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TILLAGE MODIFICATIONS OF ROOT AND SHOOT GROWTH RESPONSES TO SOIL WATER CONTENT AND NITROGEN CONCENTRATION ALTERED BY SEASONS

By

Bihu Huang

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Abstract

TILLAGE MODIFICATIONS OF ROOT AND SHOOT GROWTH RESPONSES TO SOIL WATER CONTENT AND NITROGEN CONCENTRATION ALTERED BY GROWING SEASONS

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Bihu Huang

Conventional and no tillage modifications of soil water contents and their subsequent effects on crop growth are uncertain. This study was designed to quantify the soil water content under conventional tillage (CT) and no-tillage (NT) treatment systems associated with nitrogen patterns in solution through two growing seasons. Maize root and shoot responses to tillage-modified soil water contents were quantified in field experiments conducted on a Kalamazoo loam soil (fine loamy, mixed, mesic, Typic Hapludalf) at the Kellogg Biological Station in Michigan for 1991 and 1992. This replicated study consisted of conventional moldboard plus secondary tillage and no-tillage treatments which were fertilized with 143 kg N ha^{-1} .

Conventional tillage resulted in significantly lower soil water contents in 1991. Lower soil water contents limited plant uptake of nitrogen, the growth rate and accumulation of dry matter under CT conditions, resulting in significant reductions in grain yield. The grain yield of NT was 43% higher than that of the CT treatment in 1991. Significantly greater soil water contents for both tillage

treatments in 1992 caused greater nitrate leaching, especially in the wetter NT treatments. Total recovery of nitrogen in plant shoot tissue and in the root zone portion of the soil profile was 88% in CT treatment and 59% in NT treatment during the period from 40-130 DAP, in 1992. Root growth in the no-tillage treatments was 73% and 100% greater than the CT treatments for both years. Soil water content dramatically influenced root dynamics, defined as the net accumulation of roots within the soil profiles. The greatest changes and contrasts in root growth and/or death rates occurred between CT and NT treatments during periods when soil water contents were low for both years.

Errors in predicted grain yields by CERES-Maize model were adjusted by reducing the precipitation which simulated surface runoff, reducing the amount of precipitation entering the root zone. Adjusted precipitation greatly improved the prediction of maize yields in 1991, suggesting that soil water content may have been the primary factor influencing yields in 1991.

Results of this study suggest that conventional tillage limits the grain yields of maize, especially during years when soil water content limited plant growth. Nitrate leaching from NT soils are greater during years when soil water contents were high. This tillage by soil water content interaction results in greater potentials for nitrate losses from soils receiving no tillage. Greater NO_3 leaching from the root zone of wet NT soils creates a management dilemma which could be alleviated by additional studies designed to investigate plant root-mediated intervention of leaching from the root zone.

To Baihe and Yehua,
my dear husband and my lovely daughter.

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TABLE OF CONTENT

LIST OF TABLES

Page

LIST OF FIGURES

Page

Chapter I

TILLAGE AND ITS EFFECTS

"Of the two environments in which plants grow, soil is much more complex than air. This is true whether they are each considered from the physical, chemical or biological viewpoint. Soil not only affects the development and activities of roots directly, but also, by modifying the function of roots, affects the growth and yield of the above-ground parts . . . to a large degree, soil is a product of both climate and vegetation."

Weaver (1926)

INTRODUCTION

The study of soil tillage, developed much later than other scientific studies (eg., soil fertility and crop nutrition), has contributed significantly to the sustainability of modern agriculture. The study of different tillage systems provides scientists with a better understanding of soil as an open, non-equilibrium system in which any input of energy or material will alter the output. The development of conventional and conservation tillage practices offer better opportunities to understand changes which occur in the physical and chemical properties due to mechanical manipulations of soil. Although there are publications addressing tillage or no-tillage effects on root and shoot growth of crops, there is little information showing the dynamics of the changes through seasons due to the changes of soil water which is influenced by the interaction of weather conditions and tillage manipulations. The changes in soil water condition will alter or even reverse the effects of tillage or no-tillage on crop growth. This study was designed to quantify the soil water content under conventional tillage and no-tillage system in different climatic years as associated with solution nitrogen patterns; and to quantify the dynamics of root and shoot growth under the modifications of soil water contents. The following questions will be answered:

How tillage effects on corn growth, change with seasons:

Is the weather condition an important factor for input?

Do soil water dynamics havel influence critically on corn responses to tillage?

The flow chart (Figure 1.1) is the main structure of this dissertation. The main points will be described or discussed in the following chapters.

In this chapter, a definition of tillage will be proposed; the effects of tillage on the changes of soil properties and the effect of modified soil environmental conditions on the growth of crops will be reviewed; and the general concept of modeling and CERES-Maize model will be discussed.

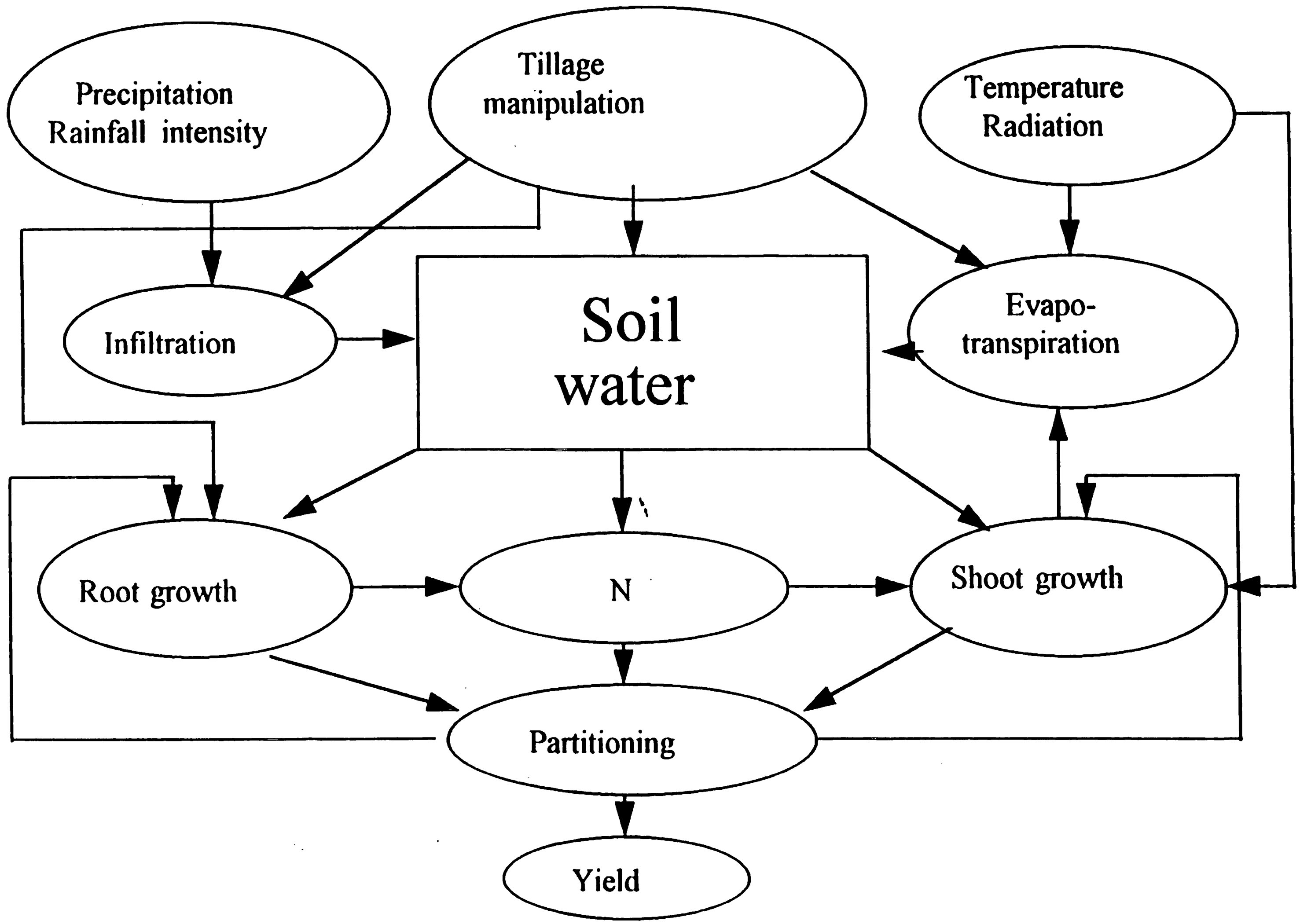


Figure 1.1. The relationships between tillage modifications of soil water content and crop growth.

DEFINITION OF TILLAGE

Lal (1977) defined tillage as physical, chemical or biological soil manipulation used to optimize conditions for seed germination, emergence and seedling establishment. Since tillage loosens, granulates, crushes or compacts soil aggregates, soil factors which influence plant growth such as bulk density, pore size distribution and the composition of the soil atmosphere are affected (Ohiri and Ezumah, 1990). In brief, the effects of tillage on soil conditions are multifaceted and are reflected in some combination of soil physical properties including texture, structure, permeability, and consistency, and are modified by chemical and biological processes depending on how the soils are managed.

When the risks of energy loss, erosion and pollution became serious problems, conservation tillage was developed. Benefits of conservation tillage were seen long before the production disadvantages were removed. The conservation-tillage-planting system, is a system in which crop residues are retained on or near the surface and/or soil surface roughness is maintained in an attempt to control soil erosion and achieve good soil-water relations (Mannering and Fenster, 1983: Allmaras et al., 1985).

According to the Conservation Tillage Information Center (1983), conservation tillage is broadly defined as any tillage or plant system that reduces soil erosion by maintaining surface residue which covers at least 30% of the soil at the time of planting. Any tillage system that does not meet the minimum residue-cover requirement is considered a form of conventional tillage.

Conservation tillage, for this study, is designated as no-tillage of the soil which had been historically tilled. Conventional tillage is designated as moldboard tillage to 20 cm, followed by surface leveling with a chisel tool. The conservation tillage system leaves plant residue on the soil surface at all times, reducing soil erosion, the use of fossile fuels, and conserving both soil and water resources.

THE AFFECTS OF TILLAGE TO SOIL PROPERTIES

Theory

Tillage alters both the physical and chemical properties of soil which in turn alters root growth and consequently; the above ground growth and yield. The modifications of soil properties included soil bulk density, total porosity, the distribution of macro and microporosity and saturated hydraulic conductivity.

When soil is tilled, a vertical pressure (6_z) which is produced by a concentrated load (F) which responds to loading forces. At any point within the soil body the vertical pressure can be calculated by the following equation:

$$6_z=3F_z^3/2\pi(r^2+z^2)^{5/2},$$

where z is depth, r is horizontal distance from the axis of the load (Hillel, 1982).

These pressures result in the rearrangement of soil particles resulting in volume changes of the three physical phases of the soil air (Va), water (Vw) and soil (Vs). On the other hand, when soil is plowed, the Va, Vw and Vs fractions change due to some macropore production and further breakage of soil aggregates. Since tillage alters the soil water retention by changing the distribution of soil porosity, a question should be presented: Would the quantity of available water remain the same even when the soil water content is changed by different tillage practices? To calculate soil water availability, soil water potential, is typically used to predict the amount of water available to plants.

The soil matric water potential (Ψ_m) is related to soil water content and soil texture by the following equation (Campbell, 1985):

$$\Psi_m=\Psi_e(\theta/\theta_s)^{-b}$$

Ψ_m is the soil matrix water potential, Ψ_e is the air entry water potential (potential at which the largest water filled pores just drain), θ is volumetric soil water content at any time, and the θ_s is volumetric soil water content at the saturated condition. The value b is determined by the slope of $\ln\Psi_m$ vs $\ln\theta$.

By fitting this equation to data presented by Hall et al. (1977) and Bache et al. (1981), the following approximate relationship of bulk density of 1.3 Mg m^{-3} can be deduced:

$$\Psi_{es}=-0.5\ dg^{-1/2}$$

$$b= -2\Psi_e+0.2\delta g$$

where dg is the geometric particle diameter and Ψ_{es} is air entry water potential of a standard bulk density of 1.3 Mg m^{-3}.

In order to predict the effects of tillage or compaction on hydraulic properties, the effects of density on water retention (an empirical correction) are considered (Campbell, 1985). This approach agrees with data provided by Hall et al. (1977):

$$\Psi_e=\Psi_e(Pb/1.3)^{0.67\ b}$$

From this equation, soil available water can be calculated numerically and compared to the effect of tillage on soil water retention.

Different tillage practices supply soil scientists with an opportunity to better understand of the rates of solute movement within soils and the effects of soil modifications on these rates. Knowing the loss rates of various solutes carried in water, moving out of the soil, assists in forming more accurate nutrient budgets and increases the understanding of nutrient cycling. There is also interest in knowing the amount and concentration of fertilizer nutrient below the root zone in order to design and minimize fertilizer losses. These varied practices facilitate the understanding of environmental pollution, such as nitrates, pesticides, heavy metals, viruses, radioactive materials, and other toxic compounds.

Chemical species dissolved in water are transported with water according to the following equation:

$$Pb(\delta s/\delta t)=(\delta c/\delta z)\Sigma f_{wi}$$

where c is solute concentration in the soil solution in kg/kg, s is solute present per unit mass of soil, z is soil depth expressed in m, Pb is bulk density expressed in kg/m^3, t is time in second, and $f_{wi}=-K_i\delta\psi/\delta z$, K_i is a function of both pore size and the number of pores in the pore size class, and f_{wi} is the water flux density per pore.

<u>Review of soil properties affected by tillage</u>

Increased bulk density in no-tillage treatments has been reported for different soils and climatic conditions (Carter, 1988; Gantzer and Blanke, 1978; Hill and Cruse, 1985; Triplett et al., 1968; Voorhees, 1987). Although some reports (Mannering and Fenster, 1983) indicate that when bulk density was measured two to three weeks after planting of row crops, it was slightly higher in the tilled system, while NT had much higher bulk densities. Blevins et al. (1983) cite two studies where NT increased bulk density over chisel plowing or moldboard plowing. Bulk densities in never tilled soil are consistently lowest in the surface 7.6 cm of soil, conventional soil was intermediate and no-till was the highest (Reinert, 1990).

However, quite a few papers reported no significant tillage-related difference in bulk density. Working with a Chalmers silt clay loam, Costamgna et al., (1982) compared fall moldboard plowing, spring field cultivating and spring disking for corn production and found no significant tillage-related differences in bulk density to a depth of 25 cm. There were no differences between June and August samplings within any of the three tillage system. Blevins et al. (1983) found no significant difference in bulk density between NT and CT after 10 years of study on a Manury silt loam (0-7.5 cm, 7.5-15 cm). They also measured no difference on a Johnson silt loam in western Kentucky (0-7.5 cm). Hill and Cruse (1985) found no significant effect of tillage on bulk density on two Iowa Mollisols: A Canisteo clay loam and a Nicollet loam.

No-tillage (NT) had the lowest total porosity, the least variation and a slightly downward trend in total porosity over the duration of Reinert's (1990) study on a Kalamazoo loam soil at Kellogg Biological Station (KBS). Never-tilled (NeT) had the highest total porosity and conventional tilled (CvT) was intermediate in the 0-7.6 cm depth with a reversal to bulk density between 7.6-15.2 cm. He also found NeT had the highest macroporosity (0-7.6 cm). No differences of macroporosity between NT and CvT was reported.

Some studies have found a decrease in porosity in the size range of 50-500 microns in the range from -60 to -600 KPa of matrix potential in no-tilled soil versus a moldboard plowed soil (Douglas et al., 1980). Others have found increasing porosity in this size range primarily due to invertebrate activity.

However, the temporal variation in soil physical properties induced by tillage was cyclic and appeared to be controlled by the variation in macroporosity. As a consequence of temporal variation, statistical significance of differences between tillage systems were time dependent, an important consideration in the interpretation of soil measurements in tillage experiments (Reinert, 1990).

AFFECTS OF MODIFIED SOIL PROPERTIES

Soil water content

Modified soil properties had been reported to be the main effect of tillage on crop growth, especially the changes of soil water content influenced by tillage practices. Tillage disturbs natural channels that have formed in soil. The increase in porosity when soil is tilled may not result in an increase in infiltration rate because of disruption of vertical continuity of the pores (Kooistra et al., 1984). Tillage disrupted continuity of pores from the surface which decreased the saturated hydraulic conductivity, while no-till soils had macropores throughout the upper 70 cm which increased the saturated hydraulic conductivity (Logsdon et al. 1990). Hydraulic conductivity of undisturbed cores was at least seven times larger than that measured in columns of disturbed soil having the same bulk density (Meek et al., 1992). Volumetric water content has been found to be consistently greater in soils maintained under a conservation tillage system than under conventional tillage systems (Lindstrom et al.,1984; Toller et al., 1984; Negi et al., 1981; Gantzer and Blanke, 1978; Pidgeon and Soane, 1977). Blevins et al., (1971) attributed this increased water throughout a period of three growing seasons to reduced evaporation and the greater ability to store water under no-till, resulting in a greater water reserve. This agrees with the work of Larson et al. (1978), who reported that as a soil began to dry, the mulching effect of surface residues slowed evaporation losses and led to increased water storage over the course of a growing season. A surface mulch in NT corn (with killed rye cover) on a Maury silt loam in Kentucky resulted in greater water use efficiency through an increase in soil shading, infiltration and a decrease in runoff and evaporation (Blevins et al., 1983).

Loss of water due to run off reduced as tillage intensity decreased (Laflen et al., 1978) which could have increased total soil water storage. The increased capability to store water would seemingly be due to a rearrangement of the pore size distribution resulting from the no-tillage method or to residue cover causing less evaporation. Soil water content was greatest early in the growing season under NT versus mold board plowing. The difference was less after canopy closure apparently due to increased plant uptake at that point in the season. Blevins et al. (1983) concluded that NT should help carry a corn crop through short-term droughts. Moreover, the surface residues prevented surface seal in no-till soil which increased the infiltration (Lal, 1978). The difference of the infiltration rate and evaporation rate caused the different water distribution in soil profile. The alteration of soil water content influences soil temperature, soil strength and the availability of nutrients. In turn, affects crop root and shoot growth, and yields.

Root and shoot growth

Previous literature review has shown that soil water and temperature are influenced by tillage practices. Root growth is affected by both soil temperature and water content; therefore, root distribution is significantly different among various tillage systems (Kovar et al., 1992). He reported the significant differences in soil temperature, water content, and root length density between two tillage systems. Root growth and distribution of a plant is primarily governed by its gene which determines the morphology of its root system. Within the genetic constraints, root growth and distribution are governed by the localized soil environment (e.g. nutrient availability and soil water content) as well as by penetration resistance of the soil (Russel, 1977). The assimilates and growth regulators among roots and shoot organs also appear to control root morphology (Kuiper, 1987; Davies and Zhang, 1991).

Tillage alters root growth patterns by the alteration of bulk density. Despite greater bulk densities under minimum tillage, barley (Hordeum Vulgare) and oat

(Avena Sativa L.) root growth increased in the top 0.12 m of the soil (Ehlers et al., 1983; Ellis et al., 1977; Gantzer and Blake, 1978). Barber (1971) found that corn root length density was greatest in the surface 0.1 m of soil in corn rows under minimum tillage despite a total root weight decline due to the increased bulk density. Root growth under minimum tillage appears to be decreased during wet years (Allmaras and Nelson, 1971).

Soil water deficits are known to increase the fraction of assimilates partitioned to root organs (Davies and Zhang 1991). Environmental factors such as soil temperature, anoxia, relative nutrient status of both plants and soil, and structural characteristics can also modify root distribution (Passioura, 1991; Russel 1977).

Anderson (1987) compared corn (Zea mays l.) root morphology and distribution in plots under minimum tillage to those under conventional tillage at N fertilization treatment of 0 to 180 kg N/ha. He reported that conventional tillage significantly increased root dry weight in only one year. Minimum tillage and N fertilization both increased root dry weight in the 0 to 0.7 m layer in 2 of the 3 years, albeit he did not find that tillage significantly affected plant growth or grain yield.

Shoot growth is often more limited than root growth when plants are grown with a restricted rooting volume (Carmi et al., 1983; Masle and Passioura, 1987). A hormonal signal from the stressed roots is postulated to be the primary cause of shoot growth reductions in stressed plants (Davies and Zhang, 1991; Masle and Farquhar, 1988; Masle et al., 1990).

Yields

Many authors' conclusions differ as to whether these differences in soil properties are responsible for the differences in plant growth, yield and fertilizer requirements. In these studies, it was concluded that corn (Zea mays L.) yield, under minimum tillage practices, can be equal to or greater than yields under conventional practices (Wilhelm et al., 1986; Olson and Schoeberl, 1970). Griffith and Mannering (1984) cite work they conducted in Indiana which shows that NT yields were reduced on a poorly drained Runnymede loam but were equal or higher on a well drained Tracy sandy loam. Herbek et al. (1986) investigated moderately well drained silt loam soils in Kentucky. Yield reductions, resulting from tractor tire compaction varied from 100% in a very dry season to 0% in a wetter season. The reduced impact of compaction in the wetter season was associated with reduced levels of soil strength during early root growth and a decreased reliance on stored subsoil water for growth. (Kirkegaard et al., 1992). Pikul et al. (1993) pointed out that there were no consistent differences in yield among four tillage systems, in either green peas or wheat. From a crop production viewpoint, changes in soil properties on these tillage plots were inconsequential. Within years, CT yields were equal to NT when precipitation was abundant; NT yields were greater in dry years.

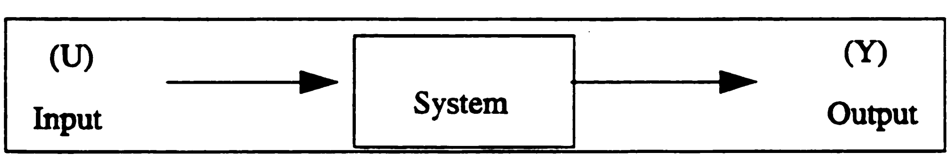
NT corn yields, average 3 years, were greater than for conventional tillage when the planting date was mid May or later; yields were comparable when corn was planted in late April or early May, which was due to the lower temperature in NT soils (Herbek et al., 1986).

MODELING

General concepts

Simulation models are useful tools for investigating questions which are difficult to examine via field studies, for designing better field experiments, and for gaining insight into how the parts of a complex system interact. Simulation models provide a method whereby a complicated system can be represented in a comprehensible manner.

Given systems are a function of the inputs and designed outputs:



Mathematically, $Y = S [U]$

Under a certain system (S), given the inputs (U), and we can expect the output (Y).

To simulate a system, usually requires ingenuity, a deep knowledge of the particular subject being studied, and knowledge of the general physical and chemical laws, and associated biological phenomena. There are two ways of constructing a simulation model. One is experimental modeling which is the selection of mathematical relationships that seem to fit observed input-output data. Another is analytical modeling which consists of a systematic application of basic physical laws to system components and the interconnection of these components.

Crop model is a principal tool to bring agronomic science into the information age. A model helps scientists better understand the mechanisms and assists in the answering of questions related to sustainable agriculture, especially the non-monetary issues related to environmental degration. It also provides an efficient transfer of scientific knowledge into a form relevant to solving particular problems. Because weather, climate, soils, management and plant characteristics all interact to determine crop yield, a modelling approach is to assist in the prediction of yield and identify seasonal conditions under which yield reduction are likely to be most severe.

CERES-Maize model

CERES-Maize model is a process-oriented, management-level crop model. It was developed by an international and interdisciplinary team of scientists over a period of years. The CERES-Maize model simulates growth, development and yield, and also simulates soil water and nitrogen balances associated with the growth of maize. The model uses the processes of phasic development or duration of growth phases as related to plant genetics, weather, and other environmental factors; apical development as related to morphogenesis of vegetative and reproductive structures; extension growth of leaves and stems, and senescence of leaves; biomass accumulation and partitioning. The model requires inputs which includes daily weather information; genetic coefficients; soil information; and initial soil water and nitrogen data.

The effects of seasonal condition on plant response make it difficult to predict the yield reduction likely to result from tillage. Evaluation of crop systems through yield models such as CERES provides a quantitative means of integrating the environmental factors.

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Chapter II

TILLAGE EFFECTS ON WATER AND SOLUBLE NITROGEN DISTRIBUTION PATTERNS AS INFLUENCED BY CLIMATE CONDITIONS

INTRODUCTION

Crop responses to tillage treatments are highly variable especially when compared across different years and management systems. These variations mostly result from differences in the availability of soil water which is altered by additions of precipitation or irrigation. Differences in the storage and availability of water within soil profiles resulting from different tillage treatments, modify both above- and below- ground plant components. Precipitation during tillage trials is an important factor to consider when determining which factors influence soil water retention and nitrogen distribution responses to tillage.

Conservation tillage, especially the practice of no-tillage, and associated plant residues reduces pesticide contamination of surface water by significantly reducing soil erosion (Kanwar et al., 1988). However, there is a concern that conservation tillage increases the risk of ground water contamination through the increased numbers of continuant macropores, e.g., worm holes, root holes and/or natural fractures, which develop in the profiles of long-term no-tilled soils (Singh et al., 1991; Kanwar et al., 1990; Everts and Kanwar 1990; Singh and Kanwar, 1991, Kluitenburg and Horton, 1990).

Recent research emphasizes the direct contributions by roots, especially tillage modifications of root distribution, on preferential water flux through the root zone (Gish and Jury, 1983; Jury et al., 1990; Smucker, 1993; Luxmoore et al., 1991). Root growth rates, accumulations, and death can be significantly altered by tillage systems which lead to contrasting soil water regimes within the soil profile (Kovar et al. 1992). The effects of tillage practices on the infiltration, retention, and deep drainage of water differ with varying amounts of applied irrigation, altering soil water contents within the soil profile (Newell and Wilhelm 1987).

Influences of tillage and no-tillage on soil water flux have been emphasized, yet these approaches did not address tillage effects on the dynamics of soil water contents caused by climatic changes. Objectives of this study were to characterize the effects of tillage on soil water and associated soluble nitrogen distribution patterns as influenced by different precipitation patterns and air temperature regime.

MATERIALS AND METHODS

Experimental design and crop culture:

A two-year field study was conducted in a Kalamazoo loam soil at Kellogg Biological Station, Michigan, 1991 and 1992. This experiment consisted of a randomized block experimental design having primary treatments of conventional moldboard plowing (23 cm) and secondary tillage (CT) and no-tillage (NT) which were replicated four times. Tillage treatments of this study were initially established on an agricultural field in 1986, and corn was grown from 1986 to 1989. Then soybean was grown in 1990. Eight plots, 27 X 40 m, were randomly distributed within a larger experimental design (Figure 2.1) across a gently rolling and stratified Kalamazoo loam soil (fine loamy, mixed, mesic Typic Hapludalf). Soil horizons associated with the Kalamazoo loam are a loamy Ap horizon from 0 - 0.2 m which overlays a clay loam Bt horizon from approximately 0.2 - 0.8 m deep, which is underlain by a coarse glacial outwash parent material. Corn (Zea mays. L.) was planted on May 16, 1991 and May 8, 1992 at a row spacing of 0.76 m, with 0.20 m between plants with a goal of 64,246 plants ha^{-1}. Nitrogen (ammonium nitrate, 34-0-0) was applied at the rate of 432 kg ha^{-1} (147 kg N ha^{-1}), 0.02 m below the seed at the time of planting. The insecticide Difonate was applied at the rate of 11.2 kg ha^{-1} over the row in a granulated form at the time of planting, to control corn root worm in 1992 as there was an infestation of corn root worm in 1991.

Instruments

Time domain reflectrometer

Soil water contents were monitored by the time domain reflectrometer (TDR) method (Topp et al., 1982). Pairs of stainless steel rods (30 x 0.5 cm) were soldered to each wire of the cable and spaced at 5 cm, by resin to form the wave

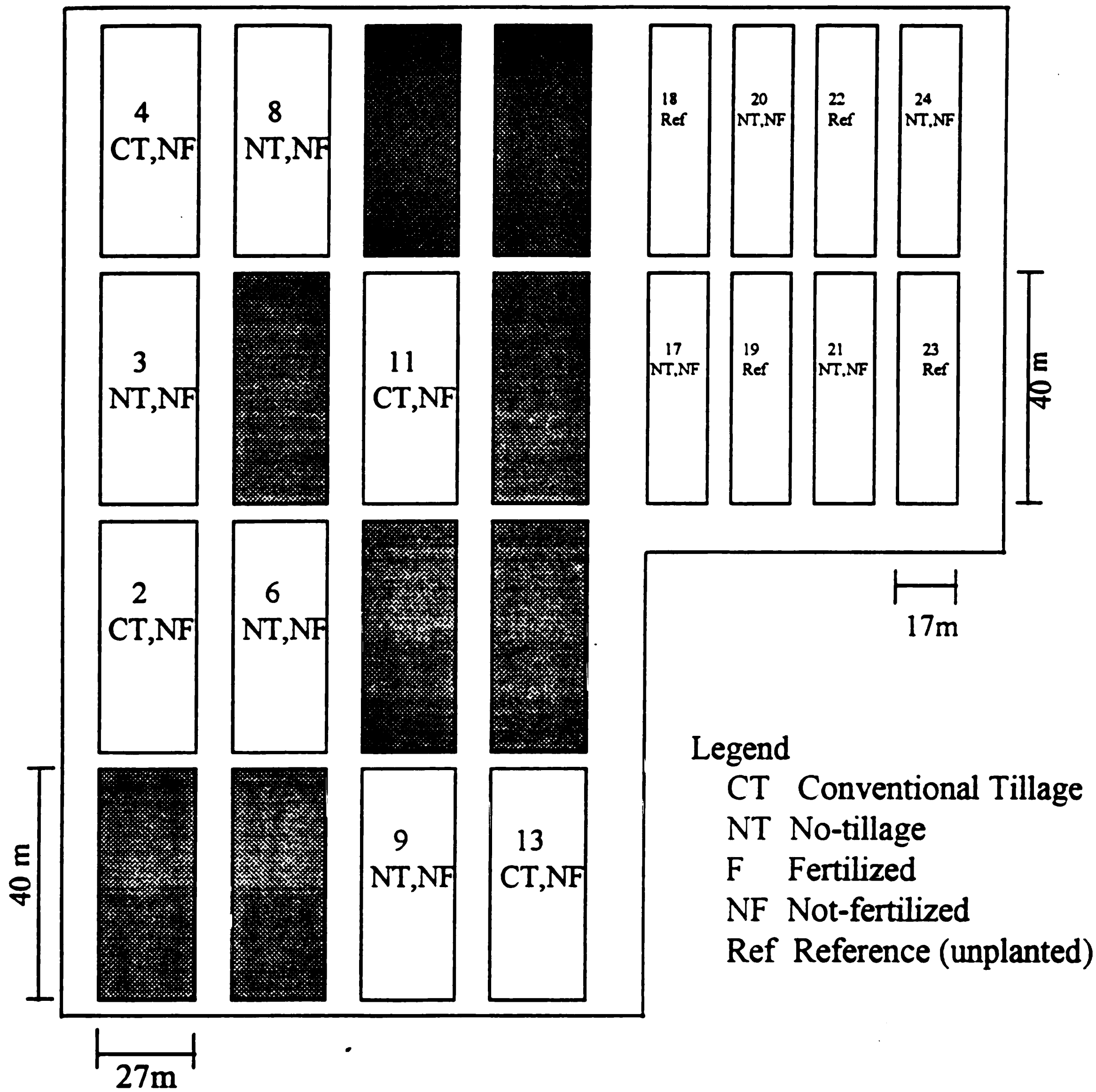


Figure 2.1. Experimental design of the larger agroecosystem interactions project on a Kalamazoo loam soil at KBS. Results from shaded plots are reported.

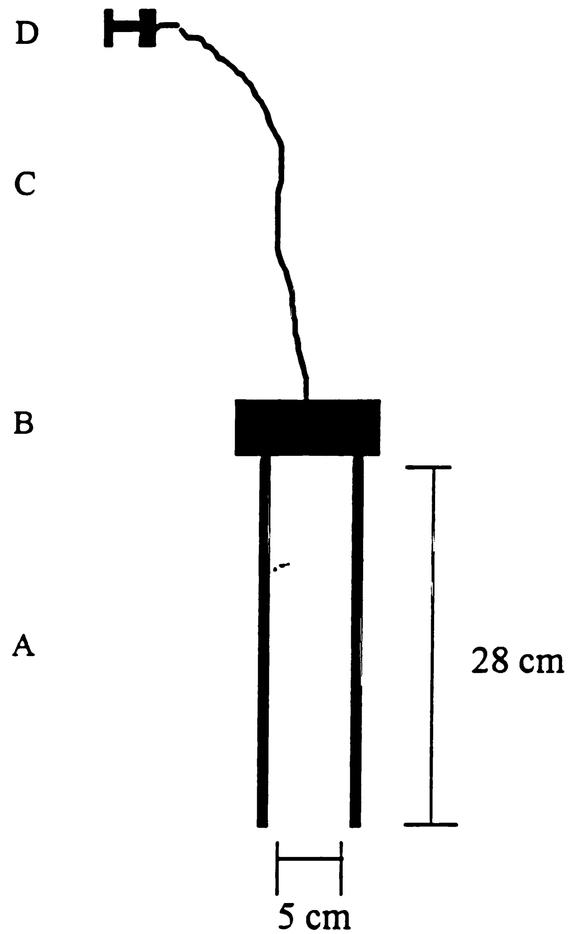


Figure 2.2. The diagram of TDR probe consisting of stainless steel wave guides (A), resin spacer and sealer (B), coaxial access cable (C), and electrical coupler (D).

guides. Wave guides were solder-connected to a coaxial cable. Electrical resin (Electrical Products Division BM St. Paul, MN 55144) was used to stabilize and seal the wave guides and the cable (Figure 2.2). These inexpensive wave guides presented clear graphic waveform displays which were easy to measure by the cable tester (Tektronic, model 1502B, Tektronic Inc. Communication Network Analyzers Division, P.O. Box 1197, Redmond, OR 97756-0227).

TDR wave guides were installed in the field by digging small access holes into the C horizon of each plot. Plastic film was placed along the surfaces of the walls of the access hole and the TDR wave guides were inserted through the plastic to minimize horizontal soil water movement between the bulk soil and the disturbed soil refilled into the access hole. TDR probes were inserted horizontally, at different depths, into soil region of the Ap, Bt, 2Bt, and C horizons (Figure 2.3).

Soil volume water contents were calculated by using the Topp equation (Topp et al., 1982):

$$\theta_v=[-5.3*10^{-2}+(2.92*10^{-2}*K_a)-(5.5*10^{-4}*K_a^2)+(4.3*10^{-6}*K_a^3)]*100.$$

where

K_a is the apparent dielectric constant and $K_a = (ct/L)^2$; t is the signal travel time in nanoseconds and $t = (B-A)/(V_p*c)$; c is propagation velocity (Vp) of an electromagnetic wave in free space and c = 30 cm/nsec; Vp = 67% in this study. L=length of the transmission line (0.28 m), which was the length of TDR rod

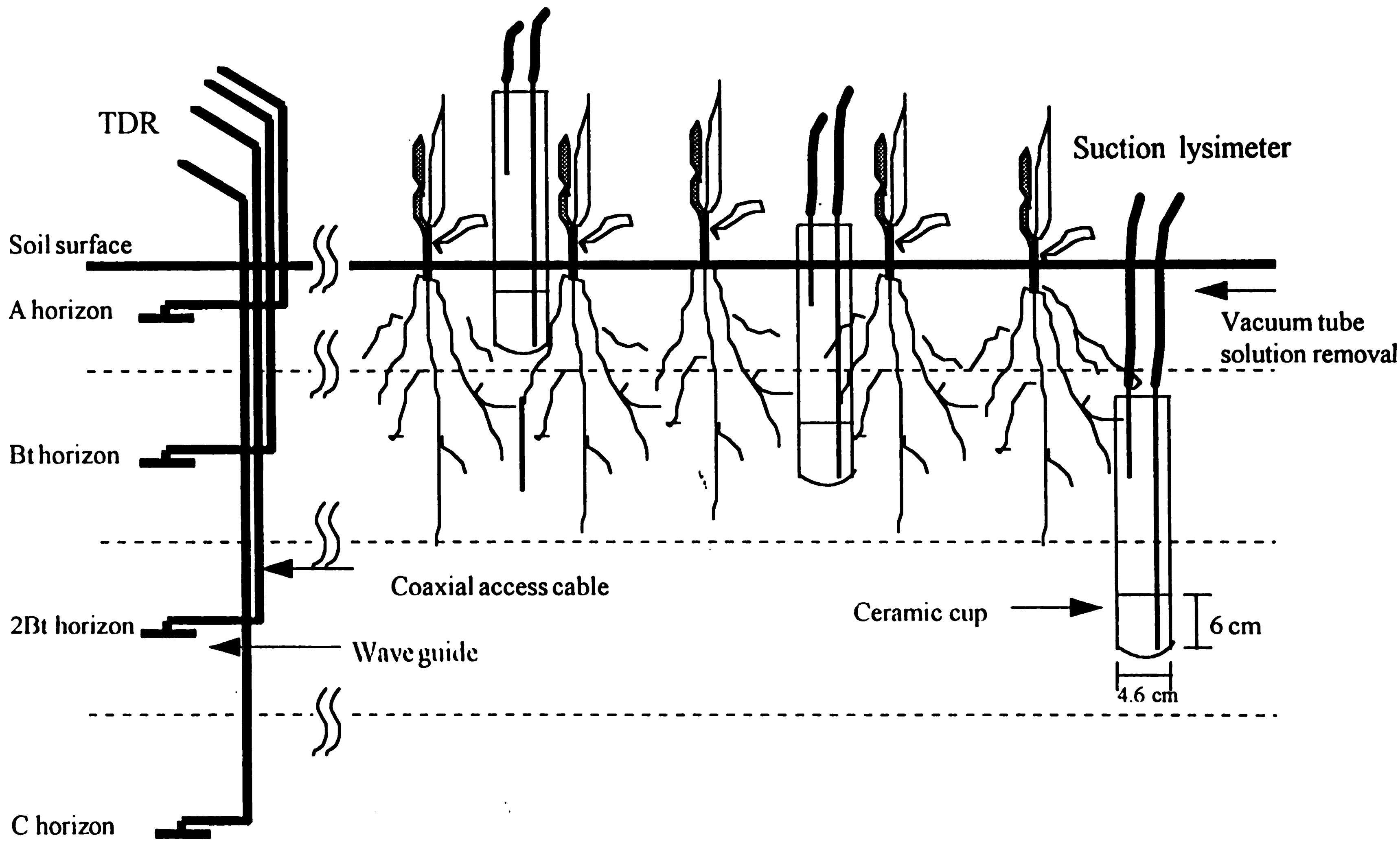


Figure 2.3. Diagrammatic representation of TDR probes and suction lysimeters in the soil horizons directly below the plant rows in the Kalamazoo loam soil at KBS.

inserted into the soil. A = distance in feet between the TDR cable and TDR rod connection joint to the pulse generator (taken as the point before the large negative slope in waveform), B=distance in feet that the reflected pulse is from the pulse generator (taken as the tangent made by the zero and positive slopes traced in the waveform).

Suction lysimeter

Soil solutions within each horizon were measured by suction lysimeters equipped with porous ceramic cups, 0.046 cm in diameter and 0.06 m long (Soil Moisture, PO Box 30025, Santa Barbara, CA 93105). Suction lysimeters were installed midway within the Ap, Bt, and 2Bt horizons the same depth as the TDR wave guides (Figure 2.3). Nitrate and ammonia concentrations of the soil solutions, extracted by the suction lysimeters, were determined by the QuikChem Automated Ion Analyzer (Lachat Instruments, 6645 West Mill Road, Milwaukee, WI 53218-1239).

Non-disturbed field lysimeter

Determination of current and cumulative outflows of water and the corresponding nitrogen concentrations were possible by extensive sampling of TDR and soil solutions within four non-disturbed field lysimeters (Richner et al., 1993) which were located within four research plots, plots 2 and 13 were CT, and plots 6 and 9 were NT, of the field plots. Each lysimeter (Figure 2.4) drained at the base of the soil profile. Continuous drainage emptied into a 58 L collection vessel,

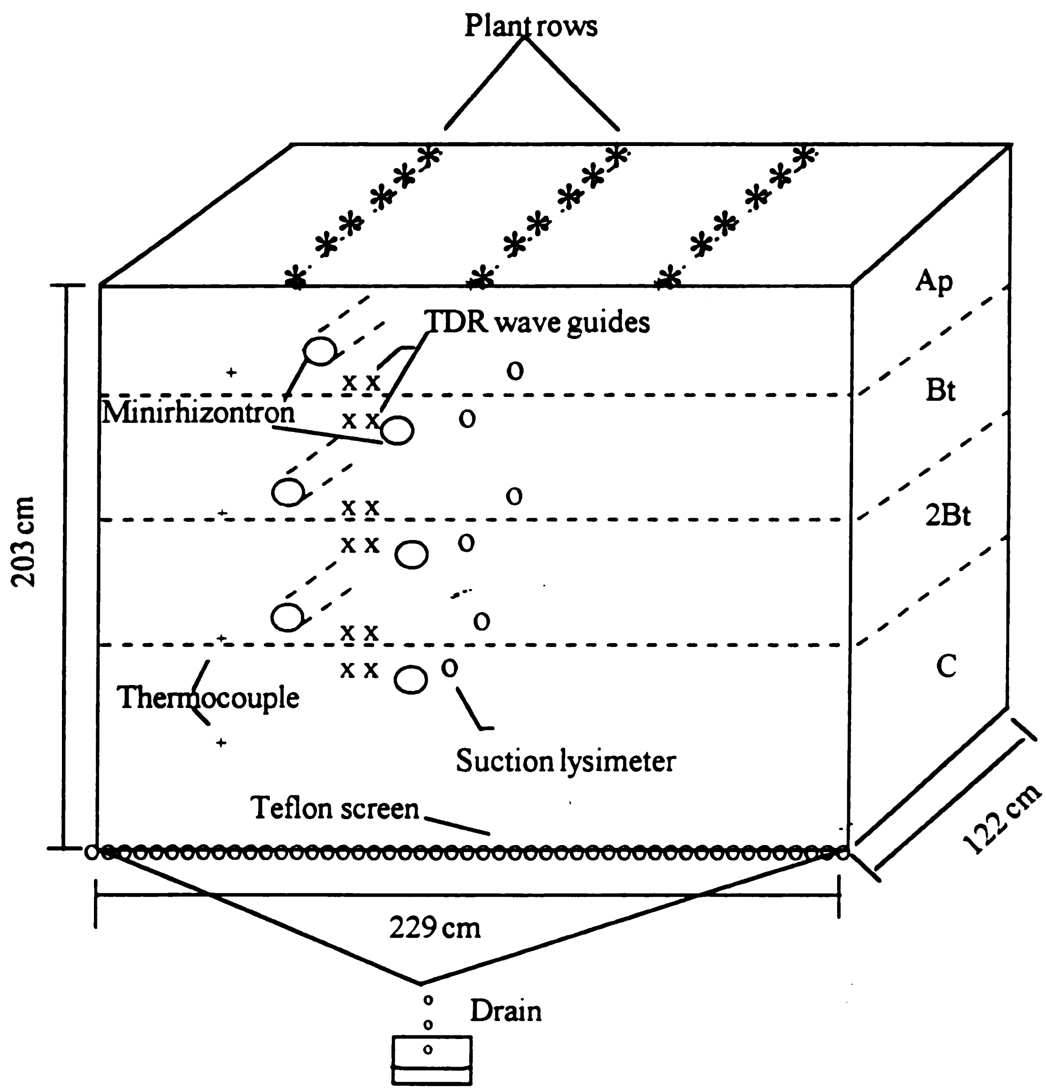


Figure 2.4. Diagram of non-disturbed field lysimeters on a Kalamazoo loam soil at KBS.

which was sampled periodically.

Data collection

Climatic data was collected from the Pond Lab, weather station at Kellogg Biological Station, which was located approximately 1000 m from the study site. Daily weather data included maximum and minimum temperature, solar radiation, and precipitation. The monthly precipitation in 1991 and 1992 were compared to a 30-year average (1951-1980). The cumulative precipitation of each ten days was calculated during the growing season of 1991 and 1992. TDR readings were taken at 7 day intervals. Soil solution samples were taken from suction lysimeter tubes each week by applying a vacuum to the tube one day prior to the collection days of soil solutions. Samples were frozen at -20 C until further chemical analyses. Cumulative water, which flowed through the soil profile, was collected each week from the non-disturbed field lysimeters.

RESULTS

Precipitation and air temperature

The monthly precipitation during the growing season in 1991 was lower than the 30-year average for June and September, and it was higher than the 30-year average for July and August (Table 2.1). Although the amounts of rainfall for July

Table 2.1 Monthly precipitation 30-year average, average monthly temperature, and days of rainfall at KBS for 1991 and 1992.

	1991	1992	30-year	1991	1992	1991	1992
	---- Rainfall ----			Rain days		Temp.	
May	43.2	19.3	78.0	10	9	10.3	6.7
Jun.	22.9	22.4	84.0	6	6	17.9	14.1
Jul.	127.5	140.5	98.0	8	15	21.5	17.0
Aug.	122.6	72.6	74.0	7	9	22.0	19.5
Sep.	44.2	115.1	76.0	11	12	22.0	18.2
Oct.	2.8	54.1	77.0	1[1]	8[1]	15.3	15.5

[1] The data were the total rain days in October 1-20.

and August in 1991 were 30 and 66% greater than the 30-year average, all the precipitation occurred during eight and seven day periods during these two months (Table 2.1). Excessive amounts of rainfall during these few days may have resulted in surface water losses by runoff, especially from the soil surface of CT treatments. The amounts of rainfall in June and September were lower than the 30-year average resulting in lower water supplies to the soil.

Higher air temperature from June - September of 1991 (Table 2.1) may have contributed to greater evapotranspiration rates, resulting in lower soil water contents within the root zone. If the infiltration rates of the large amounts of rainfall were reduced by tillage, then the greater removal of water from the soil profile by higher air temperatures, could have intensified the adverse effects of tillage on soil water contents.

The rainfall in June of 1992 was lower than the 30-year mean (Table 2.1), reducing the supply of water to the soil. The rainfall for July, August and September was equal or higher than average for 30 years and was more uniformly distributed across 15, 9 and 12 day periods, respectively. More uniformly distributed rainfall (Figure 2.5) combined within lower monthly temperatures, 2.57-4.45 degrees C lower than in 1991 (Table 2.1), would be expected to have reduced the evapotranspiration, resulting in high soil water contents for 1992.

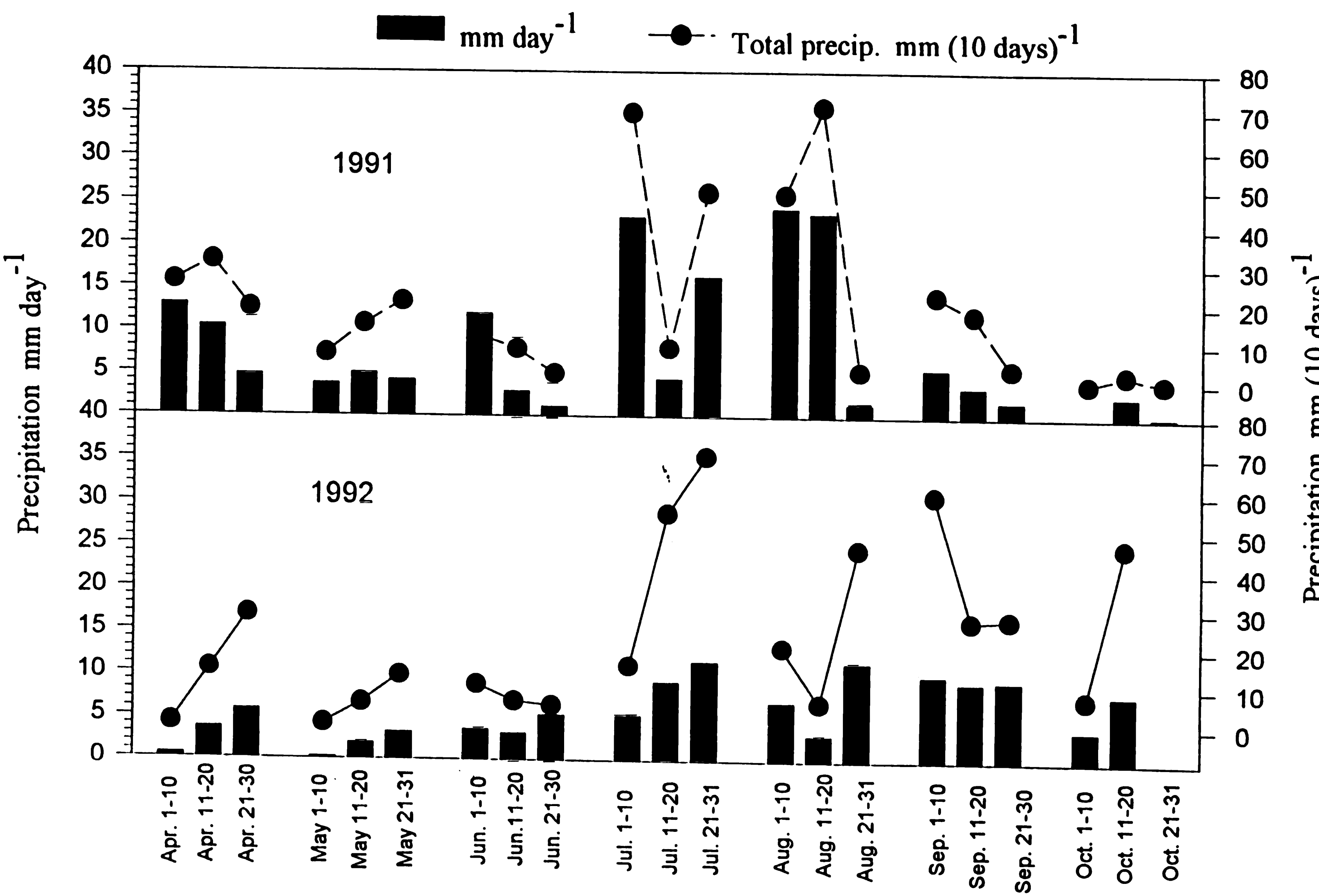


Figure 2.5. Total precipitation for 10-day period and average precipitation (mm) day^{-1} at KBS during the rainfall period in 1991 and 1992.

Soil water content

Volumetric water contents in the horizons of the Kalamazoo loam soil subjected to conventional tillage (CT) and no-tillage (NT) systems were significantly different for the 1991 and 1992 growing seasons (Figures 2.6, 2.7 and Table 2.2). Soil water contents were significantly greater in soils maintained under NT than under CT systems during the growing season in 1991. Following each rainfall, water contents in the Ap soil horizon of CT treatments increased to a range from 12 - 18%. Water contents in the 2Bt horizon fluctuated from 15 to 21% during the growing season. The soil water contents of the C horizon ranged from 3 - 7% which were relatively stable but decreased slightly with the season (Figure 2.6A). Soil water contents of the 2Bt horizon were increased slightly by each rainfall, and the water content in C horizon was influenced very little by rainfall. These soil water contents indicated that there was little to no downward water flux to deeper layers beneath the CT treatment during the growing season of 1991. In contrast, water contents in the Ap soil horizon of NT treatments increased to a range from 22 - 26% following rainfall events. Water contents in the 2Bt horizon fluctuated from 20 to 25%. Small fluctuations, 7 - 11% of soil water contents in the C horizon indicated that some water had moved into and perhaps through the C horizon of the NT soil, following each rainfall (Figure 2.6B).

In 1992, the water contents were higher than that in 1991 after 54 DAP. The soil water contents in Ap horizon ranged from 16 - 27% under CT and 18 - 27%

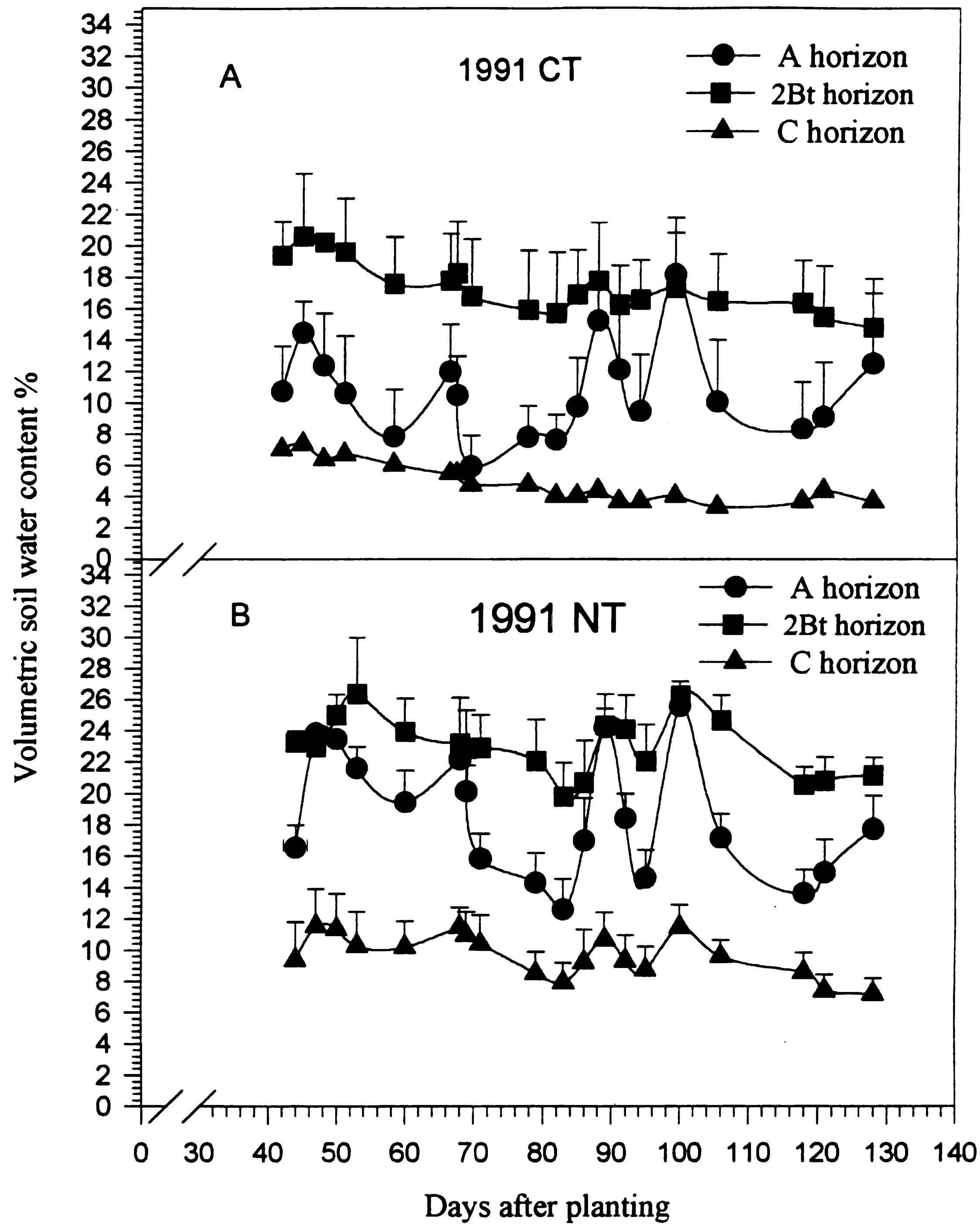


Figure 2.6. Volumetric soil water content (%) in Kalamazoo loam soil under CT (A) and NT (B) treatment in 1991 at KBS.

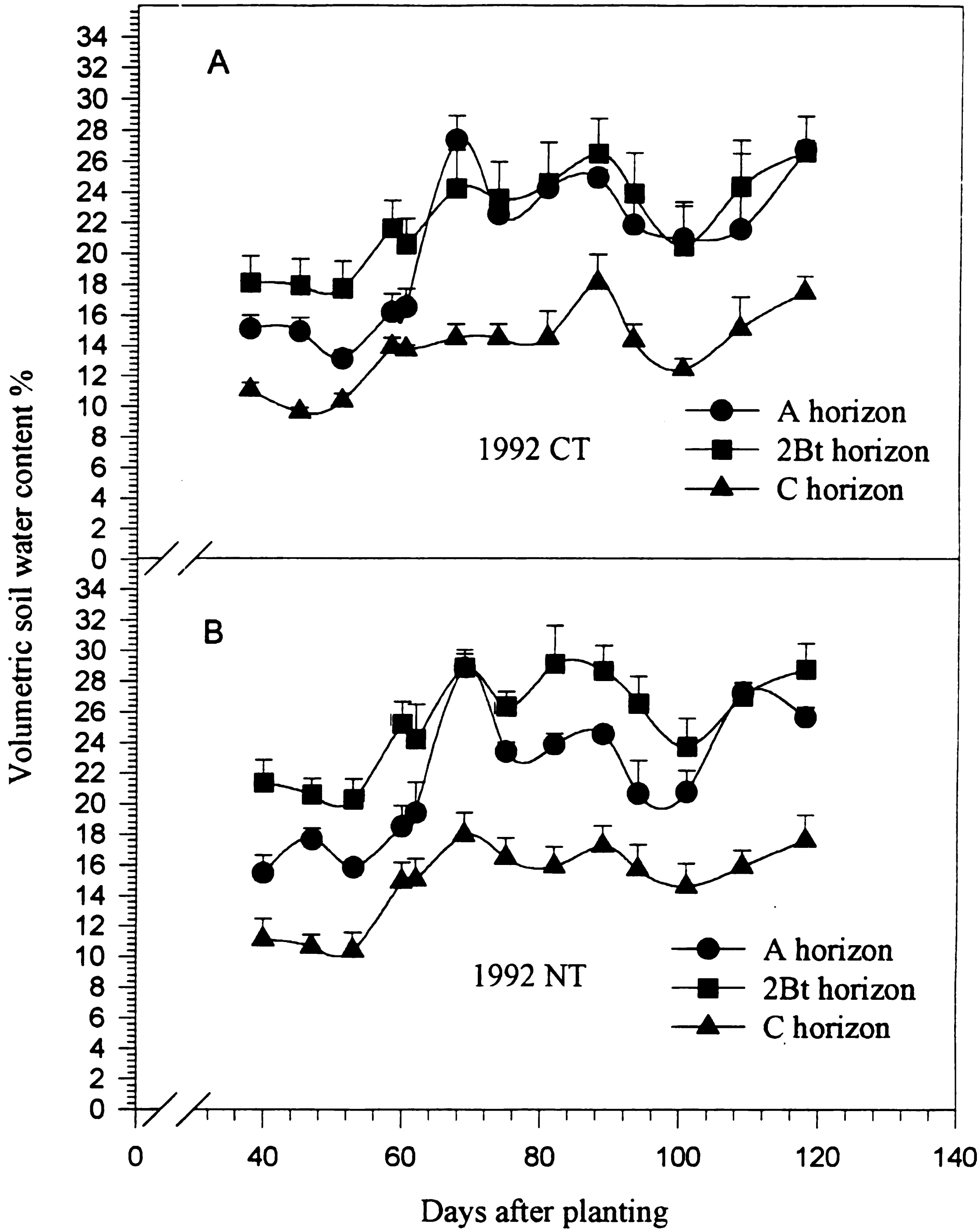


Figure 2.7. Volumetric soil water content (%) in Kalamazoo loam soil under CT (A) and NT (B) treatment in 1992 at KBS.

Table 2.2. P value in analysis of variance for comparison of soil water contents for all dates measured between tillage treatments, within natural horizons in a Kalamazoo loam soil at KBS in 1991 and 1992.

Horizon	1991	1992
	------- P value -------	
Ap	2.1E-10	3.3E-02
2Bt	9.4E-42	7.3E-11
C	4.8E-23	1.1E-03

under NT after 54 DAP (Figure 2.7). The water contents of 2Bt horizon were with a range of 21 - 26% under CT, and 24 - 29% under NT soils. The C horizon maintained a range from 12-18% under CT treatment, and 14-17% under NT treatment.

Water distribution

The soil water content in the Ap horizon of CT plots increased from 11% to 14% following a rainfall (Figure 2.8A). This small increasing was probably because most of the rainfall ran off before it could infiltrate the crusted soil surface. Since little rainfall was accepted by the soil surface, there was insufficient water for movement into successively deeper layers. As a result, there was no net increase in water content in the underlying layers of the CT treatment during a 4-day period following rainfall. Water content continued to decrease, due to root uptake and evaporation at the soil surface.

In contrast, rainfall caused the water content in Ap horizon to increase from 16% to 24% in the NT soil treatment (Figure 2.8B). Water content of the Ap horizon was slightly decreased on the second day of rain, but it increased in Bt horizon. The 2Bt horizon remained unchanged indicating that some water moved down to the 2Bt horizon to compensate for water lost (eg. uptake by roots). Soil water contents remained constant in the C horizon. On the third day, water content in the Ap horizon decreased about 2.5% and increased approximately 3.3% in the

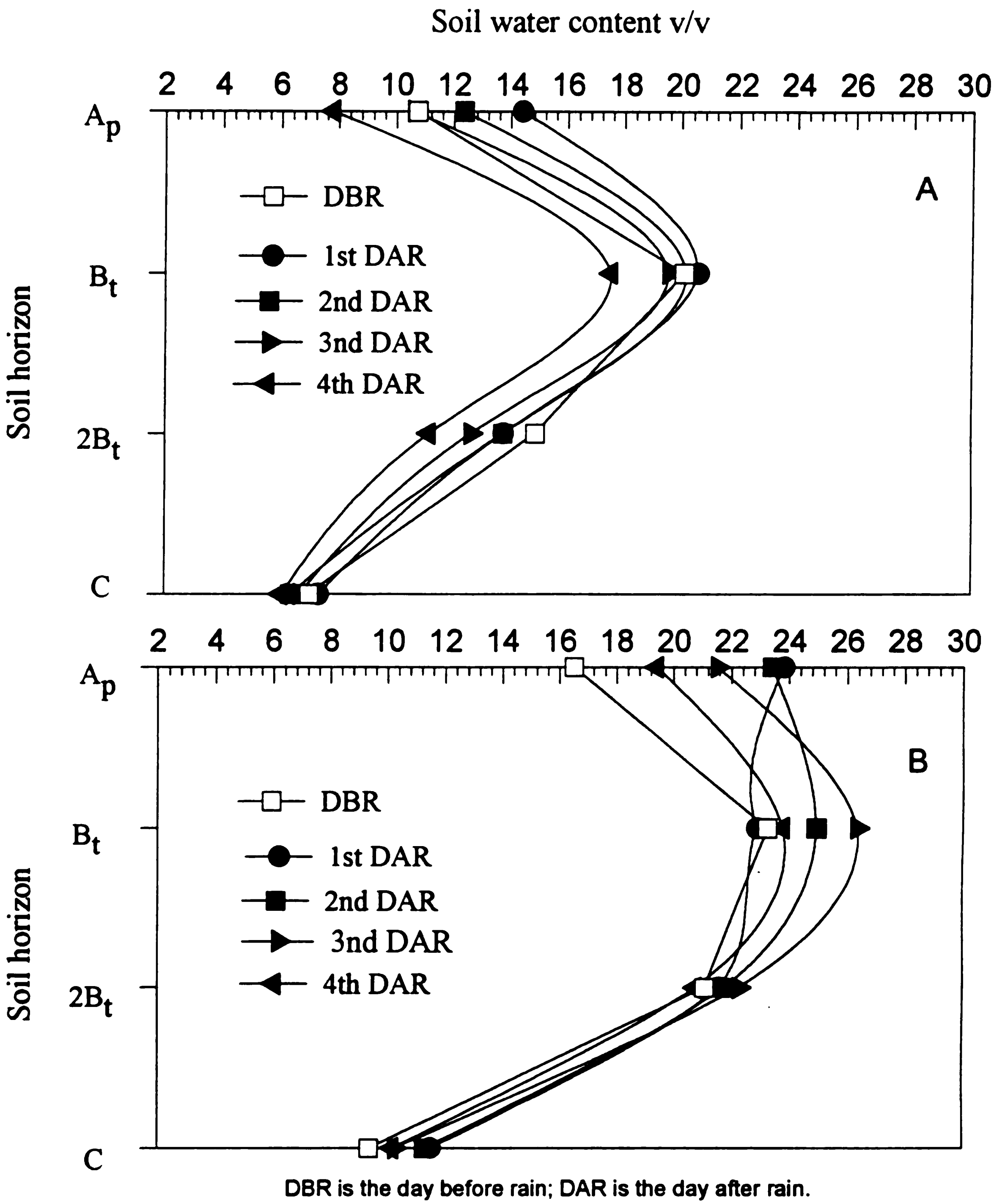


Figure 2.8. Soil water distribution in the profile of a kalamazoo loam soil subjected to CT (A) and NT (B) treatments following a 46 mm rainfall at KBS for the dates of 47-51 DAP, 1991.

Bt horizon. There was little net increase in water content of 2Bt horizon, with only a small decrease in soil water content of C horizon. On the fourth day, water contents in Ap, Bt, and 2Bt horizons deceased further, and remained constant in C horizon, which suggested that these water losses were due to internal soil drainage, evaporation, and root uptake.

Nitrogen distribution

Nitrogen concentrations in soil solution within the soil profile were influenced by soil water contents which, in turn, were altered by soil tillage (Figure 2.9 and 2.10). In 1991, the nitrogen concentrations in soil solutions were very high in the CT soil. Solution N was high because soil water contents were low and little water was extracted by the suction lysimeters at each sampling date. No data was collected from the Ap horizon for the CT treatment, later than 45 DAP, nor at all horizons, later in the season, as the soil was too dry (Figures 2.6 and 2.9A). The concentration of nitrogen under NT soils was less than 100 ug g^{-1} but showed a relatively uniform distribution (Figure 2.9B), since it had a relatively uniform soil water content (Figure 2.7). This contrasts with the 1992 data which showed that the concentration of nitrogen decreased a lot in both CT and NT plots throughout the growing season. The nitrogen concentration in Ap horizon under CT decreased from 170 ug g^{-1} at 40 DAP to 55 ug g^{-1} at 71 DAP, then decreased until the end of the growing season. The Bt and 2Bt horizons displayed the same decreasing trends throughout the season (Figure 2.10A). The concentration of nitrogen in the Ap horizon under NT soil decreased at a rate greater than CT treatment, from 165 ug g^{-1} at 40 DAP to 22 ug g^{-1} at 70 DAP. Concentrations of nitrogen in the Bt and 2Bt horizons also decreased to values of 5 ug g^{-1} or lower for most of the time after 71 DAP (Figure 2.10B).

It is clear that some nitrogen lost from the root zone in 1992. The NO_3-N in Ap horizon was about 25 g m^{-3} at the first measurement, 40 DAP, for both tillage treatments (Figure 2.11). Since there was an increase in soil water contents measured at 68 DAP (Figure 2.7), soil NO-N concentration decreased at 71 DAP for the duration of the growing season (Figure 2.11), suggesting that some NO_3-N was lost by deep leaching. Some of the NO_3-N which lost from the Ap horizon in CT soils accumulated in the Bt horizons at 71 DAP and appeared to move deeper into the 2Bt by 78 DAP. In contrast, the NO_3-N which lost from the Ap horizon of NT soils did not accumulate in any of the deeper soil horizons, as NO_3-N concentrations in the Bt and 2Bt horizons decreased as season progressed. Although NO_3-N concentrations in the Bt and 2Bt horizons of the CT soils also decreased, higher concentrations, however, were maintained during the season, especially in Ap and Bt horizons. Since the total uptake of nitrogen by the plants in the NT plots was less than that in the CT plots during 1992 (Huang and Smucker 1995), suggesting lower NO_3-N losses from the CT soils than that from NT soils. The recovery of N in plant tissue and soil of Ap, Bt, and 2Bt horizons at 128 DAP was

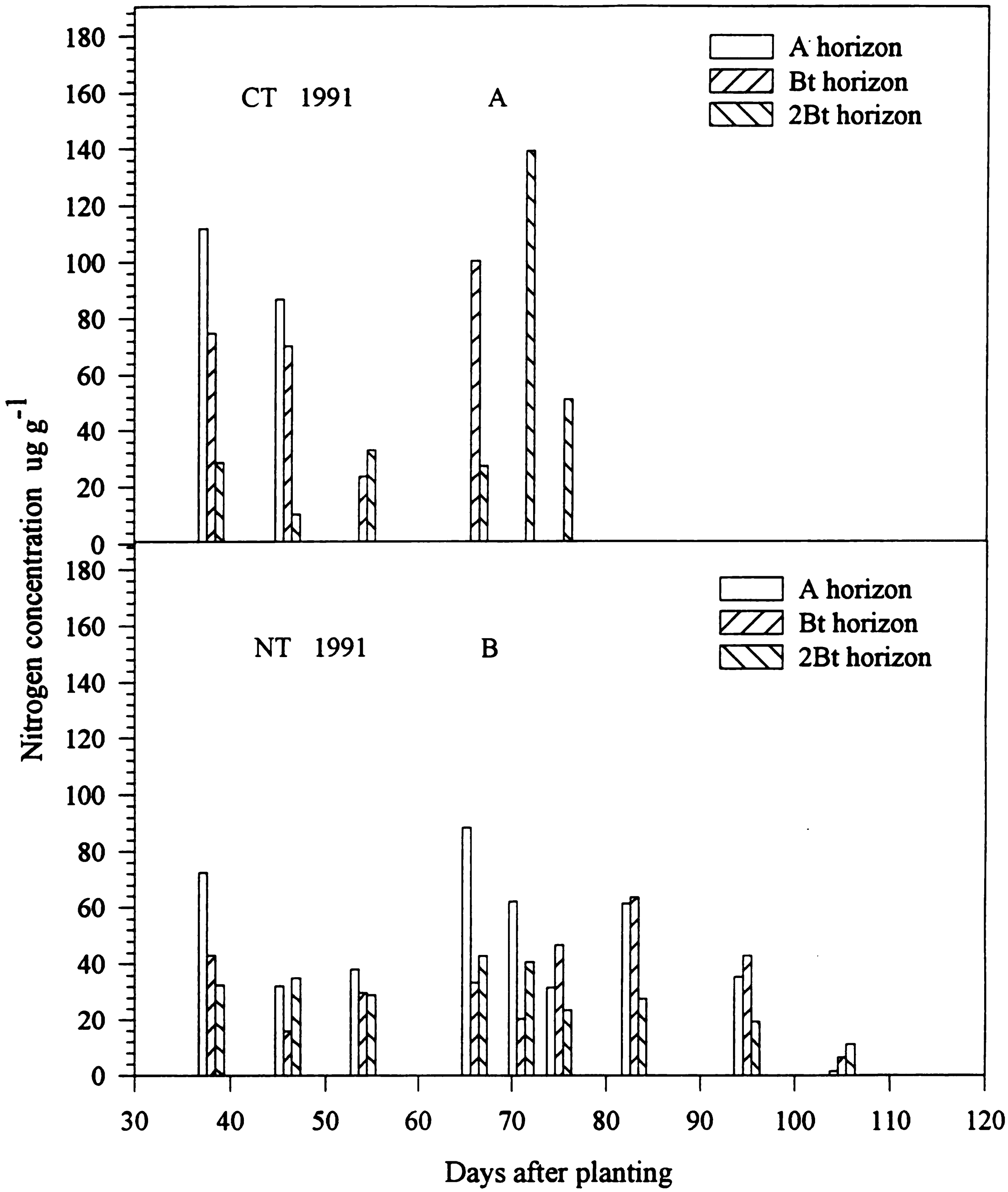


Figure 2.9. NO_3-N and NH_4-N concentrations in soil water for 3 horizons of a Kalamazoo loam soil subjected to CT (A) and NT (B) treatments at KBS, 1991.

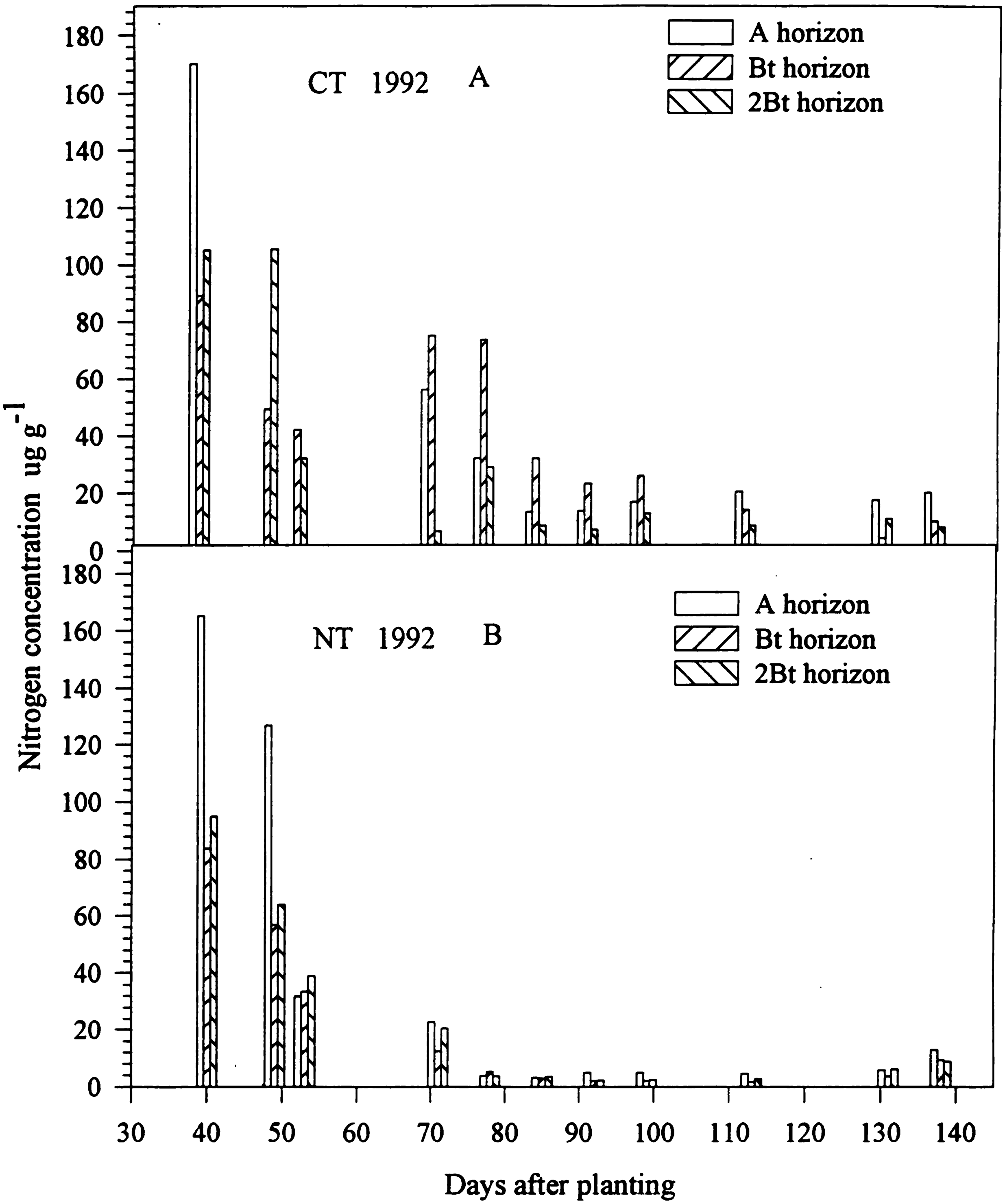


Figure 2.10. NO_3-N and NH_4-N concentration in soil water for 3 horizons of a Kalamazoo loam soil subjected to CT (A) and NT (B) at KBS, 1992.

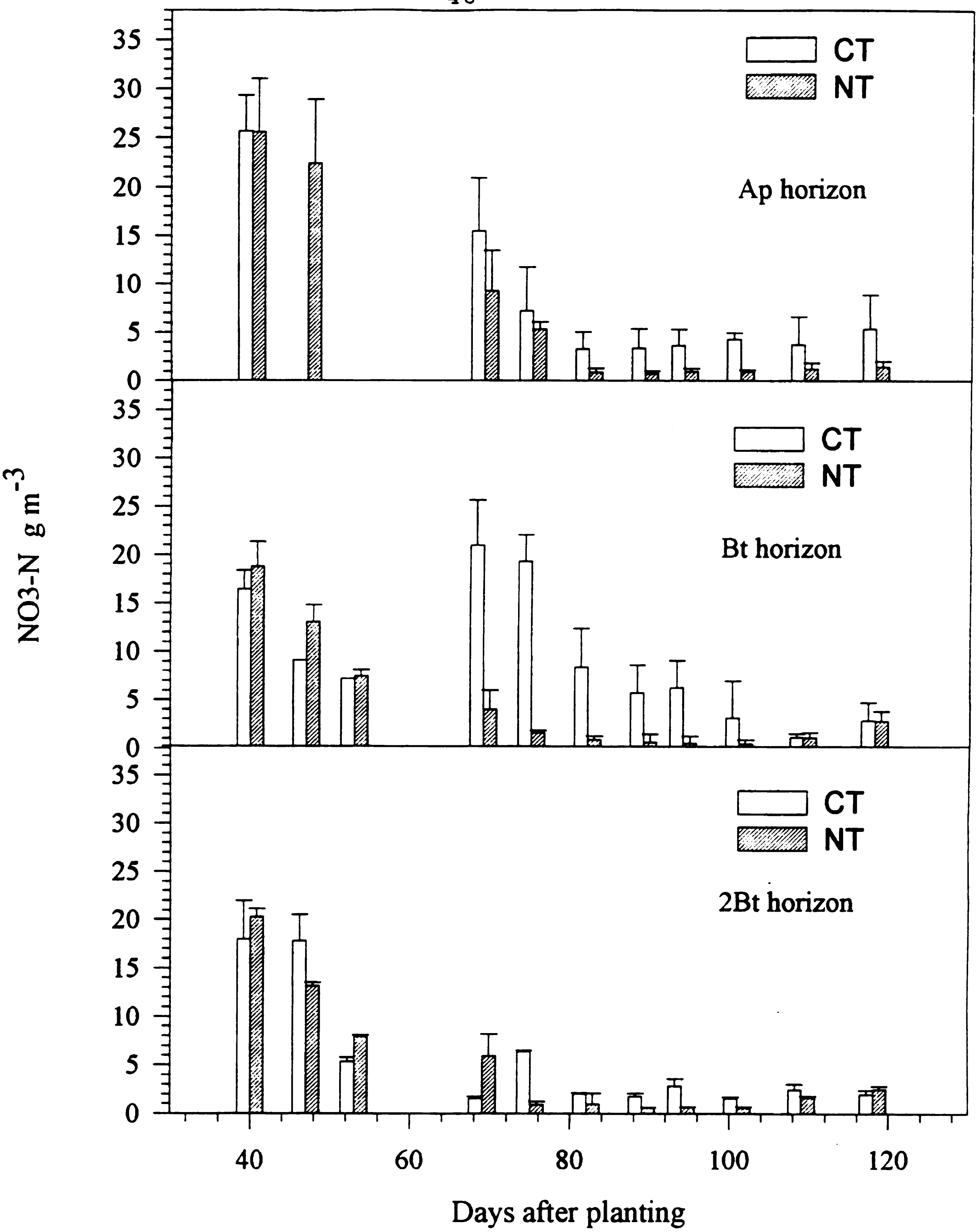


Figure 2.12. NO_3-N (g m^{-3}) in soil solution of Ap, Bt, and 2Bt natural horizons of a Kalamazoo loam soil at KBS, 1992.

88.4% for CT treatment, while only 59.3% for NT treatment based on the data measured at 40 DAP (Table 2.3).

DISCUSSION

Water content

Although water flow can be greatly increased via macropores, as the rainfall intensity and the sealing of surface pores by illuvial clay increase, the water flux will be reduced due to a change in pore continuity.

Responses of soil water storage and nitrogen distribution to conventional tillage (CT) and no-tillage (NT) varied during the different years of this study, because precipitation patterns and air temperatures were different. Although more macropores were developed in the Ap horizons by tillage of the CT plots (Reinert, 1990), the excessive rainfall in 1991 might have caused more surface pores to be sealed by clay, which in turn, increased water runoff during subsequent rainfall events. While the quantity of surface mulches in the NT plots might have reduced the impact of rainfall on soil crusting, greater water infiltration into the NT treatments of this study may have increased the water contents within the NT soils (Larson et al. 1978; Blevins et al., 1983). Moreover, root systems could also have contributed to the greater internal flux rates because of greater macropore continuities in the soil profile (Gish and Jury, 1983; Beven and Germann, 1982). Significantly larger root systems were developed in the NT plots in this study

Table 2.3 Soil and plant nitrogen contents within the corn plant and soil horizon at 40 and 128 DAP following the application of 147 kg N per hectare in a Kalamazoo loam soil at KBS, 1992.

	CT		NT	
	40 DAP[1]	128 DAP	40 DAP	128 DAP
	kg N/ha			
Soil solution [2]	198.40	34.45	213.87	24.90
Plant tissue	7.77	147.77	2.54	103.38
Total	206.17	182.22	216.41	128.28
Recovery		88.4		59.3

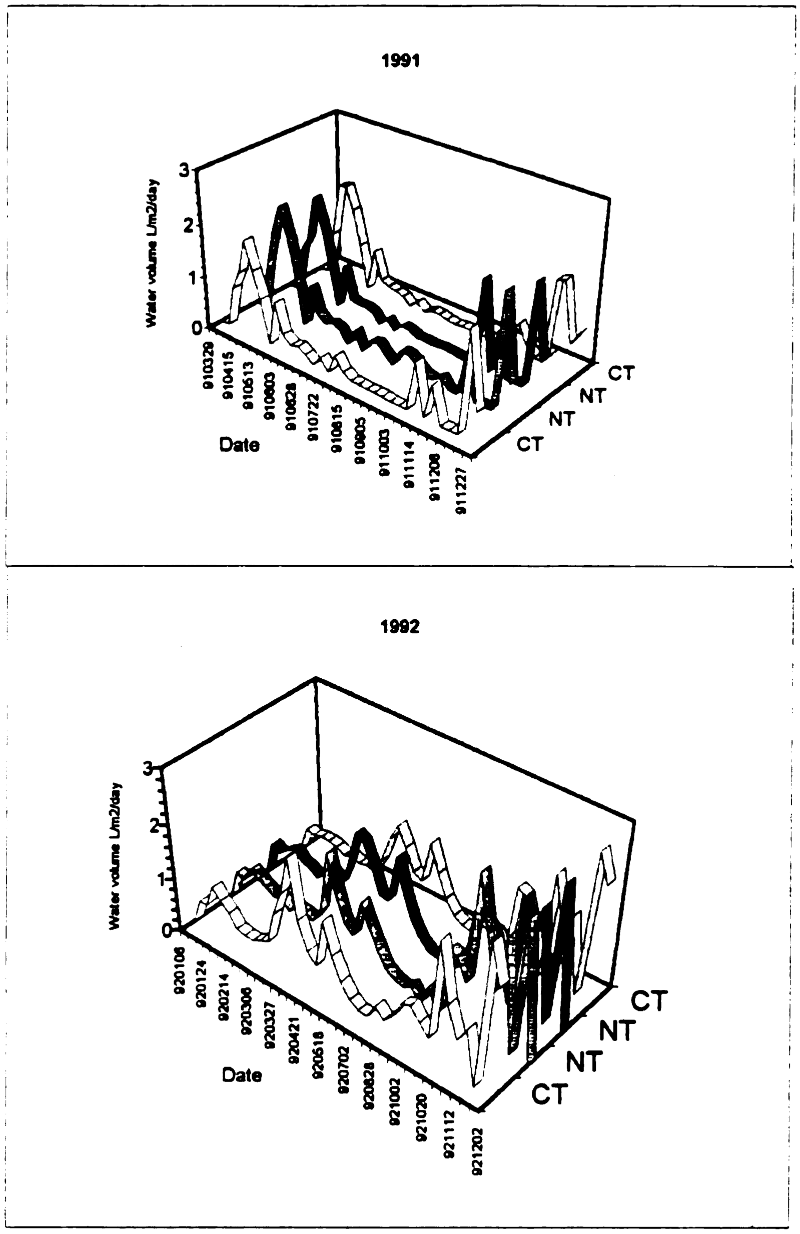
[1] DAP is sampling time for soil NO_3-N

[2] The nitrogen concentration in soil solution was culculated as ppm of nitrogen in soil solution times soil water content (v/v).

during two year experimental period (Huang and Smucker, 1995) suggesting that macropore continuity may have increased during the decay of roots in these long term CT and NT experiments.

Solution nitrogen distribution

As a result of soil water modifications, concentrations of nitrogen in the soil water were altered, especially the loss of nitrate by leaching water. In 1991, from May to September, there was an average of only 50 L of water which drained from the four field lysimeters located in same area as this study, where no commercial nitrogen fertilizer has been added for the past 4 years. Little drainage water drained from the field lysimeters during June, July and August (Figure 2.12) resulting in very little nitrate loss by leaching, during this period of the 1991 growing season. Consequently, concentrations of soil solution nitrogen were maintained at higher levels during this period of time. In 1992, an average 250 L of water drained from the field lysimeters throughout the growing season (Figure 2.12). Greater losses of water, drained from the soil profile during 1992, indicated that an excess of water had accumulated in the soil profile (Figure 2.7). Greater quantities of soil water caused nitrate to be leached out with the drainage water and also be diluted in concentration within the soil profile. Consequently, there were rapid decreases in the nitrogen concentrations from 49 -71 DAP, in 1992, for both tillage treatments (Figure 2.10).



Figuer 2.12. The water flow out through four field lysimeters (Figure 2.4) in a Kalamazoo loam soil at KBS in 1991 and 1992.

In the same season of 1992, no-tillage soils had more nitrate lost by leaching due to more water (280 L) drained from no-tillage treatment into field lysimeters than from conventional tillage soil (230 L). Greater quantities of drainage water resulted in a higher potential for nitrate losses from NT soils. Greater root systems in NT soils have been reported to play an important role for preferential flow in soil profiles (Mitchell et al., 1991; Richner and Smucker, 1993; Allmaras and Logsdon 1990). Root death opens many of these root-induced macropores, resulting in even greater bypass flow rates of soil solutions, when soil water contents approach values greater than field capacity (Disparte, 1987; Barley, 1954; Smucker and Aiken, 1992).

CONCLUSIONS

Tillage modifications of soil water content and nitrogen distribution showed nonlinear oscillations with time. Water content and nitrogen distribution responses to tillage and no-tillage varied in 1991 and 1992 as a result of different precipitation patterns and temperatures. The Kalamazoo loam soil, subjected to no-tillage retained more water than when conventionally tilled in 1991. These indirect effects of tillage on soil water contents are significant for areas where rainfall is limited and irrigation is nonexistent. Soluble nitrogen concentrations in the soil horizons were influenced more in 1992 than in 1991, by a greater soil water content. Soil NO_3-N losses under NT treatments in 1992, were significantly greater than with CT, resulting in greater potentials for pollution of the ground water by nitrate compounds in NT soils. Higher soil water regimes in the no-tilled treatments appear to promote excessive leaching of NO_3-N. Therefore, selection of the most appropriate tillage can control both the yields of corn and the losses of soil nutrients for specific soil types.

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Chapter III

MAIZE ROOT AND SHOOT RESPONSES TO TWO SOIL TILLAGE SYSTEMS

INTRODUCTION

Tillage modifies root growth patters by altering both soil physical and chemical properties in the root environment. Barber (1971) reported greater densities of corn root lengths in the 0 to 0.1 m soil depths, below the rows, under minimum tillage even though total root weights declined in comparison to conventional tillage. Anderson (1987) compared corn (Zea mays L.) root morphology and distribution in N fertilization plots under minimum tillage and conventional tillage for three years. He reported that conventional tillage significantly increased root dry weights in one year, while minimum tillage caused an increase in root dry weights for the 0 to 0.7 m soil layer for 2 of the 3 years. Kovar et al. (1992) pointed out that root distribution was significantly modified by variations in soil temperature and water regimes which are influenced by tillage practices. However, these effects of tillage practices on corn root environments can vary significantly by changing the soil water content via the supplemental irrigation (Newell and Wilhelm 1987).

Shoot growth is often more limited than root growth when plants are grown with a restricted rooting volume (Carmi et al., 1983; Masle and Passioura, 1987).

A hormonal signal from the stressed roots is postulated to be the primary cause of shoot growth reductions in stressed plants (Davies and Zhang, 1991; Masle and Farquhar, 1988; Masle et al., 1990). Although plant growth responses to tillage have been reported, seasonal effects upon root and shoots responses to tillage are not clearly defined. The objective of this study was to characterize the spatial and temporal dynamics of root and shoot growth responses to tillage during two years which had contrasting rainfall patterns. Non-destructive and repeated measurements of the spatial and temporal distribution of roots, by the minirhizotron method (Smucker, 1990), were incorporated into this study to provide essential information on below ground plant responses to seasonal changes. These root data, especially root demographics, can be incorporated into soil and plant models (Smucker and Aiken, 1992).

MATERIALS AND METHODS

Experimental design and crop culture

Corn (Zea mays. L. hybrid Pioneer 3573) was grown at Kellogg Biological Station (KBS), Hichory Corners, Michigan. This two-year field experiment consisted of a randomized block design having primary treatments of conventional moldboard and secondary tillage (CT) and no-tillage (NT) replicated four times. Tillage treatments for this study were initially established on an agricultural field in 1986. Corn was grown in this field from 1986 to 1989. Soybean was grown to reduce the infestation of corn root worm in 1990. Eight plots, 27 X 40 m, were randomly distributed within a larger experimental design (Figure 3.1) across a gently rolling and stratified Kalamazoo loam soil. Soil horizons of this Kalamazoo loam (fine loamy, mixed, mesic Typic Hapludalf), are a loamy Ap horizon from 0 - 0.2 m which overlays a clay loam Bt horizon from approximately 0.2 - 0.8 m deep, which is underlain by a coarse glacial outwash parent material. Nitrogen (ammonium nitrate, 34-0-0) was applied at the rate of 432.4 kg ha^{-1} (147 kg N ha^{-1}), 0.02 m below the seed at the time of planting. Seeds were planted on May 16, 1991 and May 8, 1992 at a row spacing of 0.762 m, with 0.203 m between plants with a goal of 64,246 plants ha^{-1}. The insecticide Difonate was applied at the rate of 11.2 kg ha^{-1} over the row in a granulated form at the time of planting, to control corn root worm in 1992 as there was an infestation of corn root worm in 1991.

Instruments and data collection

Three polybutyrate minirhizotron tubes (transparent plastic tubes, 0.05 x 1.4 m) were installed in each plot at a 45 degree angle, to the soil surface, under the crop row (Figure 3.2) after corn emerge. These tubes were used to monitor changes in root growth at each soil depth throughout the growing season.

Corn root responses to soil tillage were monitored by observing root intersections of minirhizotron (MR) tubes by a micro-video color camera equipped with an index handle (Ferguson and Smucker, 1989), (Bartz Technology Co., 650

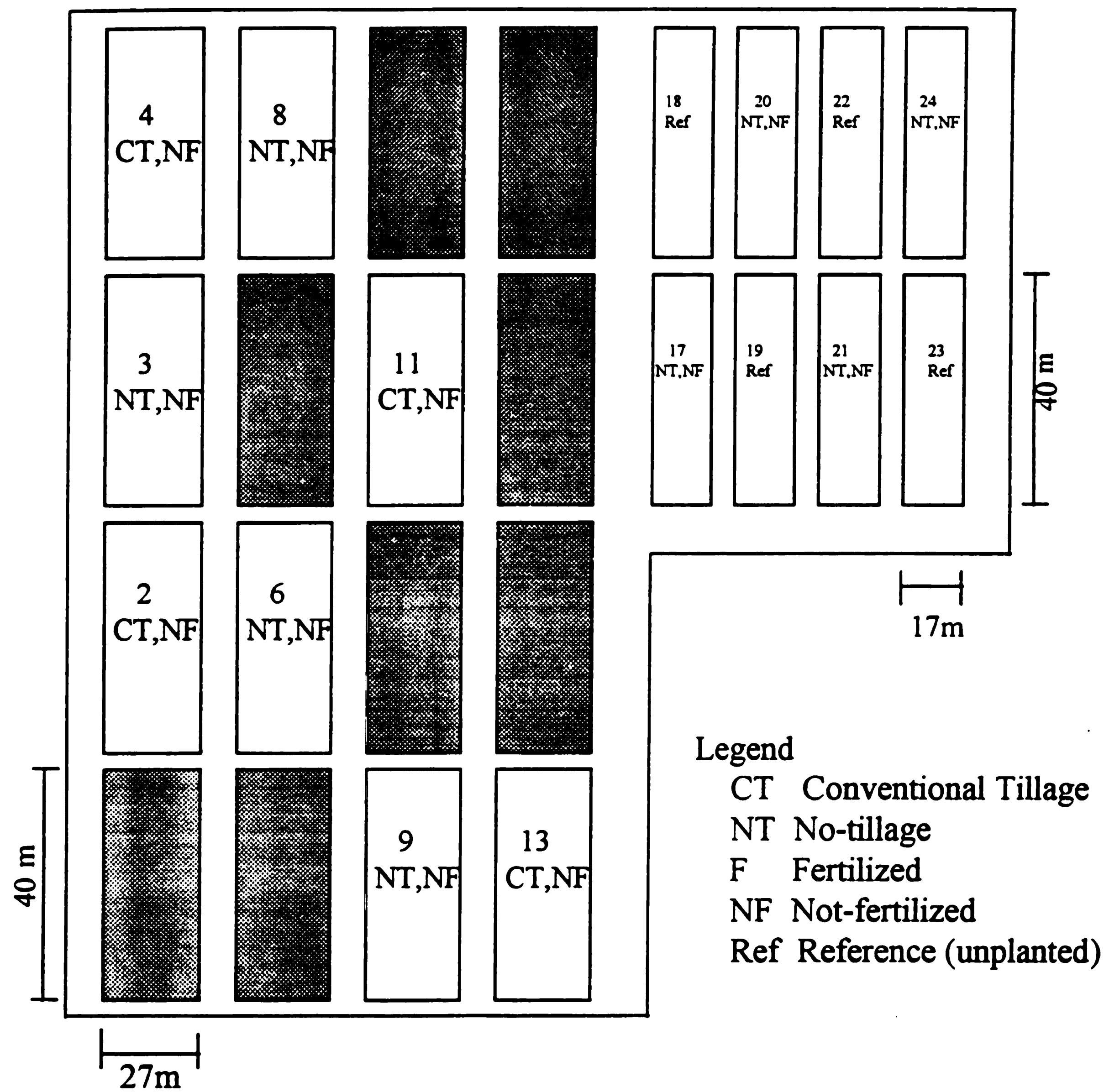


Figure 3.1. Experimental design of the larger agroecosystem interactions project on a Kalamazoo loam soil at KBS. Results from shaded plots are reported.

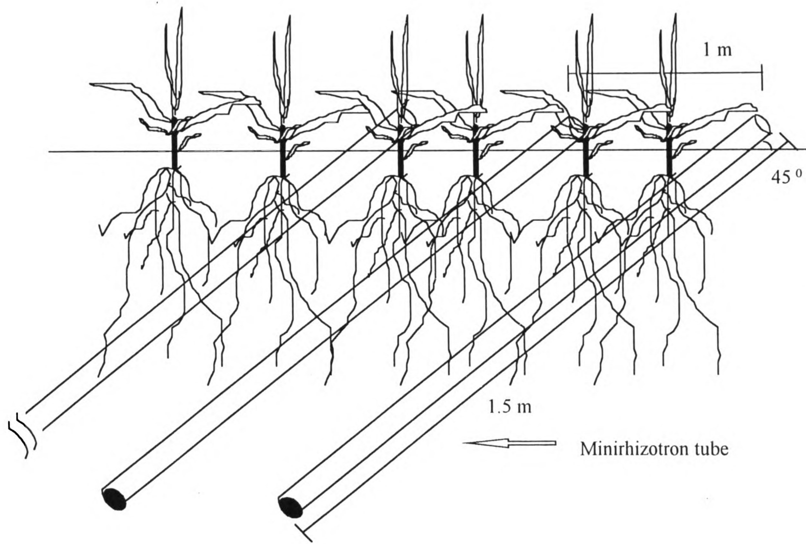


Figure 3.2. Distribution of minirhizontron tubes within plant row in Kalamazoo loam soil at KBS.

Aurorra Ave. Santa Barbara, CA 93109), and a black and white monitor. Roots intersecting a region 0.018 x 0.0135 m at the upper surface of each MR tube were video recorded on a VHS tape. Root interaction data was video recorded at multiple growth stages.

Plant samples were harvested at 43, 54, 76 and 107 DAP in 1991, and 33, 46, 60, 82, 116, 145 DAP in 1992. Plant biomass in each plot was determined by measuring the dry weights of ten plants at the juvenile stage (because plants were small), five plants at the floral stage, and three plants at silking, grainfill and black layer stages. Plant samples were oven dried at 75 C for three days and weighed. The plants were ground to pass through a 30-mesh sieve (Grinder model 84, Donaldson Company, Inc. Trorit division. P.O. Box 1299, Minneapolis, MN 55440) and stored in plastic bags at room temperature for further analysis.

Data analysis

Root intersections of each "frame" at the upper surfaces of the MR tubes were manually counted and recorded, using a simple computer algorithm "MINIROOT" (available from the Soil Biophysics Lab in Michigan State University). Although soil contact between the Kalamazoo soil and the MR tubes was excellent, an occasional small rock would be pushed aside during installation of the MR tube. This resulted in void spaces between the soil and MR wall, which resulted in the accumulation of greater quantities of roots approximately 5% of the time. These void-related accumulations were considered to be outlier root data which deviated significantly from the average number of roots in adjacent frames along certain regions along the MR tubes. Consequently, a computer smoothing algorithm program, "OUTLIER" (available from the Soil Biophysics Lab in Michigan State University) was developed to produce data files for statistical evaluations and the development of graphics and tables. The analysis of variance for comparisons of roots between tillage treatments, years within each treatment, among dates within each year for each treatment were completed, based on soil depth, by the statistical software associated with the commercial spreadsheet Excel (Version 4.0, Microsoft Corporation, One Microsoft Wy, Redmond, WA 98052-6399).

Ground plant samples (0.15 g) were digested by using standard total Kjeldahl procedures (Bremner and Mulvaney, 1982). The average of whole plant nitrogen content was analyzed by a QuikChem Automated Ion Analyzer (Lachat Instruments, 6645 West Mill Road, Milwaukee, WI 53218-1239).

RESULTS

<u>Root numbers</u>: The differences of root growth in the Kalamazoo loam soils between tillage and no-tillage treatments were significant in both years (Figures 3.3, 3.4 and Table 3.1). Root systems of corn were greater in soils subjected to NT than to CT for 1991 (Figure 3.3) and 1992 (Figure 3.4). Significantly greater root

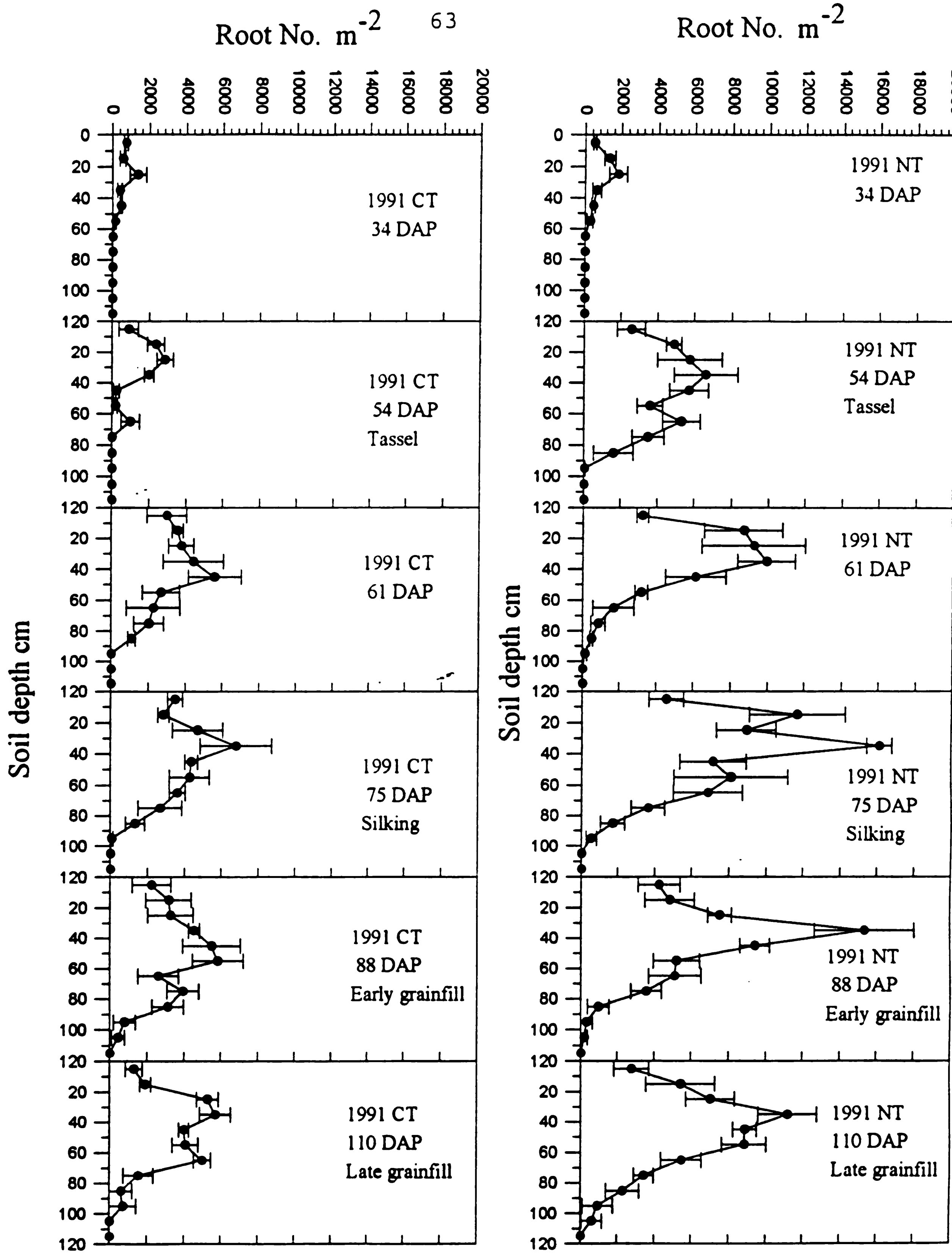


Figure 3.3. Root number in Kalamazoo loam soil at KBS with standard error bar. n=4, with three subreplications, 1991.

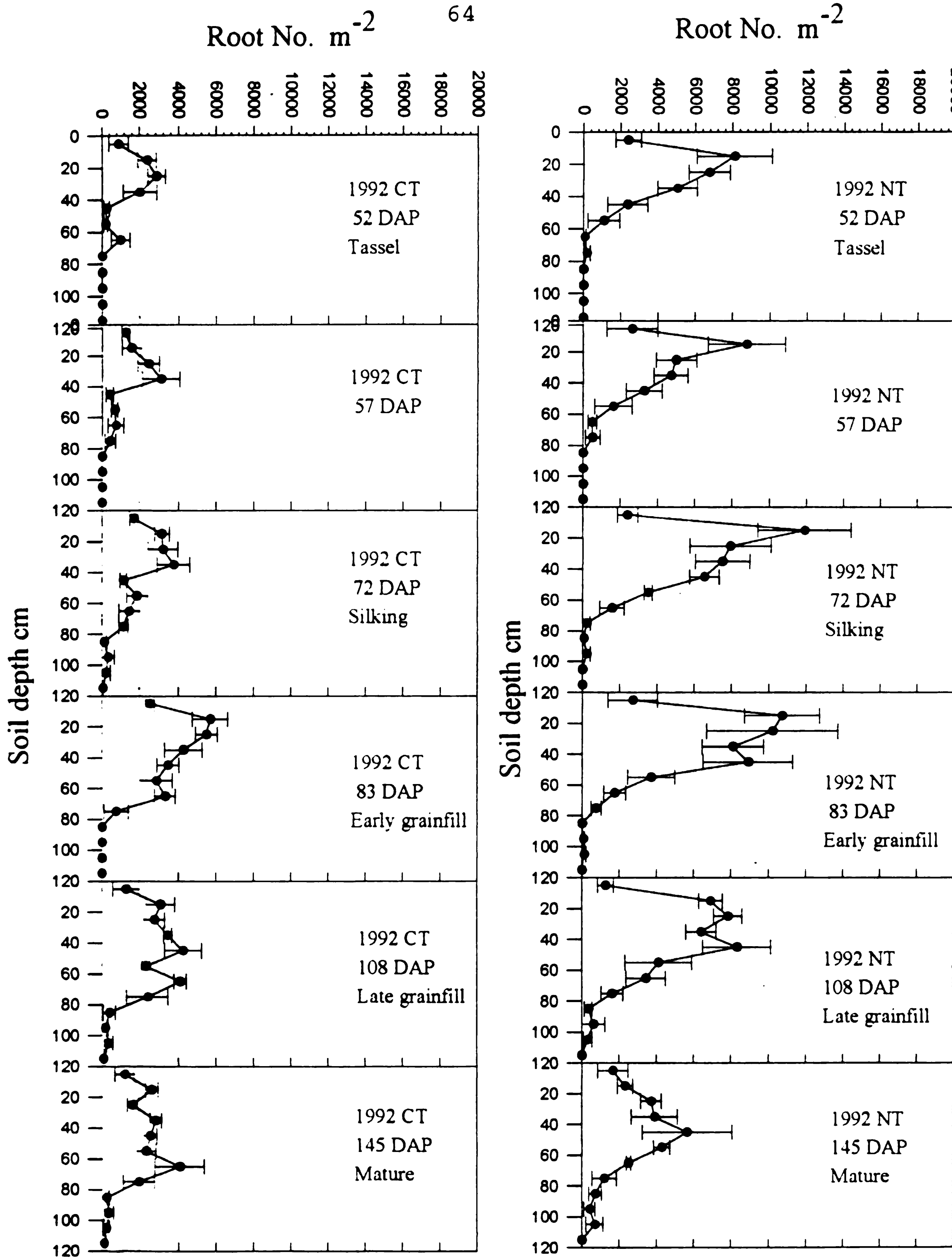


Figure 3.4 Root number in Kalamazoo loam soil at KBS with standard error bar. n=4, with three subreplications, 1992.

Table 3.1. The comparisons for the average root number between tillage treatments in a Kalamazoo loam soil at KBS during the growing seasons of 1991 and 1992.

Year	CT	NT
	---------- Roots m^{-2} ----------	
1991	21,372 (±591[1])***	36,990 (±937)***
1992	20,139 (±419)***	40,278 (±637)***

*** Significant at P value of 0.001

[1] Standard error

numbers were observed, primarily in the 0 - 0.60 m region of the soil profile, for NT treatments most of the time throughout both growing seasons. The average root system in each measurement date for the NT treatment in 1991 and 1992 were 36,990 and 40,278 roots m^{-2}. These were 73% and 100% greater than that for the CT treatments, which were 21,372 and 20,139 roots m^{-2} for 1991 and 1992, respectively (Table 3.1). The root growth varied at different measurement date and soil depth (Figs. 3.3, 3.4 and table 3.2 and 3.3), indicating the dynamic growth of corn roots throughout growing season and soil profiles.

Greater percentages of the entire root system were observed in the B (include Bt and 2Bt) horizons of the Kalamazoo loam soil for both tillage treatments during both years (Figure 3.5). In 1991, from 48 - 61% of the corn root systems accumulated in the B horizons for the period from 54 - 110 DAP. In 1992, from 51 - 65% accumulated in the B horizons during the same growth period. In 1991, the percentages of roots which accumulated in the Ap horizons of CT treatments decreased during the period from 54 to 88 DAP, while root percentages in the Ap horizons of NT treatments increased. In contrast, the percentage distribution of root numbers in 1992 decreased in the Ap horizons during the period from 52 to 108 DAP, and increased in the C horizon at the same period for both CT and NT treatments. Figure 3.5 shows a stable distribution of roots in B horizon for both tillage treatments in both years. However, the number of roots observed in the Ap and C horizons appear to reverse during the different years. The changes

Table 3.2 The P value in analysis of variance for comparison of roots among measurement dates within each year for each tillage treatment in a Kalamazoo loam soil at KBS for 1991 and 1992.

Year	CT	NT
	---------- P value ----------	
1991	1.8E-05	4.5E-10
1992	3.2E-06	1.5E-04

Table 3.3. The P value in analysis of variance for comparisons of roots among soil depths within each year for each tillage treatment in a Kalamazoo loam soil at KBS in 1991 and 1992.

Year	CT	NT
	---------- P value ----------	
1991	2.3E-08	2.7E-22
1992	2.2E-19	1.1E-37

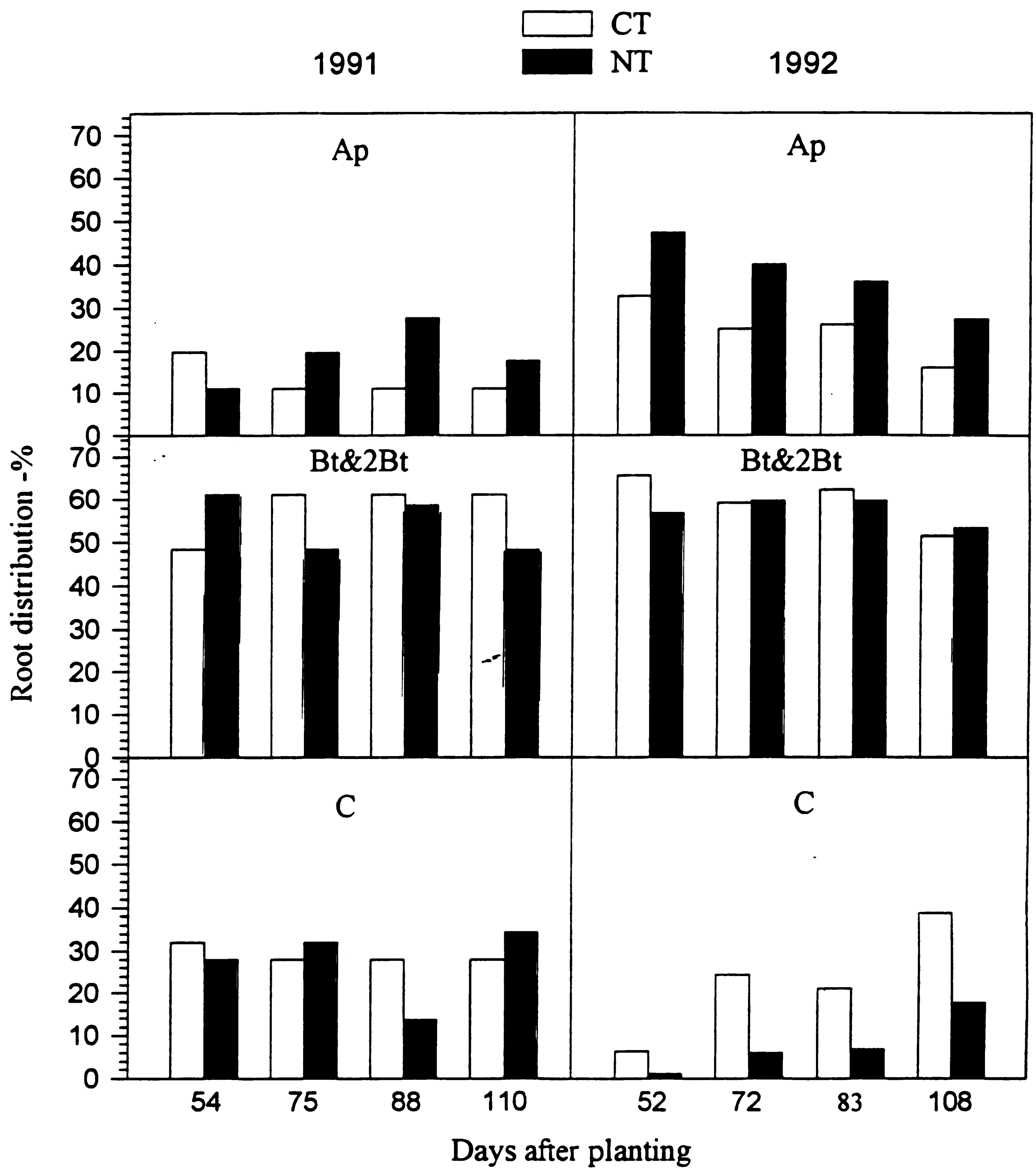


Figure 3.5 Percentage root distribution in Ap, Bt & 2Bt, and C horizons at different days after planting in a Kalamazoo loam soil at KBS for 1991 and 1992.

of root distribution patterns in Ap and C horizons with years were probably due to changes in soil water and nutrient distribution patterns (Huang and Smucker, 1995).

Root depth: Soil depths which contained maximum accumulations of corn roots were 10-20 cm deeper in CT treatments than in NT treatments during 61 and 88 DAP in 1991 (Figure 3.6A). The soil depths which contained maximum accumulations of roots were fluctuated under CT soils throughout the growing season. In contrast, the soil depths which contained maximum accumulations of roots under NT treatment were the same at stages beyond 34 DAP, throughout the growing season for 1991.

During 1992, soil depths which contained maximum accumulations of roots were deeper in CT than in NT before 72 DAP (Figure 3.6B), at which period the soil water contents were low (Huang and Smucker, 1995). However, the maximum root accumulation occurred deeper for both CT and NT treatment at 108 and 145 DAP.

Root dynamics: Root losses, negative numbers, and root gains, positive numbers, are indicators of the net decreased (turnover) and increased roots in soil profiles of the tillage treatments. Root dynamics appeared to be greater for both tillage treatments during the 1991 growing season than in 1992 (Figure 3.7). The greatest changes in root growth and/or death rates occurred between CT and NT treatments at 75, 88 and 110 DAP in 1991 growing season. In the growing season of 1992, the greatest differences of root dynamics between CT and NT were at 57

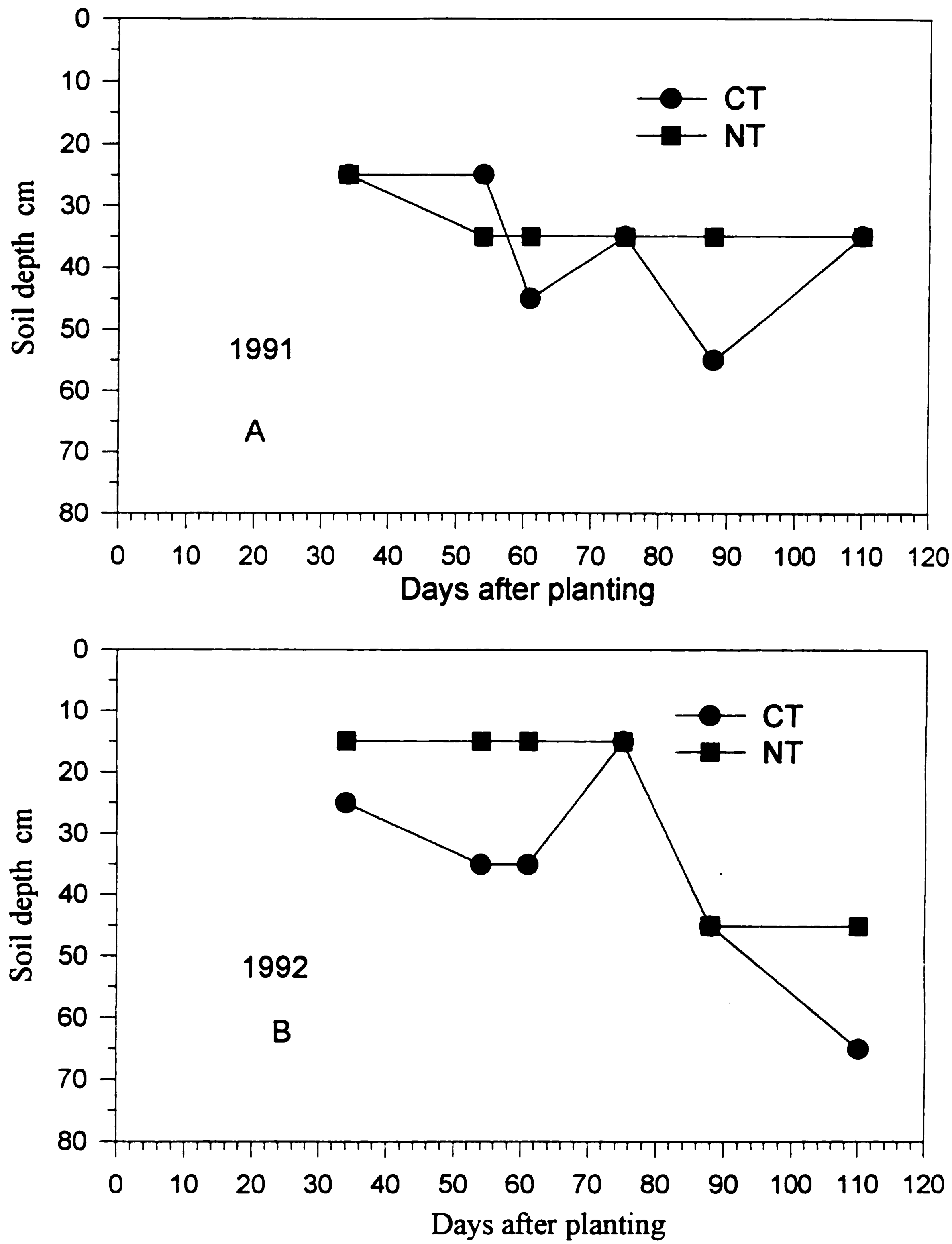


Figure 3.6. The influence of tillage and year on the soil depth which contained maximum root accumulation at different growth stages in a Kalamazoo loam soil at KBS, for 1991 and 1992.

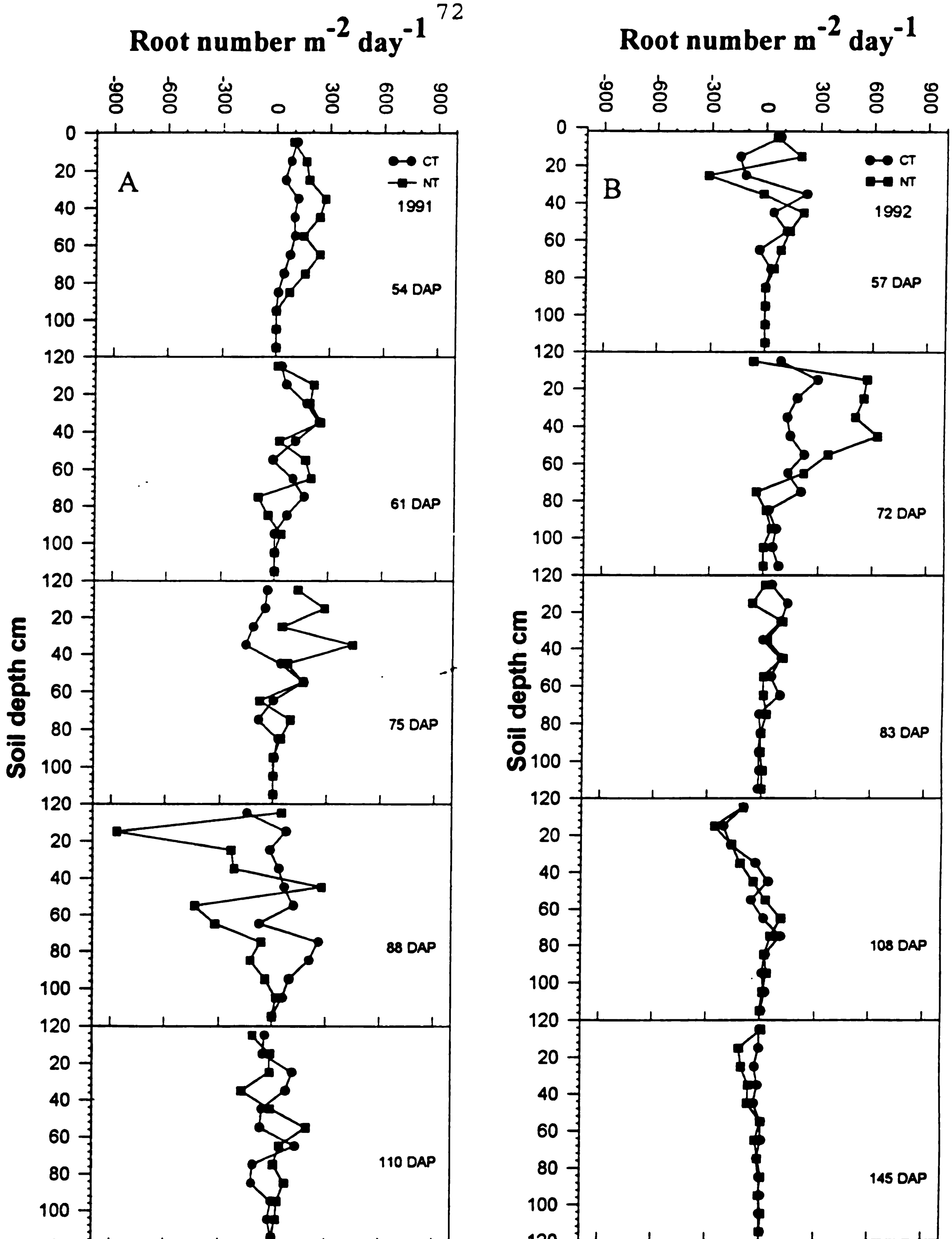


Figure 3.7. Root dynamics of corn throughout the growing seasons of 1991 (A) and 1992 (B) in a Kalamazoo loam soil at KBS.

and 72 DAP. There was little change in the dynamics of root numbers for either tillage treatment beyond 72 DAP. However the greatest difference of root dynamics between CT and NT treatments occurred during the low soil water content periods (Huang and Smucker, 1995) for both years.

Shoot growth: Corn shoot growth rates for both tillage treatments, in 1991, increased 10 and 14-fold during the period of 43 - 54 DAP under CT and NT treatment (Figure 3.8A). There was a significant decline in shoot growth rates by the period of 54 - 76 DAP resulted in lower dry weights of corn plants on CT treatments for the duration of the 1991 growing season (Figure 3.9A), even though shoot growth rates were similar for both tillage treatments during the period of 76 - 107 DAP. These data indicate that corn plants from CT treatments grew more slowly during a midseason soil water deficit period, suggesting that plants on a conventionally tilled soil suffer more from the negative effects of water deficit, when compared to plants grown on a loam soil which was not tilled.

In 1992, plant growth rates of both tillage treatments were slow early in the season, and greater than 2000 mg per day, began sometime later than 60 DAP and continued through 116 DAP (Figure 3.8B). Shoot growth rates were greater for CT treatments during the first 116 days of the growing season, resulting in greater accumulations of plant dry matter, in the CT treatment (Figure 3.9B), for the duration of the growing season. Consequently, plant shoot growth was greater for

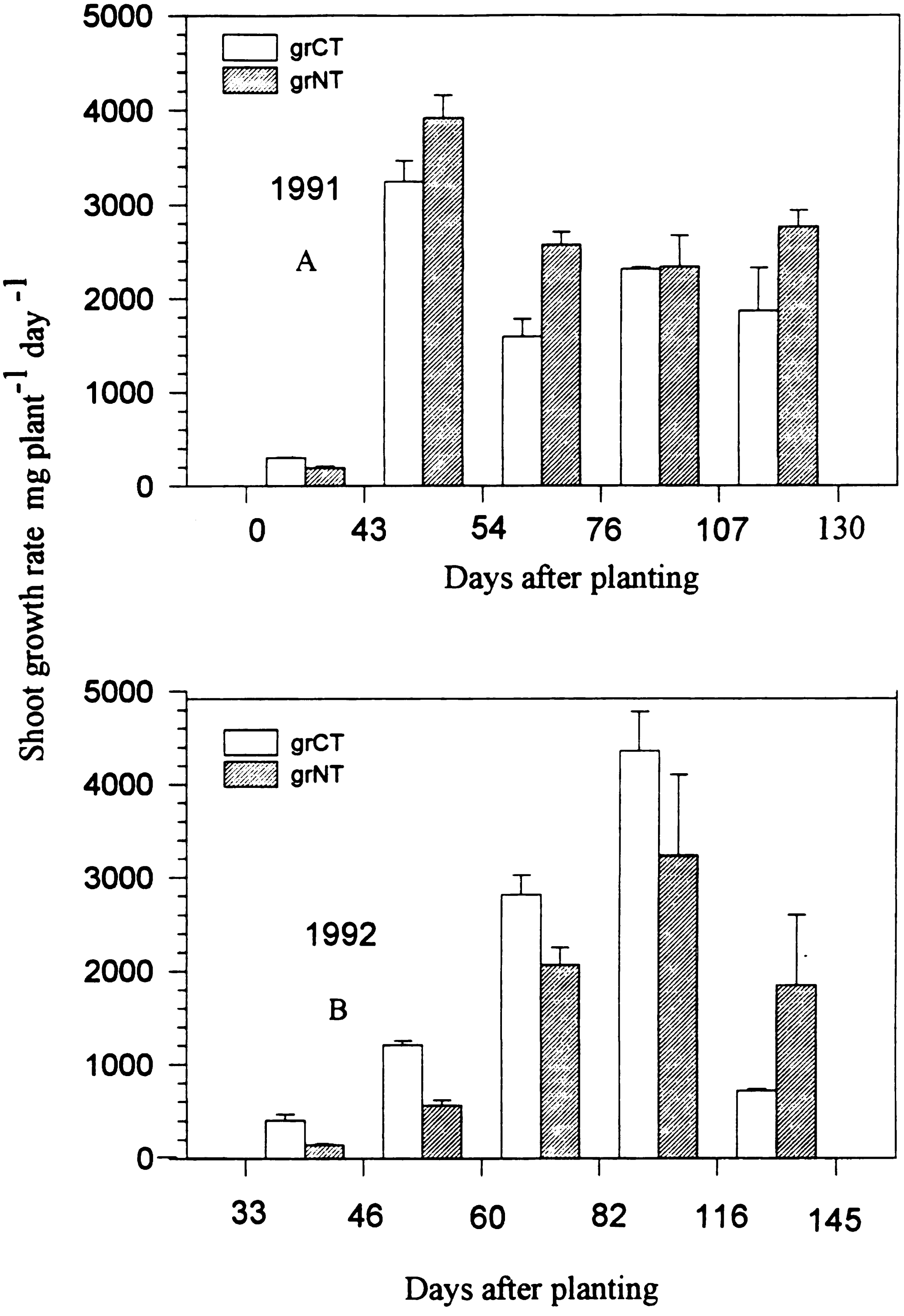


Figure 3.8. Shoot growth rate of corn at different growth stages of 1991 and 1992 in a Kalamazoo loamsoil at KBS.

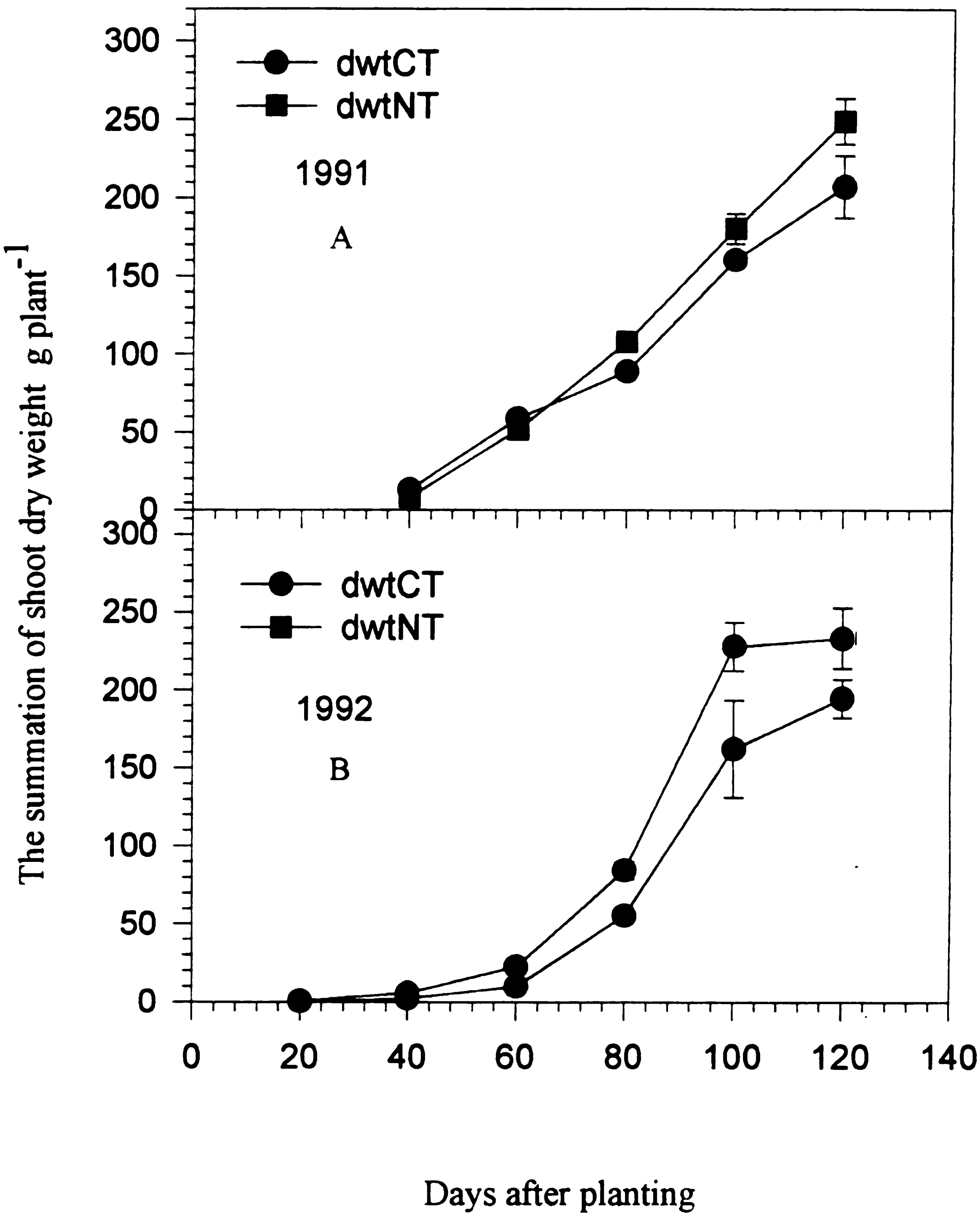


Figure 3.9. Shoot dry weight of corn at different growth stages of 1991 and 1992 in a Kalamazoo loamsoil at KBS.

the NT treatment during 1991 season, and corn shoot growth was lower for the NT treatment during the 1992 growing season (Figure 3.8).

Yields: Maize grain yields for no-tillage (NT) treatments was significantly higher than that of the conventional (CT) in 1991 (Table 3.4). Maize grain yields, average 7905 kg/ha for the NT treatment were 43% higher than that for the grain yield , average 5518 kg/ha, of CT treatmentin 1991. The grain yields for 1992 were missing.

Plant tissue nitrogen: Plant shoot tissue nitrogen concentrations in corn plants were highest at 43 and 46 DAP during the juvenile stages for 1991 and 1992 (Figure 3.10). Plant tissue nitrogen concentrations decreased during the rest of the growing season for both tillage systems in both year.

Nitrogen accumulation: Maximum nitrogen accumulation rates in corn grown in 1991 were obtained during the period of 43 - 54 DAP for both tillage treatments and appeared to decrease for the period 54 - 107 DAP (Figure 3.11). Accumulation rates of N in CT treatment were higher than those for the in NT, during the period of 0 - 43 DAP then was lower than NT during the period of 54 -76 DAP. Maximum N accumulation rates in plant tissue for the 1992 season occurred during the silking stage, 60 - 82 DAP for both of the CT and NT treatments (Figure 3.11). However, accumulation rates of N by corn plants in NT treatment were lower than those for the CT, during the periods of 46 - 82 DAP equal to CT during 82 - 116 DAP and higher than CT during 116 - 145 DAP indicating a delay accumulation

Table 3.4 Corn grain yields on a Kalamazoo loam soil under two tillage treatments at KBS for 1991.

	CT	NT	LSD
	------- kg/ha -------		
grain yield	5518	7905	1903

Differences among means for all observed yields are determined by the Least Significant Difference method at a probability of 5%.

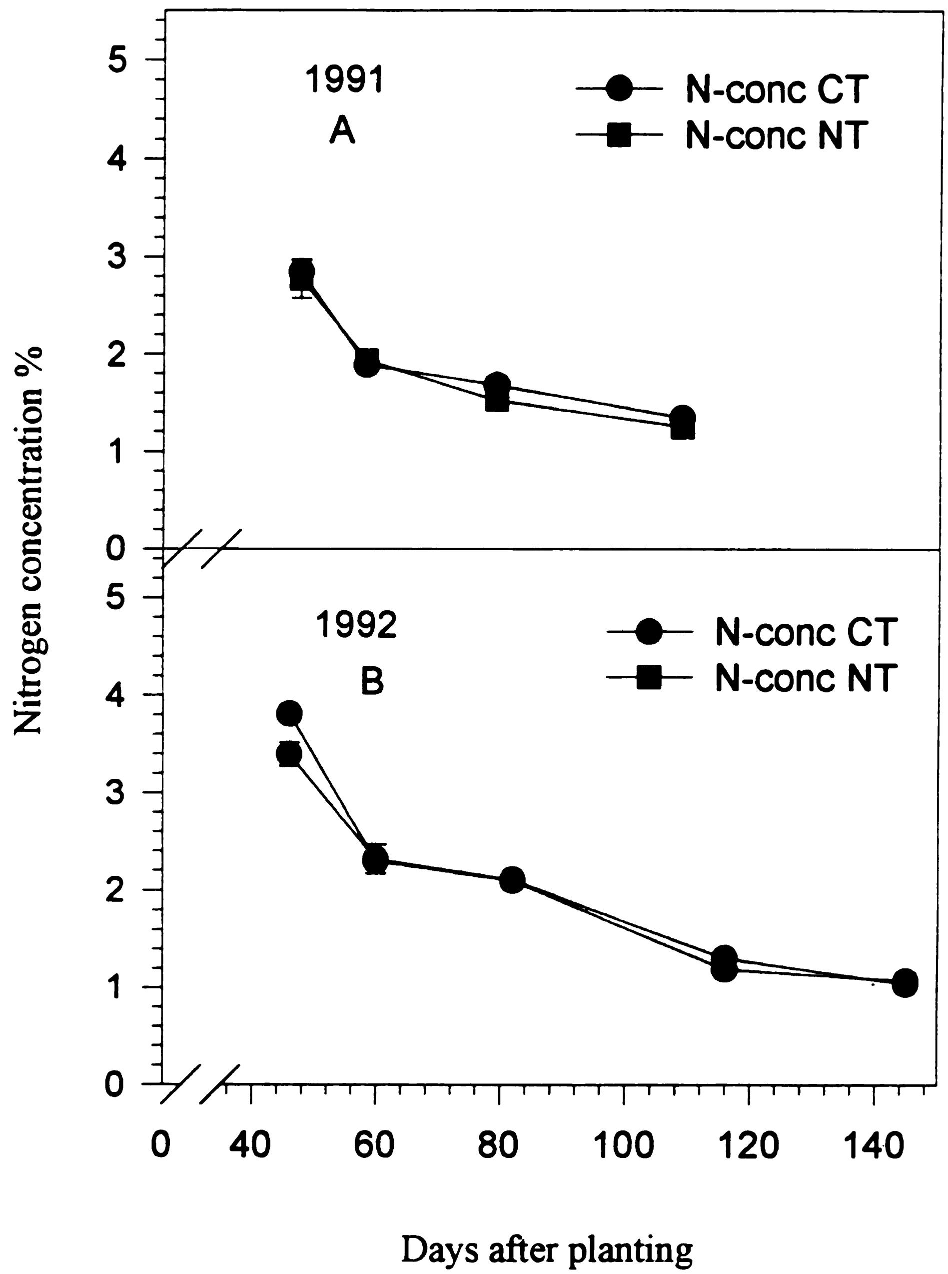
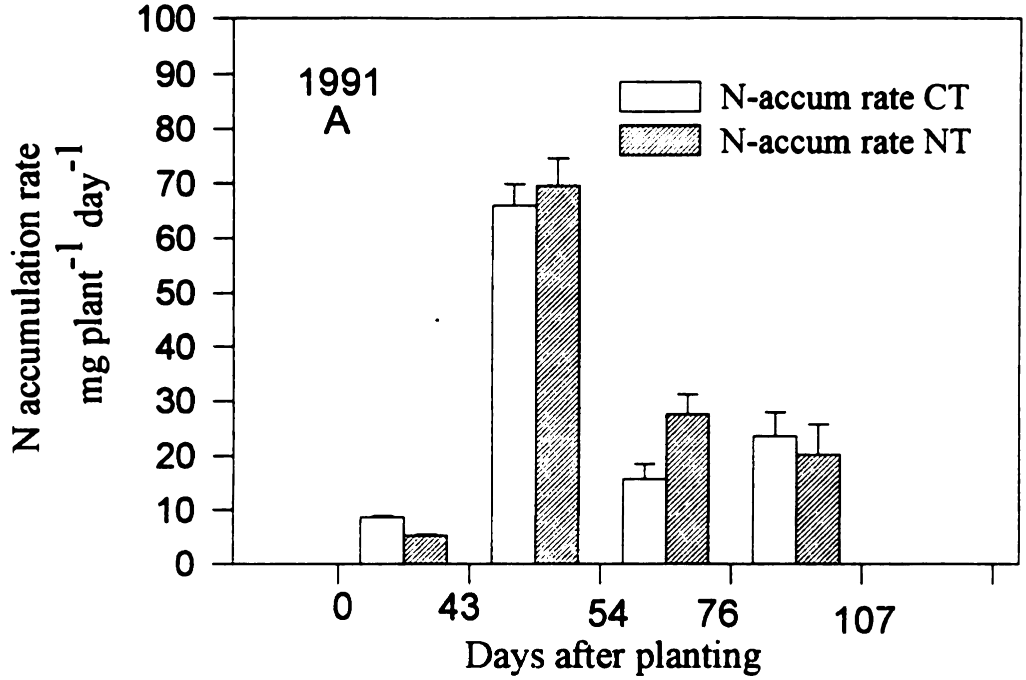


Figure 3.10. Nitrogen concentration in plant shoots for tillage and no-tillage treatments in a Kalamazoo loam soil at KBS for 1991 (A) and 1992 (B).



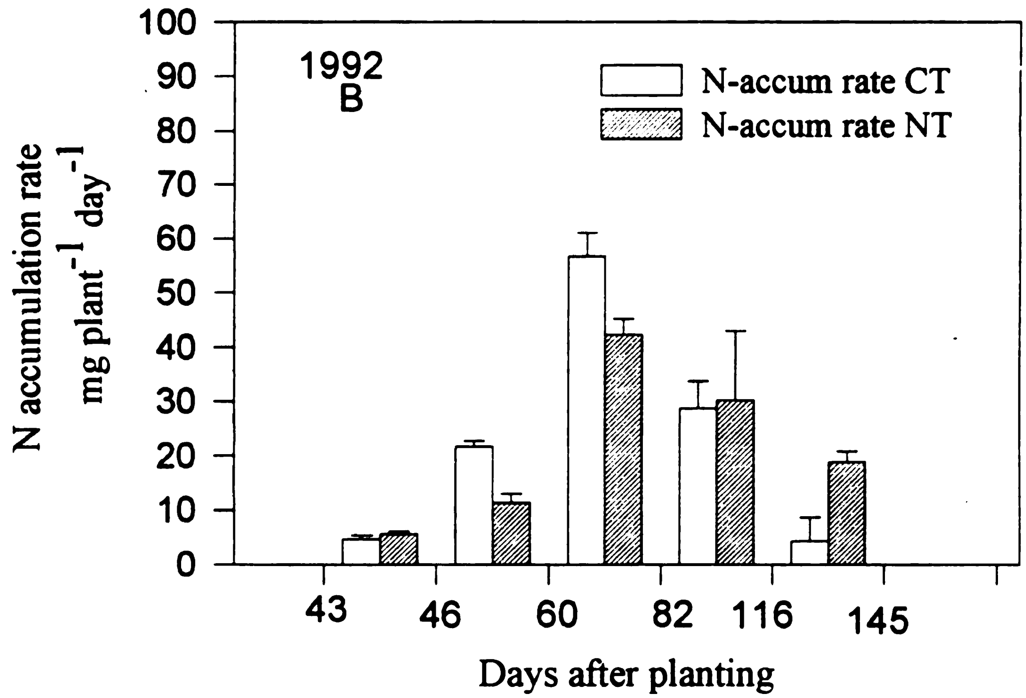


Figure 3.11. Nitrogen accumulation rates in corn shoots for tillage and no-tillage treatments in a Kalamazoo loam soil at KBS for 1991 (A) and 1992 (B).

indicating a delay accumulation of N in NT during 1992. This may be the reason which caused the delay of shoot growth rate and dry mater accumulation under NT treatment in 1992 (Figures 3.8 and 3.9).

DISCUSSION

Root growth

Estimation of the size of the plant root system in the field is important for understanding how crop plants adapt to different soil management practices. In this study, much larger root numbers developed in NT than in CT treatments, especially in the top 40 cm layers of the soil in both years. This may be due to the alteration of soil physical properties over the long term in CT and NT plots. According to Reinert (1990), bulk density in the top layer of no-tilled soil was higher than that of conventionally tilled soil in Kalamazoo loam soil at KBS. Greater bulk densities have been reported to increase the soil resistance which enhances root branching (Marschner, 1988 and Russell, 1977). Therefore, greater bulk densities in the NT treatment reported here, may have increased root branching resulting in more root intersecting at the surface of the MR tubes. More earthworm activities and old root channels in NT soil might also have contributed to the greater number of roots in the profile of soils receiving no-tillage (Singh et al., 1991; Kluitenburg and Horton. 1990; House and Parmelee, 1985).

The depth of maximum accumulation of corn roots depends on soil nutrient availability, O_2 diffusion, water content and soil resistance (Marschner, 1988). If soil moisture level are not depleted, roots prefer to grow within top layer of the soil profile, where there are higher concentrations of nutrients and greater diffusion of O_2. The low water contents in the Ap horizon in CT soil in 1991 (Huang and Smucker, 1995) might be the factor to cause more roots to accumulated in the deeper soil horizons than that under NT treatment (Figure 3.6A). Similarly soil water contents were low early during the 1992 season resulting in greater accumulations of corn roots deeper in the CT treatment than in the NT treatment. However, late in the season, the soil depths which contained maximum root accumulation were lower for both tillage treatments in 1992. This phenomena may have resulted from the decreasing of soil resistance by higher soil water content, since it had reported that unique relationships exist between penetrometer resistance and volumetric water content for all type of soils; and increased soil water content decreases soil strength (Simmons, 1992; Gerard et al. 1982). In 1992, greater soil water contents in the Ap and B horizons of both the CT and NT treatments since 70 DAP (Huang and Smucker, 1995), should have decreased soil strength resulting in a greater extension of corn roots. Nitrogen concentrations in the soil solutions of the Ap horizons decreased rapidly after 70 DAP in 1992 due to the leaching and dilution of nitrogen (Huang and Smucker, 1995). Since root growth is most rapid in those volumes of the soil where conditions are most favorable for growth, roots tended to extend deeper into soil.

Corn root distribution patterns under CT and NT treatments changed with years and dates. These fluctuations appeared to related to soil water contents which can be supported by the deeper root proliferation under CT soil (Figure 3.6) during the lowest soil water content period (Huang and Smucker, 1995). In 1991, when soil water content under CT decreased to the lowest from 60 DAP to 88 DAP, maximum accumulation of roots was deeper in CT than in NT because NT plots maintained higher water content than CT. In 1992, soil volumetric soil water contents were low early in the season, maximum accumulation of roots was deeper in CT than in NT in this period because greater soil water contents were again maintained throughout the root zone of NT soils. The greater differences of root dynamics between CT and NT treatments in Fig.3.7 supported this conclusion; the larger differences of net increase or decrease of roots occurred only during the periods when the soil water contents were low for both years (Huang and Smucker, 1995).

Shoot growth

Shoot dry weight under CT treatment was higher than that under no-tillage treatment at the beginning of 1991, which may have been due to excellent seedling emergence. However, shoot dry weight in NT treatment accumulated faster than in tillage treatment during the low soil water content period because NT soils maintained higher soil water content in the soil profile than CT treatment, and reduced the impact of water deficit. In 1992, since tillage plots had a good emergence of seed and higher nitrogen concentration in the soil profile after mid-season (Huang and Smucker, 1995), corn grew better than that in no-tillage treatments through all the seasons under adequate soil water.

Both corn shoot growth and N accumulation rates were delayed in 1992, especially in NT treatment. The delay was due to low atmospheric temperatures and radiation in 1992 (Appendix 1 and 2). The lower soil temperature (Dadoun, 1993) may have caused the further delay in plant growth under the NT soils.

Tillage effects

The responses of corn growth to CT and NT treatments were varied in this study. This agrees with the variation conclusions about tillage treatments reported before. Corn yields, under minimum tillage practices, have also been reported to be equal to or greater than yields under conventional practices (Wilhelm et al., 1986; Olson and Schoeberl, 1970). Yields were equal to both CT and NT treatments when precipitation was abundant and yields on NT treatments were greater for dry years on moderately well-drained silt loam soils (Herbek et al. 1986). Cheng at al. (1990) reported that higher root length densities obtained at 5-60 cm in CT rather than in NT. However root growth under minimum tillage

appears to decrease in wet years (Allmaras and Nelson, 1971). Anderson (1987) reported that conventional tillage significantly increased root dry weight in one of three years of research, and minimum tillage increased root dry weight in two years.

Observations of this study lead us to conclude that the effects of tillage on corn growth is largely dependent on soil water content. Soil water content affected by tillage manipulations and weather conditions, especially the distribution patterns of precipitation. Soil water contents influence soil temperature, soil nutrient availability, and also plant physiological functions associated with crop development throughout the crop life cycle. NT shoot growth appeared to be better than the CT treatment in 1991, when more water retained by NT soils, reducing the impact of soil water deficit. NT showed some limiting effects on corn shoot growth in 1992 because of poor seed emergence, lower soil temperature (Dadoun 1993), and more nitrate losses by leaching out of root zone (Huang and Smucker, 1995). The tillage modifications of corn growth influenced by climatic conditions were more evident in CT soil than in NT soil which indicated that soil physical and chemical properties of NT system were more stable and favorable for the below- and above-ground corn growth, especially during a period of low rainfall and low soil water content. Since no-tillage systems appeared to reduce the impact of water deficit due to more water infiltrates NT soils and is retained in root zone, the no-tillage system may be the recommended tillage system for corn growth in dry areas and when irrigation is not available, because corn is a high water demanding crop. However, in the area with abundant precipitation, a no-tillage system might lead to greater nitrogen leaching from the root zone, increasing ground water pollution, and reducing nitrogen uptake efficiency.

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Chapter IV

CALIBRATING THE PREDICTION OF MAIZE YIELDS BY MODIFYING PRECIPITATION IN CERES-MAIZE MODEL

INTRODUCTION

Corn yields have been shown to vary as a function of soil water content. A major function of soil is to provide the needed reservoir of water and nutrients. The supplies of water and nutrient availability throughout plant life cycles influence crop growth and ultimately crop yield. Precipitation pattern and soil management, such as conventional tillage and no-tillage manipulations, are two of several factors which influence soil water content. Variations in water supply often affect crop growth and occur both spatially and from year to year. An uncertainty in water supply, along with other important weather variations, create a risky environment for crop growth (Ritchie, 1985). Simulation models provide a method whereby a complicated system can be represented in a comprehensible manner. However, one of the principal deficiencies which keeps models from being more widely used is the lack of spatial and temporal variability in factors needed to predict crop performance accurately (Ritchie et al., 1990). Weather variability, especially the variability of precipitation and rainfall intensity in space and time is one of the fundamental factors that limits model effectiveness. The objective of this study was to calibrate the input of precipitation in the CERES maize model to predict crop yields. Modifications of precipitation were used to compare observed and predicted soil water contents and corn yields, by the CERES-Maize model (Jones and Kiniry, 1986; Ritchie et. al., 1991).

MATERIALS AND METHODS

Description of CERES-Maize model

Since climate, soil, management, and plant characteristics all interact to determine crop development and yield, evaluation of crop systems through yield models such as CERES, provide a quantitative means of integrating these important factors related to production.

The CERES-Maize model is a process-oriented, management-level model. It was developed by an interdisciplinary team of international scientists over a period of several years. It simulates plant growth, phasic development, crop yield, and soil water and nitrogen balances associated with the growth of maize. The model uses the following processes: phasic development or duration of growth phases as related to plant genetics, weather, and other environmental factors such as water and nutrients; apical development as related to morphogenesis of vegetative and reproductive structures; extension growth of leaves and stems, and senescence of leaves; and biomass accumulation and partitioning into above and belowground components. Model inputs include daily weather information, genetic coefficients, depths of soil horizonation, soil texture and bulk density, and initial soil water and nitrogen contents (Ritchie et. al., 1991). Daily weather data must available for all days of growing season, minimum requirement, beginning with day of planting and ending at crop maturity. In this study, the weather data started from May 1, and ending at end of October for 1991 and 1992 (Appendix I and II), which were both before planting and after crop maturity so that the simulation starts soil processes before planting. Soil profile properties are used in the soil water, nitrogen, and root growth sections of model. Each of plot in this study has its own soil file to run the simulation (Appendix III). The final results for each tillage treatment were reported from the average of the four replications.

Experiment design and crop culture:

A two-year field study was conducted in a Kalamazoo loam soil at Kellogg Biological Station, Hichory Corners, Michigan. This experiment consisted of a randomized block experimental design having primary treatments of conventional moldboard plowing and secondary tillage (CT) and no-tillage (NT) which were replicated four times. Tillage treatments of this study were initially established on an agricultural field in 1986. Corn (Zea mays L.) was grown from 1986 to 1989. Soybean was grown in 1990 for reducing the infestation of root warm. Corn (Zea mays L.) again was grown in 1991 and 1992 for this study. Eight plots, 27 X 40 m, were randomly distributed within a larger experimental design (Figure 4.1) across a gently rolling and stratified Kalamazoo loam soil (fine loamy, mixed,

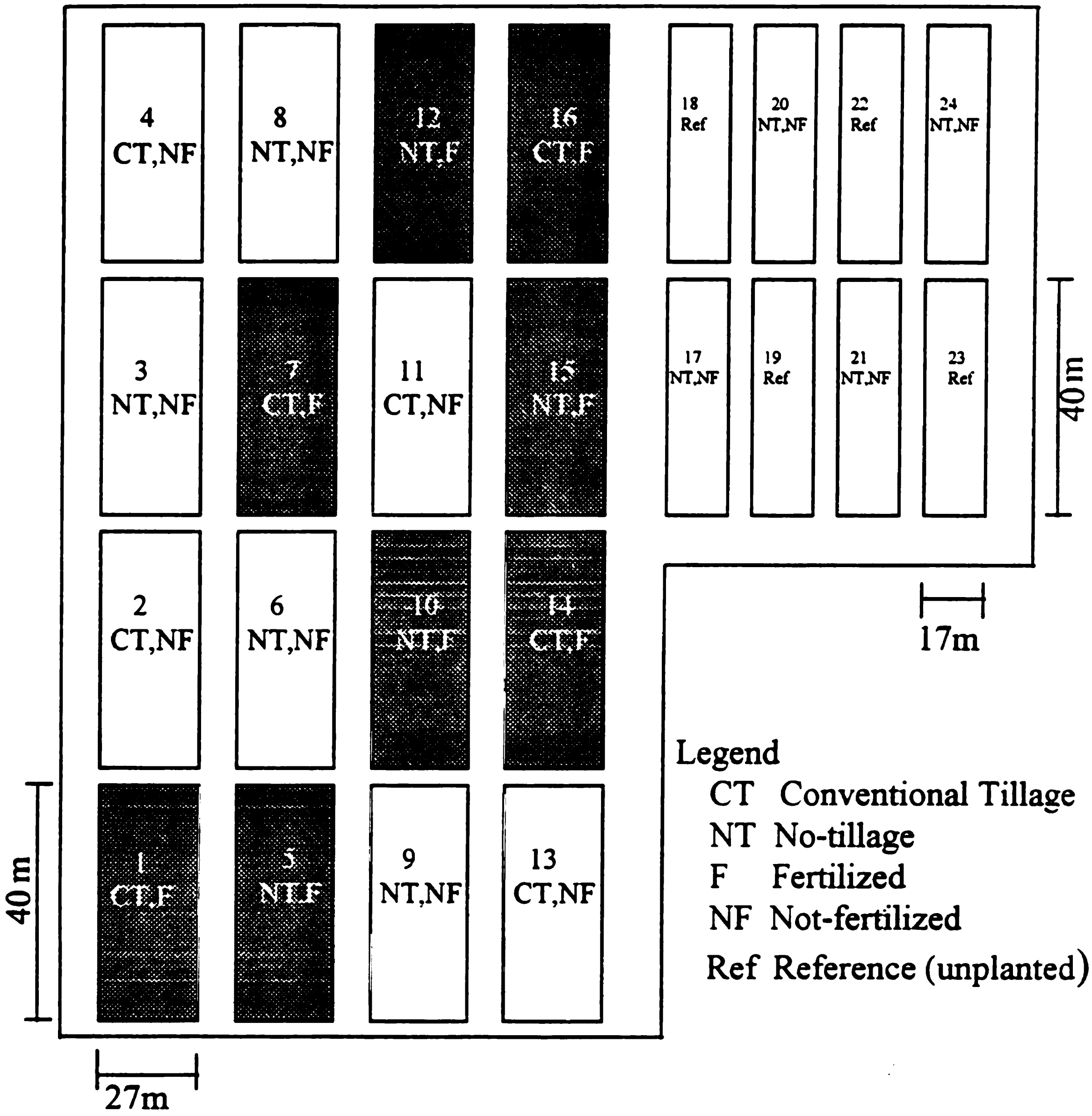

Figure 4.1. Experimental design of the larger agroecosystem interactions project on a Kalamazoo loam soil at KBS. Results from shaded plots are reported.

mesic Typic Hapludalf). Soil horizons associated with the Kalamazoo loam are a loamy Ap horizon from 0 - 0.2 m which overlays a clay loam Bt horizon from approximately 0.2 - 0.8 m deep, which is underlain by a coarse glacial outwash parent material. Corn (Zea mays. L.) was planted on May 16, 1991 and May 8, 1992 at a row spacing of 0.76 m, with 0.20 m between plants with a goal of 64,246 plants ha^{-1}. Nitrogen (ammonium nitrate, 34-0-0) was applied at the rate of 432 kg ha^{-1} (147 kg N ha^{-1}), 0.02 m below the seed at the time of planting. The insecticide Difonate was applied at the rate of 11.2 kg ha^{-1} over the row in a granulated form at the time of planting, to control corn root worm in 1992 as there was an infestation of corn root worm in 1991.

Instruments

Time domain reflectrometer

Soil water contents were monitored by the time domain reflectrometer (TDR) method (Topp et al., 1982). Pairs of stainless steel rods (30 x 0.5 cm) were soldered parallel to each other and spaced at 5 cm, to form the wave guides. Wave guides were solder-connected to a coaxial cable. Electrical resin (Electrical Products Division BM St. Paul, MN 55144) was used to stabilize and seal the wave guides and the cable (Figure 4.2). These inexpensive wave guides presented clear graphic waveform displays which were easy to measure by the cable tester

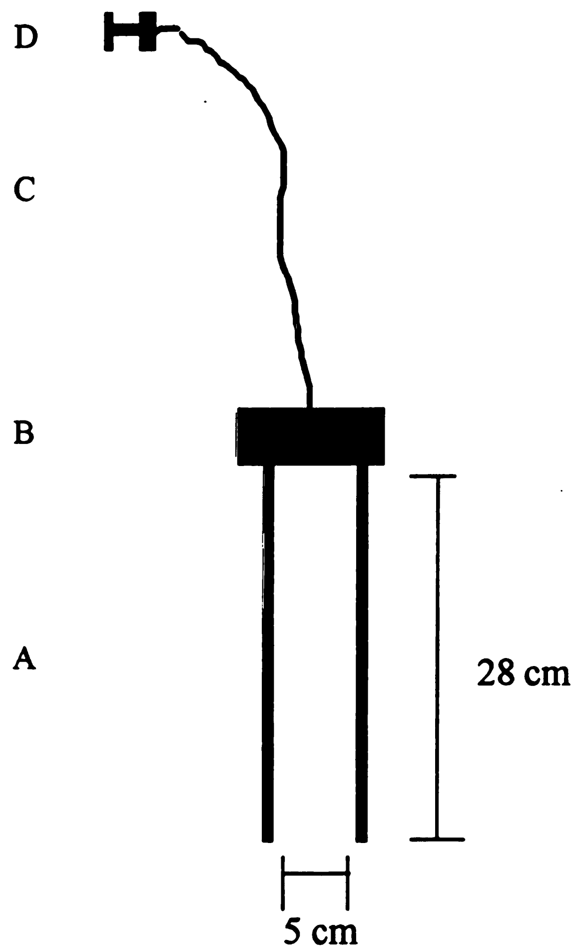

Figure 4.2. The diagram of TDR probe consisting of stainless steel wave guides (A), resin spacer and sealer (B), coaxial access cable (C), and electrical coupler (D).

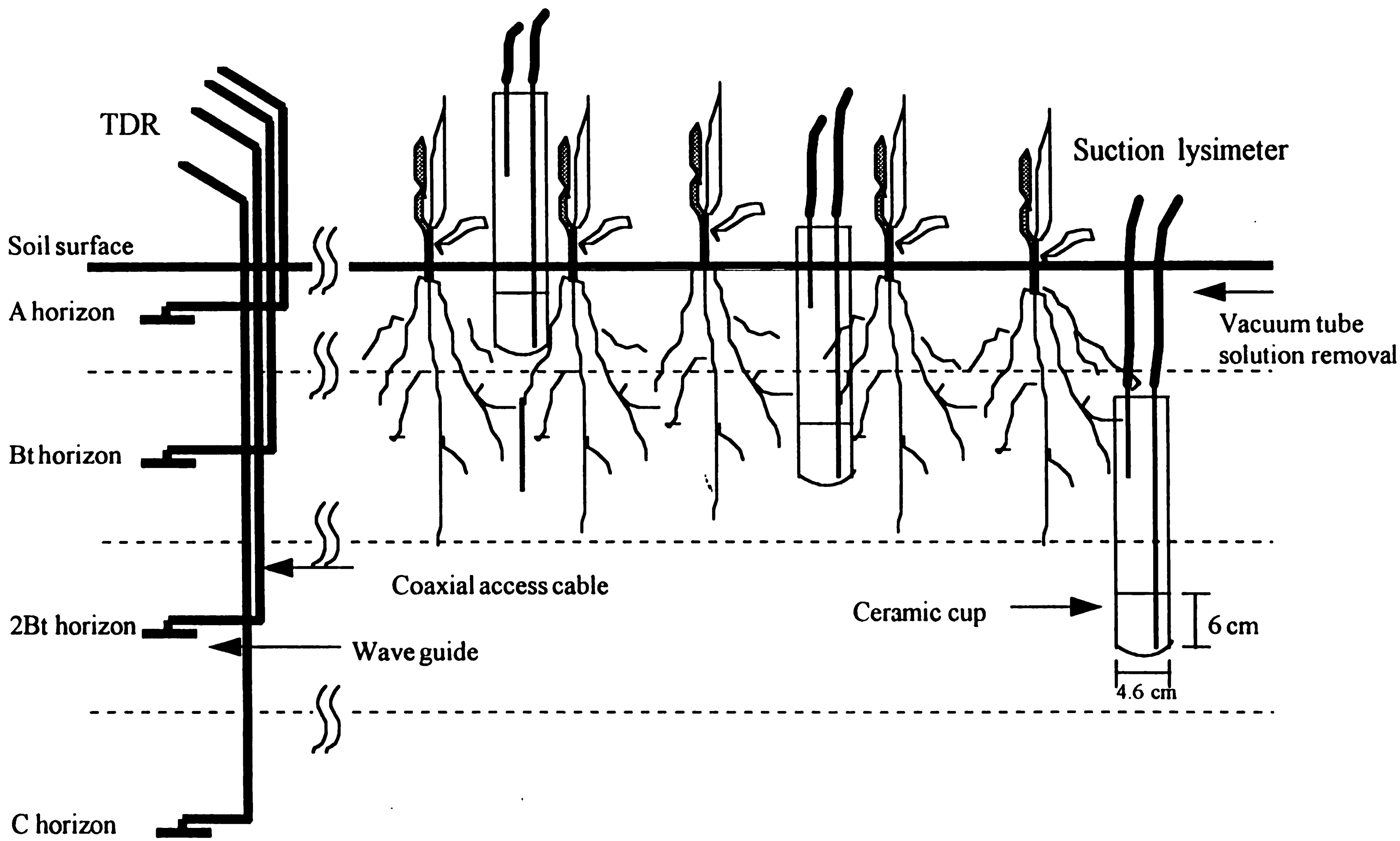

Figure 4.3. Diagrammatic representation of TDR probes and suction lysimeters in the soil horizons directly below the plant rows in the Kalamazoo loam soil at KBS.

(Tektronic, model 1502B, Tektronic Inc. Communication Network Analyzers Division, P.O. Box 1197, Redmond, OR 97756-0227).

TDR wave guides were installed in the field by digging small access holes into the C horizon of each plot. Plastic film was placed along the surfaces of the walls of the access hole and the TDR wave guides were inserted through the plastic to minimize horizontal soil water movement between the bulk soil and the disturbed soil refilled into the access hole. TDR probes were inserted horizontally, at different depths, into soil region of the Ap, Bt, 2Bt, and C horizons (Figure 4.3).

Soil volumetric water contents were calculated by using the Topp equation (Topp et al., 1982):

$$\theta_v=[-5.3*10^{-2}+(2.92*10^{-2}*K_a)-(5.5*10^{-4}*K_a^{2})+(4.3*10^{-6}*K_a^{3})]*100.$$

where

K_a is the apparent dielectric constant and $K_a = (ct/L)^2$; t is the signal travel time in nanoseconds and $t = (B-A)/(V_p*c)$; c is propagation velocity (Vp) of an electromagnetic wave in free space and C = 30 cm/nsec; Vp = 67% in this study. L=length of the transmission line, which was the length (28 cm) of TDR rod inserted into the soil. A = distance in feet between the TDR cable and TDR rod connection joint to the pulse generator (taken as the point before the large negative slope in waveform), B=distance in feet that the reflected pulse is from the pulse generator (taken as the tangent made by the zero and positive slopes traced in the waveform).

Data collection

TDR readings were taken at 7 day intervals except for the readings taken each day immediately following rainfall events which were used to determine the flux of soil water across the soil horizons.

Climatic data was collected from Pond Lab, the weather station at Kellogg Biological Station, approximately 1000 m from the study site. Daily weather data included maximum and minimum temperature, solar radiation, and precipitation. Estimated precipitation amounts used by the CERES model were 90%, 65%, and 90% and 85% of observed rainfall to predict the total amount of precipitation which infiltrated the Kalamazoo loam soils treated by NT and CT methods in 1991 and 1992, respectively. The monthly precipitation of the growing seasons in 1991 and 1992 were compared with the 30-year average amount of precipitation. The average temperature and the total days of rain in each month during growing seasons were evaluated (Table 4.3).

RESULTS

Yields: Maize grain yields for no-tillage (NT) treatments was significantly higher than that of the conventional (CT) in 1991 (Table 4.1). Maize grain yields, average 7905 kg/ha for the NT treatment were 43% higher than that for the grain yield , average 5518 kg/ha, of CT treatmentin 1991. The grain yields for 1992 were missing.

Estimated predictions of maize yields by the CERES-Maize model showed similar yields for both CT and NT treatments (Table 4.1). Estimations of runoff were evaluated by reducing actual precipitation until estimated yields would approximate observed yields (Table 4.2). In 1991, 10% reductions in precipitation reduced estimated yields from 8677 kg ha^{-1} to 7963 kg ha^{-1} for NT treatments (Table 4.2). Therefore it may be assumed that approximately 10% of the rainfall in 1991 was lost by runoff from NT treatments. Reductions of 35% were requires by the CT treatment before estimated yields approached observed yields (Table 4.1 and 4.2). Therefore, it was assumed that up to 35% of the rainfall in 1991 was lost by runoff from the soil surface of the CT plots.

Soil water contents: The observed soil water contents in Kalamazoo loam soil subject to NT was statistically higher than subjected to CT for both years; and the observed soil water contents subjected to CT and NT treatments were both higher in 1992 than in 1991 (Figures 4.4-4.7 and Huang and Smucker, 1995). The CERES-Maize model estimated soil water contents fairly accurately when soil water contents did not appear to be limiting corn yields (1992); over estimated soil water contents when soil water contents were low. In 1991, the predicted soil water content in Bt and 2Bt horizon were fairly fit the field data since the observed water contents in those two horizons under both tillage treatments were high (Figures 4.4 and 4.5). However, the soil water content were low in Ap and C horizons under CT, and was low in C horizon under NT during 1991, and the model over estimated the soil water content in those horizons (Figure 4.4 and 4.5). In 1992, the water contents were low in both CT and NT before 40 DAP, and the estimated water contents were higher than the observed data during that period. The observed data was good fit the model at the rest of the season in 1992 (Figures 4.6 and 4.7).

DISCUSSION

Yield Variation

Weather is known to affect crop yield (Kirkegaard et al. 1992a, 1992b; Gajri et al. 1991; Burwell et al. 1966; Amemiya, 1968). Our evaluations of precipitation and temperature for the 1991 and 1992 growing seasons are important to consider when discussing the yield and soil water content results for maize.

The monthly precipitation during the growing season in 1991 was lower than the 30-year average for June and September, and it was higher than the 30-year average for July and August (table 4.3). Although the amounts of rainfall for July

Table 4.1. Observed and estimated corn grain yields before adjust in precipitation in a Kalamazoo loam soil under two tillage treatments at KBS, for 1991.

	CT		NT	
	Observed	Estimated	Observed	Estimated
	kg/ha			
Grain yield	5518	8530	7905	8677

Table 4.2. Observed and estimated corn grain yields after adjusting precipitation which simulated runoff from a Kalamazoo loam soil under two tillage treatments at KBS, for 1991.

	CT		NT	
	Observed	Estimated	Observed	Estimated
	....	.... kg/ha	....	....
Grain yield	5518	5473[1]	7905	7963[2]

[1] precipitation reduced 35%
[2] precipitation reduced 10%

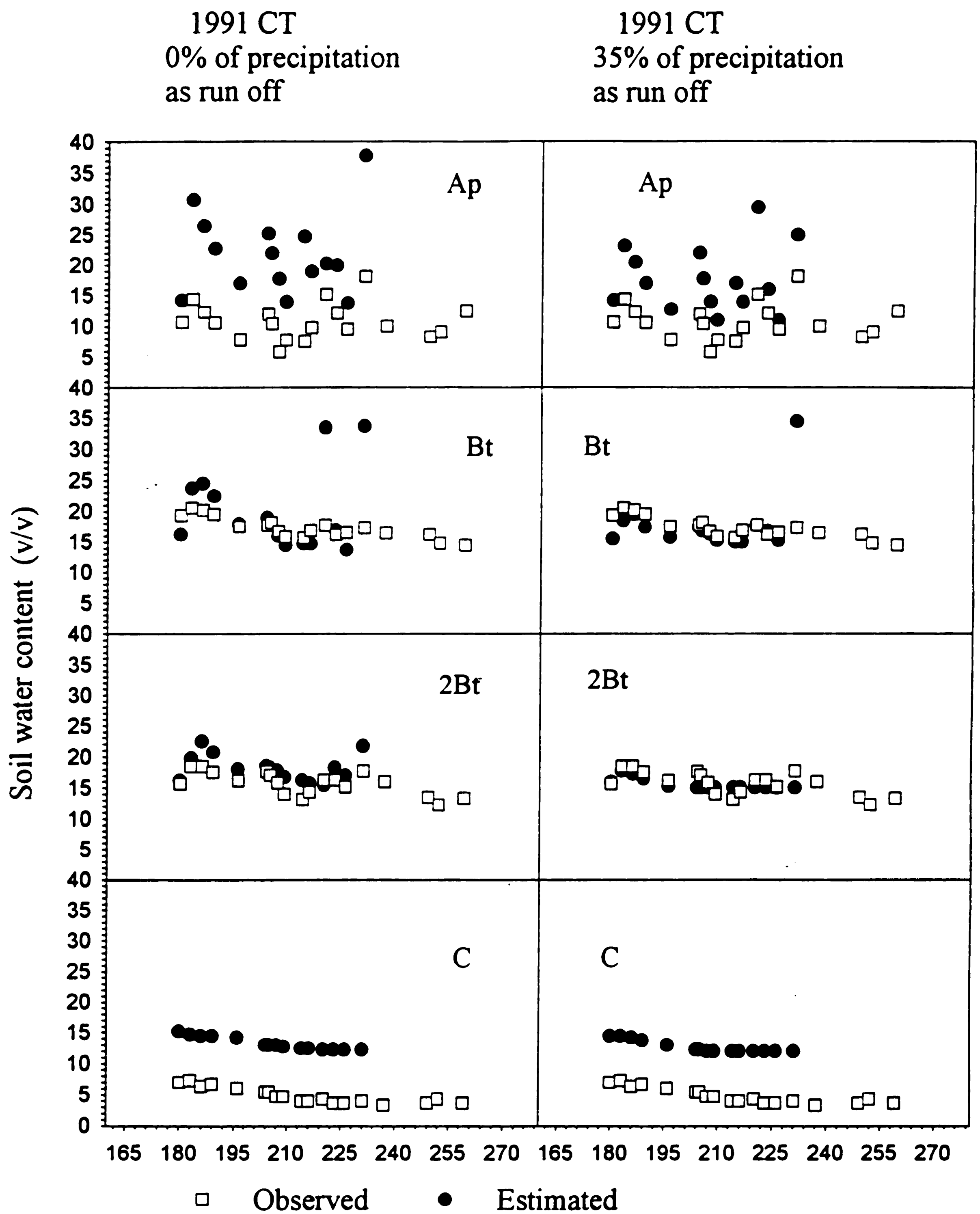

Figure 4.4. Observed and estimated soil water contents in the Ap, Bt, 2Bt, and C horizons in a Kalamazoo loam soil subjected to CT treatment during the growing season of 1991.

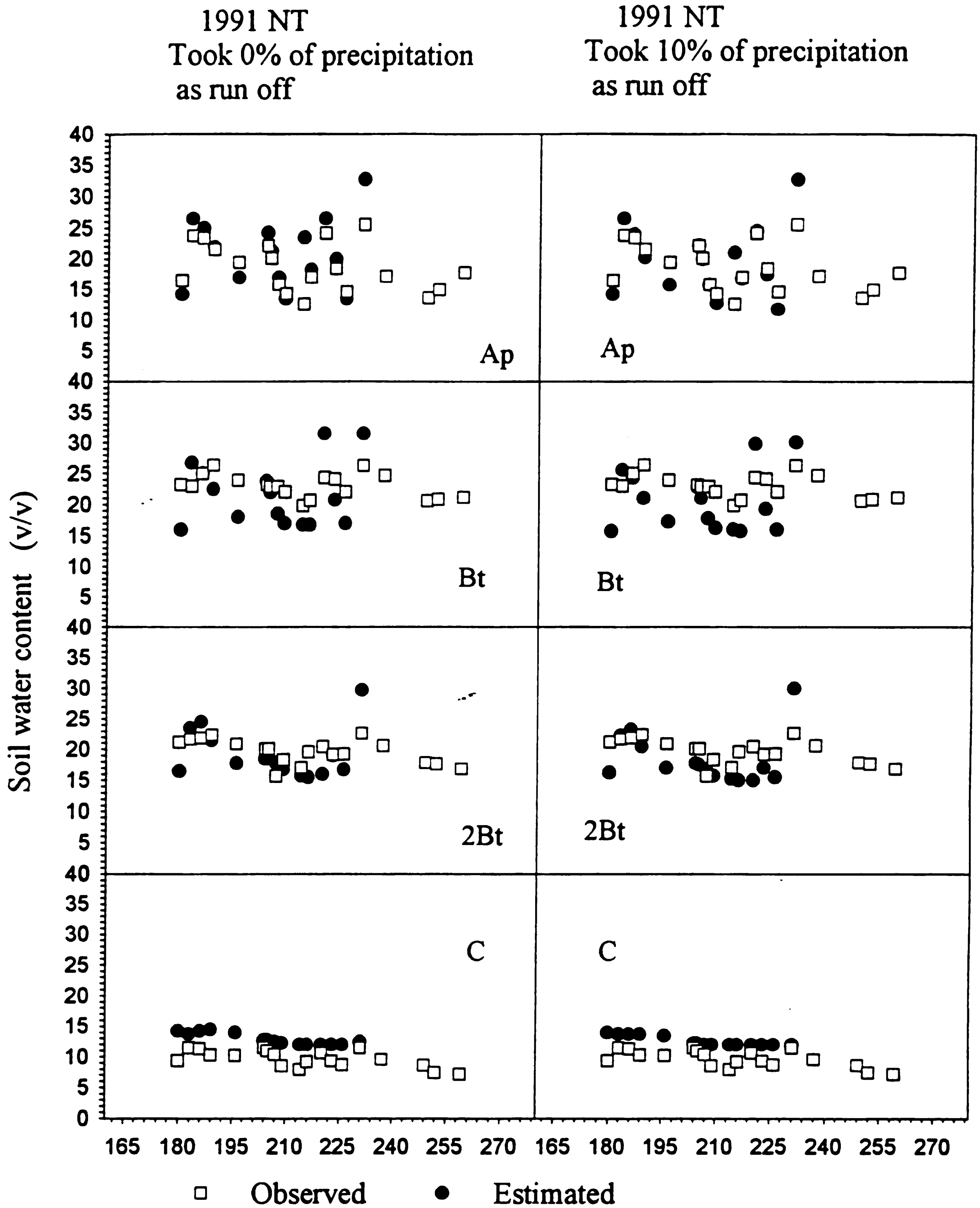

Figure 4.5. Observed and estimated soil water contents in the Ap, Bt, 2Bt, and C horizons in a Kalamazoo loam soil subjected to NT treatment during the growing season of 1991.

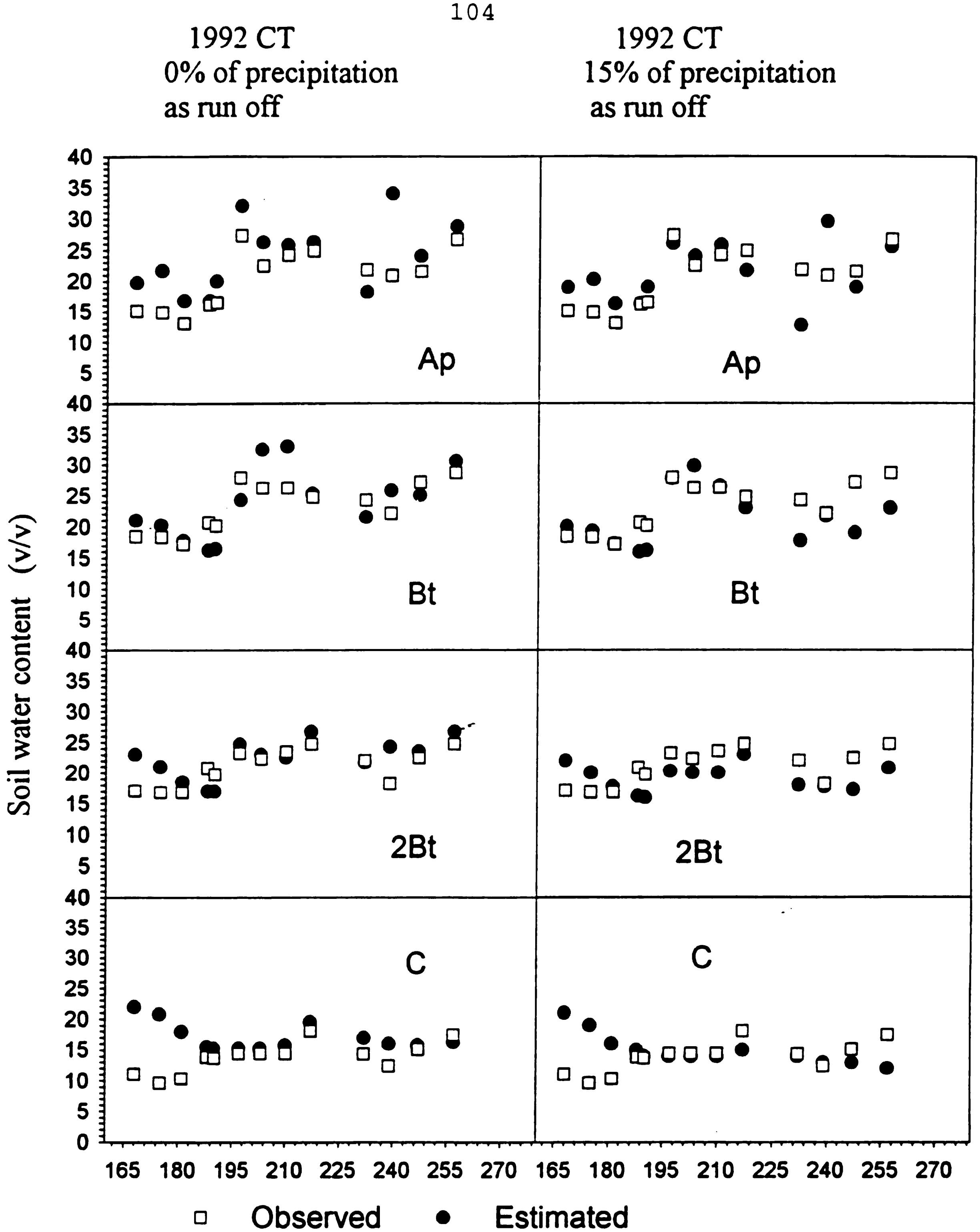

Figure 4.6. Observed and estimated soil water contents in the Ap, Bt, 2Bt, and C horizons in a Kalamazoo loam soil subjected to CT treatment during the growing season of 1992.

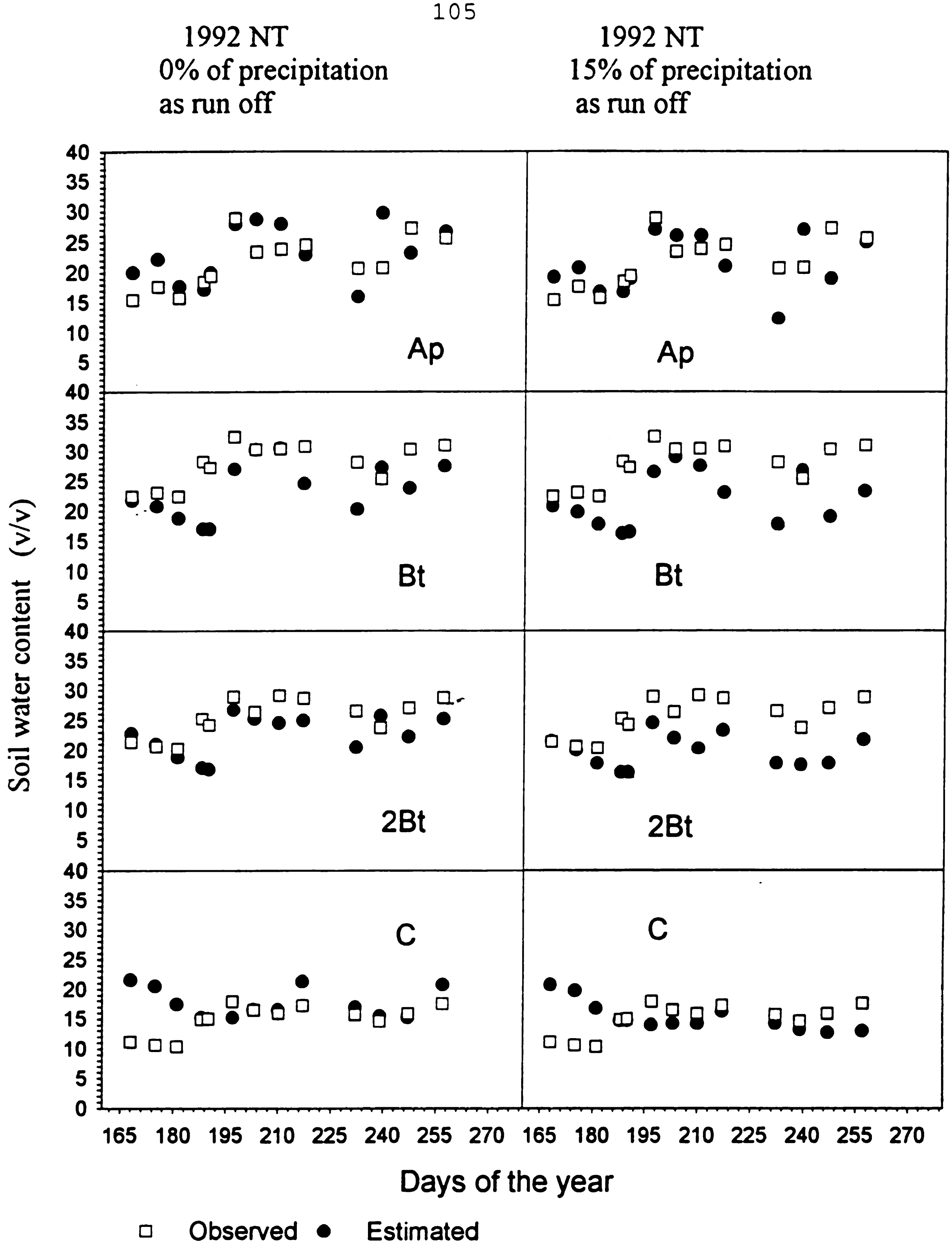

Figure 4.7. Observed and estimated soil water contents in the Ap, Bt, 2Bt, and C horizons in a Kalamazoo loam soil subjected to NT treatment during the growing season of 1992.

Table 4.3. Monthly precipitation 30-year average, average monthly temperature, and days of rainfall at KBS for 1991 and 1992.

	1991	1992	30-year	1991	1992	1991	1992
	---- Rainfall ----			Rain days		Temp.	
May	43.2	19.3	78.0	10	9	10.3	6.7
Jun.	22.9	22.4	84.0	6	6	17.9	14.1
Jul.	127.5	140.5	98.0	8	15	21.5	17.0
Aug.	122.6	72.6	74.0	7	9	22.0	19.5
Sep.	44.2	115.1	76.0	11	12	22.0	18.2
Oct.	2.8	54.1	77.0	1[1]	8[1]	15.3	15.5

[1] The data were the total rain days in October 1-20.

and August in 1991 were 30% and 66% greater than the 30-year average, all the precipitation occurred during eight and seven day periods during these two months (Table 4.3). Excessive amounts of rainfall during these few days may have resulted in surface water losses by runoff, especially from the soil surface of CT treatments. The amounts of rainfall in June and September were lower than the 30-year average resulting in lower water supplies to the soil. Greater air temperature from June - September of 1991 (Table 4.3) may have contributed to greater evapotranspiration rates, resulting in lower soil water contents within the root zone. If the infiltration rates of the higher amounts of rainfall were reduced by tillage, then the greater removal of water from the soil profile by greater air temperatures, could have intensified the adverse effects of tillage on soil water contents.

The rainfall in June of 1992 was lower than the 30-year mean (Table 4.3), reducing the supply of water to the soil. The rainfall for July, August and September was equal or higher than average for 30 years and was more uniformly distributed across 15, 9 and 12 day periods, respectively. More uniformly distributed rainfall combined within lower monthly temperatures, 2.57-4.45 degrees C lower than in 1991 (Table 4.3), could reduce the evapotranspiration, resulting in high soil water contents for 1992.

Corn yield responses to tillage treatments varied between years because there were different soil water contents altered by different precipitation patterns and temperature. Although there were excellent seed germination and emergence, the yield of corn under CT treatment in 1991 was lower than that under NT treatment because the lower soil water contents in CT treatment seams the primary factor to reduce the yield. Therefore, plants grown in NT treatment suffered less impact from water deficit and brought higher yield under NT than CT treatment.

Modification of Predictions

Predictions of maize yields did not show many differences between tillage treatments in both years before adjusting the precipitation. Infiltration of water into soil used by CERES-Maize model is calculated as the difference between precipitation and runoff. However, the procedure used to calculate runoff is the Curve Number Technique (Soil Conservation Service, 1972) which uses only total precipitation in a calendar day. Rainfall duration and intensity are ignored. Since daily-incremented weather data was utilized with the model, it was assumed that the same amount of precipitation infiltrated the soil under similar amounts of precipitation, even though there are different rainfall durations and intensities. Moreover, the model estimated similar infiltration for both tillage and no-tillage systems, although it has been reported that conventional tilled soils usually have lower infiltration rates than NT soils (Kanwar, 1991; Meek et al. 1992;). The different infiltration rates between CT and NT is significant when the rainfall intensity is large. Since the water content under CT treatment was lower than NT in 1991, we assumed that there was more runoff of rainfall from CT soil during the growing season of 1991. Therefore a greater percentage of the precipitation was withheld from the model and presumed to be run off for the CT. Consequently, predicted yields after the adjustments in precipitation, for 1991 corresponded well with the observed data. These results indicate that soil water availability was the main factor which affected yields in 1991.

Modifying precipitation did not affect the prediction of yields in 1992, suggesting that water was not the main factor which influenced yields in 1992. Greater soil water contents after June 6, 1992, indirectly indicated that much more rainfall infiltrated the soil surface instead of running off, because the total amount of precipitation in the growing season in 1992 was nearly the same as that for 1991. Lower air temperature and radiation in 1992 (Appendix I and II) should be combined as factors causing these prediction errors in 1992.

Prediction of soil water contents

The soil water content predictions were fairly accurate for the Bt and 2Bt horizons, but there were over estimations in the Ap and C horizons when soil natural water contents were low. Since the infiltration of water is calculated daily, it will be over estimated when the rainfall intensity is large. However, the soil water content will be low under large rainfall intensity due to more water runoff. Therefore the model over estimated the soil water content under those conditions.

Tillage manipulations increased soil crusting and density of the surface soils resulting in reduced infiltration rates by the CT treatment. (Meek et al. 1992; Meek et al. 1989; Burch et al. 1986). Therefore, soil profiles in the NT contained greater soil water contents than CT soils (Hang and Smucker, 1995). This variance, altered by tillage manipulation, was most evident in the top soils, so that the predicted amounts of water were greater in the Ap horizons especially under CT treatment. Since the model over estimated soil water contents in Ap horizon, more water was expected to accumulate in C horizon than the observed data especially when the soil water contents in C horizon were low. Over estimates in Ap and C horizons were larger for CT than NT treatments because CT naturally contained less water than in NT soils. The differences between observed and estimated data (where the soil water contents were over estimated) were somewhat reduced after adjusting the total amount of precipitation that entered the soil.

When predicted soil water contents did not match observed soil water contents, a significant contributing factor was that the model did not consider the dynamics of root depth or density. In the CERES model, a root weighing factor (no unit) was the only parameter which required in input using to account for root variances in each soil depth. Root growth did not change with water, nitrogen stress or any other environmental stress factors. Root growth dynamics are difficult to measure and may therefore represent the difference in the ability to accurately predict soil water content (Ritchie, 1985). Errors in soil water content predictions subsequently caused inaccurate nitrogen distribution predictions (data not show here), which influenced predictions of crop growth and ultimately the estimates of crop yield.

CONCLUSIONS

Yields of the corn crop appeared to be directly related to soil water. Soil moisture variations caused by precipitation patterns and tillage manipulation were evaluated by simulating modifications in rainfall infiltration. These adjustments were significant for the accurate predictions of yields in both conventional tillage and no-tillage practices in 1991, when soil water contents were lower. Under the similar amounts of precipitation within a year, tillage and no-tillage soils contained different soil water contents due to the different capacities for intercepting rainfall. In different years with different precipitation patterns, soil water content varied even under same tillage treatment. As a result, soil water deficit occurred in conventionally tilled soils when soil profiles contained less water, 1991. The negative feedback was to reduce crop production.

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SUMMARY AND CONCLUSIONS

Weather has been known to be an important factor which alters the effects of tillage on crop growth. This study was designed to investigate the effects of conventional tillage (CT) and no-tillage (NT) on crop growth for different growing seasons. The responses of roots, shoots, and yields were different in two years due to variations in soil water contents and associated nitrogen concentrations in soil solution. Soil water content and nitrogen distribution responses to tillage and no-tillage varied in different years as a result of different precipitation patterns.

Volumetric soil water contents were 5%-10% higher for NT than for CT treatments, in 1991. This difference may have resulted from higher infiltration through the greater number of interconnected macropore networks within the soil profile, and less evaporation resulting from the coverage of soil surface by the residues under the no tillage treatment (Beven and Germann, 1982; Blevins et al., 1971; Larson et al., 1978; Blevins et al. 1983). The lower soil water contents for both tillage treatments in 1991, suggested greater runoff in 1991 than in 1992, as these two years had similar total amount of precipitation during the two growing seasons but different precipitation patterns. Nitrogen concentration in solution was influenced by soil water content. During 1991, the nitrogen concentration was high in CT soil because only less water was extracted by suction lysimeters from these soil profiles; eventually no water was extracted in the late season. However, the nitrogen concentration in NT soil was uniformly distributed since there was a relatively uniform water content across the NT soil profile. In 1992, the nitrogen concentration decreased quickly from 70 DAP, at the time when soil water increased and remained consistently high for the rest of the growing season. Nitrogen concentrations in NT soils decreased more rapidly and maintained at lower concentrations than the CT soils for that period of time. Consequently, NT soils lost an estimated about 31% nitrogen by leaching and CT soils lost approximately 12% nitrogen from the root zone during the 40-130 DAP period of the growing season in 1992.

Reductions in soil water content greatly altered root distribution patterns. Roots in CT soil grew deeper in 1991 than in NT soil especially during periods when soil water decreased to lower levels because roots tended to grow into deeper soil horizons containing optimum water. Deeper root growth, late in the 1992 season for both tillage treatments probably due to the low soil strength after a long period of high soil water content. There were 73-100% more roots in NT soil than that in CT soil for both years. The root dynamics, which was defined the net increase or decrease in root numbers, presumably by the root growth or death, showed the differences between CT and NT treatment only when the soil water contents were lower. The differences of root dynamics between these two treatment occurred at the middle and late season of 1991 and the beginning season of 1992.

Soil water contents also influenced shoot growth and nitrogen uptake.

Reduced soil water contents for CT soils in 1991 reduced nitrogen absorption by CT plants. Less nitrogen decreased shoot growth rates and the accumulation of dry matter. Although nitrogen concentrations in soil water were higher, it was not taken up efficiently due to the presence of water deficit which reduce the supply of mineral nutrients (Marschner, 1988). This is further demonstrated by the decreased plant nitrogen in NT corn, during 1992, where high soil water contents in the soil profile increased the potential of nitrate leaching and decreased the nitrogen uptake efficiency.

The responses of corn growth to CT and NT treatments were fluctuating in this study. The observations of this study lead to the conclusion that the effects of tillage and no-tillage on corn growth are mostly dependent on soil water content and nitrogen availability that are altered by the interaction of climatic conditions and tillage manipulations. No-tillage soils retained more water than tillage soils which are significant for areas where rainfall is limited and irrigation is nonexistent. In humid climates, no-tillage causes greater nitrogen losses to ground water which can either pollute the environment or reduce nitrogen uptake efficiency. The effects of tillage on maize growth were nonlinear and oscillated with time because the tillage modifications of soil water content and nitrogen distribution were influenced by external factors such as the amount of precipitation or the precipitation patterns, which varied from year to year. Fluctuations were more evident in CT soil than in NT soil, suggesting that soil physical and chemical properties within NT systems appear to be more stable and favorable for belowground and corn shoot growth, especially during periods of soil water deficits.

The prediction of yield by CERES-Maize model was soil water related in 1991. Soil water variations caused by the interaction of precipitation patterns and tillage manipulations were evaluated by adjusting infiltration of rainfall. Since there was a significant difference in soil water contents between CT and NT treatments, it can be assumed that greater differences of infiltration existed between CT and NT. Under the same amount of precipitation in 1991, tillage and no-tillage soils maintained different soil water contents suggesting NT soil had higher infiltration rates than CT soils. However, the higher water contents in 1992 for both tillage treatments than in 1991, suggested that even the same tillage system had different water contents due to different infiltration rate under different precipitation patterns. As the result, water deficit would occur in tilled soil in dry years or nitrate leaching occurred in no-tilled soil during wet years. The negative feedback was the reduction of crop production. Root systems are important in water flux, solute transport and partitioning within a plant. It is necessary to account for them when predicting water, solute distribution in fields, and the crop production.

Conclusions for this study include:

1. No-tillage maintained higher volumetric soil water contents than CT.

2. Different water content and nitrogen distribution responses to tillage and no-tillage resulted from variations in precipitation patterns and temperatures.

3. Soil solution nitrogen contents were influenced by soil water content and tillage manipulations.

4. Root number were greater at all depth in NT soils than in CT soils.

5. Roots were deeper in CT when soil water contents were low.

6. Shoot growth and nitrogen accumulation rates in plants were lower for CT soils than for NT soils, when soil water contents were low. Whereas shoot growth was delayed in NT soils when soil water contents were high in a cooled year, 1992.

7. Yields were greater in NT treatments than in CT treatments when soil water was low.

8. Nitrate leaching from root zone was greater from NT soils than from CT soils under higher soil water contents in 1992.

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Appendix I

Initial and boundary conditions for CERES-Maize model v2.10 simulation of soil-plant interactions in Kellogg Biological Station in 1991.

Loc	Yr	Day	SR	Tmax	Tmin	prec.
MSKB	91	121	12.75	12.7	7.4	3.3
MSKB	91	122	24.90	13.4	4.5	0.0
MSKB	91	123	26.21	16.1	1.2	0.0
MSKB	91	124	20.79	17.1	6.4.	0.0
MSKB	91	125	4.20	14.4	6.9	4.1
MSKB	91	126	4.33	13.1	5.6	0.0
MSKB	91	127	20.65	13.0	4.3	0.0
MSKB	91	128	12.76	15.8	4.0	0.0
MSKB	91	129	27.59	24.9	7.5	0.0
MSKB	91	130	26.16	26.0	9.9	0.0
MSKB	91	131	22.38	27.8	11.8	0.0
MSKB	91	132	24.13	29.5	16.9	0.0
MSKB	91	133	22.36	29.7	15.6	2.5
MSKB	91	134	26.32	29.1	15.9	0.0
MSKB	91	135	29.08	31.6	11.7	0.0
MSKB	91	136	21.96	30.3	16.4	10.4
MSKB	91	137	14.52	22.8	6.6	2.0
MSKB	91	138	19.05	15.5	6.0	0.0
MSKB	91	139	28.95	21.6	7.2	0.0
MSKB	91	140	27.88	26.1	8.6	0.0
MSKB	91	141	24.85	28.3	11.3	0.0
MSKB	91	142	20.23	29.0	15.9	0.0
MSKB	91	143	11.99	25.3	19.7	0.3
MSKB	91	144	17.58	27.6	20.0	0.0
MSKB	91	145	9.16	25.3	19.7	2.0
MSKB	91	146	16.07	25.5	20.9	2.3
MSKB	91	147	24.52	28.6	20.5	0.0
MSKB	91	148	25.99	31.3	20.7	0.0
MSKB	91	149	20.93	31.1	22.0	0.0
MSKB	91	150	24.47	29.6	19.6	8.4
MSKB	91	151	24.23	29.7	19.4	7.9
MSKB	91	152	19.83	29.5	17.7	0.0
MSKB	91	153	19.31	25.7	17.6	11.9
MSKB	91	154	26.99	27.3	14.0	0.0
MSKB	91	155	30.64	19.7	9.4	0.0
MSKB	91	156	24.31	21.3	8.8	0.0
MSKB	91	157	28.40	24.5	8.6	0.0
MSKB	91	158	23.09	25.6	13.2	0.0
MSKB	91	159	27.23	28.0	12.0	0.0
MSKB	91	160	24.11	28.1	12.2	0.0
MSKB	91	161	17.94	26.5	16.6	0.0
MSKB	91	162	13.91	24.3	17.4	2.5
MSKB	91	163	28.79	27.5	16.1	1.5
MSKB	91	164	28.58	27.4	11.9	0.0

MSKB	91	165	24.89	30.8	16.1	0.0
MSKB	91	166	17.36	30.6	18.8	4.6
MSKB	91	167	17.34	29.4	24.1	0.0
MSKB	91	168	31.11	27.7	13.3	4.9
MSKB	91	169	26.22	27.7	15.5	0.0
MSKB	91	170	29.13	29.4	16.6	0.0
MSKB	91	171	29.08	32.3	17.4	0.0
MSKB	91	172	27.48	33.1	17.1	0.0
MSKB	91	173	4.24	16.7	13.4	0.8
MSKB	91	174	30.97	23.2	10.6	1.5
MSKB	91	175	26.33	26.8	11.2	0.0
MSKB	91	176	27.37	29.8	16.1	0.0
MSKB	91	177	27.58	31.3	17.2	0.0
MSKB	91	178	24.14	31.3	20.4	0.0
MSKB	91	179	24.67	30.4	20.3	0.0
MSKB	91	180	25.57	32.2	22.1	0.0
MSKB	91	181	24.72	28.5	17.6	0.0
MSKB	91	182	19.73	29.5	17.4	45.7
MSKB	91	183	25.01	28.9	19.4	0.0
MSKB	91	184	27.62	28.9	19.2	18.5
MSKB	91	185	23.86	26.2	18.3	0.0
MSKB	91	186	28.54	26.7	18.3	0.0
MSKB	91	187	23.84	31.9	16.8	0.0
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MSKB	91	189	27.49	25.4	16.5	0.0
MSKB	91	190	26.79	25.2	11.3	0.0
MSKB	91	191	24.45	27.9	14.5	0.0
MSKB	91	192	27.99	27.9	15.5	0.0
MSKB	91	193	10.84	26.5	18.6	5.8
MSKB	91	194	9.77	23.1	16.3	3.1
MSKB	91	195	27.49	26.0	15.0	0.0
MSKB	91	196	28.01	28.3	12.6	0.0
MSKB	91	197	24.82	29.5	14.0	0.0
MSKB	91	198	21.62	29.4	18.9	0.0
MSKB	91	199	23.28	31.3	20.3	0.0
MSKB	91	200	26.31	32.8	21.2	0.0
MSKB	91	201	22.84	32.5	23.5	0.0
MSKB	91	202	15.48	29.8	21.3	10.9
MSKB	91	203	17.05	32.3	21.5	27.9
MSKB	91	204	27.96	25.7	16.5	0.0
MSKB	91	205	25.65	25.4	15.5	0.0
MSKB	91	206	26.54	23.4	13.8	0.0
MSKB	91	207	24.22	23.0	11.0	0.0
MSKB	91	208	27.04	27.8	9.1	0.0
MSKB	91	209	20.17	25.0	15.0	0.0
MSKB	91	210	3.94	17.2	15.0	10.2
MSKB	91	211	21.92	23.3	14.4	0.0
MSKB	91	212	25.87	27.7	12.7	0.0
MSKB	91	213	27.40	30.0	17.2	0.0
MSKB	91	214	20.00	31.6	16.1	14.2
MSKB	91	215	8.81	31.6	18.3	0.0
MSKB	91	216	21.43	24.4	13.8	0.0

MSKB	91	217	23.30	23.8	10.5	0.0
MSKB	91	218	25.32	26.1	11.6	0.0
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MSKB	91	220	1.84	26.6	13.8	34.3
MSKB	91	221	22.85	26.1	13.3	0.0
MSKB	91	222	24.38	26.6	12.7	0.0
MSKB	91	223	25.82	27.7	12.7	0.0
MSKB	91	224	23.16	27.7	13.3	0.0
MSKB	91	225	22.42	28.3	13.3	0.0
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MSKB	91	229	12.28	25.5	17.6	2.5
MSKB	91	230	18.06	27.4	14.9	13.5
MSKB	91	231	2.59	17.9	15.6	55.9
MSKB	91	232	20.74	25.0	13.4	0.0
MSKB	91	233	22.72	26.8	11.2	0.0
MSKB	91	234	21.12	29.2	16.1	0.0
MSKB	91	235	23.84	26.2	12.9	0.0
MSKB	91	236	23.29	28.3	15.0	0.0
MSKB	91	237	22.19	32.0	14.5	0.0
MSKB	91	238	21.28	32.1	17.7	0.0
MSKB	91	239	21.74	31.4	18.9	0.0
MSKB	91	240	21.77	33.8	19.1	0.0
MSKB	91	241	14.98	33.5	19.0	0.3
MSKB	91	242	15.72	31.8	20.1	0.5
MSKB	91	243	20.97	25.1	12.2	0.0
MSKB	91	244	22.82	24.8	9.5	0.0
MSKB	91	245	22.56	28.3	8.5	0.0
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MSKB	91	250	19.15	30.0	13.8	0.0
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MSKB	91	252	17.43	31.6	18.3	12.7
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MSKB	91	254	18.38	26.6	9.4	11.4
MSKB	91	255	7.94	21.3	12.9	1.5
MSKB	91	256	8.31	22.8	15.3	0.5
MSKB	91	257	6.05	25.5	15.2	1.5
MSKB	91	258	15.67	30.5	21.0	0.0
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MSKB	91	262	10.65	16.1	7.2	0.0
MSKB	91	263	12.08	13.3	5.0	0.0
MSKB	91	264	19.77	17.2	1.1	0.0
MSKB	91	265	6.11	17.7	1.6	2.0
MSKB	91	266	15.33	16.6	8.8	1.8
MSKB	91	267	6.79	15.0	5.0	0.0
MSKB	91	268	3.79	13.3	2.7	0.0

MSKB	91	269	13.21	12.7	6.6	0.0
MSKB	91	270	15.54	13.3	1.1	0.0
MSKB	91	271	18.52	17.2	-1.1	0.0
MSKB	91	272	16.51	20.0	-1.6	0.0
MSKB	91	273	15.57	25.5	7.7	0.0
MSKB	91	274	11.92	18.7	8.7	0.0
MSKB	91	275	7.64	22.8	14.3	0.0
MSKB	91	276	12.18	21.8	12.1	0.0
MSKB	91	277	2.02	18.1	10.1	0.0
MSKB	91	278	6.71	16.0	7.0	0.0
MSKB	91	279	5.84	6.6	2.1	0.0
MSKB	91	280	14.74	11.3	3.7	0.0
MSKB	91	281	15.16	20.5	3.9	0.0
MSKB	91	282	14.87	22.3	11.8	0.0

This original precipitation were also reduced to 90% for NT and 65% for CT to run model.

Appendix II

Initial and boundary conditions for CERES-Maize model v2.10 simulation of soil-plant interactions in Kellogg Biological Station in 1992.

Loc	Yr	Day	SR	Tmax	Tmin	prec.
MSKB	92	121	23.09	29.0	8.4	0.0
MSKB	92	122	17.31	23.4	9.3	0.0
MSKB	92	123	11.24	11.4	6.1	0.0
MSKB	92	124	14.07	12.1	1.8	0.3
MSKB	92	125	18.71	12.9	0.7	0.0
MSKB	92	126	26.25	16.8	1.1	0.0
MSKB	92	127	26.00	21.8	1.7	0.0
MSKB	92	128	24.56	22.4	3.2	0.0
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MSKB	92	130	20.49	26.0	6.7	0.0
MSKB	92	131	21.75	28.5	13.7	0.0
MSKB	92	132	14.84	27.3	16.1	1.8
MSKB	92	133	21.30	22.2	7.0	2.5
MSKB	92	134	15.13	17.8	6.6	0.0
MSKB	92	135	24.67	24.9	3.2	0.0
MSKB	92	136	25.56	27.8	8.9	0.0
MSKB	92	137	16.51	28.3	15.0	1.5
MSKB	92	138	22.04	19.3	8.1	0.0
MSKB	92	139	27.33	26.6	5.4	0.0
MSKB	92	140	26.31	29.5	7.8	0.0
MSKB	92	141	22.97	29.7	12.6	0.0
MSKB	92	142	18.41	30.0	16.3	0.8
MSKB	92	143	4.65	21.5	4.8	4.3
MSKB	92	144	9.46	7.7	0.6	0.0
MSKB	92	145	17.64	14.7	-1.4	2.0
MSKB	92	146	11.13	14.0	2.9	2.3
MSKB	92	147	23.72	19.4	0.6	0.0
MSKB	92	148	26.79	23.3	1.6	0.0
MSKB	92	149	24.94	23.4	4.2	1.0
MSKB	92	150	2.79	12.8	9.9	6.9
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MSKB	92	152	24.22	24.3	7.5	0.0
MSKB	92	153	28.00	27.8	7.0	0.0
MSKB	92	154	26.86	27.4	9.5	0.0
MSKB	92	155	6.73	22.2	13.9	0.8
MSKB	92	156	11.10	23.9	15.3	4.3
MSKB	92	157	18.13	26.7	13.8	0.0
MSKB	92	158	25.19	23.9	11.0	5.6
MSKB	92	159	25.37	24.6	9.2	0.0
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MSKB	92	163	27.69	31.0	10.6	0.0
MSKB	92	164	27.06	32.7	11.5	0.0

MSKB	92	166	15.94	24.9	14.1	0.0
MSKB	92	167	25.22	29.4	11.1	0.0
MSKB	92	168	19.72	34.9	17.1	0.5
MSKB	92	169	18.06	26.0	16.9	5.8
MSKB	92	170	12.43	16.9	9.3	0.0
MSKB	92	171	10.30	15.3	6.5	0.0
MSKB	92	172	27.24	17.5	4.8	0.0
MSKB	92	173	23.18	21.7	2.7	0.0
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MSKB	92	176	23.60	24.3	8.8	0.0
MSKB	92	177	25.28	23.3	10.9	0.0
MSKB	92	178	28.34	22.5	7.9	0.0
MSKB	92	179	28.31	27.8	5.7	0.0
MSKB	92	180	26.01	30.6	14.1	0.0
MSKB	92	181	24.54	30.6	13.7	0.0
MSKB	92	182	23.18	34.4	14.9	0.0
MSKB	92	183	16.53	31.2	17.0	0.0
MSKB	92	184	14.15	24.4	15.0	0.3
MSKB	92	185	20.82	27.0	14.1	8.4
MSKB	92	186	26.16	23.5	13.4	0.0
MSKB	92	187	23.75	25.6	9.9	0.0
MSKB	92	188	21.94	27.0	10.0	0.0
MSKB	92	189	9.40	27.5	17.5	7.1
MSKB	92	190	15.13	25.4	18.8	0.0
MSKB	92	191	14.71	25.9	16.4	0.0
MSKB	92	192	21.34	29.6	14.3	0.0
MSKB	92	193	9.50	26.2	18.9	8.4
MSKB	92	194	5.05	20.2	16.5	17.0
MSKB	92	195	4.20	22.0	14.4	23.9
MSKB	92	196	12.29	23.4	13.6	0.5
MSKB	92	197	10.16	24.3	12.7	0.0
MSKB	92	198	17.54	27.4	17.7	4.8
MSKB	92	199	18.27	27.4	12.9	0.0
MSKB	92	200	13.62	23.6	14.0	0.0
MSKB	92	201	27.40	22.4	8.6	0.0
MSKB	92	202	11.91	22.7	11.3	0.8
MSKB	92	203	3.84	15.2	11.6	17.5
MSKB	92	204	11.97	23.5	15.0	0.0
MSKB	92	205	11.60	24.2	14.4	0.0
MSKB	92	206	12.65	26.0	17.7	2.8
MSKB	92	207	24.67	24.8	12.4	0.0
MSKB	92	208	21.97	27.4	12.2	0.3
MSKB	92	209	21.78	25.4	12.6	0.0
MSKB	92	210	3.17	17.2	13.1	18.3
MSKB	92	211	15.49	22.7	12.1	30.0
MSKB	92	212	24.13	24.9	11.6	0.0
MSKB	92	213	13.40	24.6	15.1	0.0
MSKB	92	214	17.17	25.1	13.5	0.0
MSKB	92	215	19.78	23.2	10.9	0.0
MSKB	92	216	23.26	25.9	9.4	0.0
MSKB	92	217	24.47	27.0	9.6	0.0

MSKB	92	218	17.76	25.8	10.7	1.5
MSKB	92	219	12.11	23.9	17.5	18.5
MSKB	92	220	22.53	31.4	17.5	0.0
MSKB	92	221	22.15	31.0	19.0	0.5
MSKB	92	222	23.36	24.6	11.9	0.0
MSKB	92	223	6.75	19.3	10.4	4.6
MSKB	92	224	14.67	20.5	11.5	0.0
MSKB	92	225	15.31	20.4	10.3	0.0
MSKB	92	226	18.10	21.7	12.0	0.0
MSKB	92	227	24.10	24.7	9.1	0.0
MSKB	92	228	23.41	26.0	7.49	0.0
MSKB	92	229	7.92	22.3	11.7	1.5
MSKB	92	230	21.00	22.7	8.8	0.0
MSKB	92	231	24.67	25.2	7.0	0.0
MSKB	92	232	23.58	26.8	7.3	0.0
MSKB	92	233	21.59	27.6	9.1	0.0
MSKB	92	234	16.69	28.2	14.4	0.0
MSKB	92	235	17.75	30.7	18.8	0.0
MSKB	92	236	16.18	30.7	19.3	9.4
MSKB	92	237	9.54	26.1	16.9	0.5
MSKB	92	238	26.15	17.7	13.4	26.2
MSKB	92	239	12.72	18.9	9.1	9.9
MSKB	92	240	16.77	20.9	8.6	0.0
MSKB	92	241	20.33	21.7	15.8	0.0
MSKB	92	242	20.39	22.1	10.4	0.0
MSKB	92	243	21.07	25.1	8.5	0.0
MSKB	92	244	4.74	19.9	13.8	4.1
MSKB	92	245	16.40	24.4	11.9	7.1
MSKB	92	246	21.43	25.0	9.2	0.0
MSKB	92	247	15.33	26.9	12.1	0.0
MSKB	92	248	13.62	28.4	17.4	5.1
MSKB	92	249	11.35	28.4	17.6	0.0
MSKB	92	250	18.70	21.0	7.2	5.3
MSKB	92	251	2.85	20.2	7.1	37.9
MSKB	92	252	17.87	18.7	9.8	0.3
MSKB	92	253	19.46	20.3	8.4	0.0
MSKB	92	254	17.40	22.1	6.4	0.0
MSKB	92	255	18.67	23.7	9.5	0.0
MSKB	92	256	16.19	27.7	14.5	0.0
MSKB	92	257	11.67	29.2	18.3	8.4
MSKB	92	258	13.10	26.8	19.1	0.0
MSKB	92	259	10.25	26.6	19.8	0.0
MSKB	92	260	9.13	21.8	10.2	14.5
MSKB	92	261	16.33	17.5	6.0	0.0
MSKB	92	262	13.97	20.3	4.2	4.6
MSKB	92	263	4.92	23.8	13.4	11.7
MSKB	92	264	16.67	17.0	3.3	0.0
MSKB	92	265	18.86	15.5	1.1	0.0
MSKB	92	266	18.14	20.2	3.8	0.0
MSKB	92	267	18.26	22.4	5.0	0.0
MSKB	92	268	4.51	19.2	8.7	5.6
MSKB	92	269	16.48	17.6	8.5	10.7

MSKB	92	270	15.64	14.9	3.0	0.0
MSKB	92	271	16.96	14.3	0.1	0.0
MSKB	92	272	15.20	17.8	1.4	0.0
MSKB	92	273	16.52	22.2	4.9	0.0
MSKB	92	274	16.23	24.0	9.2	0.0
MSKB	92	275	15.72	25.9	11.4	0.0
MSKB	92	276	15.57	19.6	5.9	0.0
MSKB	92	277	16.58	18.1	3.0	0.0
MSKB	92	278	16.33	20.3	0.8	0.0
MSKB	92	280	13.53	21.5	1.8	0.0
MSKB	92	281	4.72	18.3	5.8	6.0
MSKB	92	282	5.25	11.9	7.3	2.0

This original precipitation were also reduced to 90% and 85% to run model.

Apeendix III

Soil input file

```
 55  Conv.Till     Kalamazoo loam, mixed, mesic Typic Hapludalf
000.13   7.0 000.1   85.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   28. 00.150 00.280 00.410 00.240 00.500  1.45  2.60 15.0 10.0  6.5
   25. 00.170 00.290 00.420 00.270 00.350  1.60  1.70 10.0 20.0  6.5
   20. 00.170 00.290 00.420 00.290 00.200  1.60  0.90 10.0 20.0  6.5
   20. 00.120 00.240 00.350 00.240 00.150  1.60  0.90 10.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.050  1.60  0.80 11.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.060  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.030  1.60  0.40 10.0 10.0  6.5
   -1.
 56  Conv.Till     Kalamazoo loam, mixed, mesic Typic Hapludalf
000.13   7.0 000.1   85.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   19. 00.150 00.280 00.410 00.240 00.500  1.45  2.60 15.0 10.0  6.5
   40. 00.170 00.290 00.420 00.270 00.350  1.60  1.70 10.0 20.0  6.5
   20. 00.170 00.290 00.420 00.290 00.200  1.60  0.90 10.0 20.0  6.5
   20. 00.120 00.240 00.350 00.240 00.150  1.60  0.90 10.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.050  1.60  0.80 11.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.060  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.030  1.60  0.40 10.0 10.0  6.5
   -1.
 57  Conv.Till     Kalamazoo loam, mixed, mesic Typic Hapludalf
000.13   7.0 000.1   85.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   26. 00.150 00.280 00.410 00.240 00.500  1.45  2.60 15.0 10.0  6.5
   15. 00.170 00.290 00.420 00.270 00.350  1.60  1.70 10.0 20.0  6.5
   20. 00.170 00.290 00.420 00.290 00.200  1.60  0.90 10.0 20.0  6.5
   20. 00.120 00.240 00.350 00.240 00.150  1.60  0.90 10.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.050  1.60  0.80 11.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.060  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.030  1.60  0.40 10.0 10.0  6.5
   -1.
 58  Conv.Till     Kalamazoo loam, mixed, mesic Typic Hapludalf
000.13   7.0 000.1   85.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   25. 00.150 00.280 00.410 00.240 00.500  1.45  2.60 15.0 10.0  6.5
   14. 00.170 00.290 00.420 00.270 00.350  1.60  1.70 10.0 20.0  6.5
   23. 00.170 00.290 00.420 00.290 00.200  1.60  0.90 10.0 20.0  6.5
   20. 00.120 00.240 00.350 00.240 00.150  1.60  0.90 10.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.050  1.60  0.80 11.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.060  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.030  1.60  0.40 10.0 10.0  6.5
   -1.
 59  No Till       Kalamazoo loam, mixed, mesic Typic Hapludalf
000.13   9.0 000.6   78.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   23. 00.150 00.290 00.420 00.240 00.950  1.50  2.60 15.0 10.0  6.5
   12. 00.170 00.290 00.420 00.270 00.850  1.60  1.70 10.0 20.0  6.5
   20. 00.170 00.290 00.420 00.290 00.650  1.60  0.90 10.0 20.0  6.5
   20. 00.120 00.240 00.350 00.240 00.400  1.60  0.80 11.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.250  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.100  1.60  0.40 10.0 10.0  6.5
   30. 00.040 00.150 00.350 00.150 00.050  1.60  0.40 12.0 10.0  6.5
   -1.
 60  No Till       Kalamazoo loam, mixed, mesic Typic Hapludalf
```

```
000.13   9.0 000.6   78.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   19. 00.150 00.290 00.420 00.200 00.900  1.50  2.90 20.0 10.0  6.5
   18. 00.170 00.290 00.420 00.270 00.850  1.60  1.70 10.0 20.0  6.5
   11. 00.170 00.290 00.420 00.290 00.650  1.60  0.90 10.0 20.0  6.5
   20. 00.120 00.240 00.350 00.240 00.400  1.60  0.80 11.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.250  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.100  1.60  0.40 10.0 10.0  6.5
   30. 00.040 00.150 00.350 00.150 00.050  1.60  0.40 12.0 10.0  6.5
   -1.
 61  No Till      Kalamazoo loam, mixed, mesic Typic Hapludalf
000.13   9.0 000.6   78.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   25. 00.150 00.290 00.420 00.200 00.900  1.50  2.90 20.0 10.0  6.5
   10. 00.170 00.290 00.420 00.270 00.850  1.60  1.70 10.0 20.0  6.5
   21. 00.170 00.290 00.420 00.290 00.650  1.60  0.90 10.0 20.0  6.5
   20. 00.120 00.240 00.350 00.240 00.400  1.60  0.80 11.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.250  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.100  1.60  0.40 10.0 10.0  6.5
   30. 00.040 00.150 00.350 00.150 00.050  1.60  0.40 12.0 10.0  6.5
   -1.
 62  No Till      Kalamazoo loam, mixed, mesic Typic Hapludalf
000.13   9.0 000.6   78.00  10.0  17.0 1.0 2.67E-3   58.0   6.68
0.03  1.00
   20. 00.150 00.290 00.420 00.200 00.900  1.50  2.90 20.0 10.0  6.5
   12. 00.170 00.290 00.420 00.270 00.850  1.60  1.70 10.0 20.0  6.5
   10. 00.170 00.290 00.420 00.290 00.650  1.60  0.90 10.0 20.0  6.5
   22. 00.120 00.240 00.350 00.240 00.400  1.60  0.80 11.0 20.0  6.5
   20. 00.070 00.180 00.350 00.180 00.250  1.60  0.40 10.0 20.0  6.5
   30. 00.040 00.150 00.350 00.150 00.100  1.60  0.40 10.0 10.0  6.5
   30. 00.040 00.150 00.350 00.150 00.050  1.60  0.40 12.0 10.0  6.5
   -1.
```