The experimental design consists of a replicated randomized block with one replication of each tillage treatment for each of four blocks (Fig. 1). Plot size for each treatment measures 36.6 meters by 7.3 meters. The conservation tillage treatments compared are: (i) two passes with the disk harrow; (ii) chisel cultivator followed by disking (in 1981 a single pass with the disk harrow was used instead of the chisel plow); and (iii) no-tillage. Moldboard plowing followed by one pass with a disk harrow was the fourth tillage treatment and acted as the control. In 1980 a portion of Block I (Fig. 1) was planted to alfalfa and lupines, while all of Block II was planted into soybeans. At the start of these tillage experiments in 1981, Block I received additional organic matter in the form of manure slurry at a rate of 33.6×10^3 kg/ha. Depth of soil disturbance by the treatment was estimated to be 25 cm for plowing, 12 cm for disking, and 10 cm for chisel plowing.

Fertilizer was broadcast prior to tillage at rates of 155 kg/ha of potassium as murate of potash and 173 kg/ha of nitrogen as ammonium of nitrate. Phosphorus was banded at the time of planting using a 10-20-10 starter fertilizer at a rate of 336 kg P_2O_5/ha. Premergence

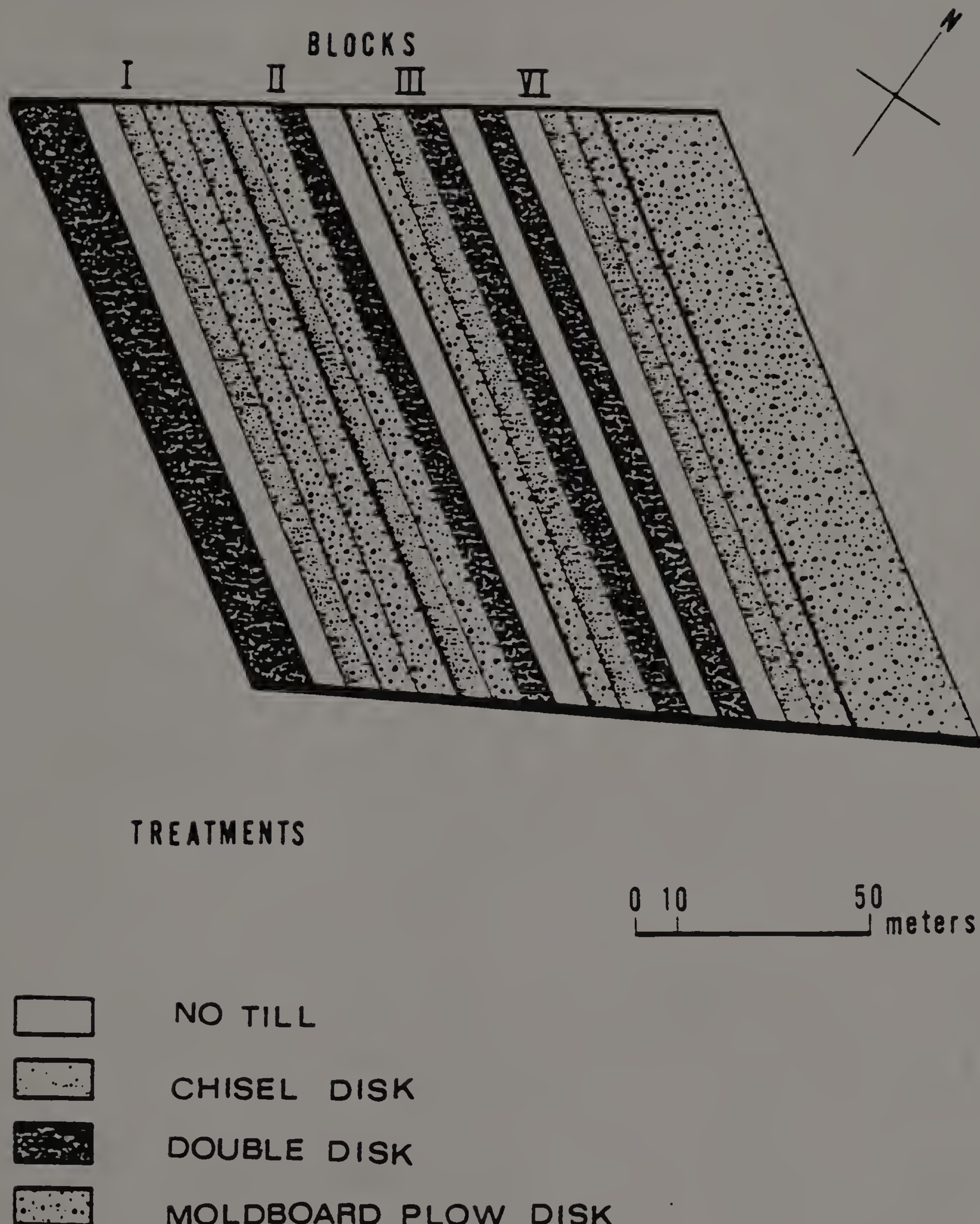


Fig. 1. Experimental design of the experimental site showing blocks with one replication of each treatment per block.

herbicide was sprayed after planting using 2.2 kg/ha Lasso, 1.1 kg/ha Atrazine, and 0.5 kg/ha Paraquat.

All treatments were planted to Agway 584S field corn on May 18, 1983 with an International Harvestor model no. 295 planter modified with a third disk, mounted ahead of the double disk opener, for the no-till planting. A Massey Ferguson 175 diesel tractor was used for all of the tillage operations as well as for planting and herbicide application.

2.2. Field measurements

Matric potential. Matric potential was measured with tensiometers installed at depths of 15 cm, 30 cm, and 60 cm. These depths correspond to the middle of the Ap horizon, the plow pan, and the subsoil, respectively. Each tensiometer measurement was replicated twice for each depth in all of the treatments of these blocks.

Tensiometers were constructed from rigid plastic tubing (1.9 cm dia.) cut to the desired lengths and epoxied to 6.4 cm long porous ceramic cups (Soil Moisture Equipment, Inc.). This assembly was installed with the center of the ceramic cup at the appropriate depth with the tube protruding about 8 cm above the soil surface. A 0.3 cm diameter hole was drilled about 4 cm from the top and semi-rigid nylon tubing (0.3 cm dia.) was inserted through the Soil Mositure Tube Clamp Assembly (Item #2326). The other end of the nylon tubing was put in a container with mercury which, together with a calibrated scale, formed a manometer. The tensiometer system was filled with deaired water and refilled as necessary. Measurements were taken three times weekly from

April to October with interruptions for tillage, harvesting, and dry periods when the matric potential exceeded -0.075 MPa.

Soil Temperature

Soil temperatures were measured weekly from October, 1982 to March, 1983 by means of thermistors (Yellow Springs Instruments model #401) with a portable tele-thermometer (YSI series 400) at depths of 5, 15, 30, 60 and 130 cm in the tillage treatments of Blocks II, III and IV.

Mechanical Impedence

A Proctor Penetrometer (Soil Test, Inc. model CN-433) was used to measure mechanical impedence due to crust development at the soil surface and soil strength at depths of 15, 30, 45, and 60 cm. A needle head 5 cm in diameter was constructed to permit penetrometer measurements in freshly tilled soil.

Frost Heaving

Evidence of frost heave action in the none compacted interrow spaces was measured within the various tillage treatments by relative changes in tube height and soil bulk density. Tubes were made from rigid plastic tubing (1.9 cm dia.) sealed at both ends. The tubes were placed 15 cm apart, in all the treatments of Blocks II, III, and IV at depths of 5, 15, 30, 60, and 130 cm. During placement of the tubes into the soil a steel pipe of equal diameter as the tubes, but with a beveled end, was used for accurate depth placement and minimal soil disturbance. Aluminum foil was used to cover the above ground portion of the tubes.

A flange was made in the foil at the soil surface to prevent precipitation from moving downwards along the tube surface into the soil.

Tubes at the 130 cm depth level were below the frostline and therefore were used as a reference point to gauge the movement of the other tubes in a treatment. Vertical tube movement, in relation to the reference point was measured in millimeters with a surveying level and a measuring staff with a horizontal bubble level.

Thermistors were placed at identical depths as the tubes. Temperature measurements were made weekly from October 13th, 1982 to March 30th, 1983. When the soil temperature reached 0°C on December 8th, 1982, frost heave measurements were initiated at all sites and continued at roughly biweekly intervals until March 30th, 1983.

Soil bulk density was measured after harvesting 1982 and before tillage 1983 to measure changes that might be due to frost heave action.

Earthworm Activity

Earthworm activity was measured before and after tillage and harvesting by recording the number of casts, vegetative mounds and biopores in three replications of 50 x 50 cm quadrangle for all treatments in all blocks.

In Situ Infiltration Rate

To measure the infiltration rate of the interrow spaces, a double ring infiltrometer as described by Bertrand (1965) was constructed. The inside and outside rings were made of 14 gauge galvanized steel with diameters of 45 cm and 68 cm, respectively. Data was collected using the constant head method for all treatments in blocks I and II before and after both tillage and harvesting.

Plant Height

The plant height for each tillage treatment in all blocks was monitored every two weeks throughout the growing season. Mean plant height was determined from the highest leaf stretched for ten plants in each treatment.

Shoot Growth

The mean plant height determination was used to select three plants from each treatment for dry weight determination. Samples were taken every two weeks throughout the growing seasons at the first node above the soil surface, vegetative matter was sectioned when necessary, bagged and dried in an oven at 82°C for 4 days.

Root Growth

Pinboards were constructed using two similar sized pieces of plywood 2 cm and 1 cm thick, respectively. In the 2 cm thick board, 0.35 cm holes were drilled in vertical and horizontal rows 5 cm apart to hold pins made from steel wire (0.3 cm dia.) bent into a L-shape with a 5 cm base and length of 17 cm. The second piece of plywood was screwed onto the first as backing, and prevented movement of the pins when the pinboard was driven into the soil. The dimensions of the pinboard were 60 cm by 45 cm which correspond to half of the interrow spacing.

Rootgrowth was measured with the pinboards from two weeks after emergence through harvest. During the second and fourth week of the sampling period the pinboard was used parallel to the plant row. From the sixth through the fourteenth week, the pinboard was set transversely to the plant row. To sample a root system using the pinboard, a pit was dug about half of a meter square, and the vertical wall against the plant to be sampled was smoothed off with a blade. Following this, the pinboard was held vertically with the pins against the profile face so that the top row of pins was at ground level, and the point where the above surface plant enters the soil was in the upper left corner. The pinboard was then driven into the soil with a hydraulic jack. Soil underneath the pinboard was cleared to a distance of a few centimeters beyond the tips of the pins. Soil from the profile face was cut away on either side of the board, and the jack was raised until the soil facing the pinboard failed. The jack then supported the pinboard which was hand lifted from the pit.

Upon removal, the pinboard sample was saturated from four shower heads under low water pressure elevated two meters above the horizontal pinboard. To reduce shower impact during the saturation stage, a 1 mm mesh screen was placed between the shower and the sample. After saturation, the water pressure was increased and washing was continued until roots were free of soil material.

When all soil was removed, the roots, impaled on the pinboard, were then photographed with a 35 mm SLR camera using Tri-X film (ASA 400) in a water tank. Submerged in water, the natural position of the finer roots is more effectively preserved than in a dry state. To avoid reflection from the water surface and to create even illumination, four 100 watt bulbs were mounted obliquely to the direction of the camera.

Before oven drying for dry weight determination, root samples were first air-dried and then rewetted in a 270 gram per 100 liter solution of sodium-hexametaphosphate $(NaPO_3)_6$ and allowed to soak for 12-24 hours with rewashing as needed (Schuurman and Goedewaagen 1971). This procedure is necessary to remove residual soil material that would affect dry matter determination. Upon removal of the soil material the root samples were bagged and oven-dried at 82°C for 4 days.

Nitrogen Fertilizer Rates

Each block of the experimental design was subdivided into three smaller subblocks of 366 m^2 each. Nitrogen fertilizer was broadcast as ammonium-nitrate (NH_4NO_3) and applied to these subblocks one day before tillage. Fertilizer rates consisted of 67 KgN/ha and 291 kgN/ha, respectively. The recommended nitrogen rate for silage corn in Massachusetts of 179 kgN/ha was used as the intermediate rate. The subblocks for the three rates of nitrogen fertilizer were selected randomly. Just prior to harvest of the entire field three meters of row from each subblock were sampled for silage, moisture content, grain/stalk ratio, and percent of dry weight ears.

2.3. Laboratory Determinations

Moisture Retention

Soil moisture characteristic curves were determined for all locations and depths where tensiometer measurements were made. Undisturbed core samples, taken before and after tillage and harvesting were obtained with a hammerdriven core sampler and placed into Tempe cells (Soil Moisture Equipment, Inc., cat #1400). The cells were saturated through application of a hydraulic head of a few centimeters, and upon saturation selected pressures of .002, .004, .008, 0.01, 0.025, 0.05, 0.075 and .1 MPa were applied. Upon reaching equilibrium after each pressure change, the mass of the samples were determined. After the last measurement, total dry mass was determined for bulk density calculation. The core samples were then broken apart in a mortar and passed through a #10 (2 mm) sieve. The sieved soil material was placed into a 1 cm high metal ring contained by a nylon screen held firmly in place by an outer plastic ring. Using the pressure membrane apparatus, these samples were wetted and subjected to pressures of .5 and 1.5 MPa. The moisture retention curve for each depth was replicated three times and averaged values are reported.

Thin Section Analysis

Undisturbed surface samples were taken for thin sectioning to study surface crust development. Thin plastic rings 15 cm in diameter and 8 cm high were pushed into the soil surface to a depth of about 5 cm. Parafin wax, melted on a portable gas stove, was poured into the ring sealing and protected the crust from disturbance during excavation and subsequent handling of the sample. Upon drying, samples were impregnated in a laboratory under vacuum with Spurr Low Viscosity Embedding Medium (Polysciences, Inc.) according to the manufacturer's recommended procedure for firm hardness. Samples were allowed to cure for at least three weeks and then cut with a diamond-edge saw, rough polished with silicon carbide abrasives (grit #'s 220, 320, 600, and 1000), and micropolished with alumina powders 0.3 and 0.05 um respectively. Mounted on a petrographic glass slide, the samples were again cut and polished back to a thickness of approximately 35 um. The micromorphological features were observed by means of a binocular microscope using circular polarized light (Ruark et al. 1982). These features were described using terminology developed by Brewer (1976).

Bulk Density

Bulk density samples were taken using the core method as described by Blake (1965). Volume of the core equalled 137.3 cm, and samples were oven dried at 105°C for dry mass determination. From the center of the interrow spaces a composite sample of three replications per depth were taken at 0, 15, 30, 45, and 60 cm, respectively. Data were collected three weeks before and after both, tillage and harvest operations for all treatments in the four blocks.

Hydraulic Conductivity

Unidsiturbed core samples, with a volume of 137.3 cm were taken three weeks after tillage and prepared for saturated hydraulic conductivity using the constant-head method described by Klute (965). Depths tested were the same as for bulk density and mechanical impedence.

Soil Fertility

In the spring of 1983, the Ap horizon was tested for pH, available nitrogen, phosphorus, potassium, and organic carbon using standard methods (Soil Survey Staff 1972). Fifteen point composite samples for each treatment in all blocks were taken using a 50 cm long tube sampler. The composite samples were first air dried, then passed through a 0.2 cm sieve. A sub-sample was used for all chemical tests after first being ground to pass a 0.5 cm sieve.

CHAPTER III

RESEARCH RESULTS

3.1. Tillage Treatment Influence on Frost Heave Action

Results

A one-way analysis of variance showed no significant difference in bulk density among the various tillage treatments either in the fall of 1982 or in the spring of 1983 (Table 7). The analysis of variance did show, however, a significant depth effect in both sampling periods.

At the soil surface only the No-Till (NT) treatment showed a lower bulk density in the spring of 1983 (Fig. 2). The other tillage treatments all show increases in bulk density as compared to the fall measurements (Fig. 2). Highest bulk density values for the tillage treatments in the fall of 1982 can be directly correlated to the tillage implement used. In the Double Disk (DD) treatment a compacted layer seems to have been created just below the tillage depth at 15 cm. The Moldboard Plow (MP) treatment seems to have induced a compacted layer at the 30 cm depth even though actual tillage depth was only to 20 cm. In the Chisel-Disk (CD) treatment, at 30 cm depth, evidence is found of a relic plow pan from previous conventional tillage use as well as a second compaction layer at 15 cm from disking.

Some reduction in soil density from the fall of 1982 to the spring of 1983 is evident in all the tillage treatments (Fig. 2). The uniformity of bulk density reduction with depth in the NT, while not statisti-

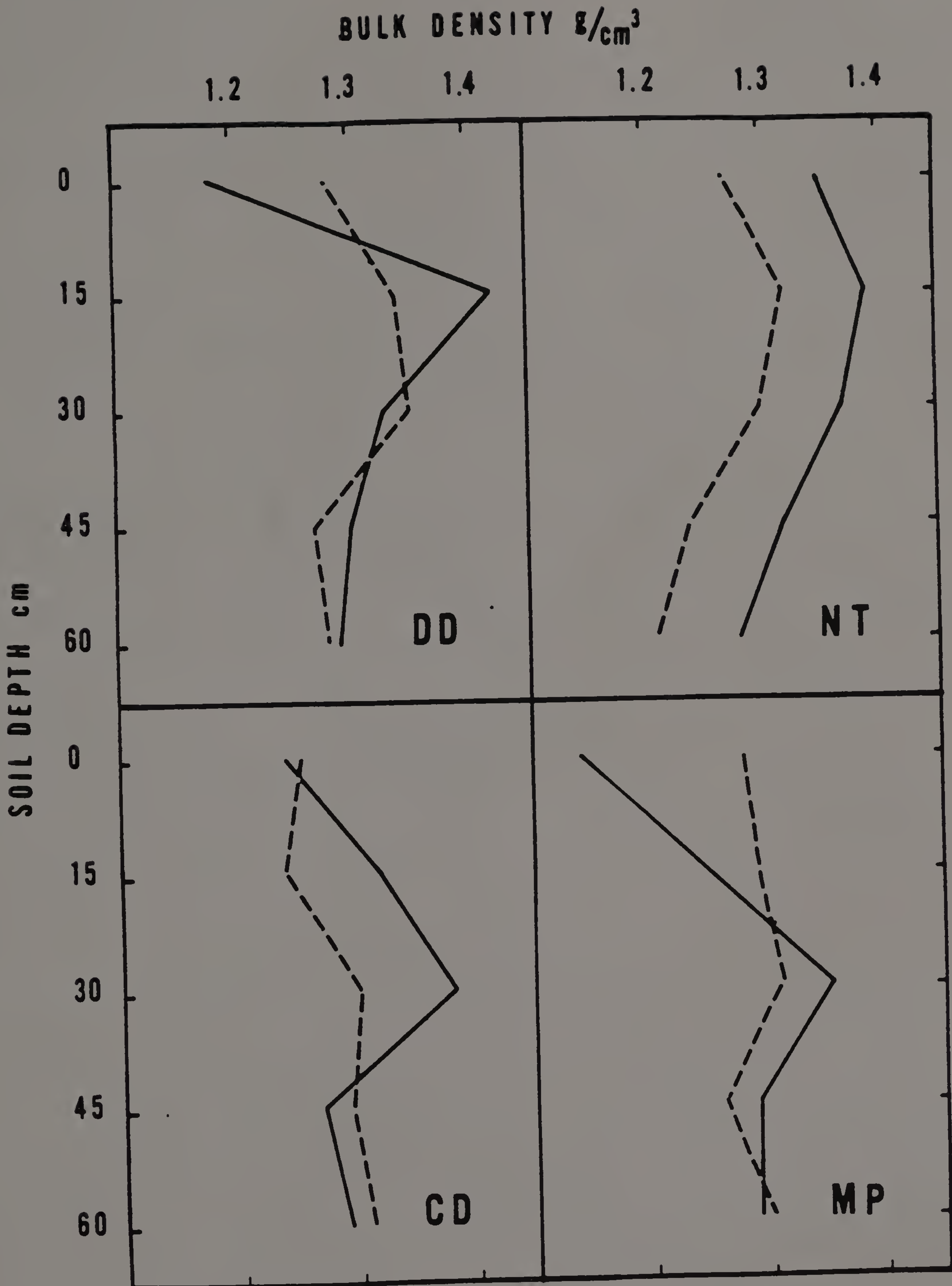


Fig. 2. Comparison of bulk density for the 1982 after-harvest period (solid line) and the 1983 before-tillage period (dashed line) for tillage treatments double-disk (DD), no-till (NT), chisel-disk (CD) and moldboard-plow (MP).

cally significant from the other tillage treatments, indicates a strong trend that type of tillage may influence frost heave action.

Figure 2, also shows that in all of the tillage treatments except NT, the soil density at the soil surface increased by the spring of 1983. Such increases in tilled soil density from over-wintering was also noted by Domby and Kohnke (1955).

Differential movement of the frost heave measuring tubes, was greatest for the CD and DD treatments and least for the MP and NT treatments (Figs. 3 and 4). The February 26th sampling date showed the greatest slumping for all tube depths in the CD treatment while slumping only occurred at the 5 cm and 15 cm depths in the DD treatment (Fig. 4). At the same time the highest lift was produced in the MP treatment at the 5 cm depth with snow accumulations of 20 cm to 25 cm (Fig. 3). The period with highest lift for NT occured on January 3rd when snow accumulations were less than 5 cm (Fig. 3).

The coefficient of variation value (Appendix A) for total relative tube movement (lifting and slumping) at all depths during the study is 16 for CD, 14.3 for the DD, 58 for the MP, and 22 for the NT treatment. Differences in the coefficient of variation for lift only, for the same tillage treatments are 180, 53, 119, and 29, respectively (Appendix A). Differences for total slumping are 47, 93, 48 and 79 respectively (Table 5).

Soil temperature variation with depth was greatest for the MP and NT treatments for the period of January 16th through February 8th (Figs. 5 and 6). In the NT treatment all depths down to 30 cm registered tem-

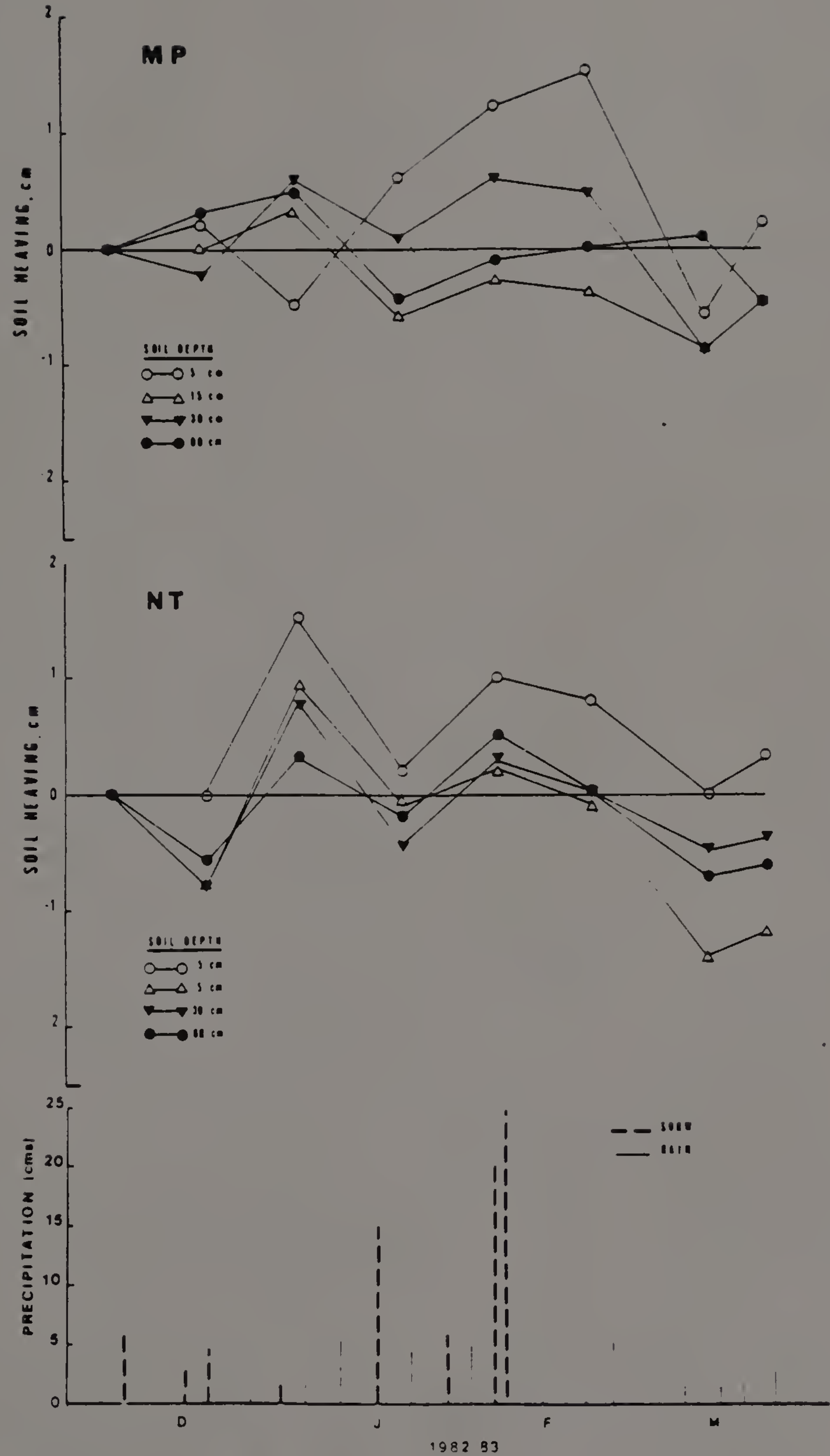


Fig. 3. Variation in relative frost heave action at selected depths for the moldboard plow (MP) and no-till (NT) treatments.

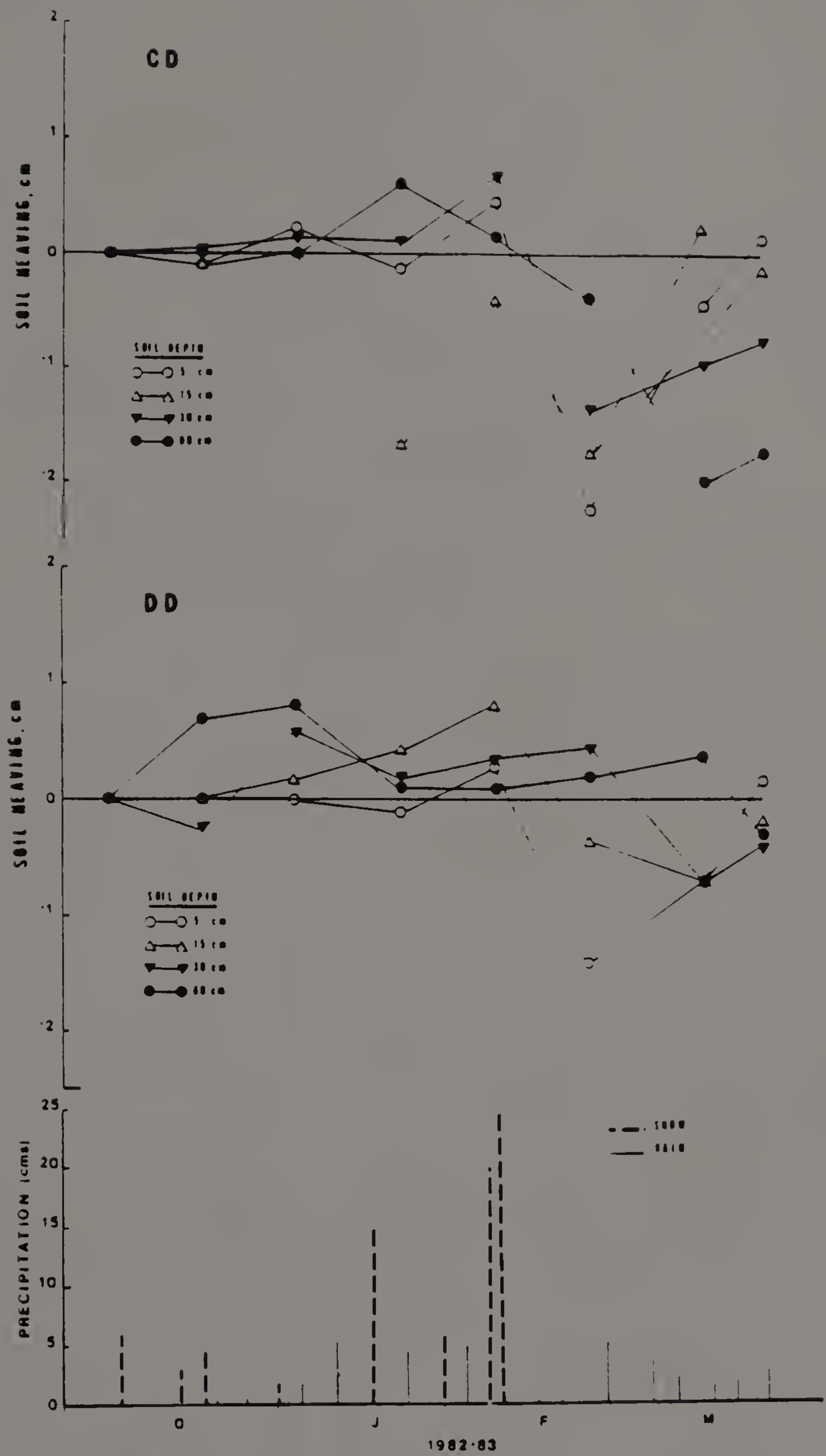


Fig. 4. Variation in relative frost heave action at selected depths for the chisel disk (CD) and double disk (DD) treatments.

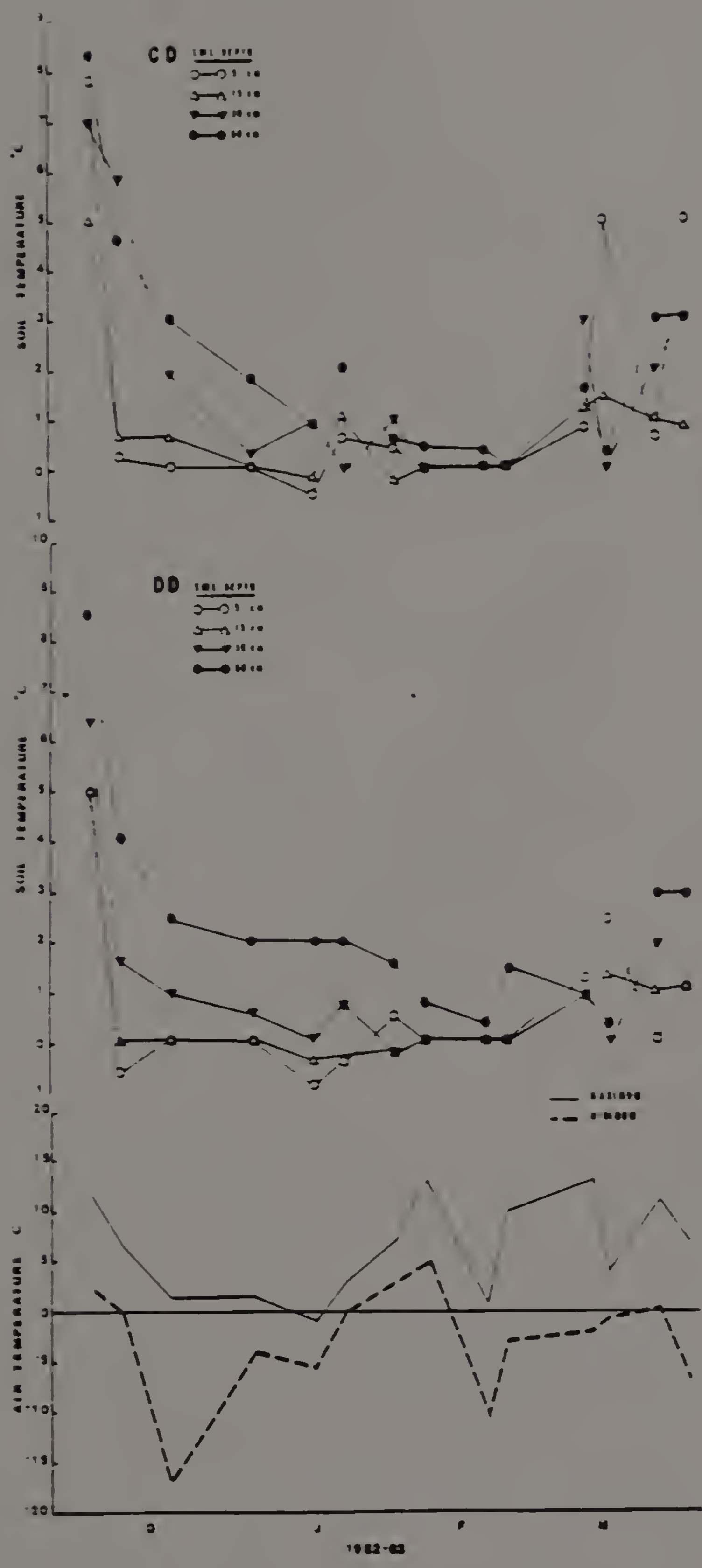


Fig. 5. Variation in soil temperatures during the 1982/83 winter at selected depths for the chisel-disk (CD) and double-disk (DD) treatments.

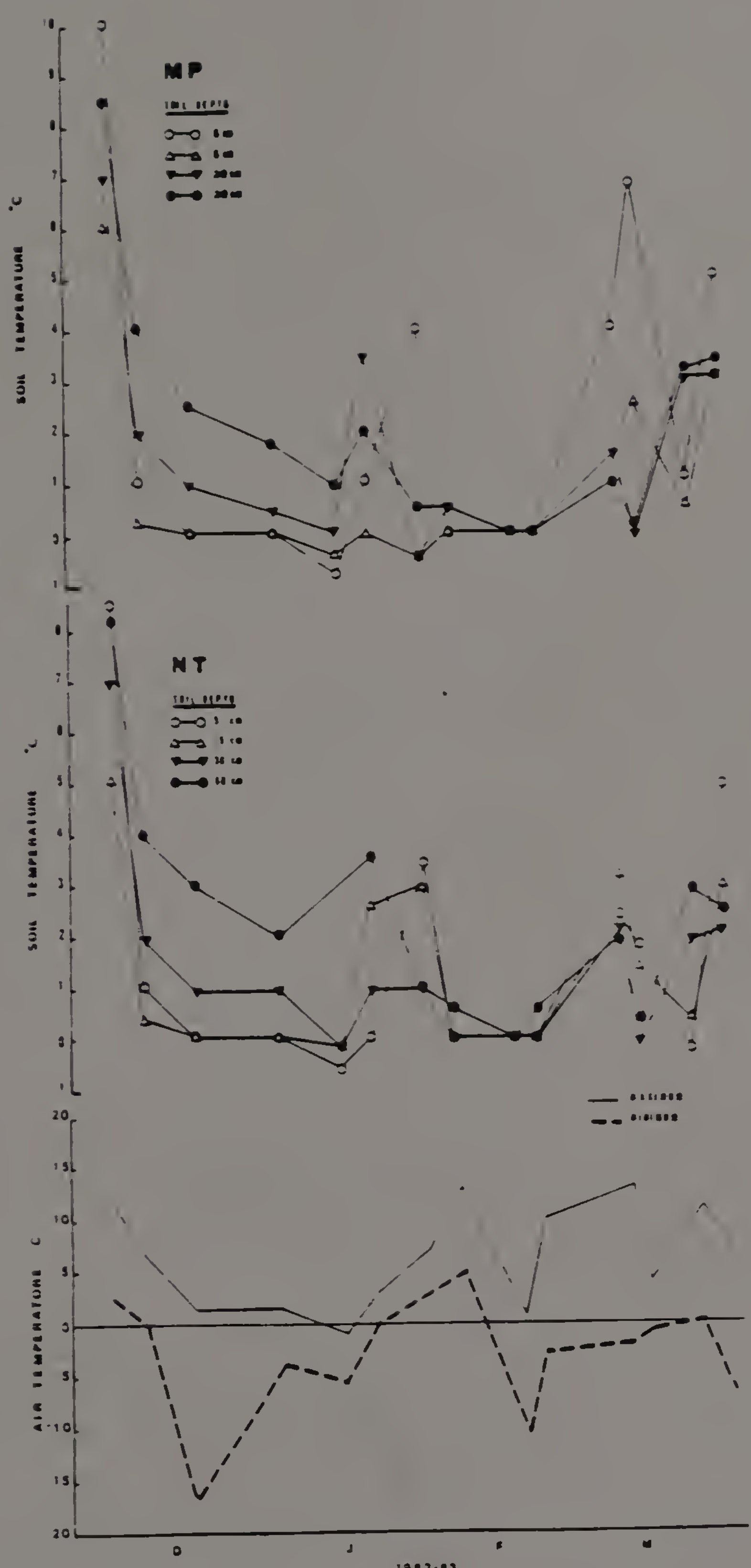


Fig. 6. Variation in soil temperature during the 1982/83 winter at selected depths for the moldboard-plow (MP) and no-till (NT) treatments.

peratures of 0°C or less (Fig. 5). By February 16th all depths measured 0°C in the NT and MP and not until February 29th did this happen in the CD treatment (Figs. 5 and 6). The 60 cm depth in the DD treatment did not register a temperature below 0.5°C throughout the study period (Fig. 6).

Discussion

The presence of the silt loam texture in the A horizon and the rather uniform distribution of the sandy loam through the experimental site (Fig. 7) favors formation of ice lenses. Differences in soil bulk density due to the various tillage treatments probably will account for the greatest part of the variation in frost heaving. Soil vegetative cover also should be included when assessing the effect of tillage on frost heave action. Taber (1930) reported that differential heaving is sometimes produced if there is sufficient variation in the infiltration capacity due to the soil cover so that freezing does not begin everywhere at the same time. Vegetative cover in the interrow spaces included accumulation of weeds at the end of the growing season and for the NT treatment remnants of the 1981 rye cover crop. A Duncan multiple range test (Appendix A) indicated differences in weed accumulation to be significant between the conservation treatments (NT, DD, CD) and the MP treatment. Judging from the similarity in uniform soil lifting and slumping of the MP and NT treatments, it appears unlikely that the vegetative cover had much influence on heaving differences.

Minimal snow cover and widely fluctuating air temperatures were reported by Holmes and Robertson (1980) to be important in producing

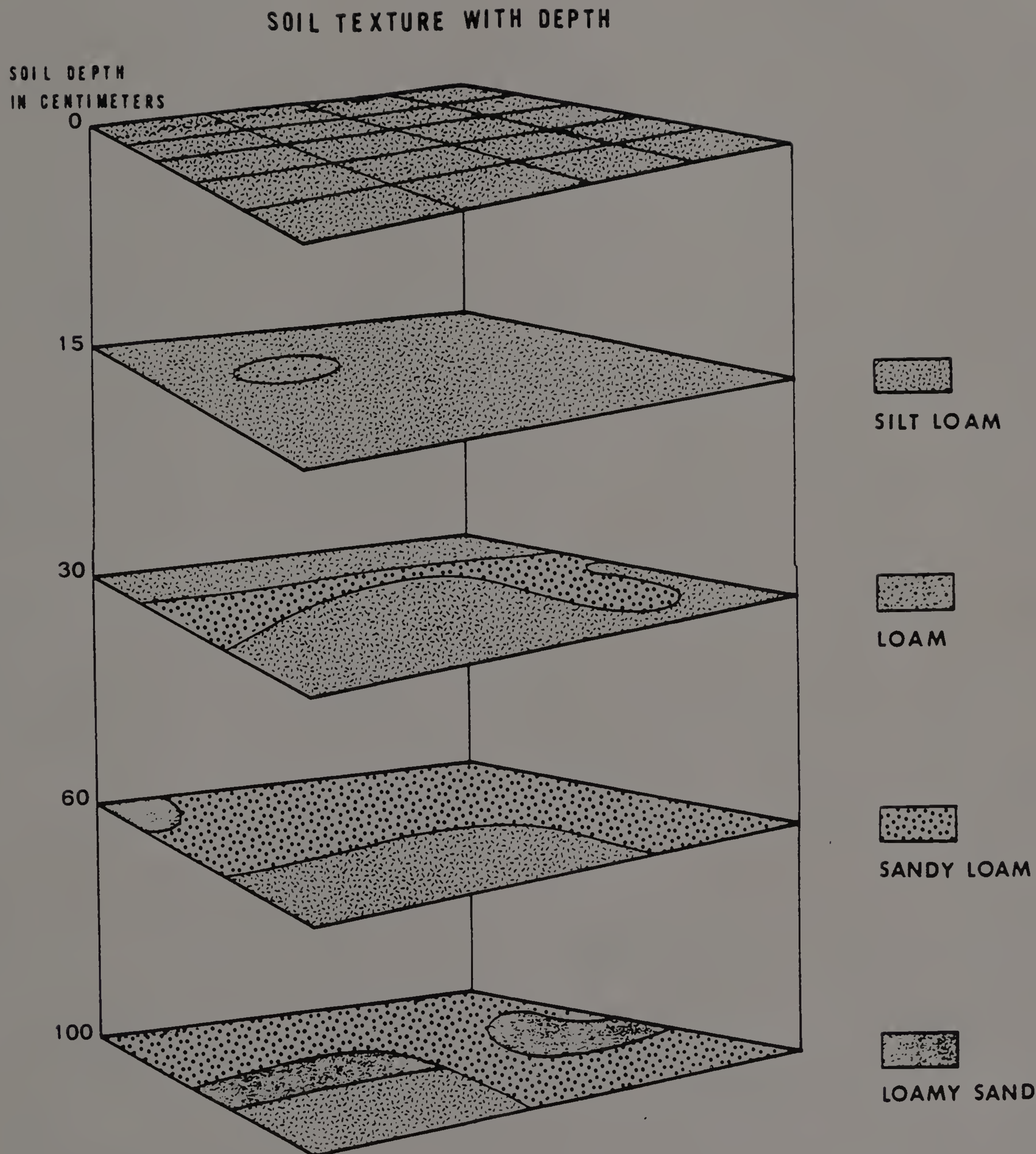


Fig. 7. Soil texture variation with depth at the experimental site.

frost heave. Partz (1967) and Decker and Ronningen (1957) both described heavy precipitation as necessary for the conditions of heaving. During the period of this study (December 1982 through March 1983) there was sufficient temperature fluctuation for ice lens development but total precipitation was relatively low and snow accumulation was not significant until the end of February (Fig. 5 and 6).

The highest soil temperature at the 5 cm depth was in the MP treatment (Fig. 5). There was one sharp soil temperature increase toward the end of January and a second one in the middle of March. Peaks in air temperature appear earlier, as measured by Dr. Ives (1983) at Amherst College, than soil temperature. This is probably due to the soils lower thermal conductivity. The NT treatment showed similar temperature peaks but at the 30 cm and 15 cm depths. This perhaps is a reflection of a greater soil uniformity of this NT treatment. Soil bulk density data (Fig. 2) seems to indicate that the NT treatment has fewer physical barriers which may affect the balance of heat flow in the soil. When a soil is compacted the internal geometry can become sufficiently modified to increase the heat flux (Larson and Allmaras 1971). This appears evident when temperature variation for the CD and DD treatments are compared to the NT and MP treatment (Figs. 5 and 6). Besides the influence of soil bulk density on the thermal conductivity of the soil it seems also likely that water movement will be influenced, limiting ice lens development to specific depths and restricting the size of the lens as well as the extent of the subsequent heaving.

The more uniform soil bulk density of the No-Till treatment as compared to the other tillage treatments indicates the extent frost heave action may take when compacted layers from the tillage operation are avoided. The data also point to the idea that fall tillage in this silt loam soil may be counter-productive by increasing the soil bulk density of the A horizon by the following spring.

3.2. Effects of Tillage Method on Selected Soil Physical Properties

Result

Bulk density samples were taken from all treatments and blocks at depths 0, 15, 30, 45 and 60 cm, before tillage on May 13th, after tillage on June 6th, before harvest on September 9th and after harvest on October 10th (Fig. 8). The events prior to each bulk density sampling period were considered to be sufficiently unique to allow for independent statistical analysis rather than grouping the sampling periods and testing for a trend over time (Appendix A).

Data from all four of the sampling periods showed a significant depth effect in both the before tillage and after harvest periods. There was no significant difference among the tillage treatments below 15 cm in either the after tillage or before harvest sampling periods (Fig. 8). Figure 8 also shows significant differences due to tillage and harvesting and less of an effect was noted during the growing season.

Soil moisture tension for the 1983 growing season averaged from Blocks II and III and are shown in Fig. 9 and 10. There was little difference among the treatments prior to tillage. On May 18th all tensiometers were removed and five days after the completed tillage operation all tensiometers were reinstalled.

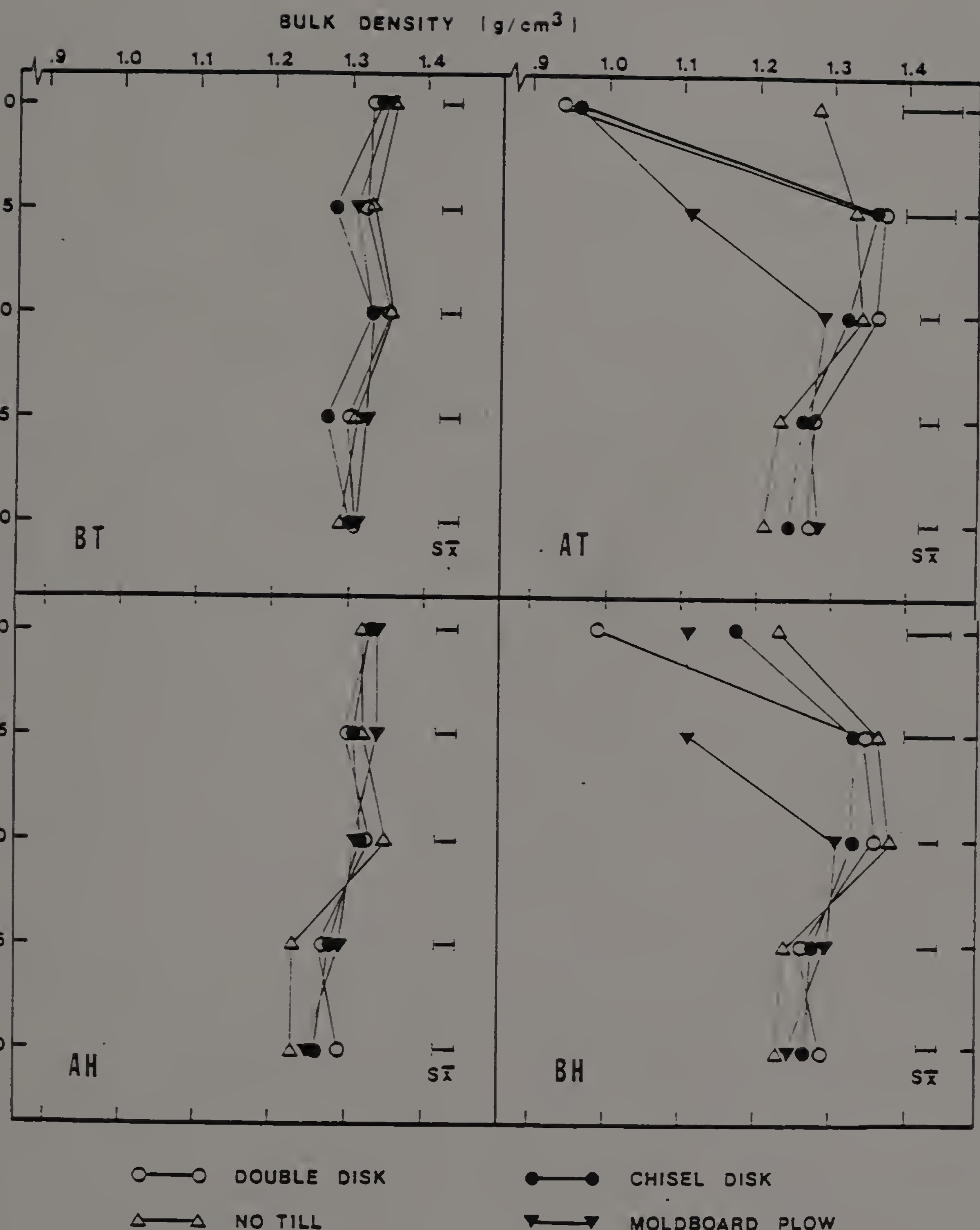


Fig. 8. Differences in bulk density between the tillage treatments for the before-tillage (BT), after-tillage (AT), after-harvest (AH), and before-harvest (BH) time Periods.

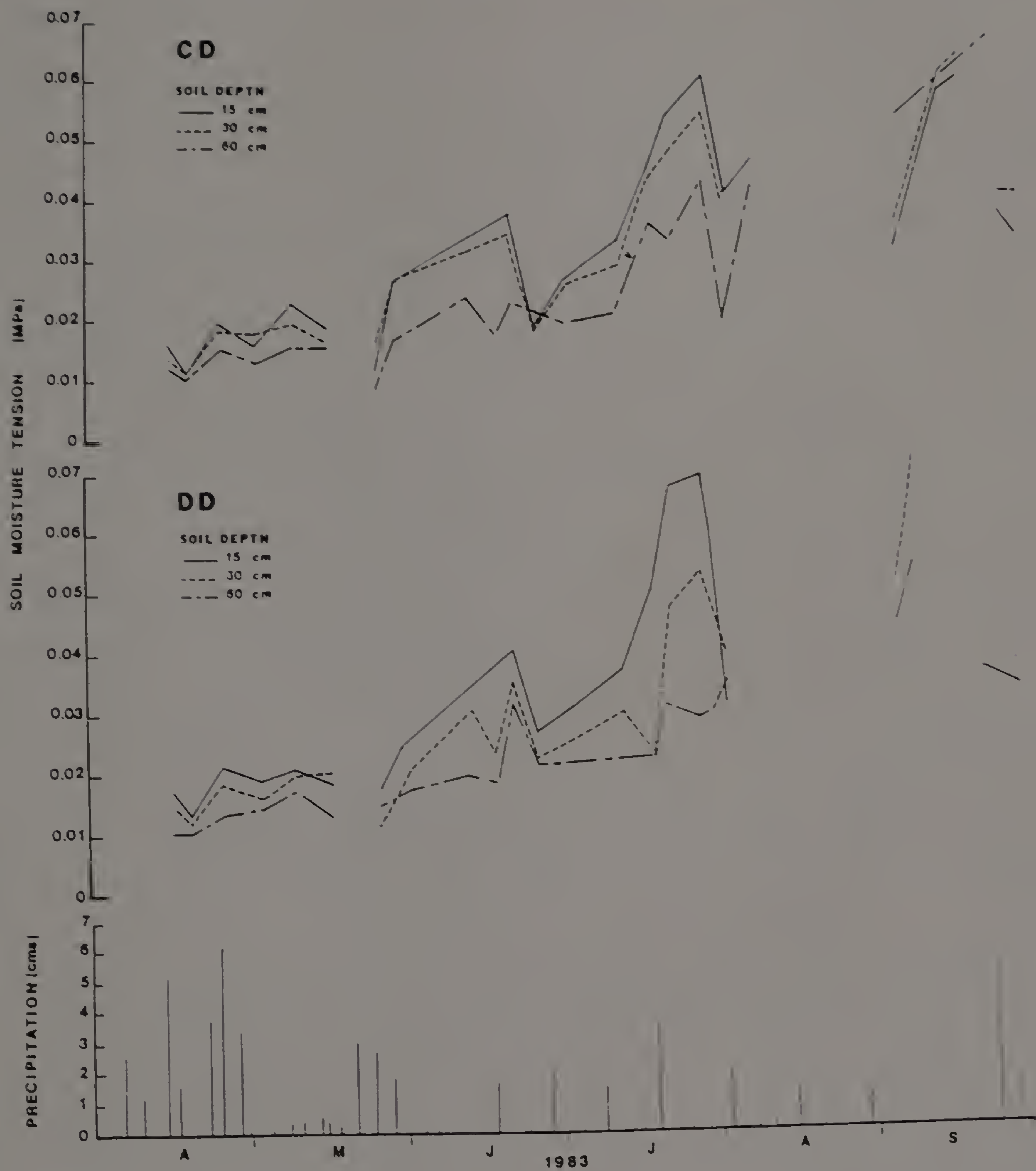


Fig. 9. Variation in soil moisture tension averaged for blocks II and III, during the 1983 growing season for the chisel disk (CD) and double disk (DD) treatments.

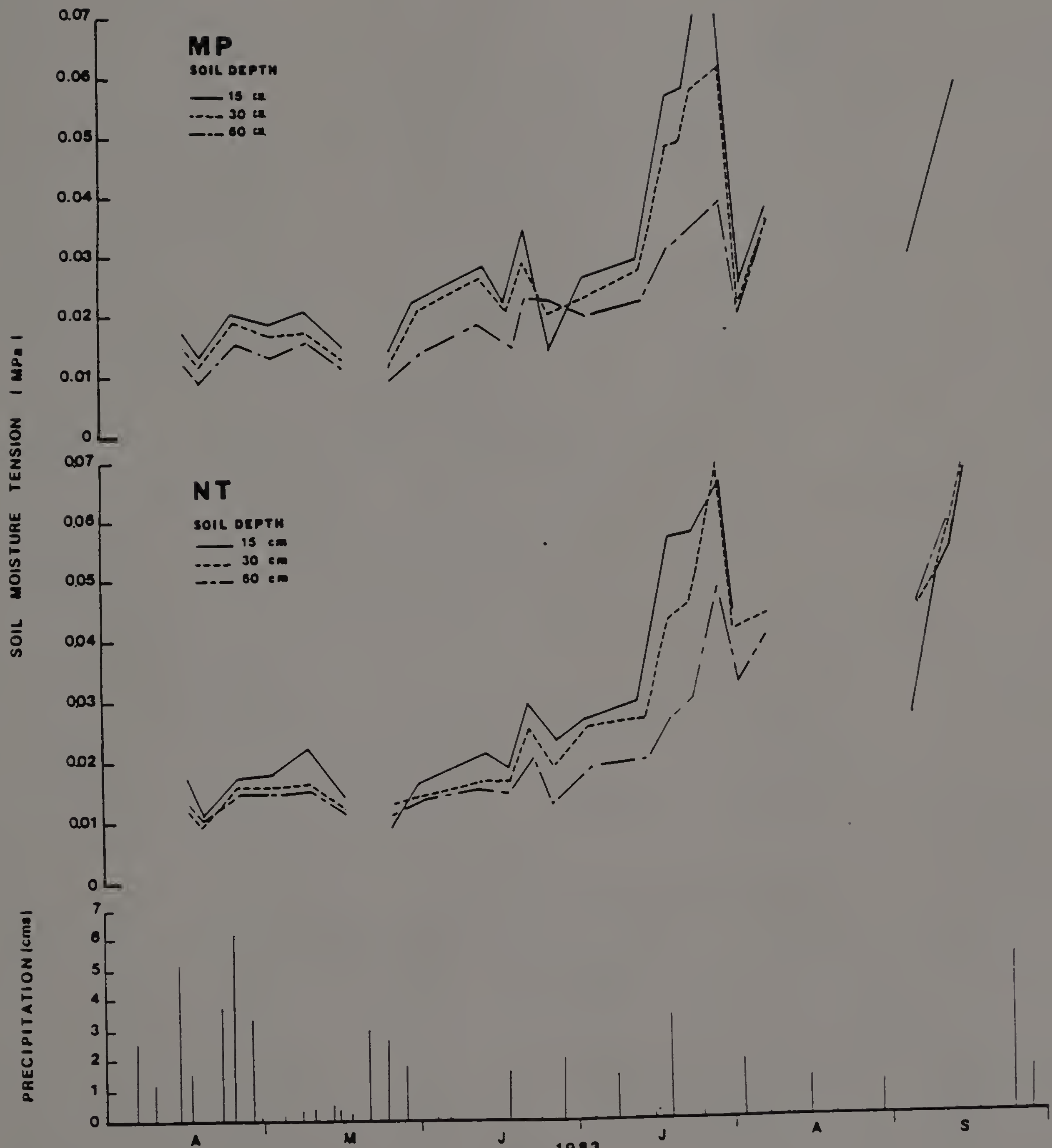


Fig. 10. Variation in soil moisture tension averaged for blocks II and III during the 1983 growing season for the moldboard-plow (MP) and no-till (NT) treatments.

The NT treatment showed consistently lower moisture tension readings than the other treatments at the 15 and 30 cm depths. By July 24th moisture tensions at the 15 cm depth in the MP treatment exceeded the measuring capacity of the manometer. At this same time period the DD treatment at 60 cm depth was considerably lower at 0.027 MPa than the other tillage treatments. The NT treatment showed almost equal readings of 0.069 MPa at the 30 cm depth and 0.066 MPa at the 15 cm depth, respectively.

The effect of tillage method on moisture content was evaluated by comparing soil moisture characteristic data from samples taken at the before tillage and after tillage sampling periods (Figs. 11-14). Differences in moisture content at 15 cm depth were negligible. Both the 30 cm and 60 cm depths in the NT treatment prior to tillage showed higher moisture contents when saturated than the other treatments, indicating a greater porosity.

After tillage, all treatments showed an increase in moisture content at the 60 cm depth. At 0.025 MPa of soil tension, the NT treatment had the greatest increase. There was a reduction in moisture content at the 15 cm depth for the DD and MP treatments when compared to the before tillage situation, while the 30 cm depth seemed little affected by tillage. Both the CD and NT treatments showed reductions in porosity at this depth.

Correlation coefficients for tillage treatments CD, MP, DD, and NT, were found to be .01, .37, .46, and -.17 respectively when gravimetric moisture content of the soil surface was compared to mechanical impedance values (Fig. 15). Variation in mechanical impedance seemed to be

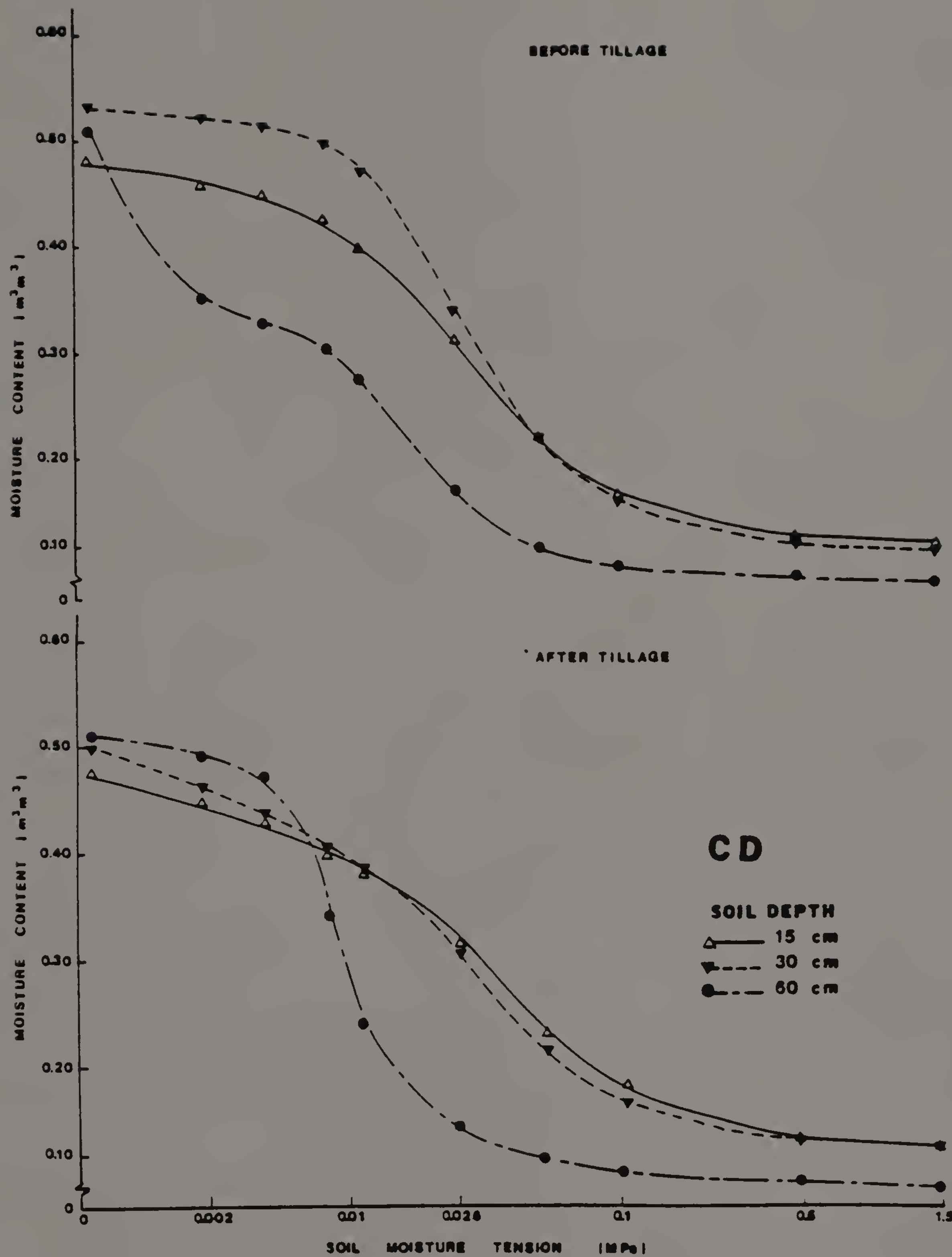


Fig. 11. Moisture characteristic curves before and after tillage for at three selected depths for the chisel-disk (CD) treatment.

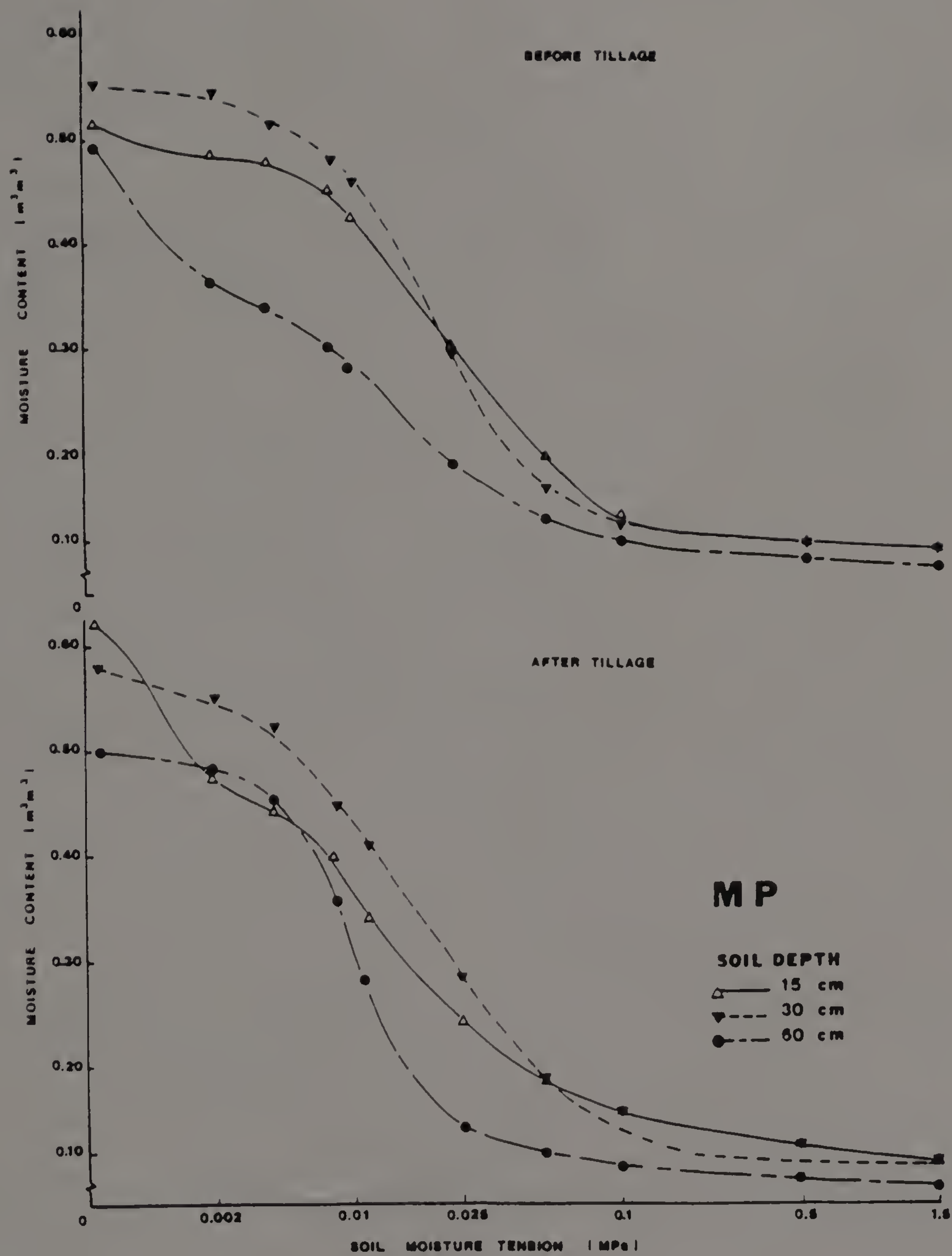


Fig. 12. Moisture characteristic curves before and after tillage at three selected depths for the moldboard plow (MP) treatment.

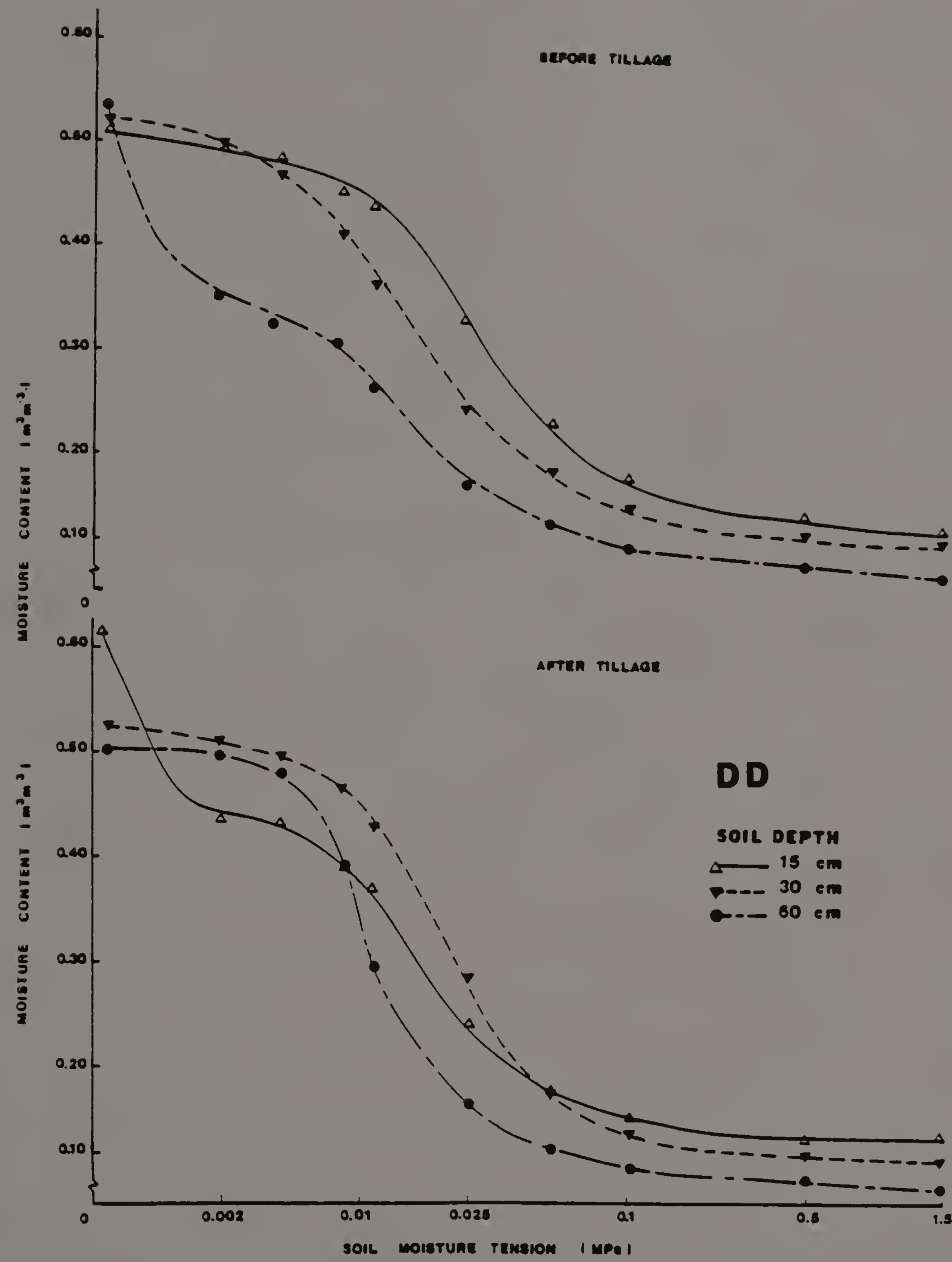


Fig. 13. Moisture characteristic curves before and after tillage at three selected depths for the double-disk (DD) treatment.

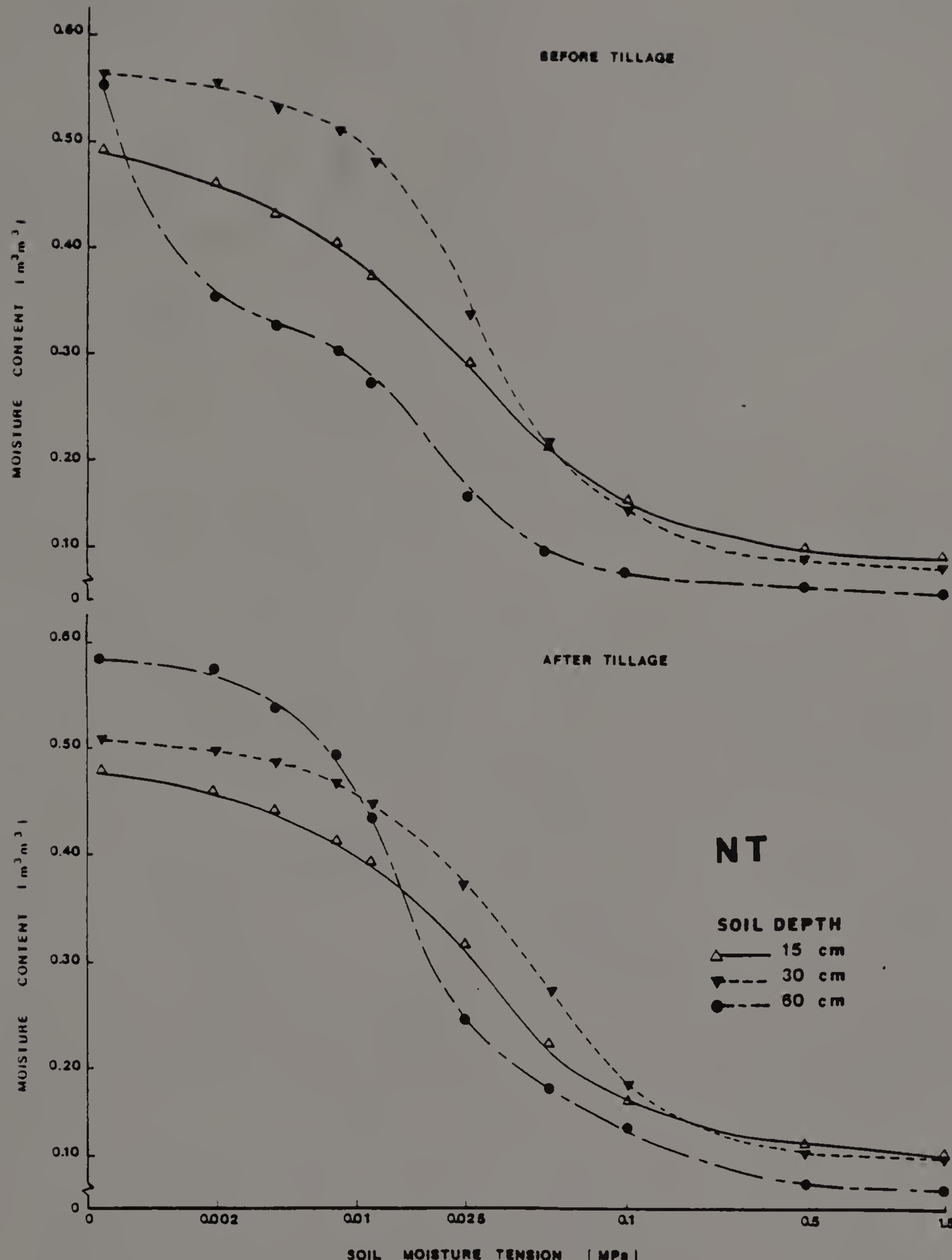


Fig. 14. Moisture characteristic curves before and after tillage at three selected depths for the no-till (NT) treatment.

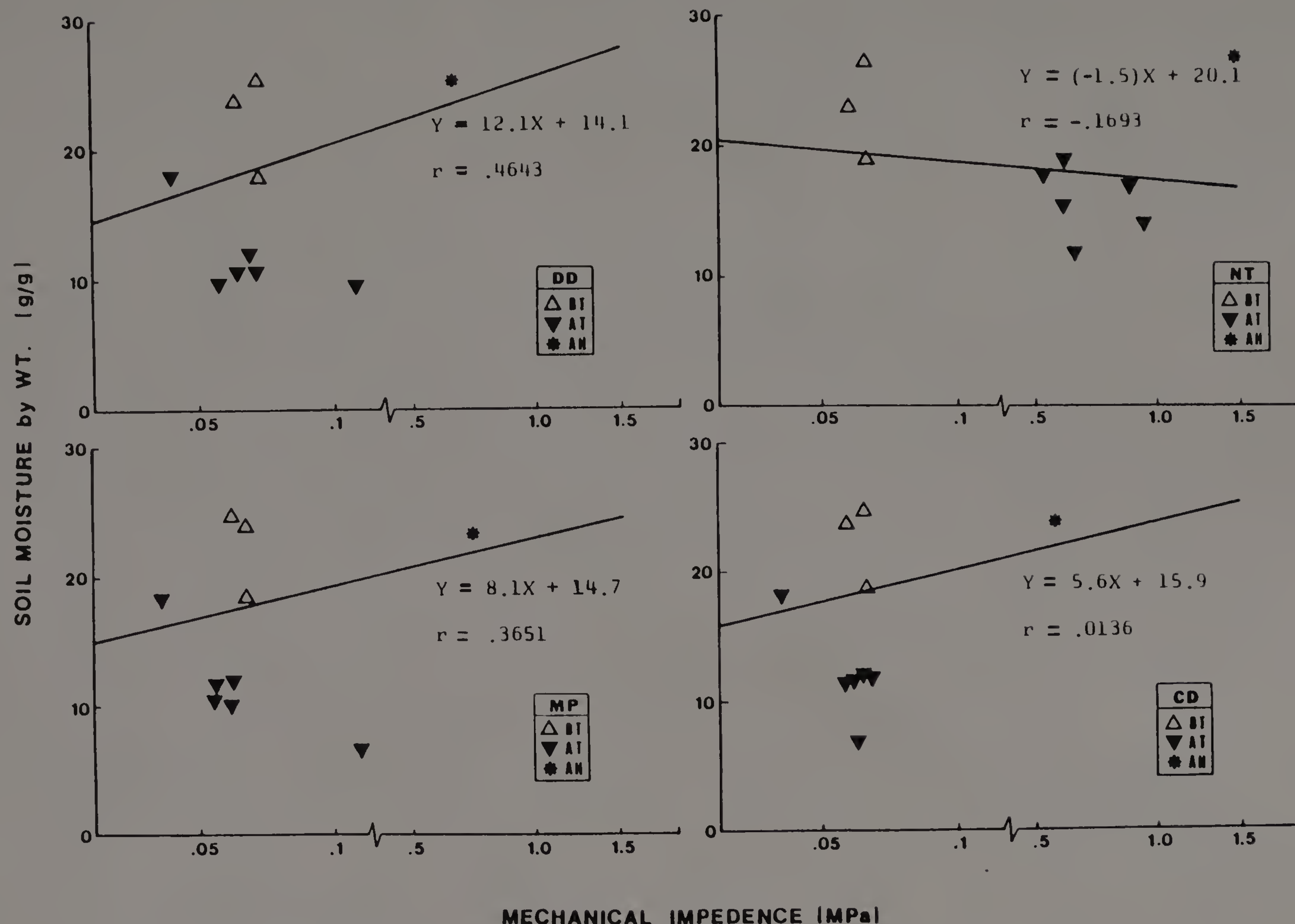


Fig. 15. Relationship between mechanical impedance and gravimetric soil moisture content for the double disk (DD), no-till (NT), moldboard plow (MP) and chisel disk (CD) treatments.

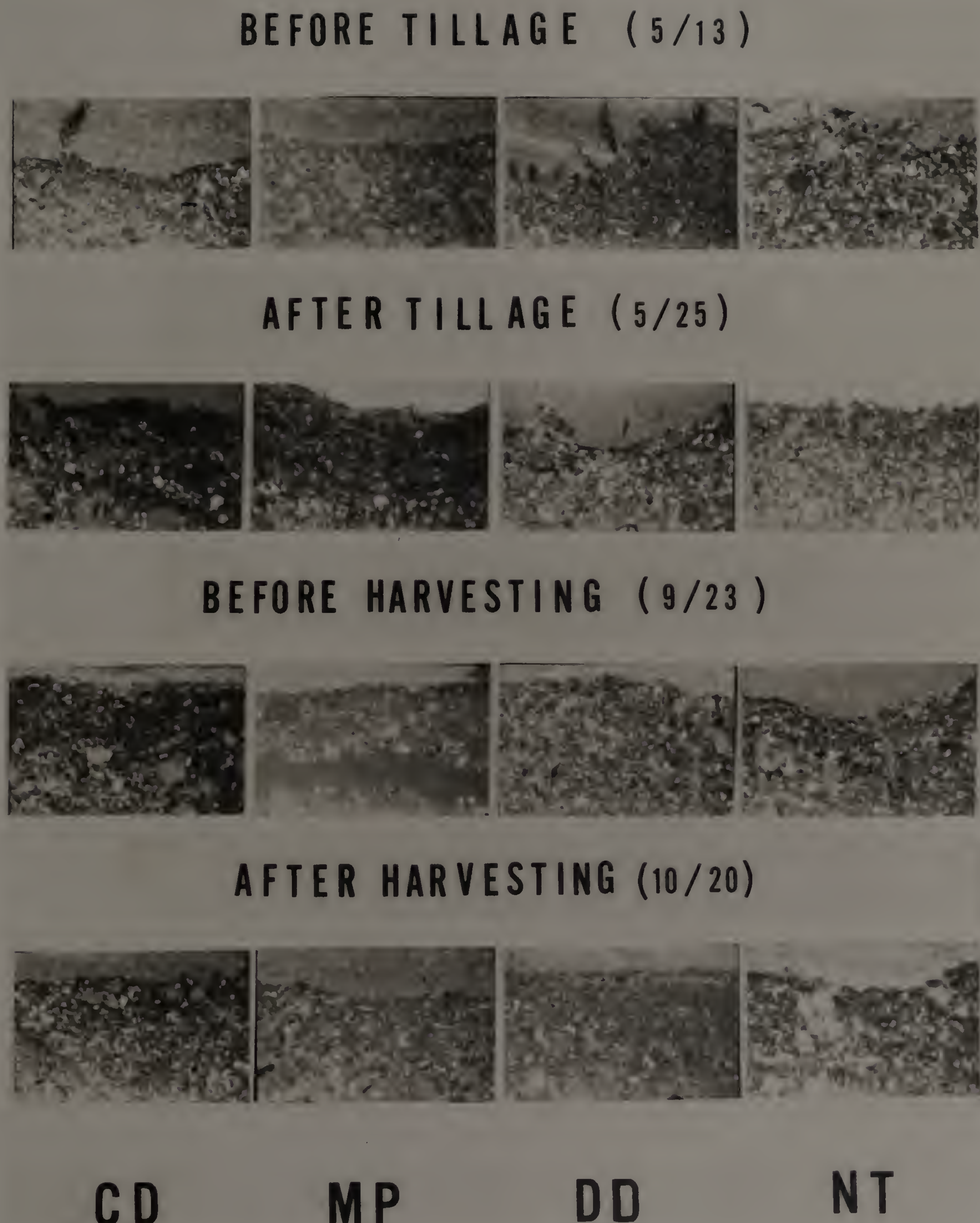
influenced more by the tillage and harvesting operation than either soil moisture or surface crust development. The MP and DD treatments do, however, suggest a slight trend towards increasing crustal strength with decreasing moisture content.

When photomicrographs of soil thin sections were examined (Fig. 16), a surface crust, not detectable by the penetrometer, showed very distinct differences among the tillage treatments. Soil thin section samples taken in conjunction with mechanical impedence measurements showed that crustal development by washing and layering was greatest in the MP treatment and least for the NT treatment. Banding of vesicles was observed in all thin sections taken from the MP treatment after tillage. Vesicles were not detected in the NT treatment at any time period and only at the before harvest period were vesicles found in the DD and CD treatments. A complete description of each photomicrograph can be found in Appendix B.

Discussion

Only the non-compacted interrow spaces can truly reflect the direct effect of a particular tillage method on the soil. This may be of considerable practical difficulty as the proportion of an agricultural field covered with tractor wheels during seedbed preparation by traditional tillage is approximately 90 percent (Soane and Pedgeon 1975). Bulk density data taken from uncompacted plots (Fig. 8) show that the tillage operation not only directly influences the tilled zone of the soil but goes beyond the active depth of tillage. The extent to which the soil is modified is therefore tillage method dependent.

Fig 16. Thin sections of soil surface crust development for the tillage treatments at selected sampling date. Photographed under circular polarization magnification 30x.


BEFORE TILLAGE (5/13)
AFTER TILLAGE (5/25)
BEFORE HARVESTING (9/23)
AFTER HARVESTING (10/20)
CD
MP
DD
NT

Data shown in Figure 8 indicate that just prior to tillage the bulk density in all of the treatments was fairly uniform, although a significant depth effect was found to exist. This effect might also be contributed to the natural variation of the soil samples. After tillage, significant differences among the tillage treatments can be observed especially above the 30 cm depth. Even though the 30 cm depth is below the active level of any tillage implement the bulk density for this depth is consistently greater, though not significantly different, than either the 45 or 60 cm depths. Further examination of the data in Fig. 8 for all sampling periods suggests that the sampling depth of 30 cm has been subjected to forces created by the moldboard plow from current as well as past use. Effects from the individual tillage operations were much more evident from moisture retention curve data (Figs. 11-14) than from bulk density values (Fig. 8).

The amount of water retained below a water potential of -0.1 MPa depends primarily upon capillary effect and the pore-size distribution (Archer and Smith 1972) and hence is strongly affected by the structure produced by tillage. The reason that differences in moisture retention are not as easily indicated by bulk density may be due to the fact that although compaction decreases total porosity, and especially the volume of the large interaggregate pores, the volume of intermediate size pores are likely to be somewhat greater in a compacted soil (Hillel 1982).

Data in Figs. 11-14 at the 60 cm depths for all the tillage treatments indicate a volume change of the intermediate size pores. It is unlikely these changes could have been caused by the shallow plowing tillage implements used; therefore, a more likely contributing factor to this volume change at the 60 cm depth may come from tractor traffic which compacted interrow spaces on either side of the non-compacted interrow sampling sites. The sandy loam texture at the 60 cm depth (Fig. 7) would seem to have a sufficient sand fraction that when compacted would allow for the pore volume increase indicated by the moisture retention data. A breakdown of the different particle size fractions composing Fig. 7 is available in Appendix B.

Changes in moisture content at the 15 cm depth can be explained by tillage induced soil loosening effects. At the 30 cm depth the relatively small increases in moisture content for the MP and DD treatments might be due to the downward forces created by the tillage implements or are merely differences within the sample field of variability. Decreases in moisture content for the NT and CD treatment are not clear from these data.

The tillage operation has been shown to change the pore size distribution of a soil which will also have a corresponding effect on the volumetric water content. Soil air volume is affected by both bulk density and water content. Plant growth is likely to be limited when air filled porosity is less than two percent at a soil water potential of -0.0005 MPa (Archer and Smith 1972; Larson 1964).

Using a value of 2.65 for particle density the total porosity was determined to be not less than 45.6% for any sample taken. When air filled porosity is calculated from the moisture retention curve data reported in Fig. 13 and 14, changes in air filled porosity before and after tillage can be examined. All the tillage treatments had air filled porosities greater than 10 percent, with the exception of the NT treatment at the 30 cm depth prior to tillage. Changes in air filled porosity did not appear to be a problem during the 1983 growing season. The lack of treatment variation in air filled porosity after tillage would indicate that even during a wetter season as was experienced in 1982, air filled porosity levels for conservation tillage, should not have a negative effect on plant growth of this soil.

Particle size analysis for the plow layer determined throughout the study site showed average values of 40.1% sand, 50.7% silt and 9.2% clay (Appendix B). Crust development should be favored by the high silt content of this soil.

Surface crusts formed by the washing in and filling of depressions and voids will change the orientation of the particles and should be expected to contribute to the rigidity of the crust (Evans and Buol 1968). Corn seeds that germinated in the CD, DD and MP after May 30th needed to pass through a soil surface crust with a penetrometer resistance of 0.06 MPa (Fig. 15). In the NT treatment shoots were emerging through a partially closed planting track while the penetrometer resistance for the surface crust was 0.55 MPa (Fig. 15).

Thin sections of soil surface offered a more accurate measure and clearer interpretation of crustal development than was possible with the penetrometer. The photomicrographs pictured in Fig. 16 for the before tillage time period show that all treatments are experiencing signs of surface crusting. The NT treatment appeared to have a broken surface crust which may have been due in part to the activity of abundant small plants. These plants are probably mosses of the division Bryophyta which were also observed in the CD and DD treatments.

While there were some differences in surface crust continuity all treatments appeared to have a dense particle zone 1-1.5 cm thick below the crust followed by irregular ortho-joint planes. These fractures probably originate through shrinking (Brewer 1964). Because the thin sections were taken in the non-compacted interrow spaces the zone of increased density observed in the thin sections was probably in part due to frost heave action and the settling out of soil particles during the saturation stage of surface thawing.

Vesicles, which are described by Brewer (1964) to be gas bubbles trapped by surface crusting, were only observed in the MP treatment at the before tillage sampling period. The mosses at the soil surface may help to reduce the presence of vesicle banding in the other treatments by the rooting activity of these plants.

The irregular ortho-joint planes present in the tillage treatments from shrink-swell action were replaced by irregular ortho-vughs upon soil tillage. Vesicle banding was not observed at this time in any of the tillage treatments, even though there appeared to be a clear washing and layering process in progress. The thickness of the surface layering due to washing varied between the treatments by several millimeters, yet was not detectable by the penetrometer. It would seem that a more reliable use of the penetrometer might be found by measuring the soil resistance of the plow layer at several depths below the soil surface. In this way depth of tillage and the impact of a tillage implement on the soil below tilled zone could be measured.

By the end of the growing season, stable surface crusts seem to have sealed the soil surface sufficiently to allow for vesicle development in all the treatments except NT. The greater thickness and more extensive layering in the MP treatment may have helped to increase the surface crust susceptibility to fracturing due to soil moisture changes. This is probably the case as vesicles have developed both above and below the joint plane in the photomicrograph of the MP treatment at this time. Evidence of an increased pore system in the NT treatment may be due to soil animal activity, as indicated by the vertical channels.

Compaction from the harvesting operation seems to have eliminated any major differences in soil surface structure between the CD, DD and MP treatments. The recover capacity at the soil surface of the NT treatment from harvesting compaction is evident by the presence of micropores continuous to the soil surface.

The type of tillage method induces measurable changes in bulk density, moisture content, air filled porosity and soil surface structure. Individually these selected soil physical properties give less information than when considered collectively. By combining these measurements a picture develops which may help to explain how the tillage operation affects the soil. To determine whether or not the differences in soil physical properties between the tillage treatments are sufficient to change plant growth and possibly affect yield, changes in the soil chemical properties as well as plant growth will be evaluated in subsequent sections.

3.3. Effect of tillage method on selected chemical properties, soil infiltration rate and earthworm activity.

Results

Selected soil chemical properties were determined for each tillage treatment in the spring of 1983 prior to tillage. Results were statistically examined by analysis of variance (Appendix A) in order to determine plot variation. Significant main effects for tillage treatments were found at the 99% level for both potassium and pH. A Duncan's Multiple Range Test was used to determine significant differences among treatments (Table 1). The NT treatment showed significantly higher values for potassium at 163.1 ug/g, while the MP treatment was lowest at 126.2 ug/g. No significant difference in potassium accumulation was observed between the CD and DD treatments. There also was a significant difference in pH values between the MP and DD treatments on one hand and CD and NT treatment on the other hand. No statistical significant differences (95% level) were observed for nitrogen (N), phosphorus (P) and organic matter (OM).

To determine the variation in chemical properties between blocks, all blocks were partitioned into groups for comparison by further analysis of variance (Appendix A). Block I was found to be significantly different at the 99% level from Blocks II, III, and IV for pH, N and OM. Block II also showed significance for OM when compared to Block III and IV.

Soil moisture tension data reported in Section 3.2. applied only to the mean of the values recorded from Blocks II and III. When these data are compared to soil moisture tension data from Block I (Figs. 17-20), a

Table 1. Selected Soil Chemical Properties for the Ap Horizon, Spring 1983.

Tillage Treatment	Chemical Properties				
	N %	P ug/g	K ug/g	O.M. %	pH
CD	0.06a*	27.4a	144.0b	1.59a	6.61b
MP	0.06a	28.9a	126.3a	1.58a	6.42a
DD	0.06a	30.5a	150.6b	1.57a	6.46a
NT	0.05a	31.5a	163.1c	1.67a	6.62b

*Number followed by the same letter are not significantly different. Duncan's multiple range test at the 5% level.

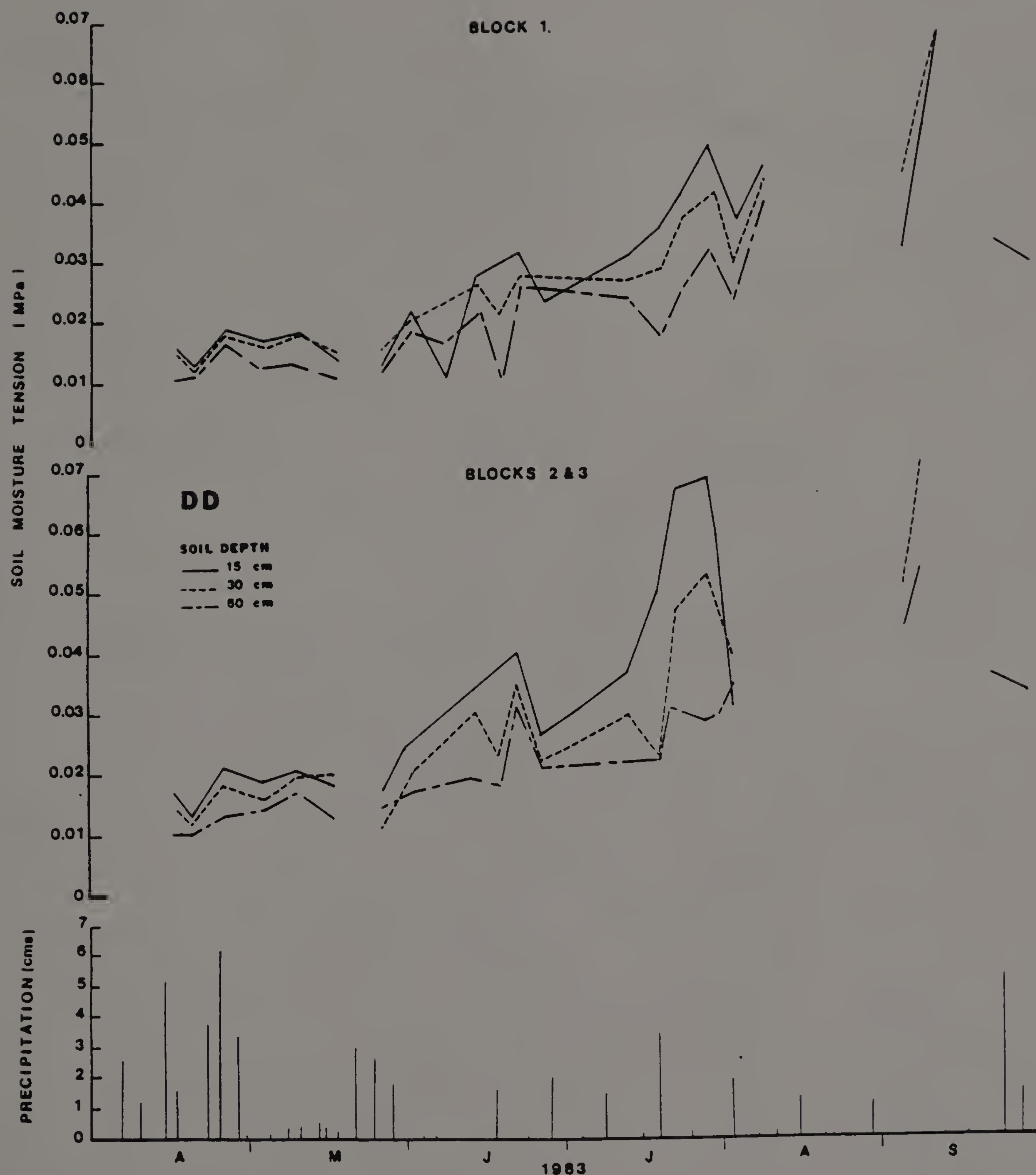


Fig. 17. Soil moisture tension in selected blocks for the double disk (DD) treatment.

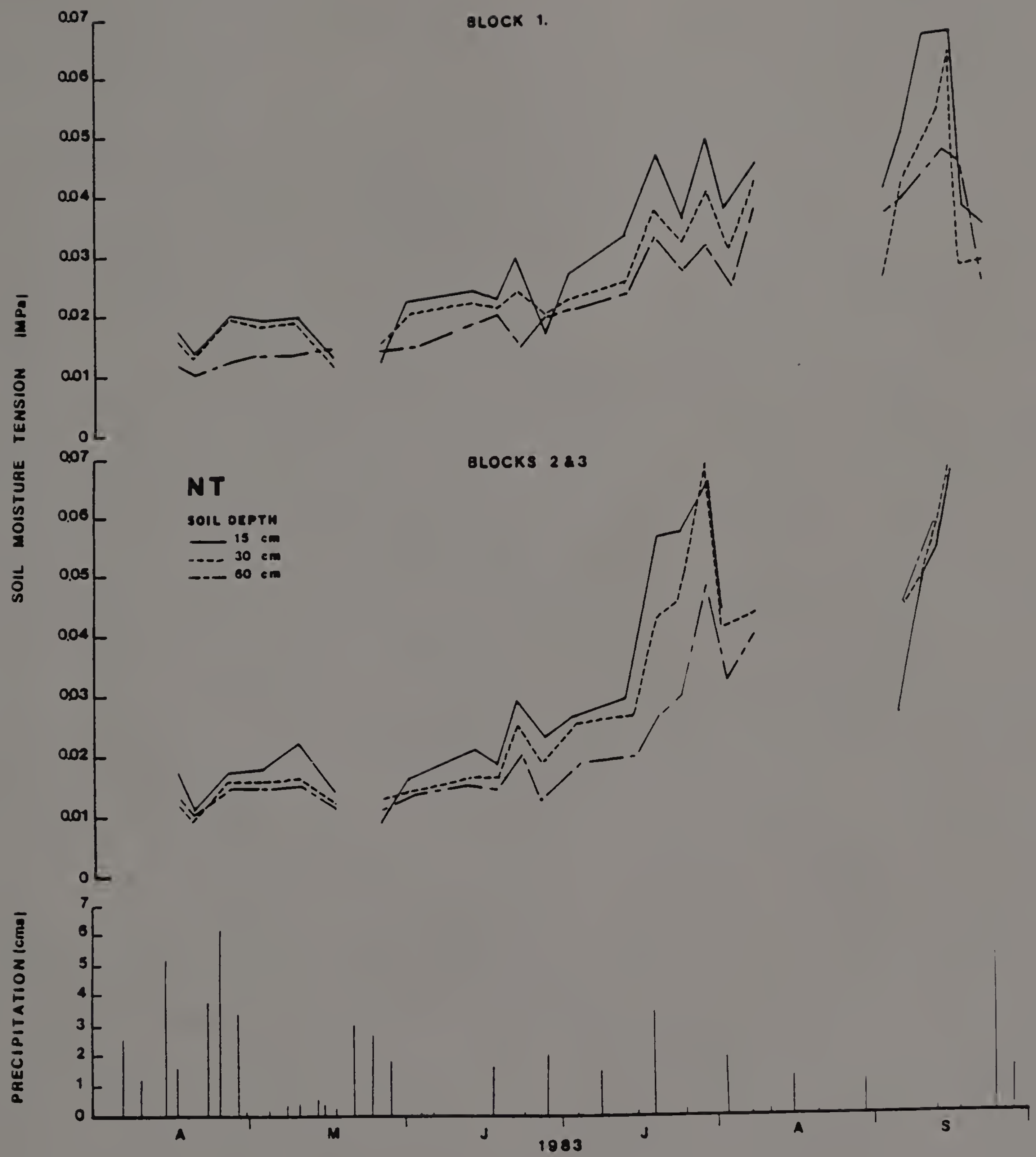


Fig. 18. Soil moisture tension in selected blocks for the no-till (NT) treatment.

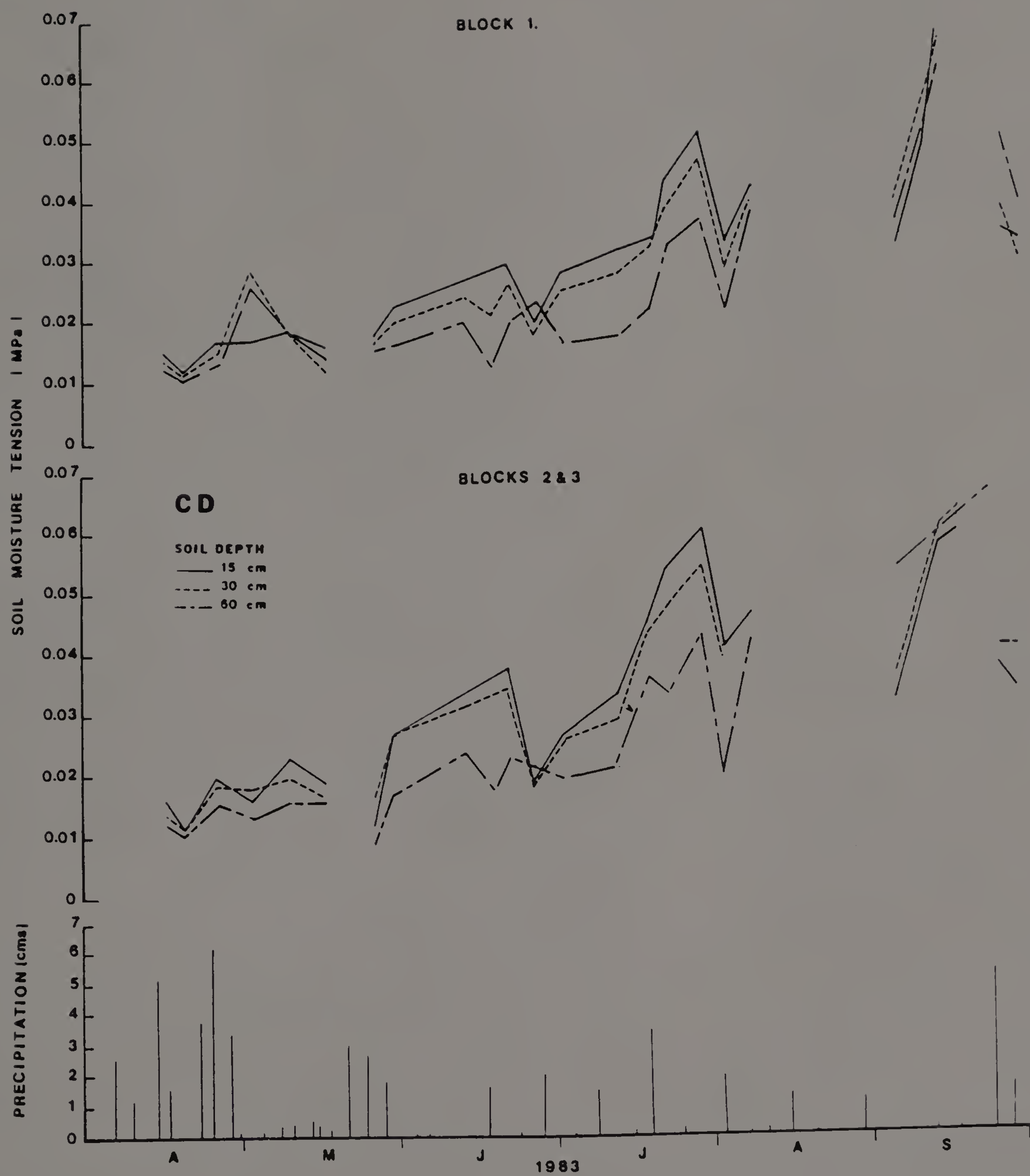


Fig. 19. Soil moisture tension data in selected blocks for the chisel disk (CD) treament.

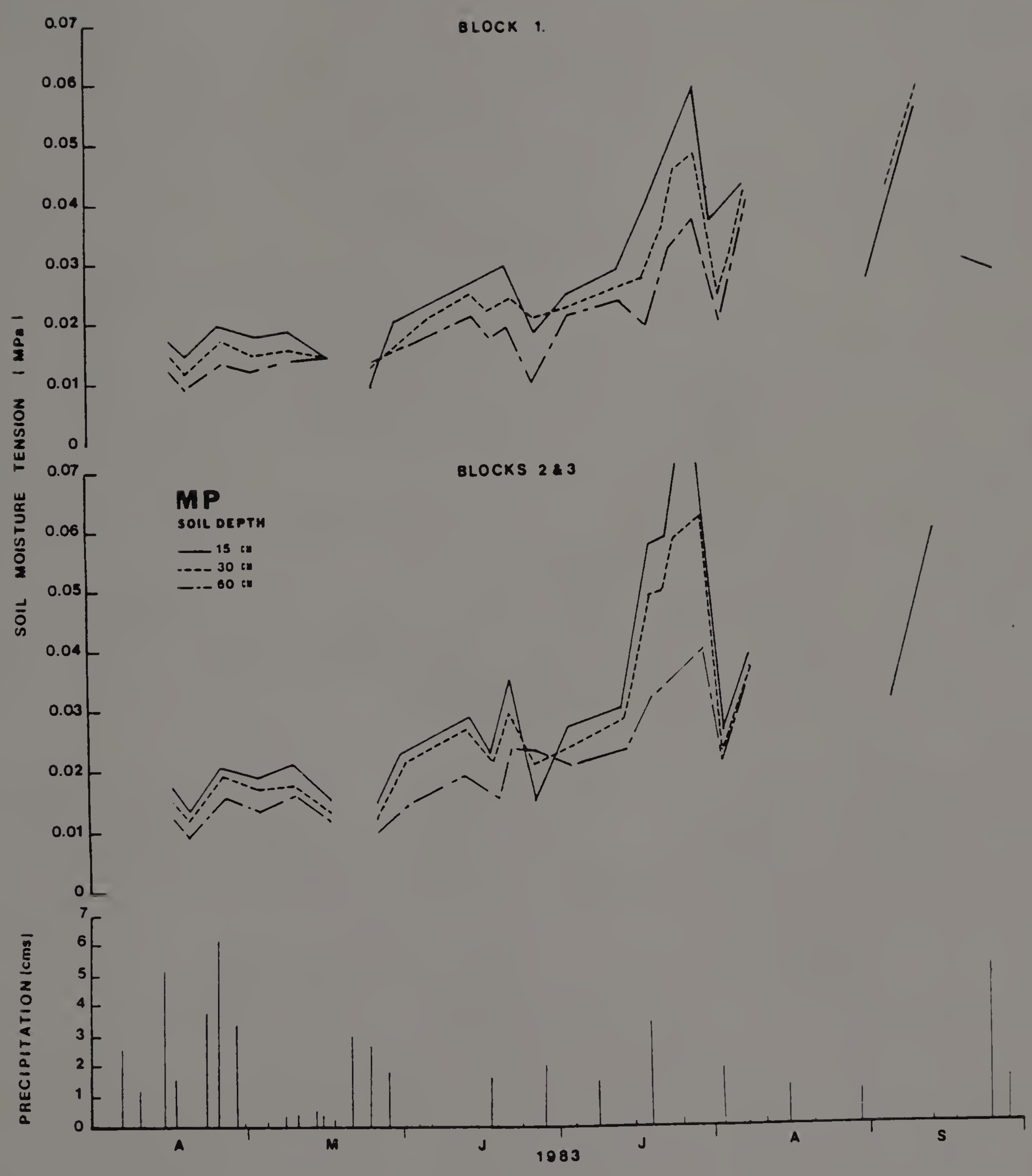


Fig. 20. Soil moisture tension data in selected blocks for the moldboard plow (MP) treatment.

decrease in soil moisture tension is evident at all depths in all treatments for Block I. This combined with moisture retention data (Figs. 11 -14) indicates that more moisture is available to the plants in Block I. During most of the month of August and September soil moisture tension exceeded the measuring range of the manometers. Even with increased precipitation in September, the soil moisture tension data from Blocks II and III often exceeded the calibrated range. Variation in soil moisture tension within the various treatments was also greater in Block I than the other blocks.

Double ring infiltrometer measurements during the fall of 1982 indicated substantial deviation in infiltration rates between Block I and the other blocks combined. Because of the low variation in saturated infiltration between Blocks II, III and IV the 1983 measurements concentrated only in Blocks I and II (Fig. 21).

All treatments within Block I had higher saturated infiltration rates when compared to the treatment equivalent in Block II. This was especially evident in the NT treatment. After tillage the infiltration rate increased with little difference between the CD, DD and MP treatments or for the same treatments between blocks. The NT plots showed a significant difference between Blocks I and II, while infiltration rates were comparable to those prior to tillage. Increased infiltration rates were found during the testing period just prior to harvest for all treatments in Block I and II but with a much greater rate for Block I. The NT treatment showed a nearly doubled rate at this time to equal the rate of the CD treatment. The smallest difference between blocks was for the MP treatment.

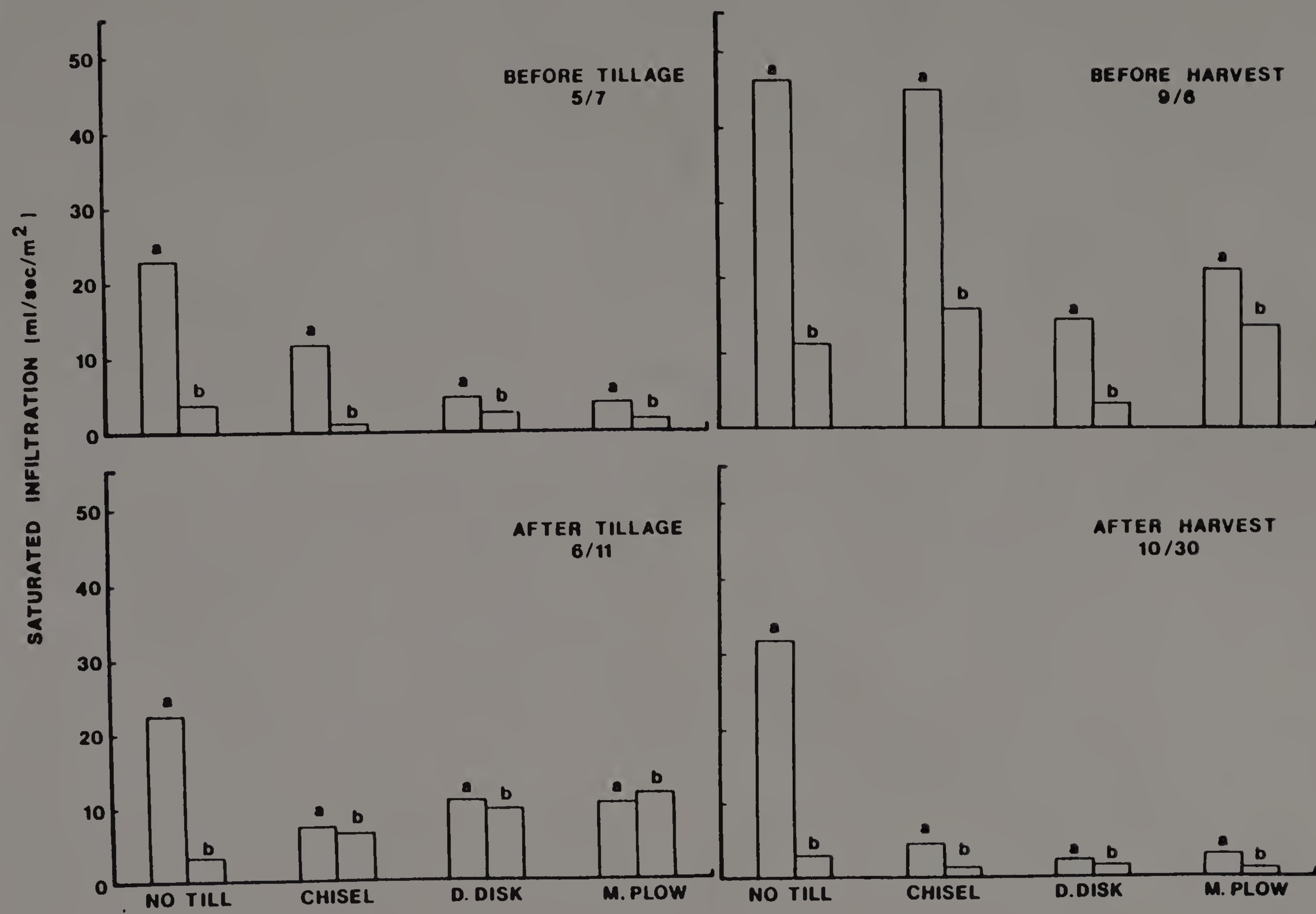


Fig. 21. Infiltration rates in block I(a) and block II(b) during the 1983 growing season for the tillage treatments.

Harvesting drastically reduced infiltration rates to levels almost equal to those recorded at the before tillage period with the exception of the NT treatment.

Figure 22 showed the initial infiltration rate after spring tillage was lowest at all depths for the NT treatment, yet when the infiltration test was repeated over time, the NT treatment exhibited the highest infiltration rate after the first five minutes of infiltration (Fig. 23).

Earthworm activity (Fig. 24) showed differences similar to the infiltration rates when block I was compared to the average values of blocks II, III, and IV. Throughout the study period evidence of earthworm activity was consistently higher for the NT treatment with decreasing activity in the following order of tillage treatments: CC > DD > MP.

Linear regression for infiltration rates and earthworm activity showed a higher correlation coefficient for the treatments in block I than the combined blocks II, III and IV (Table 2). Correlation coefficients were higher overall in block I than the combined blocks, except for the NT treatment where the same r-value between the blocks was found.

Discussion

The observed block differences were not anticipated when the experiment was designed and initiated, and became obvious only during the course of data analyses. While a significant main effect for blocks is unfortunate from a statistical perspective, the data collected on the

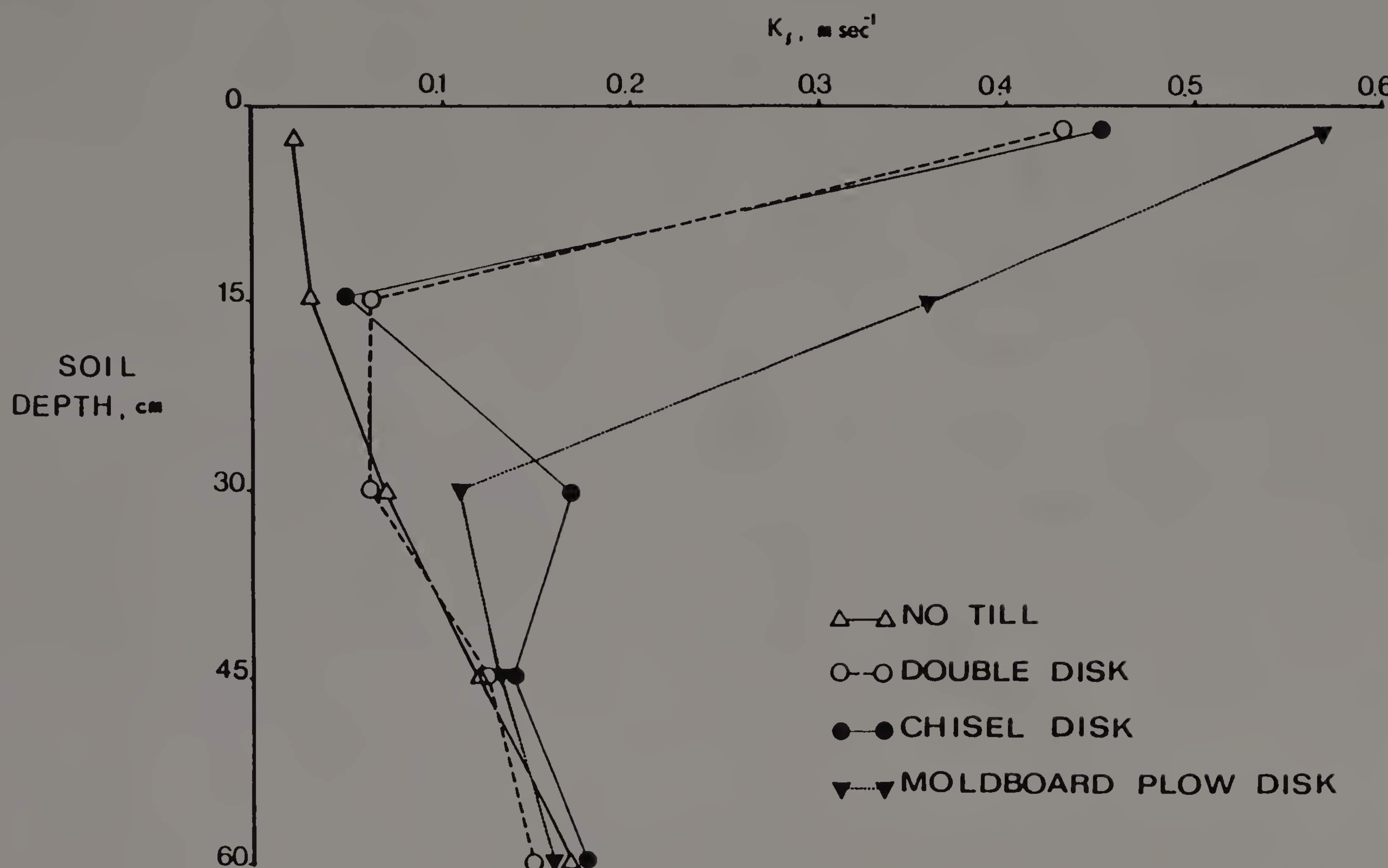


Fig. 22. Saturated hydraulic conductivity after tillage at selected depths for the tillage treatments.

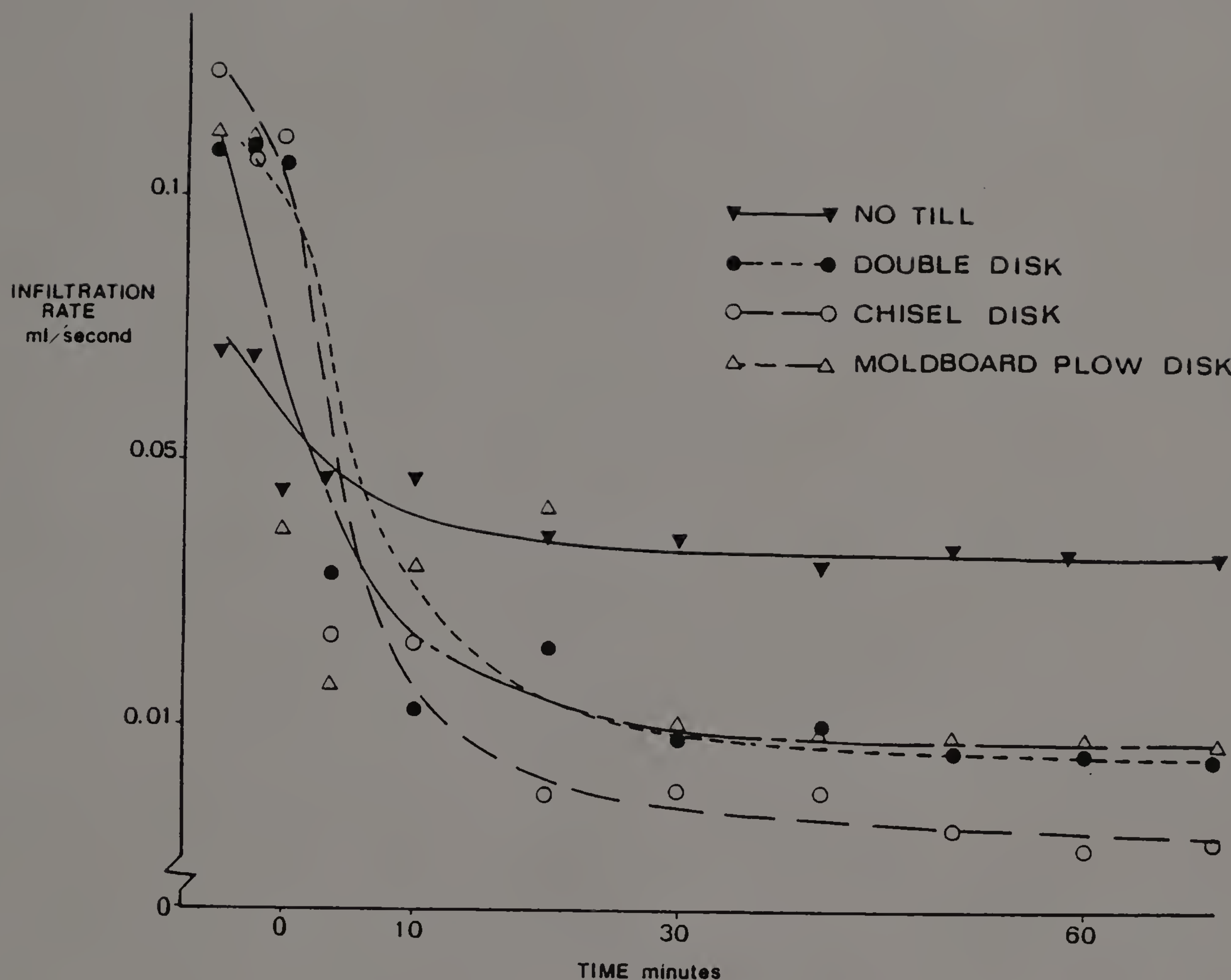


Fig. 23. Infiltration rates over time after tillage for the four tillage treatments.

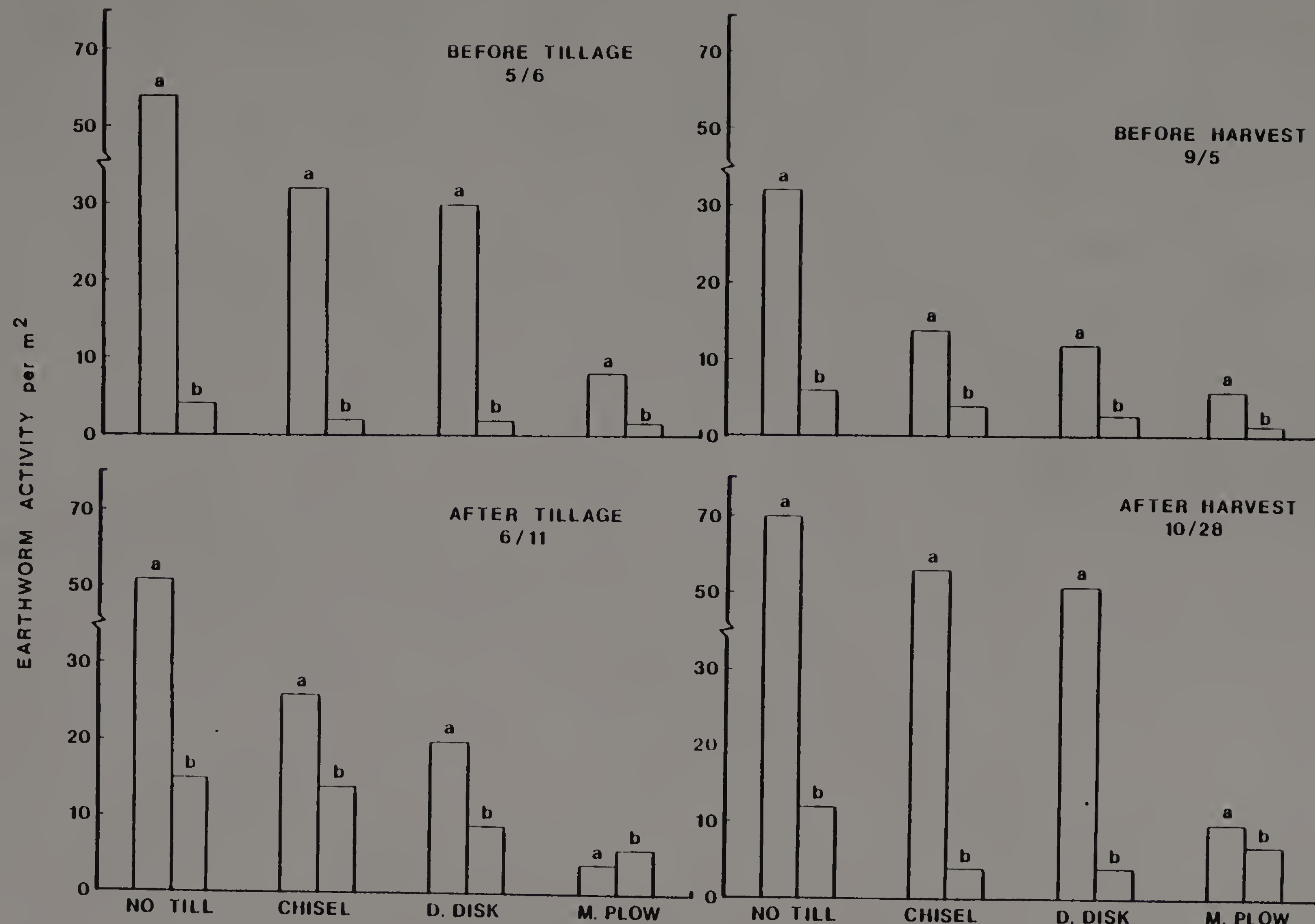


Fig. 24. Earthworm activity in blocks I(a) and the mean of blocks II,III,IV(b).

Table 2. Linear Correlation Coefficients Between Infiltration Rates and Earthworm Activity Index by Tillage Treatment and Various Blocks.

Tillage Treatments	Block I	Blocks II, III, and IV
Chisel-Disk	-.80	.08
Moldboard-plow	-.69	-.19
Double Disk	-.98	.64
No-till	-.68	-.68

possible influence of the chemical properties reveal some interesting trend about implications of soil management on yield and associated growth parameters.

Block variation in organic matter, nitrogen, pH, soil moisture potential and earthworm activity is believed to be due to the past cropping practices and soil amendments.

In 1980 Block I of the experimental site was planted in alfalfa and lupines while Block II was cropped to soybeans. The remaining blocks were left fallow. Upon initiation of this project in 1981, Block I received additional organic matter in the form of 33.6 x 10^3 kg/ha of manure slurry.

When manure or crop residue is added to soil only a small portion (2-4%/yr) of the organic carbon, nitrogen and sulfur is converted to humus (Brady 1974). In this form the elements are released only very slowly; thus, even after two years of tillage organic matter levels within the blocks can still be determined and differences will probably continue for several years.

While the levels of organic matter and phosphorus were not significantly different among the tillage treatments, Table 2 does suggest an increase in these properties for the NT treatment that may become significant in the future.

It has recently been questioned whether soil samples from the traditional 0-20 cm depth of the Ap horizon can accurately reflect the actual soil chemistry at the soil surface (Letaw et al. 1984). Surface applied fertilizer that is not incorporated by tillage must rely on entry into the soil either by solution and subsequent leaching, or by diffusion. Within the soil, diffusion is regarded as the main method for the transport of potassium and phosphorus to roots (Parish 1971). At the soil surface movement of nutrients will be much slower due to less soil contact and therefore may accumulate.

Measurement of earthworm activity included the recording of the number of biopores (Grantz and Blake 1978), casts and vegetative mounds. Because the species of earthworm was not identified the term earthworm will refer to any terrestrial living Oligochaeta. It is believed, however, that the majority of the species involved was L. terrestris because of the mound building and extensive vertical channeling that exceeded 100 cm in depth. Earthworm population effects on soil may be of considerable practical importance. This process includes improved soil aeration and drainage (Barly 1961; Edwards 1980), increased number of water stable aggregates, and generally improved soil structure (Hopp 1949; Grantz and Blake 1978). The fact that earthworm populations were found to be higher in block I when compared to the other, block II (Fig. 24), indicated that the organic matter amendments to the soil probably contributed to this migration. As a rule, the development of root macrofauna requires a well-aerated environment, adequate moisture and warm temperatures. Manure additions tend to foster these conditions (Alexander 1977). Variation in the amount of earthworm activity found within blocks points also to a tillage treatment effect. Edwards and Lofty (1978) found that direct drilling encouraged earthworm populations but that any continuous aerable cultivation practice will reduce earthworm populations.

The high infiltration rates in the NT treatment are not due only to earthworm activity during the current season. Abandoned earthworm channels of past years, old root channels and desiccation cracks in the soil surface, as well as the tillage implement itself will contribute to higher infiltration rates.

Water infiltration in the field will occur only during saturated soil conditions as created either by heavy precipitation or by a decrease in permeability due to crusting. Biopores may be the only means of water infiltration and increasing earthworm population therefore would benefit any tillage system.

Differences in soil moisture tension between the various blocks appears to be due to the soil amendments of 1980 and 1981. Textural data (Fig. 7) indicated that the soil texture at the 30 cm depth in Block I was a sandy loam rather than the silt loam texture at the same depth for Blocks II and III. This textural difference may have caused some ponding of water on the textural break interface in block I, allowing for lower moisture tensions at the 15 cm depth.

The NT treatment showed lower moisture tensions than the MP treatment in Blocks II and III. The OM was incorporated into the soil of Block I prior to the start of the experiment. Table 1 indicates a trend towards higher OM contents in NT. This effect is probably more pronounced in soils having more OM and more favorable pore size to retain water. In low OM soil this effect is negligible and the MP treatment probably favors the creation of intermediate sized pores.

3.4. Effect of Tillage Method and Various Rates of Nitrogen Fertilization on yield.

Results

Three levels of nitrogen fertilizer applications were evaluated to determine the influence tillage might have on yield. Differences in organic matter levels between various blocks (see section 3.3) led to a different response to N-fertilizer application (Fig. 25). Blocks I and II (solid line in Fig. 25) had received significant additions of organic matter just prior to the tillage experiment initiation and were compared to blocks III and IV (dashed line in Fig. 25), which did not. The significance of higher soil organic matter contents is evident in the CD and NT treatments where yields in plots with more organic matter were significantly higher. This effect is less pronounced in the DD and MP treatments where yields were higher in Blocks III and IV at the 179 kg N/ha rate. Low N-rates reduced the yield in the NT treatment for the high organic matter blocks while the highest nitrogen rate usually increased yields.

Discussion

Nitrogen fertilizer application to corn is necessary each year because soils do not retain nitrogen well, it being subject to leaching and/or denitrification processes. The effect of surface applied nitrogen is that it can be rapidly taken up and immobilized by microorganisms (Belevins et al. 1983) whose populations and activity are affected by increased organic matter and higher soil moisture content. This phenomenon is perhaps indicated by the yield response at low nitrogen levels for the NT treatment in high organic matter blocks of Fig. 25.

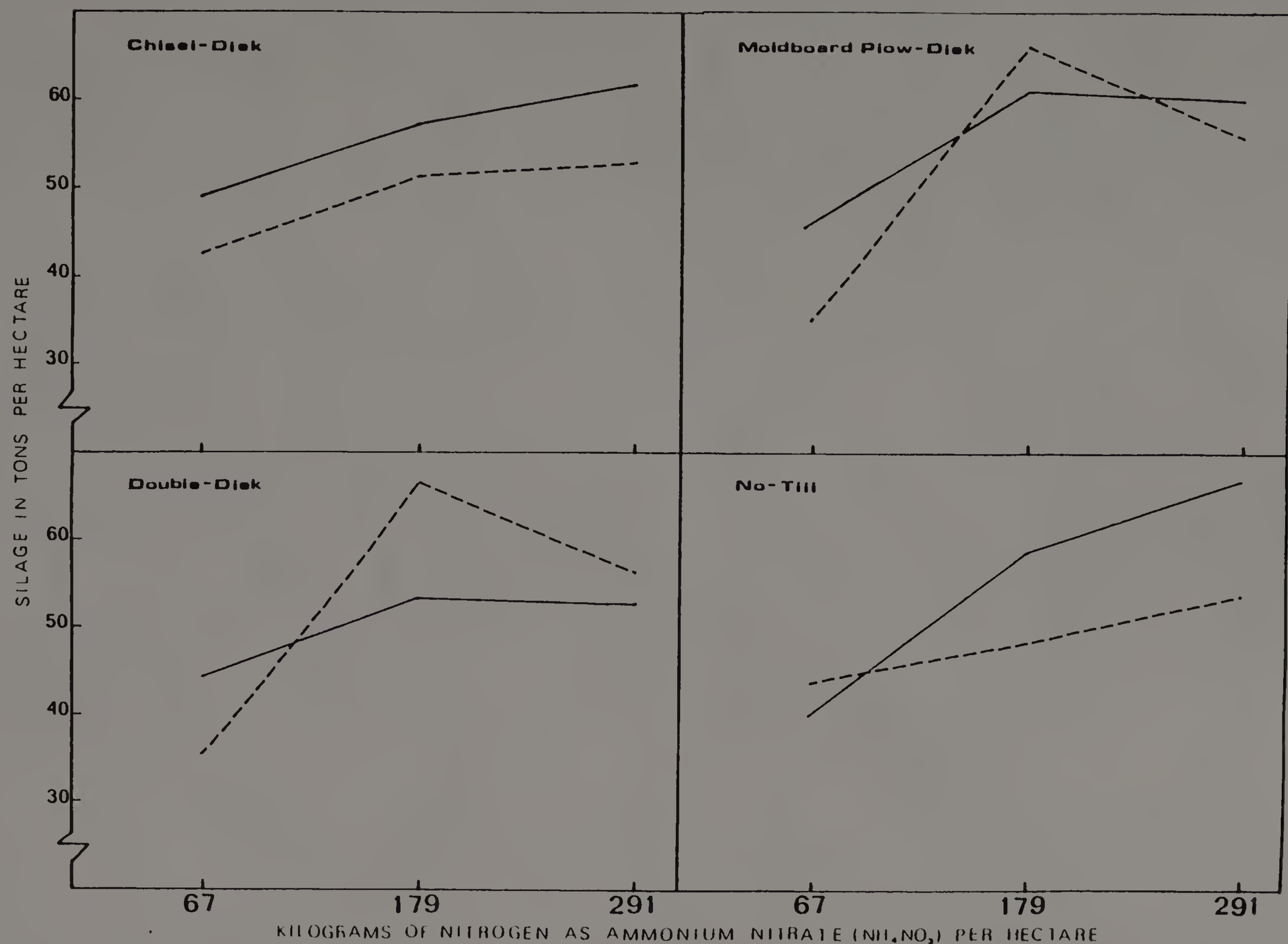


Fig. 25. Effects of different nitrogen fertilizer rates on yield in blocks I and II (solid line) and blocks III and IV (dashed line).

Table 3. Tillage influence on corn yields for three consecutive years.

Treatments	1981		1982		1983	
	Silage*	%Ears	Silage	%Ears	Silage	%Ears
Moldboard plow	58.0	59.1	46.0	43.8	56.3	54.3
Double disk	57.6	55.6	44.1	42.2	52.9	56.0
Chisel disk†	56.4	55.3	41.6	41.0	54.3	60.0
No-till	57.1	56.0	40.1	43.4	53.4	54.3

* tonnes/ha

† treatment in 1981 was a single pass with the disk.

Heavy N-fertilizer use has been shown to increase yields in years with ample rainfall but not in dry years (Black 1966). Table 3 shows the influence of tillage method on corn yields for the past three consecutive seasons. The summer quarterly precipitation for 1981, 1982 and 1983 was 24.2 cm, 40.1 cm and 18.1 cm, respectively (Ives 1983). This reduction in precipitation may have lowered yields at the highest nitrogen rate for the DD and MP treatment suggesting a quadratic effect to fertilizer rates. In the conservation tillage treatments, increased nitrogen seems to have had a beneficial effect on yield having a more linear influence. Increased nitrogen fertilizer rates as well as increasing soil organic matter levels would seem to benefit CD and NT treatments over the MP and DD treatments.

3.5 Corn Shoot/Root Development Under Different Tillage Practices

Results

Differences between root distribution, plant morphology and yield were compared over the course of the 1983 growing season. At approximately two week intervals both root and shoot samples were taken for dry weight determination. Vegetative samples were also measured for plant height.

Trend analysis for both plant height and dry weight indicated a linear effect for height at the 79% level and a highly significant linear, quadratic and cubic effect at the 99% level (Appendix A) for plant dry weight. However, there was no significant difference due to tillage treatments for either plant height or dry weight.

When linear regression is used to compare plant height and vegetative dry weight with root dry weight, a definite tillage treatment effect is indicated (Figs. 26 and 27). Root/shoot ratios produced high correlation coefficients for the DD, CD and MP treatments at .94, .83, and .77 respectively. The no-till treatment showed the lowest correlation with an r-value at .47. Root/plant height ratios indicated higher correlation coefficients for the CD and NT treatments at .98 and .77. Correlation coefficients remained high for the other tillage treatments with a small increase in the r-value of the MP treatment to .99.

Tillage appeared to influence root growth and development as shown by the change in root dry weight over time in Table 4 and root pattern descriptions in Appendix C. When the soil was plowed corn root developed more extensively and to a greater depth than where the soil was not tilled. Roots were found to be finer and longer in the tilled soil and less so in the reduced and no-till plots. At 38 days after planting the NT treatment had the greatest dry weight at 9.8 g (Table 4). The peak in root dry weight was reached at 65 days after planting for the NT at 46.3 g, 95 days for the MP at 46.1 g, and 112 days for the DD and CD at 44.3 g and for the CD at 45.0 g, respectively.

Considerable differences due to tillage treatment were also observed in the angle and lateral spread and depth of root penetration. Changes in root development as indicated by the photographs were not always found to be correlated with changes in plant height and dry weight.

Analysis of variance using a whole and split plot design showed no significant difference between treatments for either silage, moisture

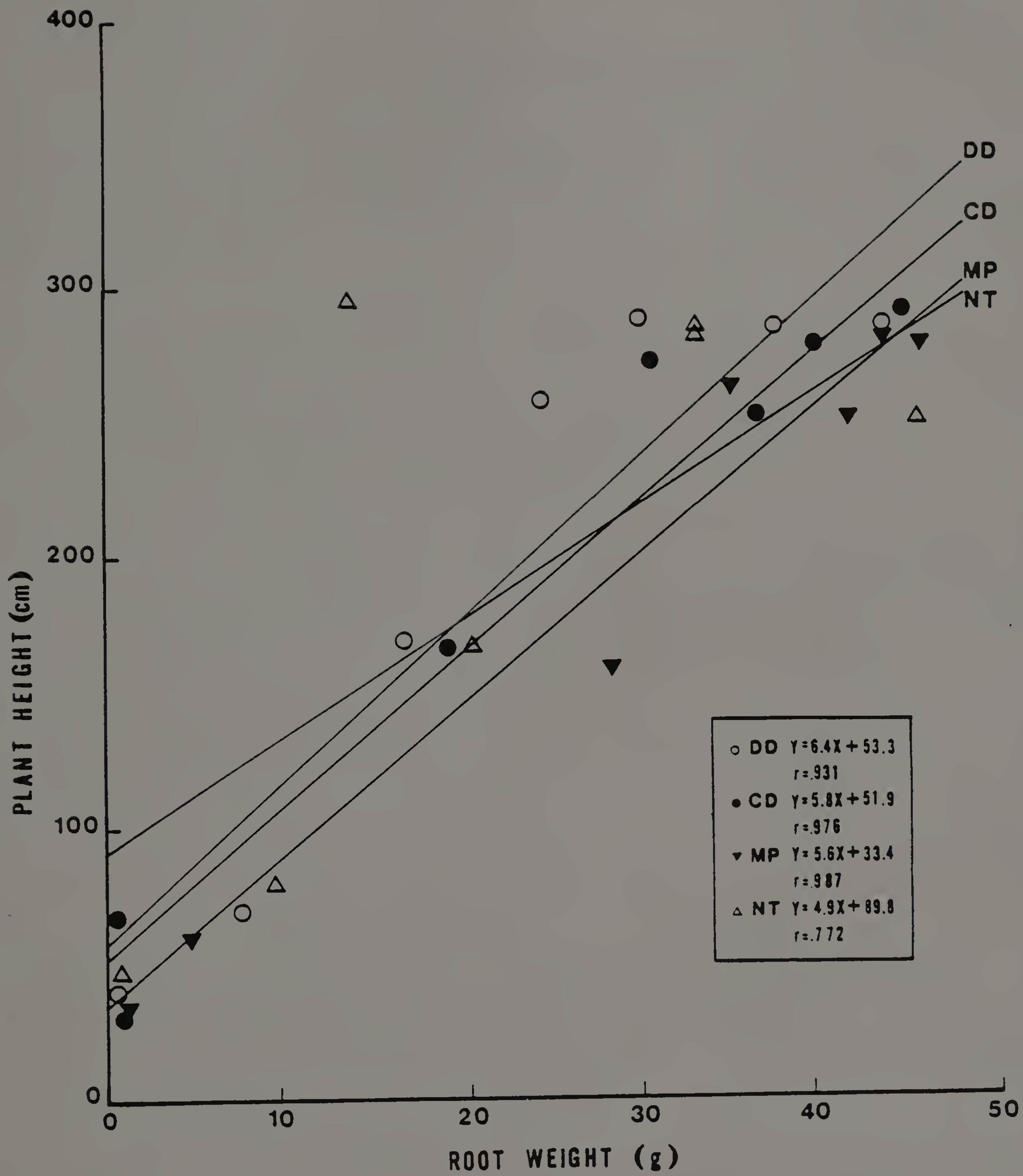


Fig. 26. Relationship of plant height and root dry weight during the 1983 growing season.

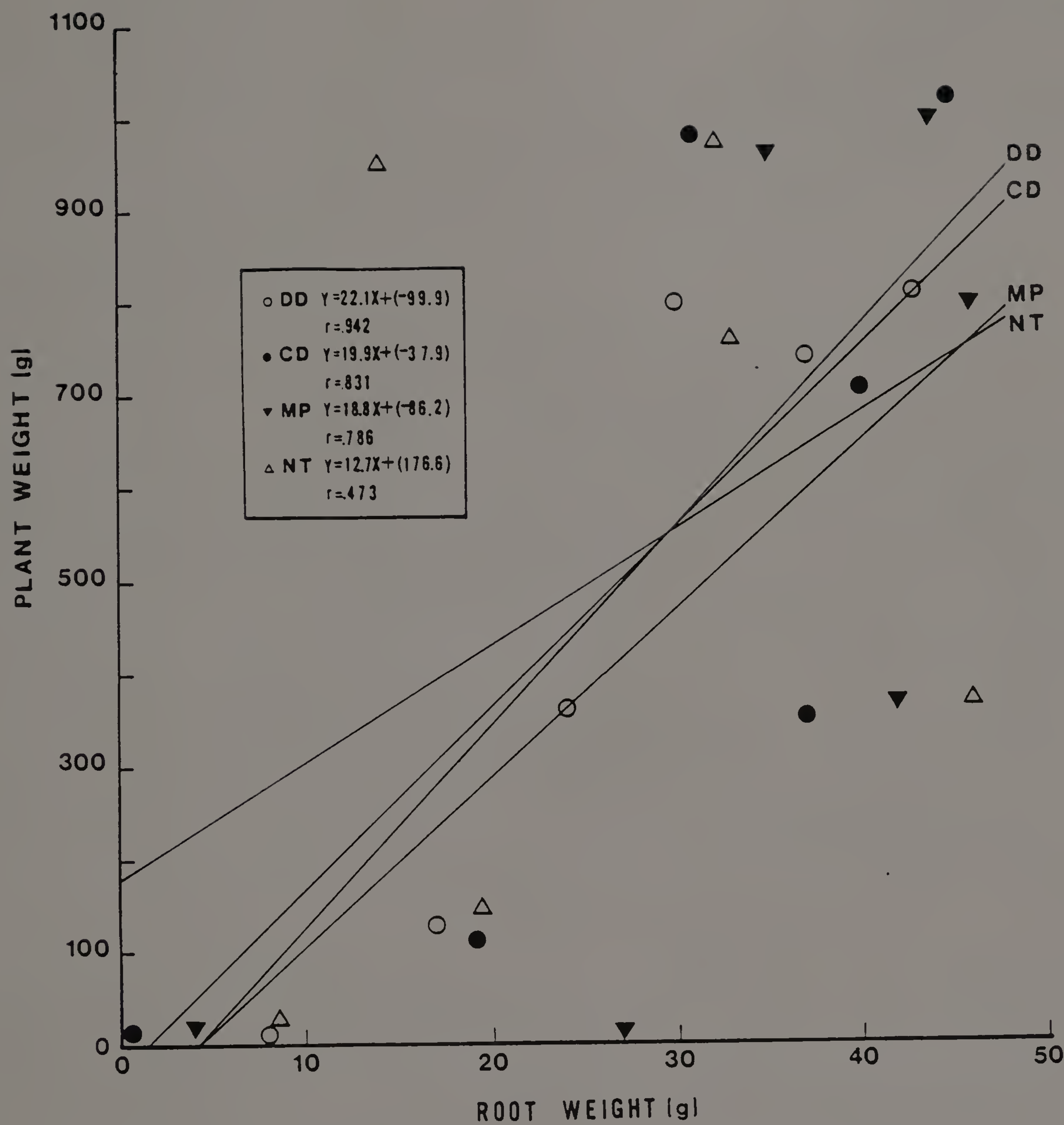


Fig. 27. Plant dry weight and corresponding root weight during the 1983 growing season.

Table 4. Root Dry Weight Between the Tillage Treatments for the 1983 Growing Season

Tillage Treatment	Days After Planting — g —					
	38	52	65	95	112	125
CD	5.8	19.7	37.1	40.2	45.0	32
MP	4.6	27.9	42.4	46.1	44.2	34
DD	8.5	17.0	24.0	38.1	44.3	30
NT	9.8	19.9	46.3	39.9	33.1	28.3

content, or grain/stalk ratio (Appendix A). There was, however, a significant difference between the tillage treatments at the 95% level for percent ears (Table 3).

Discussion

Since tillage has been shown to affect porosity, bulk density, and fertilizer distribution it probably will also affect root morphology. Corn root growth in the field and root distribution in the soil under different tillage methods has not been studied. Knowledge of the variations due to tillage practices of root density, both vertical and horizontal in the soil could lead to development of the most effective placement of fertilizer as well as information on root stress vulnerability that could have a major effect on plant growth and yield.

The interdependence of the root and shoot growth is due to the fact that roots receive photosynthates and growth hormones from shoots and in return furnish water and essential minerals to the shoots (Taylor and Arkin 1981). While root configuration and dry weight were found to be dependent on tillage method, increased root weight and lateral root proliferation did not seem to be sufficient to influence yield.

Sumner and Boswell (1981) noted that reduced early growth in conservation tillage plots could be associated with a modification of the root system.

Roots examined 38 days after planting showed signs of both stage 1 and stage 2 in root development according to Foth (1962). Downward diagonal root growth characteristics of stage one in root development seemed to be halted in both the CD and DD treatments and root filling in the upper root layers had begun. Additional evidence of difficulty in root penetration into the soil is indicated by the lateral growth and thickening of roots. Compensatory growth (Russell _et al_. 1975) is an important general characteristic of roots and most obvious at the 30 cm depth of all treatments throughout the growing season.

Soils where the restrictive layer is the result of a recently applied compaction force, such as tillage, commonly have a medium texture (loam, silt loam, sandy loam) (Raney _et al_. 1955). The zone of highest bulk density and lowest permeability is usually found just below the zone disturbed by the tillage operation. Fig. 28 shows the bulk density and penetrometer resistance for all tillage treatments after tillage. While bulk density tends to be highest at the 15 cm depth, the penetrometer resistance is generally highest at the 30 cm depth. Barly (1963) found that corn root elongation stopped when penetrometer resistance was above 1.8 MPa. Penetro-meter resistance at the 30 cm depth for all treatments was above 1.8 MPa. The CD and DD treatments showed penetrometer resistance values above 1.8 MPa at the 15 cm depth as well.

At 65 days after planting the vertical development of adventitious and brace roots is restricted in all treatments in the MP. This third stage of root development is somewhat different in the CD, DD, and NT tillage treatments. Root filling and lateral growth continued by evidence of a fine root network in the upper soil layers at this time.

The root top will enter compacted layers as shown in the NT treatment, if a pore or crack larger than the root cap diameter is available (Taylor 1971). Under favorable conditions a limited zone of soil should

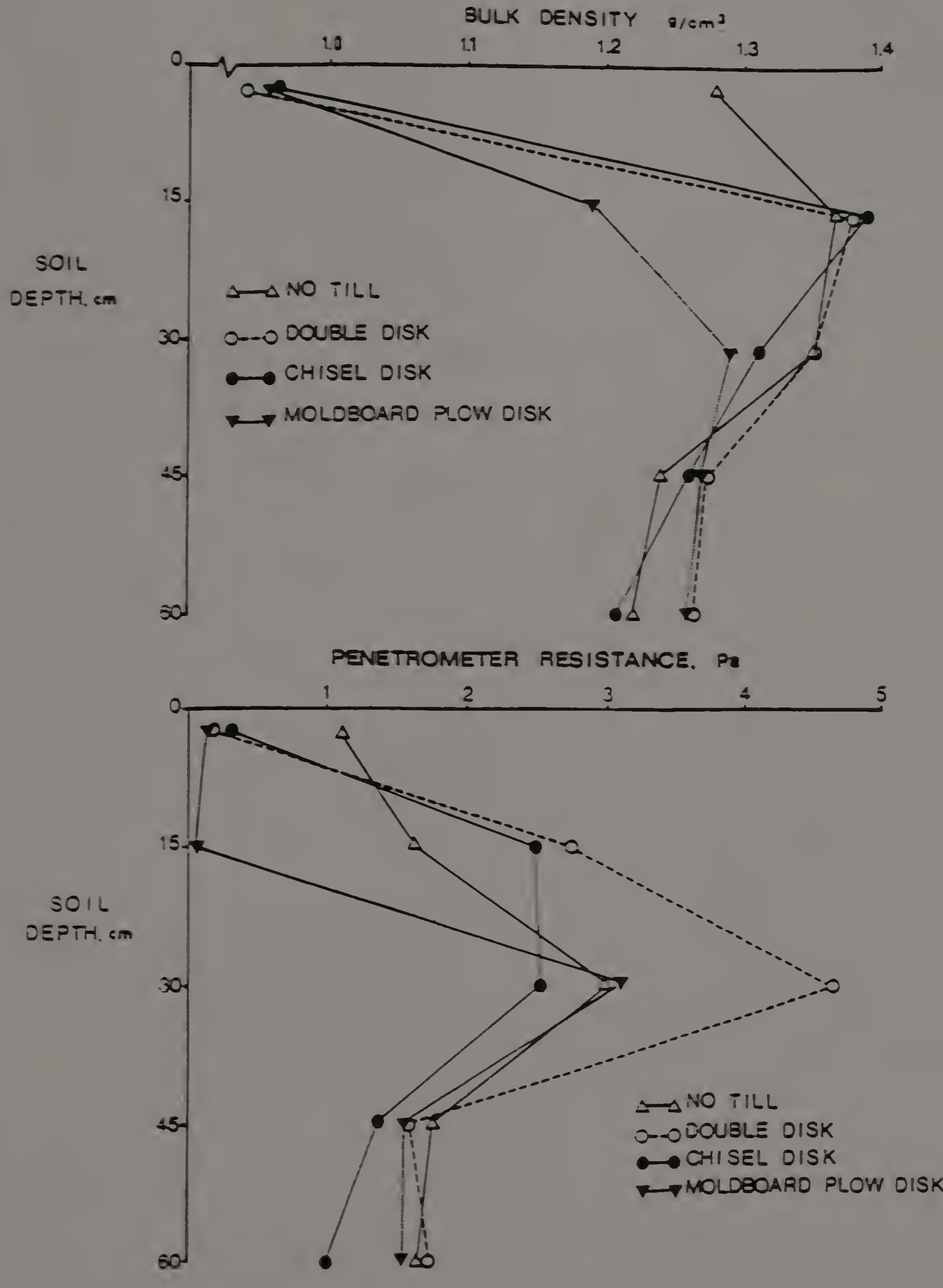


Fig. 28. Bulk density and penetrometer resistance at selected soil depths for the four tillage treatments after tillage.

be adequate to support the plant but restricted root systems would of course be vulnerable to drought.

At the fourth stage of corn root development according to Foth (1962) the ear should be in the milk stage and the brace root system should be complete. Ninety-five days after planting all treatments passed through the 3rd stage of root vertical growth. Brace roots however, seem to be still elongating in the NT at least.

During the grain filling stage photosynthates are monopolized by the developing ear and root growth slows substantially (Taylor and Akin 1981; Mengel and Barber, 1974). At 95 days root dry weight was reduced in all treatments but visual evidence of dieback did not appear until 112 to 125 days after planting. At this stage of corn root development (Foth 1962) maturation of the seed is believed to have occurred while no significant root growth occurs at this time: Some differences in brace root development, as well as degrees of dieback existed however, that probably influenced the linear regression of Figs. 24 and 25.

While there was no significant statistical difference in yield between the tillage treatments over the past three growing seasons (section 3.3) differences in root morphology indicate possible trends in yield difference.

CHAPTER IV

SYNTHESIS OF RESULTS AND DISCUSSION

Research into soil tillage and its affects may take many forms. This study has concentrated on the effect of tillage on plant growth and associated edaphic properties. Historically, this type of research has used crop growth or yield as the sole measurement of tillage performance. To develop a more theoretical approach, additional indicators of the growth environment needed to be examined.

Frost heave action during the 1982/83 winter did not produce significant differences in soil bulk density among the tillage treatments. Measurements of frost heaving by plastic tube movement clearly shows that there were changes in soil physical properties due to tillage that affected both heat and moisture flow in the soil. After two seasons of this tillage experiment the NT produced more uniform and earlier heaving of tubes at all depths, as compared to other treatments.

The increase in soil density at the 0 to 15 cm depth for the CD, DD, and MP treatments is probably due to differences induced by the compacting action of tillage which would alter the heat exchange capacity of the soil. Higher densities as indicated by penetrometer resistance at the 30 cm depth in the MP and at 15 and 30 cm depths in the CD and DD treatments would allow more rapid warming of the soil surface, causing slumping of tubes during soil thaw, and quicker freezing during cold periods.

Differences in bulk density among the treatments were found to be significant only after the tillage operation and before harvest at the 0 and 15 cm depths. Moisture characteristic data on the other hand showed that after tillage all treatments experienced increase in volumetric moisture content at the 60 cm depth which is possibly due to the influence of wheel traffic compaction on either side of the sampling area.

The net effect of this soil compaction would be to increase soil water at the expense of soil air. Rooting patterns appeared to be influenced by differences in soil density rather than by moisture or porosity.

Soil moisture tension varied among the treatments in the following order: CD < NT < DD < MP at the 15 cm depth. Conservation tillage is usually credited with conserving soil moisture particularly when NT is employed: Soil moisture tension was lowest for the NT approximately three weeks after tillage. Total porosity for all bulk density values did not go below 45.6% and in none of the treatments was the air filled porosity less then 10%.

The increased soil moisture content, while not statisticaly significant, may have helped to produce differences in root dry weight at the first sampling period. At this time the NT had the highest root dry weight at 9.2 g while the MP was at 4.7 g. At 52 days after planting the MP root dry weight had increased to 27.9 g with vertical root growth beyond the 30 cm depth. The other treatments averaged 18.7 g for root dry weight with root growth confined to the surface 30 cm. This would indicate that soil density becomes more important during later growth stages.

Weed control on a dry weight basis was found to decrease with increasing conservation tillage but differences were not found to be correlated with yields suggesting little influence from weed competition.

The effect of higher levels of soil organic matter in Block I were evidenced by increased surface infiltration, lower soil moisture tension and increased earthworm activity. Yields in the conservation tillage practices CD and NT were higher due to increased organic matter content in conjunction with increased nitrogen fertilizer rates in the DD or MP treatment during 1983 growing season.

There appear three separate areas of soil physical conditions at the experimental site: the compacted interrow space, the non-compacted intrarow spaces and the non-compacted interrow spaces. All data collected concentrated on only the non-compacted interrow areas. Penetrometer data, usually a reliable indicator of soil resistance, showed a significant difference at the soil surface between the CD, DD, and MP treatments. Comparisons between the different inter and intra row spaces may have yielded more useful information.

Thin sections of the soil surface offered descriptive information indicating differences among all four tillage treatments. Through thin section examination only the NT was found to maintain continuous macropores to the soil surface at all sampling periods allowing for greater soil moisture absorption capability, as well as increased soil oxygen/carbon dioxide exchange.

CHAPTER V

SUGGESTED FURTHER RESEARCH

When this project was started it was not known which edaphic properties would best be suitable to assess the effect of conservation tillage. Since research results applicable to New England conditions had not been published previously, the project was forced to examine a broad spectrum of properties. This wide range perspective allowed for the collecting of a great number of data but was limiting in depth that each area could be pursued. At the completion of the project it becomes obvious that additional research would be helpful in some areas. The following is a list of those areas where continued or additional research is recommended:

1. The study of selected soil physical properties should be extended to include measurements within the compacted interrow spaces. Data comparing compacted and non-compacted rows would help determine the need or effectiveness of controlled traffic.

2. Rooting patterns and dry weight determinations need to include measurements of root density changes with soil depth over the course of the growing season. Differences between the primary root system and the later developing brace root system should be noted and separated for dry weight determination.

3. Vegetative growth of the corn plant should be monitored for morphological changes (time of silking, tasseling, seed maturation, ear-filling, etc.) between tillage treatments.

4. Organic matter should be added to all blocks to obtain identical levels. This also would allow for the studying of earthworm population movement and establishment.

5. Rate of evolvement and climax species development of weed and insect populations need to be determined. The appropriate pesticide recommendations should take these changes into account.

6. Electrical resistance or use of the neutron moisture probe would expand the effective monitoring range of soil moisture changes.

7. The chisel cultivator used in this project should be replaced by a conventional chisel-plow and the disking of the treatment dropped.

8. The mechanisms for fertilizer and seed placement on the No-Till planter need to be redesigned or replaced.

9. Variations in fall tillage implement use and number of passes should be included when evaluating tillage influence on frost heave action.

10. Experimenting with changes in row width and seed density might be necessary to make conservation tillage yields comparable to conventional tillage.

11. Economic changes in the farm management system produced by conservation tillage need to be examined under the small farm conditions of New England.

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APPENDIX A

Table 5. Weed Control on a Dry Weight Basis Between the Tillage Treatments for the 1982 and 1983 Growing Season.

Tillage Treatments	Weed Dry Weight in Groups†	
	1982+	1983§
CD	45.9b†	65.9b†
MP	14.0a	3.5a
DD	68.1bc	52.9b
NT	91.8c	87.1C

*Number followed by the same letters are not significantly different. Duncan's Multiple Range Test at the 5% level.

†Each value is the mean of 8 50 x 50 cm^2 sample areas.

+Samples collected after harvest 1982.

§Samples collected before harvest 1983.

Table 6. Coefficient of Variation for Frost Heave Tube Movement

Tillage Treatment	Coefficient of Variation*		
	Total Movement	Heaving	Slumping
CD	16	180	47
MP	58	119	48
DD	14.3	53	93
NT	22	29	79

* COV = Std. dev./mean (100)

Table 7. Analysis of Varience by the 'F' Test for Bulk Density Values After Harvest '82 and Before Tillage '83. (Probability of a larger F is less than; 0.010 = *).

Source of Variation	d.f.	After Harvest '82	f	Before Tillage '83
Whole Plot				
Block	3	0.85740		0.7319
Treatment	3	0.2518		0.5087
Error 1	9			
Split Plot				
Depth	4	11.2374*		4.1852*
Depth by Block	12	1.1099		0.8205
Depth by Treatment	12	0.5931		1.4242
Error 2	36			

Table 8. Trend Analysis Changes in Bulk Density Over the Soil Depth For Sample Periods BT, AT, BH and AT. (Probability of a larger F is less than; 0.005 = ***, 0.050 = **, 0.100 = *).

Source of Variation	d.f.	Before Tillage	After Tillage	Before Harvest	After Harvest
		f value			
Whole plot					
Block	3	0.79	1.10***	0.46*	0.37
Treatment	3	0.49	5.67	4.20	0.68
Error 1	9				
Split plot					
Depth	4	4.11*	91.51	62.19	9.71***
(Linear)	1	4.31	82.31***	85.45***	35.80***
(Quadratic)	1	1.33	355.52***	178.06***	7.36**
(Cubic)	1	0.00	86.90***	17.47***	0.95
(Quartic)	1	32.23***	0.02	3.35*	4.56
Depth by Treatment	12	1.46	14.38***	2.10***	0.91
Depth by Block	12	0.81	2.98	2.15**	1.29
Error 2	36				

Table 9. Trend Analysis by the 'F' Test for Nitrogen Fertilizer Rate on 1983 Yield. (Probability of a Larger F is less than; 0.050 = **).

Source of Variation	d.f.	MS	f
Block	3	0.2544	1.1452
Treatment	3	0.1289	0.5807
Nitrogen (Linear)	1	0.1689	0.7603
Nitrogen (Quadratic)	1	0.6568	3.4520**
Treatment by Block	9	0.1971	0.8873
Error	36	0.1902	

Table 10. Analysis of Varience by the 'F' Test with Block Comparisons for Organic Matter, Nitrogen + pH. (Probability of a larger F is less than; 0.005 = ***, 0.050 = **, 0.100 = *).

Source of Variation	Organic Matter			Nitrogen		pH	
	d.f.	MS	F	MS	F	MS	F
Treatment	3	0.0034	0.1215	0.0017	1.1192	0.0913	5.8032***
Sample site	2	0.2493	8.8219***	0.0009	20.5313***	0.1277	8.1180***
Block I vs. II, III, & IV	1	0.4203	14.8712***	0.0167	39.0760	0.4354	27.6202***
Block II vs. III & IV.	1	1.1654	41.2296***	0.0317	1.0857	0.0501	3.1872
Block III vs. IV	1	0.0294	1.0401	0.0009	2.0196*	0.0771	4.8989*
Treatment by Block	9	0.0206	0.7311	0.0016	0.3562	0.4622	2.9380*
Treatment by Site	6	0.0178	0.6290	0.0003	1.6874	0.0143	0.9065
Site by Block	6	0.0467	1.6537	0.0014		0.0475	3.0172*
Error	18	0.0283		0.0008		0.0157	

Table 11. Trend Analysis for Plant Height and Shoot Dry Weight Over 1983 Growing Season. (Probability of a larger F is less than; 0.005 = ***)

Source of Variation	Height			Shoot Dry Weight		
	d.f.	MS	F value	d.f.	MS	F
Whole plot						
Block	3	0.0016	0.85	3	0.1640	3.80
Treatment	3	0.0026	1.33	3	0.0467	1.08
Error 1	9	0.0019		9	0.0431	
Split plot						
Date	7	1.2627	2573.83	5	23.1410	491.93
(Linear)	1	4.9754†	8579.44***	1	151.4692+	2611.22***
(Quadratic)	1	1.2728	4520.32***	1	0.0000	0.00
(Cubic)	1	0.1524	25.51***	1	7.3995	187.79***
Date by Treatment	21	0.0009	1.78	15	0.0457	0.97
Date by Block	21	0.0007	1.46	15	0.0543	1.15
Error 2	63	0.0005		45	0.4704	

†79% of the sum of squares is covered by the linear effect.

+94% of the sum of squares are covered by the linear effect.

Table 12. Analysis of Varience by the 'F' Test for 1983 Sillage, Moisture Content, Grain/Stock Ratio and % Ears. (Probability of a Large F is less than; 0.005 = ***, 0.01 = **)

Source of Variation	d.f.	Sillage MS	Sillage F	Moisture Content MS	Moisture Content F	Grain/Stalk MS	Grain/Stalk F	% Ears MS	% Ears F
Whole plot									
Block	3	2.5442	1.2907	3.5741	1.0268	3.0864	1.0562	7.8398	2.1765
Treatment	3	1.2895	0.6544	3.1624	0.9085	3.5203	1.2047	13.3837	3.7156*
Error 1	9	1.9711		3.4807		2.9221		3.6020	
Split plot									
Nitrogen	2	4.1288	1.8585	5.9084	1.6661	4.7156	1.4822	42.9726	7.1372**
Nitrogen by Treatment	6	1.8489	0.8323	3.6833	1.0386	2.4616	0.7737	3.5708	0.5931
Nitrogen by Block	6	1.7974	0.8091	3.5979	1.0145	2.5461	0.8003	2.2577	0.3499
Error 2	18	2.2215		3.5463		3.1815	6.0287		

APPENDIX B

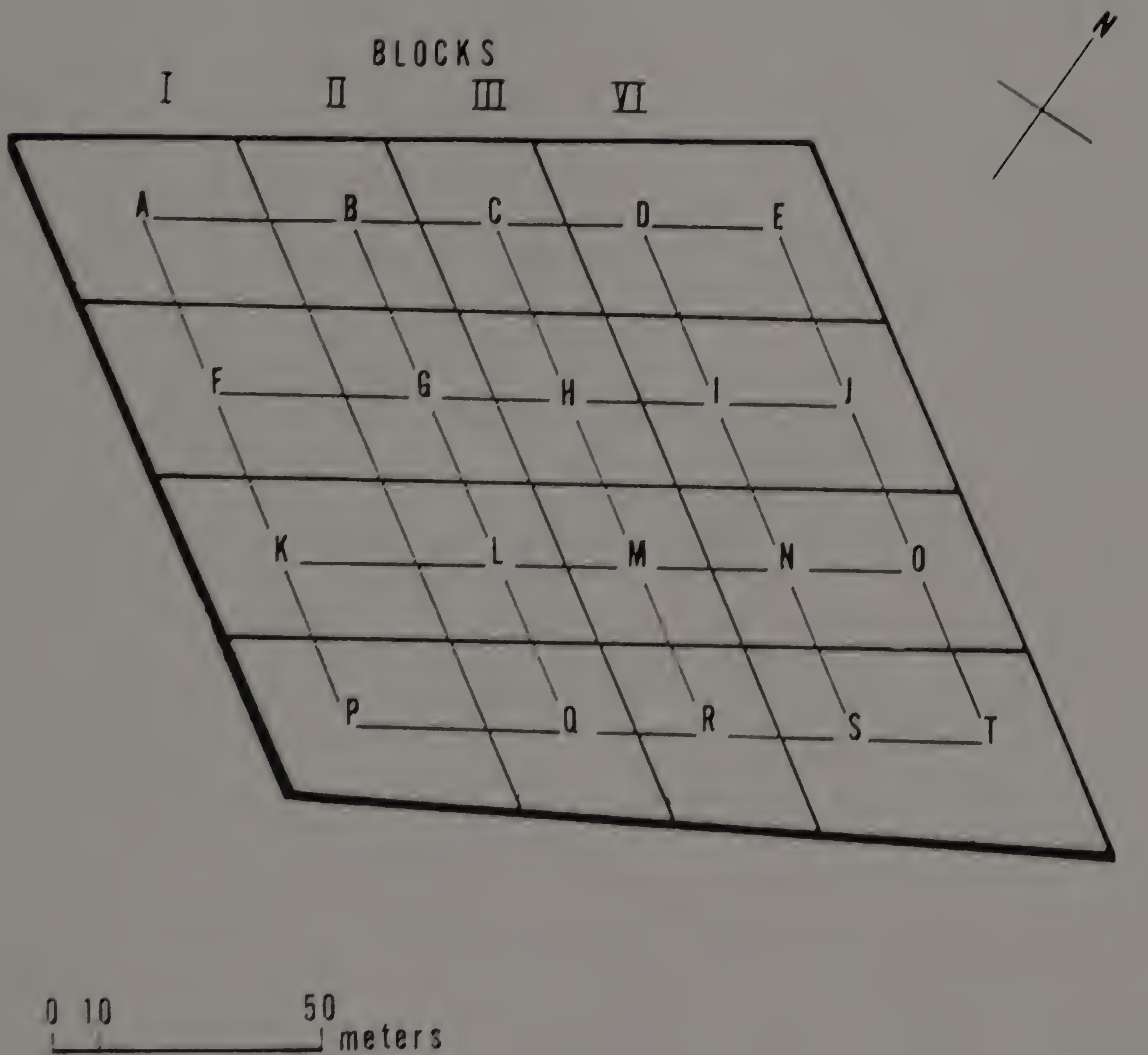


Fig. 29. Soil sampling sites (A-T) in the experimental area for particle size analysis.

Table 13. Particle Size Analysis at Selected Sites and Depths for the Experimental Area

Soil Depth (cm)	% Sand Fraction					%	%
	Very Coarse	Coarse	Medium Fine	Fine	Very Fine	Silt	Clay
Soil Site A							
15	0.08	0.16	0.24	0.64	13.24	80.4	53
30	0.04	0.04	0.88	4.28	33.73	55.1	6
60	0.01	0.01	0.04	7.29	31.86	57.6	3.3
100	0.04	0.08	0.04	5.32	48.12	37.8	8.6
Soil Site B							
15	0.28	0.68	1.36	4.36	13.81	75.3	4.2
30	0.04	0.12	1.16	6.88	23.93	65.1	2.8
60	0.16	0.16	0.28	4.88	57.45	30.1	7
100	0.8	1.92	7.16	8.6	41.92	35.6	4
Soil Site C							
15	0.01	0.21	0.28	0.69	12.82	82.2	3.8
30	0.08	0.16	0.20	4.08	31.481	56.0	8
60	0.16	0.12	0.72	16.50	52.43	24.2	5.9
100	0.04	0.04	0.21	5.72	44.10	48.7	1.2

Table 14. Particle Size Analysis at Selected Sites and Depths for the Experimental Area

Soil Depth (cm)	% Sand Fraction					%	%
	Very Coarse	Coarse	Medium Fine	Fine	Very Fine	Silt	Clay
	Soil Site D						
15	0.04	0.04	0.28	2.32	20.23	71.4	5.5
30	0.32	0.64	1.6	6.4	24.91	53.6	2.6
60	0.00	0.2	5.9	28.4	38.72	21.6	5.2
100	0.2	5.6	5.7	10.9	48.08	23.5	6.1
Soil Site E							
15	0.20	.88	2.44	7.5	22.07	60.5	6.4
30	0.00	0.20	0.88	15.34	49.13	32.5	2.0
60	0.00	0.08	0.48	13.84	39.16	44.2	2.4
100	0.00	0.04	0.12	7.96	52.25	36.4	3.2
Soil Site G							
15	0.2	0.04	2.2	1.1	32.8	55.6	8.3
30	0.12	0.12	0.28	6.2	43.34	45.1	4.9
60	0.00	0.16	0.2	11.8	40.59	42.5	4.8
100	0.00	0.04	0.28	8.2	50.93	40.6	0.0

Table 15. Particle Size Analysis at Selected Sites and Depths for the Experimental Area

Soil Depth (cm)	% Sand Fraction					%	%
	Very Coarse	Coarse	Medium Fine	Fine	Very Fine	Silt	Clay
	Soil Site						
15	0.04	0.08	0.36	4.88	36.71	54.7	2.35
30	0.01	0.03	0.18	25.6	41.02	27.9	5.2
60	0.00	0.01	0.04	26.4	39.30	31.1	3.1
100	0.00	0.04	0.21	40.7	47.10	39.2	2.8
	Soil Site I						
15	0.00	0.00	0.89	6.31	39.62	49.3	3.9
30	0.02	0.04	0.04	28.2	37.67	27.9	6.2
60	0.01	0.00	0.72	32.1	28.73	34.7	3.7
100	0.00	0.00	6.53	39.1	28.21	21.1	5.1
	Soil Site K						
15	0.02	0.04	0.43	5.89	41.02	47.4	5.2
30	0.00	0.08	0.86	17.2	43.12	36.4	2.4
60	0.00	0.07	0.53	13.9	38.25	45.3	2.0
100	0.00	.24	7.12	37	41.00	12.3	2.7

Table 16. Particle Size Analysis at Selected Sites and Depths for the Experimental Area

Soil Depth (cm)	% Sand Fraction					%	%
	Very Coarse	Coarse	Medium Fine	Fine	Very Fine	Silt	Clay
Soil Site L							
15	0.01	0.01	0.10	11.20	17.13	67.4	4.2
30	0.01	0.01	0.85	18.31	49.2	25.3	6.3
60	0.0	0.08	0.52	16.31	37.5	39.5	6.1
100	0.01	0.79	8.01	29	46	15.09	1.1
Soil Site M							
15	.01	.03	.07	3.64	36.6	57.6	2.1
30	0.2	0.88	2.44	17.52	35.01	42.5	1.5
60	0.1	0.21	.63	15.3	54.6	24.3	4.8
100	0.0	0.0	.81	16.3	52.4	24.2	5.3
Soil Site N							
15	0.04	0.04	0.27	3.56	21.1	71.9	3.1
30	0.01	0.13	0.56	17.9	48.1	28.5	4.8
60	0.01	0.10	0.21	13.8	49.3	33.9	2.6
100	0.00	0.00	1.31	31.3	42.8	21.09	3.5

Table 17. Particle Size Analysis at Selected Sites and Depths for the Experimental Area

Soil Depth (cm)	% Sand Fraction					%	%
	Very Coarse	Coarse	Medium Fine	Fine	Very Fine	Silt	Clay
	Soil Site P						
15	0.02	0.16	0.02	4.85	19.30	73.6	2.1
30	0.04	0.01	0.81	6.31	10.97	75.7	3.8
60	0.01	0.04	0.04	7.55	13.70	73.1	5.6
100	0.01	0.08	0.04	3.21	23.3	71.2	2.2
	Soil Site Q						
15	0.01	0.12	0.04	6.81	10.02	77.4	5.6
30	0.02	0.01	0.53	7.95	9.89	76.8	4.8
60	0.04	0.15	0.63	6.52	17.06	73.5	2.1
100	0.04	0.16	0.04	4.31	11.75	80.0	3.7
	Soil Site R						
15	0.08	0.16	0.04	9.16	9.04	75.1	5.7
30	0.01	0.01	0.02	7.85	12.21	75.6	4.3
60	0.01	0.04	6.84	5.61	13.26	72.1	2.1
100	0.2	0.4	5.7	10.8	45.6	32.2	5.1

Table 18. Particle Size Analysis at Selected Sites and Depths for the Experimental Area

Soil Depth (cm)	% Sand Fraction					%	%
	Very Coarse	Coarse	Medium Fine	Fine	Very Fine	Silt	Clay
	Soil Site H						
15	0.04	0.00	0.36	4.22	19.81	73.5	2.1
30	0.68	0.00	1.90	4.22	21.30	68.1	3.8
60	0.01	0.04	0.31	15.32	39.83	42.4	2.1
100	0.0	0.4	0.13	8.55	51.41	35.8	3.8

Table 19. Descriptive Notes on Thin Sections of Soil Before Tillage

Soil Depth (cm)	Double-Disk Treatment
0	- No visible macropores continuous to soil surface.
1.6	- Fine dense plasma to this depth followed by irregular ortho vughs and ortho joints.
	- No visible banding of vesicles.
Soil Depth (cm)	**No-Till Treatment**
0	- Presence of macropores continuous to soil surface.
0.2	- Evidence of crust breaking up, some buried organic matter.
1.5	- Irregular ortho joints, extending to surface in some cases.
4.8	- Skeleton grains appear planar.

Table 20. Descriptive Notes on Thin Sections of Soil Before Tillage

Soil Depth (cm)	Chisel-Disk Treatment
0	- Surface appears irregular, some plant growth, surface crust is .02cm thick.
0.4	- Some angular skeletal grains, below this is plasma or organic matter.
	- No macropores continuous to soil surface.
0.5	- Evidence of vesicle banding below crust.
0.8	- Irregular ortho joint planes.
Soil Depth (cm)	**Mold Board Plow-Disk Treatment**
0	- Surface crust of plasma, .2mm-.3mm thick.
0.04	- Surface crust is level with banded vesicles.
	- Dense plasma, .4mm thick, below surface crust.
1.	- Several ortho joints below surface crust.

Table 21. Description Notes on Thin Sections of Soil After Tillage

Soil Depth (cm)	Double-Disk Treatment
0	- Surface very irregular.
0.5-0.8	- Multiple layering, note deposits in depressions.
	- Irregular ortho vughs directly below layers
1.8	- Packed dense plasma, some 1.6cm in diameter at this depth.

Soil Depth (cm)	No-Till Treatment
0	- Macropores found to be continuous to soil surface.
	- No visible crust development.
	- Fewer skeleton grains in surface 4mm of soil.
1.5	- Ortho joints still present.

Table 22. Descriptive Notes on Thin Sections of Soil After Tillage

Soil Depth (cm)	Chisel-Disk Treatment
0	- Soil surface appears loose, with continuous macropores to surface.
0 to .4	- meta vughs present in top 0.4cm of soil, irregular and smooth.
	- Crust depth is 0.02-0.04cm.
.6 to .8	- Irregular ortho vughs.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
0 to .15	- Surface crust thickness.
	- Depressions are filled into some 0.8cm deep.
1.5	- Second crusted layer visible 0.08cm thick.
1.7	- Several large irregular ortho vughs present no joints.

Table 23. Descriptive Notes on Thin Sections of Soil Before Harvest

Soil Depth (cm)	Chisel-Disk Treatment
0	- Continuous fine plasma covering surface, crust is level, 3cm thick.
	- Note layered wash in areas.
1.2	- Fine plasma.
1.6	- Ortho vughs.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
0 to .08	- Irregular ortho joints.
.1	- Fine wash in material composing level surface crust.
1.5	- Vughs.

Table 24. Descriptive Notes on Thin Sections of Soil Before Harvest

Soil Depth (cm)	Double-Disk Treatment
	- Surface is leveling.
.02	- Banded vesicles below crust.
.02 to .06	- Dense compacted region.
1.6	- Irregular ortho vughs.
1.8	- Large compacted clods no longer visible.

Soil Depth (cm)	No-Till Treatment
1.5	- Irregular ortho joints are gone.
1.5	- Some vughs present.

Table 25. Descriptive Notes on Thin Sections of Soil After Harvest

Soil Depth (cm)	Chisel-Disk Treatment
0 to .02	- Crust thickness.
	- Area below crust has few pores, some vesicles.
.5	- Several bands of organic matter.
	- No vughs or joints visible.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
	- No continuous macropores to soil surface.
	- No joints or vesicles present.
.3	- Layering of fine plasma.
1.3	- Parallel alignment of skeleton grains.

Table 26. Descriptive Notes on Thin Sections of Soil After Harvest

Soil Depth (cm)	Double-Disk Treatment
0 to 0.14	- Layering, no continuous pores to surface.
0.2	- Many banded vesicles below crust.

Soil Depth (cm)	No-Till Treatment
0	- Surface not level.
.4 to .6	- Irregular ortho vughs.
	- No vesicles.

APPENDIX C

Table 27. Descriptive Notes on Root Pattern Development 38 Days After Planting

Soil Depth (cm)	Chisel-Disk Treatment
	- Fine roots at soil surface.
15	- Wide angle and lateral growth.
	- Confined thick root growth.
30	- No penetration below this depth.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
	- Note space between plants and finer main roots.
	- Angle of root growth is more vertical.
30	- Growth seems to slow, start of lateral growth.
	- Not as much curving of root patterns as the other treatments.

Table 28. Descriptive Notes on Root Pattern Development 38 Days After Planting

Soil Depth (cm)	Double-Disk Treatment
	- Root system is shallow, main roots are thick.
15	- No noticable lateral growth.
	- Note space between roots.
	- Brace root development beginning.

Soil Depth (cm)	No-Till Treatment
0 to 15	- Confined root growth, many curves.
0 to 15	- Individual roots are thick.
15	- Some lateral growth.
30	- Growth appears halted.
50 to 55	- Two vertical roots.

Table 29. Descriptive Notes on Root Pattern Development 52 Days After Planting

Soil Depth (cm)	Chisel-Disk Treatment
0 to 15	- Filling of upper soil by root system has not occurred.
0 to 15	- Still evidence of diagonal growth.
30	- Some root growth below this depth.
	- Note fine roots near surface.
	- Brace roots developing.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
0 to 10	- No root growth in this area.
0 to 30	- Large diverse root system developing.
	- Filling of upper soil layers complete.
30	- Vertical root growth below this depth.
	- Little evidence of lateral growth.

Table 30. Descriptive Notes on Root Pattern Development 52 Days After Planting

Soil Depth (cm)	Double-Disk Treatment
0 to 30	- Filling of fine roots still in progress.
0 to 5	- Note roots close to soil surface.
0 to 10	- Diagonal growth still obvious.
	- Note interrow space not yet filled.
30	- Some vertical roots beyond this point.
Soil Depth (cm)	**No-Till Treatment**
0 to 30	- Note root density marking completion of upper soil layer filling.
0 to 5	- Note spaces below soil surface in root system.
30	- Most root development confined at this depth.
50	- One vertical root.

Table 31. Descriptive Notes on Root Development

65 Days After Planting

Soil Depth (cm)	Chisel-Disk Treatment
0 to 30	- Upper soil root filling is complete.
30	- No vertical root growth beyond this depth.
	- Brace roots are branched.

Soil Depth (cm)	Mold Board Plow-Dish Treatment
0	- Long profusely branched brace roots.
0 to 30	- Limited growth, die back beginning, keeping pace with new growth.

Table 32. Descriptive Notes on Root Development 65 Days After Planting

Soil Depth (cm)	Double-Disk Treatment
0 to 30	- Root filling is continuing.
	- Interrow space has been filled.
30 to 50	- Some vertical root growth.
	- Brace roots are branching.
	- Root system is closer to soil surface than in the MP. treatment.

Soil Depth (cm)	No-Till Treatment
	- Maximum root dry weight at 46.3 grams.
0 to 30	- Dense uniform root growth.
	- Filling and die back going on.
15	- Vertical root growth.
0 to 15	- Brace roots starting to branch.

Table 33. Descriptive Notes on Root Development

95 Days After Planting

Soil Depth (cm)	Chisel-Disk Treatment
0 to 30	- Die back and root growth period.
0 to 10	- Brace roots extending and finer roots at soil surface.
30 to 60	- Vertical roots.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
0 to 15	- No roots.
	- Highest root dry weight at 46.1 grams.
45	- Extension of root mass.
	- Brace root system complete.

Table 34. Descriptive Notes on Root Development

95 Days After Planting

Soil Depth (cm)	Double-Disk Treatment
0 to 30	- Root dry weight still increasing.
	- Regrowth of root system is greater than die back.
30 to 60	- Vertical root extensions.

Soil Depth (cm)	No-Till Treatment
	- Root dry weight decreasing (39.9 grams).
	- No significant new growth of roots.
0 to 15	- Brace root system appears complete.

Table 35. Descriptive Notes on Root Development 112 Days After Planting

Soil Depth (cm)	Double-Disk Treatment
30 to 60	- Maximum root weight at 44.3 grams. - No significant change in roots. - Root growth is confined to brace roots.

Soil Depth (cm)	No-Till Treatment
0 to 10	- Note roots close to soil surface. - Root dry weight is decreasing to 33.1 grams.

Table 36. Descriptive Notes on Root Development 112 Days After Planting

Soil Depth (cm)	Chisel-Disk Treatment
30 to 60	- Maximum root dry weight at 45.0 grams. - Profuse branching of brace roots. - Vertical root extension is filling subsoil.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
30	- Brace root system complete. - No significant root growth. - Area of plow pan inhibiting root movement is still visible.

Table 37. Descriptive Notes on Root Development 125 Days After Planting

Soil Depth (cm)	Chisel-Disk Treatment
	- Root dry weight 32 grams. - Note elongation of brace roots and roots near soil surface.

Soil Depth (cm)	Mold Board Plow-Disk Treatment
0 to 30	- Massive non-living root network. - Brace roots not as long as CD. - Decay of old root system appears more internal at this stage than in the other treatments.

Table 38. Descriptive Notes on Root Development 125 Days After Planning

Soil Depth (cm)	Double-Disk Treatment
0 to 30	- Extended brace root system. - Root dry weight has fallen to 30.0 grams. - Note possible contribution of decaying roots to soil.

Soil Depth (cm)	No-Till Treatment
0 to 30	- Extended brace root system shorter and more branching than the other treatments. - Root dry weight at 12 grams. - Possible indication of higher rate of decay.

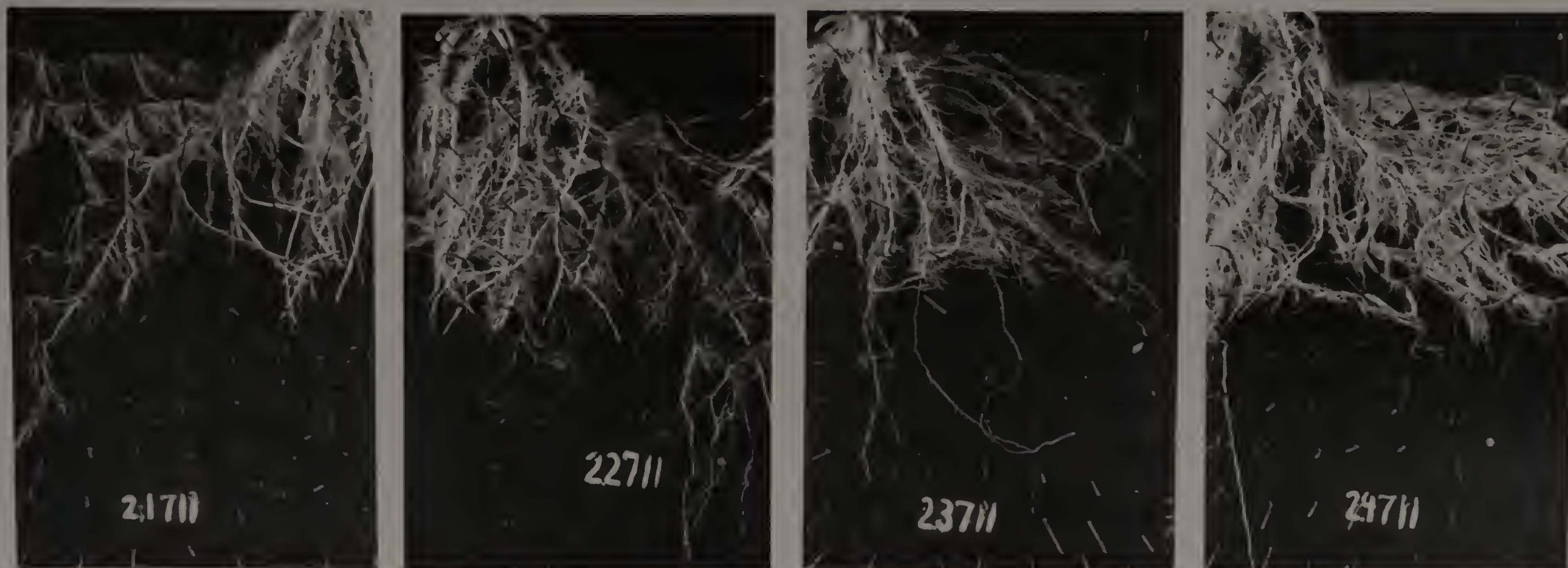
Fig 30. Root development 38 days after planting for tillage treatments (CD), moldboard plow (MP), double disk (DD) and no-till (NT). Pinboard samples were taken parallel to the row.

38 DAYS AFTER PLANTING

CD MP DD NT

Fig 31. Root development 52 days after planting for tillage treatments (CD), moldboard plow (MP), double disk (DD) and no-till (NT). Pinboard samples were taken perpendicular to the row.

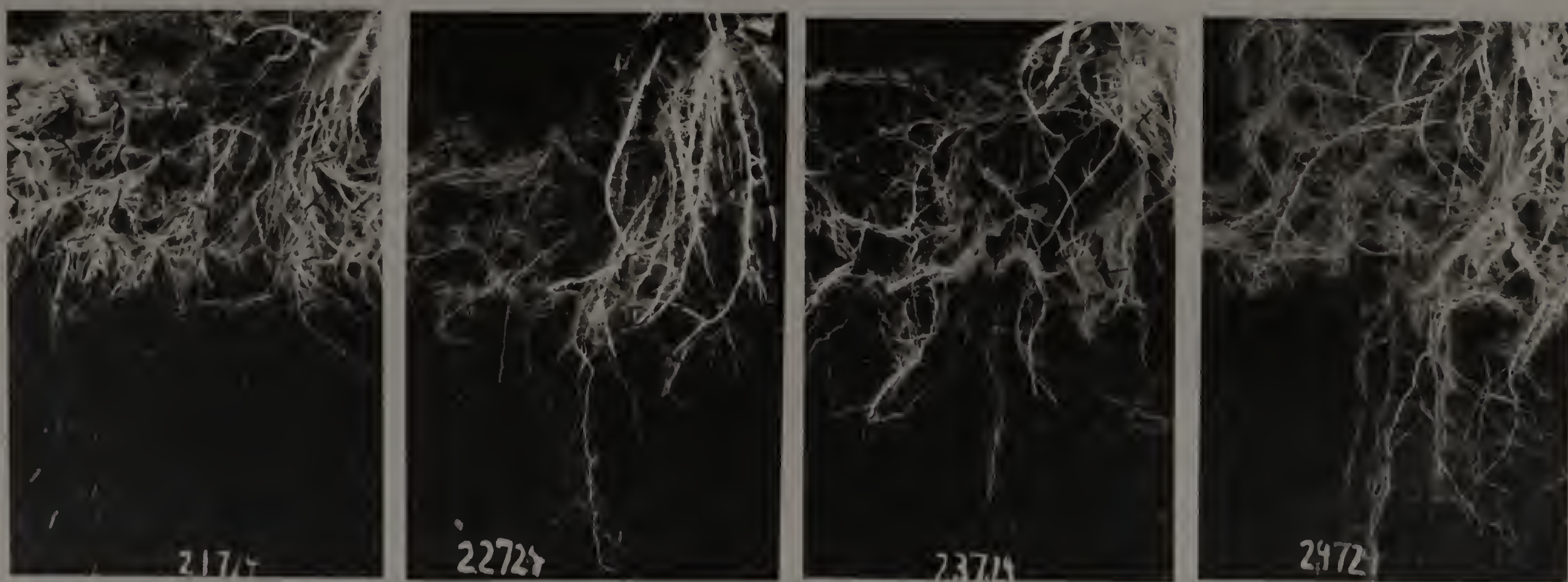
52 DAYS AFTER PLANTING



CD MP DD NT

Fig 32. Root development 65 days after planting for tillage treatments (CD), moldboard plow (MP), double disk (DD) and no-till (NT). Pinboard samples were taken perpendicular to the row.

65 DAYS AFTER PLANTING



CD MP DD NT

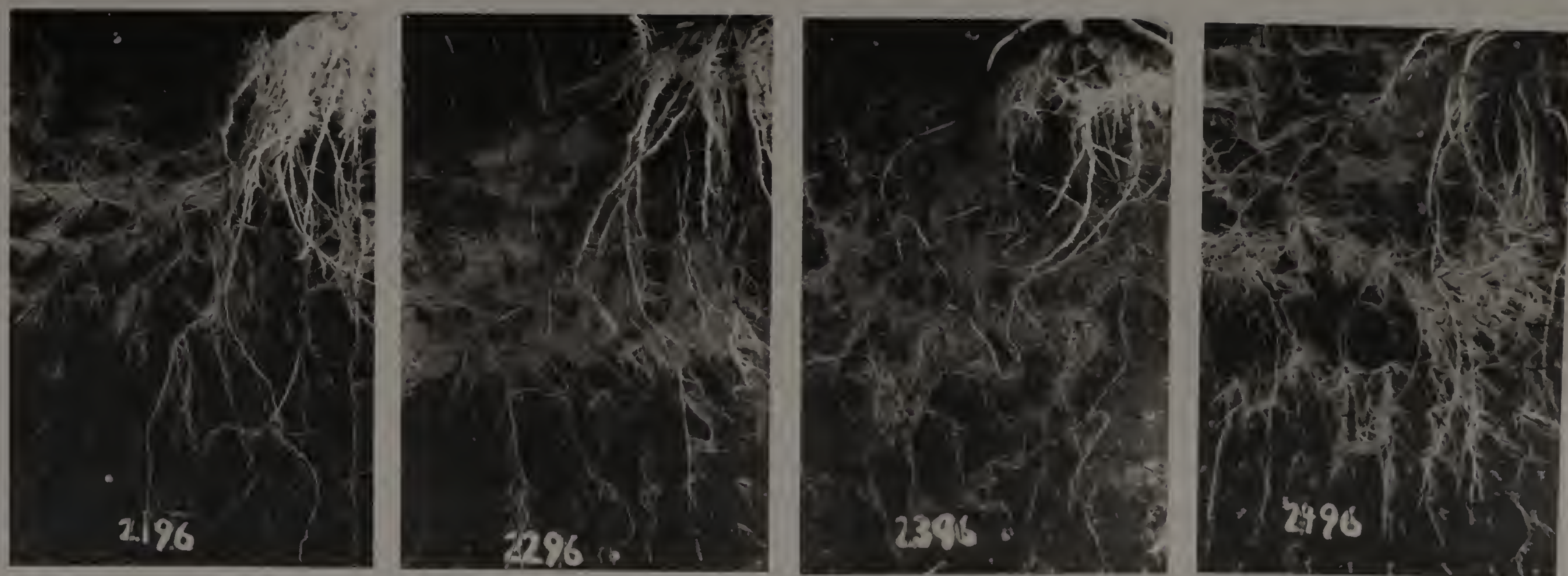
Fig 33. Root development 95 days after planting for tillage treatments (CD), moldboard plow (MP), double disk (DD) and no-till (NT). Pinboard samples were taken perpendicular to the row.

95 DAYS AFTER PLANTING

CD MP DD NT

Fig 34. Root development 112 days after planting for tillage treatments (CD), moldboard plow (MP), double disk (DD) and no-till (NT). Pinboard samples were taken perpendicular to the row.

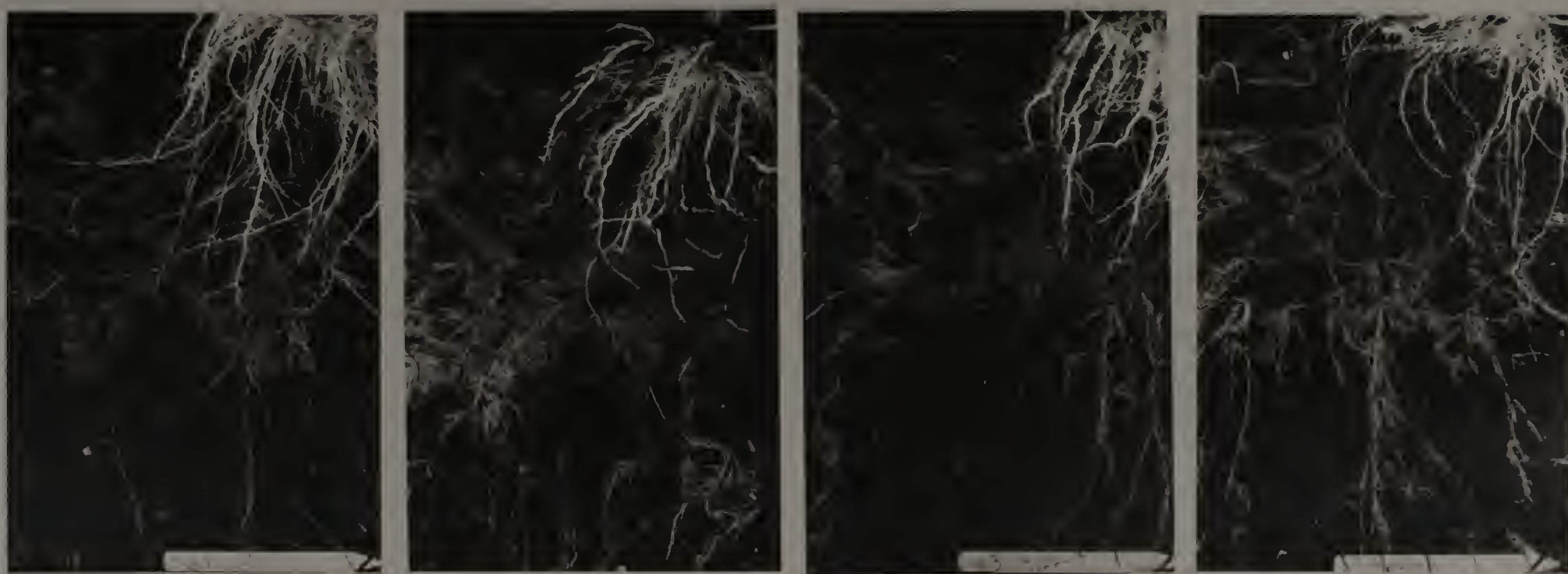
112 DAYS AFTER PLANTING



CD MP DD NT

Fig 35. Root development 125 days after planting for tillage treatments (CD), moldboard plow (MP), double disk (DD) and no-till (NT). Pinboard samples were taken perpendicular to the row.

125 DAYS AFTER PLANTING



CD MP DD NT