This is to certify that the

thesis entitled

THE EFFECT OF TILLAGE METHOD AND FERTILIZATION ON THE YIELD AND ELEMENTAL COMPOSITION OF CORN AND SOYBEANS

presented by

William H. Darlington

has been accepted towards fulfillment
of the requirements for

M.S. degree in Soil Science

Maurice L. Vitosh
Major professor

Date June 8, 1983

O-7639

*MSU is an Affirmative Action/Equal Opportunity Institution*

# THE EFFECT OF TILLAGE METHOD AND FERTILIZATION ON THE YIELD AND ELEMENTAL COMPOSITION OF CORN AND SOYBEANS

By

William Henry Darlington

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Science

1983

ABSTRACT

THE EFFECT OF TILLAGE METHOD AND FERTILIZATION ON THE YIELD AND ELEMENTAL COMPOSITION OF CORN AND SOYBEANS

by

William H. Darlington

Corn (Zea Mays L.) and soybeans (Glycine Max. L. Merr) were grown under no-tillage and conventional tillage systems. The effects of two K rates and banded versus broadcast P on yields and nutrient composition of plant and grain samples were determined. Two N rates in the corn study and two soybean varieties were also evaluated.

Corn grain yields were higher in no-till than conventional plots. Soybean yields averaged 4,300 $kg/ha^2$ in both tillage systems although final plant population was 17% lower in no-till. Early N and P uptake was greater in no-till corn than in conventionally tilled corn. Lower N content was observed in no-till ear leaf samples at silking and stover and grain at harvest, particularly at the low N rate. High N increased corn grain and stover yields.

Surface residue in no-till plots had little effect on soil temperatures, soil moisture and corn root distribution. Tillage decreased soil bulk density and increased aeration.

ACKNOWLEDGEMENTS

Sincere gratitude and appreciation is expressed to Dr. M. L. Vitosh for his encouragement, support and constructive criticism during each phase of this project.

Gratitude is expressed to Dr. A. E. Erickson for his suggestions and support during this study.

I sincerely thank Dr. L. S. Robertson and Dr. D. Krauskopf for their assistance on my guidance committee.

To Dallas Hyde and Jon Dahl, for encouragement and invaluable assistance I am deeply grateful.

Thanks are due to Calvin Bricker and Rosie Cabrera for their instruction and assistance in the laboratory and to Mark Collins, Gregg Vanek, Bob Every and many others for their assistance in the field.

Funding was provided by Sohio and the Michigan Soybean Committee.

TABLE OF CONTENTS

LIST OF TABLES

## LIST OF FIGURES

# INTRODUCTION

For more than 100 years, U.S. agriculture has relied upon the moldboard plow, disk and harrow to prepare soil to produce crops (70). Intensive cultivation was needed to control weeds. In the late 1940's selective herbicides were developed; therefore, it became feasible to grow many crops with less tillage or even without tilling the soil.

No-till is a crop production system whereby a crop is planted directly into a seedbed not tilled since harvest of the previous crop (2). Coulters or disk openers are often used on the planter to allow placement and coverage of the seed and fertilizer with soil. Weeds are controlled by chemical herbicides, and soil amendments, such as lime and fertilizer, are applied to the soil surface.

The land area used for row crops and forage crops grown with the no-till system is increasing rapidly. In 1974, the U.S. Department of Agriculture (25) estimated that the acreage of no-till cropland in the United States was 2.2 million hectares. In 1981, an estimated 2.9 million hectares of crops were grown with this system (3). Some authorities predict that 62 million hectares or 45 percent of the total U.S. cropland will be under the no-till system by 2000 (25). In Michigan, 45,507 hectares of corn (*Zea mays* L.) and 5,714 hectares of soybeans (*Glycine max* L. Merr.) were grown in 1982 using no-till accounting for 3.5 and 1.5 percent of the total acreage of these crops, respectively (4,25).

The major advantages of the no-till cropping system are (i) soil erosion caused by wind and water is reduced, (ii) fuel and labor requirements are reduced (73,90), (iii) planting operations can be more timely, particularly in regions were climate allows for double-cropping (19,36,76), and (iv) soil water is conserved because of reduced evaporation and greater infiltration.

There are also several potential problems associated with the no-tillage system (i) heavy residues often cause inadequate or non-uniform stands, (ii) the populations of weeds, disease-producing organisms and rodents may be higher than conventional tillage systems (42,55,56,72,92), (iii) soil temperatures are lower at planting which may delay planting or germination, and (iv) the availability of applied nutrients may be reduced. Special management is required to minimize these problems.

The objectives of this study were (1) to define management practices needed to grow high yields of corn and soybeans with the no-tillage and conventional tillage systems, (2) to evaluate the effects of two tillage system and several fertility treatments on the yield and elemental composition of corn and soybeans, and (3) to determine the differences in physical and chemical properties of the soil as affected by two tillage systems.

# LITERATURE REVIEW

## Tillage Systems

No-till soils differ physically, biologically and chemically from conventionally tilled soils. The differences between no-till and coventionally tilled soils can significantly affect yield, nutrient uptake and fertilizer efficiency. Researchers have tried to identify soil properties affecting yield, nutrient uptake and fertilizer efficiency under no-till systems and to develop management practices to maximize these parameters.

Much of the current literature dealing with tillage contains terminology that is inconsistent and incomplete. The following tillage systems terms, defined by the Soil Science Society of America (2), will be used in this report.

> **conventional tillage**-The combined primary and secondary tillage operations normally performed in preparing a seedbed for a given geographical area.
>
> **minimum tillage**-The minimum soil manipulation necessary for crop production or meeting tillage requirements under the existing soil and climatic conditions.
>
> **no-tillage**-A crop production system whereby a crop is planted directly into a seedbed not tilled since harvest of the previous crop.
>
> **reduced tillage**-A tillage sequence in which the primary operation is performed in conjunction with planting procedures in order to reduce or eliminate secondary tillage operations.

## Soil Properties Affected by Tillage and Crop Residue

The soil physical properties of no-till soils are often markedly different than conventionally tilled soils. Soil moisture, soil temperature, bulk density, porosity and soil structure are affected by tillage practices and residue management. The magnitude of the differences in soil physical properties and the effects of these differences on crop growth and yield depend on the soil type, climatic conditions, the type and degree of soil manipulation by tillage and the type and amount of residue left on the soil surface.

### Soil Moisture

The quantity and distribution of water in the soil profile is affected by tillage practices and residue management. No-till fields generally have more available water in the surface 30 cm than tilled fields (13,14,22,30,35,39,47,51,87,93,99). The greatest difference occurs in the 0 to 8 cm depth, with no-till soils averaging 15 to 30 percent more water. Below a depth of 60 cm, tillage has little influence on soil moisture. The soil moisture distribution with depth in conventionally tilled soils is normally characterized by the lowest soil moisture values at the surface and increasing moisture with depth. No-till soils have high moisture values near the surface decreasing with depth until a high clay content region is reached (13). Moisture retention values are often higher in no-till soils (47). Little data is available on the moisture characteristics of no-till soils under irrigation.

The surface residue associated with no-till systems promotes moisture conservation. Surface residue in no-till fields acts as an insulator to reduce moisture loss by direct evaporation during the early growing period (13,14,35,39,87,93). Infiltration is greater in no-till soils because of the surface mulch (13,14,30,47,93). The mulch dissipates the energy of the raindrops and decreases dispersion and surface sealing. The presence of undisturbed but decaying plant roots may form root channels that serve as avenues for water infiltration into the soil (13). In some studies greater earthworm activity has also led to high infiltration rates in no-till plots (31,47). Increased infiltration reduces surface runoff from no-till soils. Moisture retention is increased by changes in organic matter content and differences in the structure and texture of the surface horizon.

No general statement can be made about the effect of soil moisture characteristics of no-till soils on corn growth and yield, since growth and yield responses depend on soil type and climatic conditions. On soils with low water holding capacities increased yields from no-till compared with plowing have been reported in Virginia, Kentucky and southern Illinois (49). On these soils, decreased evaporation under no-till and the greater ability of the soil to store moisture resulted in a moisture reserve in the no-till plots. This moisture reserve can carry the crop through periods of short-term drought without severe moisture stresses developing in the plants. In Ohio and Indiana (49), however, no-till corn was the first to show water stress. In Ohio, the greater wilting in no-till plots was attributed to less available water and in Indiana to either a reduction in root growth or less soil moisture because of reduced infiltration. In Ohio (91), corn yields were increased by no-till on well drained sandy soils, but decreased by 5 to 15 percent on poorly drained soils. Experiences in Minnesota and on poorly drained soils in northern Illinois (49) indicate yields may be reduced by no-till. On poorly drained soils, wet conditions at planting may lead to low aeration unfavorable for germination and seedling development and to increased incidence of disease.

## Bulk Density and Soil Aeration

The effect of continuous no-till corn production on soil compaction is not clear. Virginia workers (78) found that after 6 years of continuous no-till and conventional corn production, there was no significant difference in soil compaction between the two tillage systems. Researchers in Kentucky (15) found that after 5 years, no-till and conventional tillage treatments had nearly identical bulk density values at the 0 to 8 cm depth. Many researchers, however, have found higher levels of soil compaction in no-till fields. Gantzer, however, (30) found bulk densities averaged 10 percent higher within the surface 30 cm under no-till compared to conventional tillage. Bulk density differences due to tillage were not significant at depths greater than 30 cm. As the growing season progressed, the differences in surface bulk density between types of tillage were reduced because of increased densities under conventional tillage. Others have reported an increase in bulk densities under no-till (15,21,60,81). Bulk density increases with no-till are also supported by penetrometer data (44,60).

Increased soil bulk densities can reduce yields by reducing root proliferation and changing root morphology (33). Increasing bulk density can also decrease the air-filled porosity and thus cause soil aeration problems.

Air-filled porosities of surface samples are frequently lower in no-till soils. Gantzer (30) found that after 6 years of continuous no-till corn production on a clay loam soil, air-filled porosities of surface samples were lower under no-till than under conventional tillage at all water potentials measured. At -100 mb tension, no-till surface samples averaged 14 percent air-filled porosity compared to 20 percent for conventional tillage. After 3 years of no-till production in Michigan, A. E. Erickson (personal communication) found that air-filled porosities at -60 mb tension averaged 17 percent for plowed plots compared to 9 percent for no-till plots in a sandy loam soil. On a loam soil, conventional plots averaged 15 percent air-filled porosity compared to 10 percent for no-till plots. Baeumer and Bakermans (5) have cited several researchers who found air-filled porosities of less than 10 percent at -100 mb tension with no-till on fine and medium textured soils.

Air-filled porosity of 10 percent is a lower limit for most common crops which are grown on drained land (100). Below this value oxygen diffusion is severly restricted and aeration conditions become unfavorable for germination and seedling development. Low yields in poorly-drained no-till fields in Minnesota and northern Illinois (49) were attributed to poor aeration conditions.

## Soil Aggregation

No-till and minimum tillage systems help to maintain and improve soil structure as evidenced by greater aggregation. Beale, Nutt, and Peele (9) compared plowed versus minimum tillage plots for 10 years.

Soil aggregation in the surface 15 cm layer was substantially higher in minimum tillage plots than in plowed plots. Free (29) found higher aggregate stability in minimum tilled plots compared to conventionally tilled plots. In Indiana (18), minimum tillage resulted in more water-soluble aggregates than conventional tillage treatments. These results were attributed to the increased breakdown of aggregates due to conventional tillage rather than an improvement in aggregation in minimum tillage plots (20,82). Residues can protect soil aggregates from direct impact of raindrops, and reduce slaking. As a result, soil crusting is less of a problem in no-till systems (42,43,76).

Soil Temperature

Crop residues on the soil surface usually reduce soil temperatures when compared to soils without surface cover. Residues reduce soil temperatures as a result of reflection of solar energy, insulation of the soil surface and the greater heat capacity of the soil beneath the residue due to increased moisture. Studies in Kentucky (13) showed daytime maximum temperatures at a depth of 5 cm between 2.7 and 5.5 degrees (C) cooler while nighttime minimum temperatures averaged between 1.2 and 4.0 degrees warmer under no-till compared to adjacent tilled plots. These effects were magnified if a heavy mulch or a period of extremely dry weather occurred. After corn seedlings reached sufficient height to shade between the rows, no differnces in temperature were observed between no-tillage and conventional tillage. In Minnesota, Larson et al. (49) predicted that residue remaining from a6,300 kg/ha corn crop reduces the 10 cm soil temperature by about 1.1 degrees (C), or about 0.4 degrees for each ton of residue. Lower temperatures under crop residues have been reported in many other locations (32,47,67). In northern areas the lower soil temperatures may inhibit germination and early growth (49). In southern climates and the tropics, however, lower soil temperatures have little affect on yield (13,47).

Effect of Residues on Yields

Differences in corn yields between no-till and conventional systems are related to to the amount and type of mulch cover. In Ohio (49), on a crusting silt loam with no residue cover, no-till corn yields were less than a conventional treatment. With a complete mulch cover, yields from no-till were greater than plowed treatments. The no-till corn yield advantage was greater following a fescue sod than corn because the sod resulted in a better mulch cover. On a silty clay loam, the amount of mulch cover or the type of tillage had no effect on yield. In Kentucky (13), yields were lower in treatments with a rye cover crop than in treatments with no cover crop because vigorous growth of the cover crop in the Spring prior to being chemically killed removed some of the water reserve. In Delaware (59), eight cover crops, killed before planting, were evaluated for no-tillage corn production. Treatments consisted of combinations of spring oats (Avena sativa L.),hairy vetch (Vicia villosa Roth), crimson clover (Trifolium incarnatum L.), winter rye (Secale creale L.) and annual ryegrass (Lolium multiflorum Lam.). A surface mulch resulted in higher corn yields. Yields were generally higher under leguminous covers than beneath rye because of better stands, higher soil temperatures and increased available nitrogen. In Nigeria (47), crop rotation in no-till was required to maintain adequate residue on the surface and to maximize yields. Crops that did not leave a significant amount of residue on the soil surface could not be grown continuously without soil physical properties seriously deteriorating..

## Nitrogen Transformations as Affected by Tillage and Residue

The physical, biological, and chemical characteristics of no-till soils as compared to plowed soils explain the lower availability of N to plants under reduced tillage. Nitrogen availability is reduced because of more rapid downward movement of nitrate, lower rates of nitrification and mineralization, greater rates of N immobilization and greater losses of N through denitrification and volatilization. Reduced evaporation from the soil surface and increased water infiltration in no-till soils leads to increased water movement through the soil profile. Nitrate-nitrogen moves with the percolating water and is leached from the surface horizons. Thomas, et al. (87) found about half the nitrate-nitrogen was lost from the surface 15 cm of soil under a surface mulch, and a 50 percent gain in nitrate-nitrogen with conventional tilled soil. The higher soil moisture content in the no-till soils may have also led to increased denitrification and less mineralization of N (72).

The tillage system may indirectly alter nitrogen availability by altering the microbial populations of the soil. Doran (21,22) has studied the soil microbial and biochemical changes associated with reduced tillage. He concluded that the changes in the physical characteristics of the surface of no-till soil compared to plowed soil result in large increases in all microbial groups in the qurface 7.5 cm of no-till soils. This increase is a result of higher moisture and organic matter content in the surface of no-till soils. Deeper in the soil (7.5 to 15 cm), aerobic organism populations are 25 to 51 percent lower with no-till than with plowing. Facultative anaerobes and denitrifers occur in greater numbers and represent a greater proportion of the total microbial population in no-till soils than in plowed soils. Consequently, the potential rate of mineralization and nitrification is higher with conventional tillage, while the rate of denitrification is higher with no-till. The increase in microorganism population in the surface 7.5 cm of no-till soil leads to an increase in immobilization of 20 to 70 kg N/ha over plowed soils (8,11). Thus, a greater proportion of the fertilizer N, applied to the surface of no-till soils will be tied up in microbial cells.

Lindeman et al. (52) studied the effects of tillage on soybean nodulation, acetylene reduction and seed yield. The no-till treatments had higher nodulation and acetylene reduction values than conventional tillage treatments early in the season and lower values in the last half of the season. Cumulative acetylene reduction and nodule weight was not affected by tillage. Yields were significantly lower in no-till treatments primarly due to weed competition.

In addition to the potential for increased leaching, immobilization and denitrification, the potential for ammonia volatiliization is high in no-till corn production. There is greater potential for volatilization in no-till systems because: (1) N fertilizers are usually not incorporated; (2) N is often applied in solutions as a broadcast spray; and (3) organic matter accumulation and increased biological activity of the soil surface may stimulate urease activity, insuring rapid enzymatic breakdown of urea (87). Researchers attribute the decreased efficiency of surface applied urea to volatilization (8,27,86,88). Fox and Hoffman (27) found that as much as 35 percent of surface applied urea is lost through this process.

## Fertilizer Use Efficiency as Affected by Tillage and Surface Residues

### N-Rate Studies

Several potential N problems exist in no-till production. Early studies concentrated on the effect of N rate on yield, N uptake and N efficiency. Triplett and Van Doren (89) conducted one of the first no-till N fertilizer studies. Nitrogen as ammonium nitrate was applied to the soil surface at 67, 134 and 268 kg N/ha. The nitrogen was incorporated in plowed plots but left on the surface of no-till plots. Grain yields were higher for corn grown on the untilled treatments all 6 years of the study. Yields increased with the second increment of nitrogen on the untilled treatments but not on the conventional treatments. Nitrogen concentration of plant leaves was not affected by tillage method.

Moschler, Marten and Shear (64,65) and Legg (51) also obtained equivalent or higher yields under no-till as compared to conventional tillage when moisture was adequate. These studies showed equivalent or increased N recovery (N uptake plus soil N) under no-till as compared to conventional tillage. N recovery increases were primarily due to increases in organic N in the surface soil of the no-till treatments (15,62).

The relative efficiency of N in no-till versus conventional treatments depends on the level of N fertilization. Moschler and Marten (62) observed lower N efficiencies on no-till treatments than on coventional tillage treatments at low N rates (67.3 and 201.8 kg N/ha). At a high N rate (470 kg N/ha), however, they observed lower N efficiency on the conventional treatments.

Moncrief and Schulte (60) observed similar responses to N fertilizer. At low rates of broadcast N, corn yields and N uptake were less under no-till than under moldboard and chisel systems. At high rates, the differences in yield and N uptake decreased among the three tillage systems. At the highest N rate (336 kg/ha), yield and N uptake were higher on no-till treatments at several locations.

Bandel et al. (7) applied N to tillage treatments at rates of 0,45,90,135 and 180 kg N/ha. At suboptimal N rates, N deficiency symptoms were more severe on no-till plots than on plowed plots. However, the optimal rate for maximum corn yields was similar for both tillage methods. No differences due to tillage were observed in the N status of the soil.

## N-Source Studies

Ammonium nitrate was commonly used in early no-till fertility research because it is relatively non-volatile. Ammonium nitrate, however, is not the most commonly used N source in most corn-producing areas. Therefore, much research has been conducted to determine the influence of nitrogen source on N efficiency in no-till systems. Moschler and Jones (61) in Virginia and Bandel et al. (8) in Maryland compared the relative effectiveness of surface-applied ammonium nitrate, urea and urea-ammonium nitrate solution (UAN). Moschler and Jones observed that on both fertile and infertile soils, ammonium nitrate, urea and UAN were equally effective per unit of N applied. The two years of the experiment were relatively wet. Rainfall shortly after planting minimized volatilization losses from urea and UAN.

Bandel et al. (8) noted a distinct relationship between rainfall and the effectiveness of urea and UAN. At Poplar Hill, little differences between ammonium nitrate, urea and UAN was observed. Bandel attributed this to significant rainfall shortly after N application. At Wye Institute and Forage Research Farm ammonium nitrate was the most effective source during years when rainfall did not occur in the first few days after N application. UAN treatments in most cases slightly out-yielded urea treatments.

Fox and Hoffman (27) in Pennsylvania conducted experiments similar to Bandel et al. Ammonium nitrate, urea, UAN and ammonium sulfate were applied at five rates to no-till corn plots. Yields and N uptake were highest for ammonium nitrate and ammonium sulfate and lowest with UAN and urea. Fox and Hoffman postulated the following relationship between rainfall and the effectiveness of urea and UAN:

1. There was insignificant $NH_3$ volatilization loss from unincorporated urea fertilizers if at least 10 mm of rain fell within 48 hours after fertilizer application.
2. If 10 mm or more rain fell 3 days after the urea was applied, volatilization losses were slight (<10%).
3. If 3 to 5 mm of rain fell within 5 days after the urea was applied, volatilization losses could be moderate (10 to 30%).
4. If no rain fell within 6 days, the loss could be substantial (>30%).

Fox and Hoffman also recorded the surface pH for the 5 years of the study. The pH in the surface 2.5 cm of soil was approximately 5.7 in the plots receiving 202 kg/ha/yr of N as ammonium nitrate, urea or UAN. This pH was one unit lower than a check which had received no N for the 5 years. In plots receiving the same rate of ammonium sulfate, the soil pH was 4.7 in the 0 to 2.5 cm layer.

N-Placement Studies

Bandel et al. (8) also studied N-placement. Bandel concluded that ". . . for no-tillage, urea or urea solutions should be banded beneath the soil surface." Several studies have indicated that urea and UAN placement methods may affect their performance. Mengel et al. (58) in Indiana found that injecting $NH_3$ or UAN below the surface resulted in higher corn grain yields and higher N content in leaves than surface application of UAN, ammonium nitrate or urea. At a N rate of 165 kg N/ha, injection treatment yields averaged 8,600 kg/ha compared to 7,560 kg/ha for surface-applied treatments. The greater efficiency of subsurface N fertilizer placement was attributed to reduced $NH_3$ volatilization and reduced immobilization of N by soil organisms associated with the surface residues.

Touchton and Hargrove (88) in Georgia also studied the effect of N sources and application methods on corn yield and N uptake. As in previous studies, the order of efficiency of surface-applied nitrogen fertilizers was generally urea<UAN<ammonium nitrate. Three methods of application were evaluated: broadcast spraying, incorporation banding and surface banding. Incorporation banding and surface banding resulted in higher corn yields and N uptake than broadcast spraying. Surface banding of UAN obtained near maximum N efficiency without the additional expense of incorporation or injection.

To reduce leaching and denitrification losses of N, Frye et al. (29) in Kentucky studied the effectiveness of a nitrification inhibitor (nitrapyrin) with surface applied N on no-till corn. Nitrogen fertilizers were applied at yield-limiting rates, and the potential for leaching and denitrification was high. Under these conditions, nitrapyrin sprayed on the surface of ammonium nitrate and urea increased corn yields. The authors suggested two possible explanations for the effectiveness of nitrapyrin in spite of its volatility. First, the method of application resulted in a concentration of $NH_4$ and nitrapyrin in the soil in the immediate vicinity of where the fertilizer fell. Therefore, some nitrapyrin could have volatilized while an adequate amount remained in the soil to inhibit nitrification. Second, the nitrapyrin may have been adsorbed on the mulch cover resulting in decreased volatilization.

## Phosphorus Studies

Large applications of fertilizer and lime cannot be incorporated into the soil in a continuous no-till system. Application of high rates of fertilizer (especially N and K) when banded near the seed can cause injury to seedlings. Therefore, most of the fertilizer must be surface-applied in no-till systems. Due to the low mobility of P, and to a lesser extent K, concern is often expressed about the ability of crops to utilize surface applied P and K.

Movement of broadcast P in the soil profile is slow in no-till systems. In Ohio (89), equal applications of $P_2O_5$ were made over a six-year period on no-tillage and conventional tillage areas. Part of the P was banded and part was broadcast prior to tillage. Phosphorus was uniformly distributed to a depth of 7.5 cm in the row of un-tilled plots, reflecting the annual row application to that depth. Most of the

P remained in the top 2.5 cm between rows on no-till plots with little evidence of downward movement. In the tilled plots, P levels were uniform throughout the plow layer. Many recent studies confirm that most surface applied P remains in the top 7.5 cm in untilled plots (21,40,41,44,48,49,53,62,64,65,78 97).

Some research indicates a higher level of available P under no-tillage conditions (34,44,62,64,65,78). In Virginia, Moschler (62) applied equal applications of P over a three-year period on conventional and no-tillage areas. The available P in the top centimeter of soil was the same for both tillage methods despite 50 percent higher crop removal of P under no-tillage culture. In another study (64), equal applications of P were made over an eleven-year period for two tillage methods. Residual fertility data was obtained by repeated greenhouse cropping using soil from the field experiments. This was followed by testing the soil for pH and acid-extractable nutrients. Considerably more P was recovered in the greenhouse corn from the 0 to 20 cm soil depth when no-tillage soil was used than when conventionally tilled soil was used. Acid extractable P, after greenhouse cropping, was higher in no-tillage soil than conventionally tilled soil. In Ontario, Ketcheson (44) found after 6 years of corn production that P soil tests were higher for no-till than coventional plots when averaged over depth (30 cm). They suggested that there may be higher localized fertilizer concentrations and less P fixation from surface application on the no-till plots.

Plant analysis shows comparable P uptake between tillage systems (10,16,24,26,41,44,45,48,53,60,62,64,65,70,71,78,79,89). Virginia researchers (79) broadcast $P^{32}$ labelled superphosphate in no-till and conventional plots. In both years of the study the total P content of early corn leaves was higher when the P remained on the soil surface. There were no significant differences in P content at the later sample dates. Accumulation of P near the soil surface may be an advantage due to greater plant absorption in early growth stages (26,79,89).

The effectiveness of surface applications of P fertilizers in no-till systems depends on the initial P level in the soil. In soils well supplied with P, yield and plant analysis show no significant difference between banding and surface applications of P fertilizers in no-till systems (10,41,71,89). In Ohio, Johnson (37) and Eckert (23) found that banding P fertilizer 5 cm below and 5 cm to the side of the seed was superior to broadcast P applications on soils with low soil test values for P. Kang and Yunusa (41) indicate that banded treatments are more effective than broadcast application of P at low P rates (<20 kg P/ha) on no-till soils with low soil P levels.

The most common reason given for the availability of surface applied P in no-till is an increase in root activity in the upper soil region. The increased root activity is due to the higher moisture content under the surface mulch. Phillips et al. (69) reported 10 times more corn roots in the top 5.1 cm of soil under no-tillage than under conventional tillage. Kang and Yunusa (41) found a marked increase in root density at the 0 to 10 cm depth with minimum tillage with and without P application. Barber (6) found that tillage affected the depth at which maximum root density and root length occurred. The depths of maximum density and length were 10 to 30 cm for conventional tillage, 5 to 15 cm for chisel plowing and 0 to 10 cm for no-tillage. In general, corn grown under conventional tillage had more roots deeper in the soil than no-tillage. No-tillage treatments had less roots, but those it had were larger in diameter.

Increased moisture in the surface soil of no-till may also improve the diffusion rate of P to the roots which proliferate in that zone. Moncrief and Schulte (60) cite data from Lawton (50) suggesting that poorer aeration conditions in no-till soils may enhance P uptake. Increased earthworm activity in no-till soils may also redistribute P and other nutrients in the profile making them available to a larger number of roots (31,77).

## Potassium Studies

Potassium like phosphorus is fairly immobile in soils. Therefore, K also becomes stratified in no-tillage systems where surface-applied fertilizers are not incorporated (40,44,89,97). Potassium has been shown to move to greater depths than P (26,78,89). The stratification of soil K may lead to an increase in the total amount of available K in the rooting zone (15,44,48).

Stratification of surface-applied K does not reduce the availability of K to crops in no-till systems. In K fertility trials, yield and K uptake are equal or higher with no-till treatments (24,44,48,53,62,65,78,89). In several studies, early uptake of K was higher in no-till plots than in conventional plots (65,78,89).

Some researchers, however, observe that under certain conditions K availability is reduced with minimum tillage. Ketcheson (40) found that K concentration of no-till corn was lower than conventionally grown corn at a low rate of K fertilizer (95 kg K/ha). Moncrief and Schulte (60) found a striking reduction in K availability with no-till. The problem could be partially overcome with row applied K. They felt that poor soil aeration in the no-till plots reduced K uptake. In Ohio, Johnson (37) found that on a soil with low levels of soil K banded application of K fertilizer had a significantly greater response than broadcast K.

The application of N and P fertilizers or lime may influence the uptake of K in no-till corn. Lal (48), Moncrief and Schulte (60) and Lutz (53) observed increased K uptake with increasing P fertility. Lal (48) found that nitrogen fertilization increased the K concentration in corn ear leaves. Estes (24) and Moschler et al. (64) observed a K by Ca by Mg interaction in no-tillage corn studies. Moschler et al. found that high Mg uptake in no-till soils were accompanied by lower K uptake. Estes (24) found that increased K uptake in no-till treatments resulted in reduced Ca and Mg tissue concentrations. The K, Ca and Mg behavior in these studies may reflect cation balance.

## Calcium and Magnesium Studies

There are many contradictions in the literature regarding the availability of Ca and Mg with conservation tillage systems. Juo and Lal (40), Lal (48) and Box et al. (16) observed that no-till treatments maintained a significantly higher level of exchangeable Ca and Mg in the surface 0 to 5 cm. No-till treatments also had higher organic matter contents in the surface layer which led to an increase in CEC. Blevins et al. (15), however, found more exchangeable Ca and Mg in conventional tillage treatments throughout the surface 30 cm in both limed and unlimed plots. Nitrogen fertilization and liming significantly alter the distribution of Ca and Mg in no-till soils (15,63).

Leaf analysis data also suggests that no general statements can be made regarding Ca and Mg availability in no-till soils. Lal (48) and Moschler et al. (65) found that the Ca content of corn ear leaves was equal or higher in no-tillage treatments. Estes (24), however, found significantly lower levels of Ca and Mg in corn leaves under no-till conditions. A study with vegetable crops (45) indicates that Ca concentration is generally lower in no-till than conventional tillage plots at early sampling dates, but equal or higher in no-till plots at later sampling dates. In the same study, tillage system did not affect Mg uptake.

## Soil Acidity and Liming Studies

A gradual increase in soil acidity often accompanies the use of most N fertilizers. Surface applications of N fertilizers quickly lower the surface pH of no-till soils, particularly those which are sandy and have relatively low buffering capacities (15,27,34,40,63,78,84,89,97). Lime placement on the soil surface is effective in no-tillage systems because the soil surface is the zone most likely to become acid. In the few studies conducted to date, there have been no adverse effects on no-till crop yields from surface-applied lime (15,63,78,89). The beneficial effect of liming on corn yields was even more pronounced on untilled than plowed soils in Virginia studies (63,78).

Because of the stratification of pH in no-till soils, standard soil sampling procedures do not accurately represent the pH of the surface soil. Michigan State University Soil Testing laboratory recommends that two samples be collected from no-till fields where surface applications of high rates of nitrogen have been used (57). One sample to a depth of 2 inches is used for pH evaluation and lime recommendations; another sample collected to a standard sampling depth is used for fertilizer recommendations.

There may be a need for more frequent but smaller lime applications to neutralize the surface acidity in no-till systems. Special problems of liming may exist in areas where toxic factors associated with subsoil acidity (e. g., soluble aluminum) restrict root development (34,84). In these situations and in soils with low pH throughout the rooting zone, incorporation of needed lime is desirable before going to no-till (94).

## Micronutrients Studies

Little data is available on the availability of micronutrients in no-till systems. Hargrove et al. (34) observed that Zn and Mn are redistributed by no-tillage with greater concentrations in the surface 7.5 cm. These nutrients are taken up by plants and remain on the soil surface when the crop residues decompose. The extractable Cu levels were similar for all soil depths and tillage treatments. Estes (24) found that the concentration of Zn, Mo, B, and Al in corn leaf tissue was significantly reduced under no-till conditions. He speculated that surface liming adversely affects the availability of Zn and B. No differences have been noted in tissue levels of Fe and Mn between tillage methods (24,48,53). Manganese uptake, however, is often increased with increasing N rate (48,53). The usual methods of adding micronutrients should be equally effective in no-tillage.

# EXPERIMENTAL METHODS

## CORN AND SOYBEAN TILLAGE STUDIES

Corn and soybean field studies were conducted on the Michigan State University Soil Research Farm at East Lansing in 1982. The studies were conducted to evaluate the effects of two tillage systems and several fertility treatments on the yield and elemental composition of corn and soybeans. Soil physical measurements were made to determine what soil factors are influenced by the tillage treatments.

### Experimental Design and Management Practices for Corn

The soil in the corn tillage study was a Capac-Colwood complex. Capac loam is a fine-loamy, mixed, mesic Aeric Ochraqualf which is naturally somewhat poorly drained and Colwood loam is a fine-loamy, mixed, mesic Typic Haplaqualls which is naturally poorly drained. The differences in drainage between the two soils was reduced by installation of tile drainage lines every 17 meters..

The experimental design was a split-plot with four replications. Tillage systems were represented as whole plots and fertilizer treatments as subplots. Plot dimensions were 305 by 1524 cm.

Two tillage systems were evaluated in this study, a conventional system and a no-till system. The conventional system consisted of

Spring moldboard plowing to a depth of 20 cm followed by one pass with a spring-tooth field cultivator. The no-till system involved no primary or secondary tillage. The field had previously been cropped with soybeans. Rye (Secale cereale L.) was drilled after the soybeans were harvested to serve as a cover crop for this study. The rye was killed with Roundup prior to Spring tillage.

Treatments were established to evaluate fertility level and fertilizer placement interactions within the two tillage systems. The treatments consisted of two levels of nitrogen (168 and 336 kg N/ha), two methods of phosphorus placement (broadcasted versus banded) at 56 kg $P_2O_5$/ha and two levels of potassium (56 and 168 kg $K_2O$/ha). The 16 treatments for this study are listed in Table 1a.

Nitrogen was applied at three different times. Ammonium nitrate ($NH_4NO_3$) at a rate of 112 kg N/ha was broadcast to all plots before tillage. The remaining nitrogen was banded at planting (56 kg N/ha as urea) on all plots and top-dressed at the mid-whorl stage (168 kg N/ha as $NH_4NO_3$) on the high nitrogen treatments. Top-dressing consisted of broadcasting $NH_4NO_3$ on both sides of each corn row.

Phosphorus (0-46-0) was either banded at planting or broadcast before tillage. Potassium (0-0-60) was banded at planting at a rate of 56 kg $K_2O$/ha on all plots. In addition, the high potassium treatments received 112 kg $K_2O$/ha broadcast before tillage.

Planting was done on April 30 with a John Deere Max-Emerge planter equipped with fluted coulters. Pioneer 3572 hybrid corn was planted at 76 cm row spacing at a rate of 84,000 seeds per hectare. Planting depth was 3.8 cm. Banded fertilizer was placed 5.1 cm to the side and 5.1 cm below the seed. Fertilizer application rates were adjusted by changing the fertilizer auger speed and size. Lorsban insecticide was applied over the row at 1.5 kg active ingredient (a.i.) per hectare.

Weed control was accomplished with a preemergence application of Atrazine (0.84 kg a.i./ha), Bladex (1.68 kg a.i./ha) and Lasso (2.8 kg a.i./ha). Localized infestations of yellow nutsedge (Cyperus esculentus L.), canada thistle (Cirsium arvense) and velvetleaf (Abutilon theophrasti) were controlled by hand weeding.

Tensiometers were installed to a depth of 31 cm in the row of eight plots and read 3 times a week. Irrigation was initiated when the tensiometers averaged 50 to 60 centibars suction. Water was applied at a rate of 2.5 cm per application five times during the growing season by means of a traveling irrigation gun.

One center row of each plot was hand harvested for grain on October 12, and the other center row was machine harvested for grain on October 18. Stover was hand harvested on October 14 from the row which was hand harvested and then fed through a silage chopper.

## Experimental Design and Management Practices for Soybeans

This study was conducted on a tiled Capac-Celina complex. Capac loam is a fine-loamy, mixed, mesic Aeric Ochraqualf. Celina loam is a fine-loamy, mixed, mesic Aquic Hapludalf. The previously crop was corn.

The experimental design was a split-plot with four replications. Tillage systems were represented as whole plots with fertilizer and variety treatments as subplots. Plot dimensions were 305 X 1524 cm.

The two tillage systems evaluated in this study were a conventional and a no-till system. The conventional system consisted of

Fall chopping of corn stalks and Spring moldboard plowing to a depth of 20 cm followed by two passes with a tandem disk. The no-till system involved chopping the corn stalks, but no primary or secondary tillage.

Treatments were established to evaluate fertility and variety interactions within the two tillage systems. Treatments consisted of two levels of potassium (0 and 56 kg $K_2O$/ha banded at planting), two methods of phosphorus placement (broadcast versus banded) at 56 kg $P_2O_5$/ha and two varieties (Corsoy 79 and SRF-200). The 16 treatments are listed in Table 6a.

Planting was done on May 13, 1982. Narrow row spacing (38 cm) was accomplished by first planting 76 cm rows and then back-planting in between. Seed depth was 3.8 cm; seeding rate was 530,000 plants per hectare. Starter fertilizer consisted of 22.4 kg N/ha as urea on all plots and either 0 or 56 kg $K_2O$/ha (0-0-60) and 0 or 56 kg $P_2O_5$/ha (0-46-0) depending on the treatment. All plots were planted perpendicular to the original corn rows.

Weed control was accomplished with a preemergence application of Lexone (0.42 kg a.i./ha), Amiben (2.24 kg a.i./ha) and Lasso (2.24 kg a.i./ha). Quackgrass (Agropyron repens) was controlled with postemergence spot applications of Fusilade (0.56 kg a.i./ha) plus crop oil concentrate. Hand weeding was required to control yellow nutsedge and mustard (Brassica kaber) in several plots.

Tensiometers were installed to a depth of 30.5 cm in the row of eight plots and read 3 times each week. Irrigation was initiated when the tensiometer readings averaged 55 to 70 centibars suction. Water was applied at a rate of 2.5 cm per application five times during the growing season by means of a traveling irrigation gun.

Benlate fungicide was applied on all plots on August 27 at a rate of 0.84 kg/ha for protection from seed and pod diseases.

All plots were combine harvested on October 27. The middle six rows of each plot were harvested (914 cm X 244 cm).

## Growth and Yield

Growth stages of the corn plants and general visual observations were recorded throughout the growing season. At harvest, grain yields were calculated and adjusted to 15.5 percent moisture. Stover yields were calculated on a dry weight basis. Final plant populations and the percentage of barren stalks were recorded at harvest. The percentage of tall, weak stalks due to late germinating seed was also recorded.

Soybean stand counts were made to determine the effect of tillage and variety on final plant population. Grain yields were measured and adjusted to 13 percent moisture.

## Chemical Analysis

### Soil

Soil samples from the plow layer (0 through 20 cm) and subsoil (20 through 46 cm) were taken from each corn plot in the Fall of 1981. Soybean plots were sampled in the Spring of 1982 to a depth of 20 cm.

All samples were analyzed at the Michigan State University Soil Testing Laboratory. Samples were air dried at room temperature and ground to pass an 18 mesh screen. Soil pH was determined using a 1:1 soil water mixture.

Soil phosphorus was determined by the Bray P-1 method (46). The extracting solution was 0.025 N HCl in 0.03 N $NH_4F$. The reducing agent was amino-napthol-sulfonic acid. Phosphorus concentration in the extract was measured spectophotometrically.

Exchangeable K, Ca and Mg were determined by extraction with 1.0 N $NH_4OAc$ (17). The K, Ca, Mg levels in the extracts were measured on a Technicon autoanalyzer.

Zinc and manganese , extracted with 0.1 N HCl (101), were measured by atomic absorption spectrophotometry.

Percent organic matter of one replication of plow layer samples from the corn study was determined by a Leco carbon analyzer.

Cation exchange capcity was calculated using the equation:

CEC = (ppm Exch. Ca/200) + (ppm Exch. Mg/120) + (ppm Exch. K/390)

The initial nutrient levels of the two fields are shown in Tables 1 and 2. In both fields, pH is adequate; Bray P-1 and exchangeable K are considered high (98); exchangeable Ca and Mg and extractable Zn and Mn levels are typical for these soils at this pH (74,75,95).

## Plant Nutrient Composition

Corn whole plant samples were collected from the border rows of all plots at early whorl stage (June 4). Ear leaf samples were taken from the harvest rows at early silking. Grain and stover samples were stored at harvest. Soybean study, leaf samples were taken at early flowering. The most recently matured trifoliate was taken. Grain samples were also taken from all plots.

All samples were dried in forced air ovens at 60 degrees C for approximately 7 days. Plant samples were ground to pass through a 40

Table 1. Soil test levels for the corn tillage study.

| | | | Exchangeable | | | Extractable | | | Organic |
|---|---|---|---|---|---|---|---|---|---|
| Depth | pH | Bray-P | K | Ca | Mg | Zn | Mn | CEC | matter |
| cm | | ppm | | | | | | me/100 g | % |
| 0-20 | 6.9 | 47 | 111 | 2,303 | 352 | 4.2 | 26.4 | 15 | 3.87 |
| 20-46 | 7.2 | 20 | 85 | 2,078 | 353 | 2.3 | 17.2 | 14 | -- |

Table 2. Soil test levels for the soybean tillage study.

| | | | Exchangeable | | | Extractable | | |
|---|---|---|---|---|---|---|---|---|
| Depth | pH | Bray-P | K | Ca | Mg | Zn | Mn | CEC |
| cm | | ppm | | | | | | me/100 g |
| 0-20 | 6.9 | 54 | 112 | 2,259 | 354 | 3.2 | 51 | 15 |

mesh screen using a Wiley mill. Grain samples were ground to pass through a 20 mesh screen.

Duplicate samples from each plot were digested by a modified version of the wet oxidation procedure described by Parkinson and Allen (68). The digestion solution was prepared by mixing 350 ml of $H_2O_2$, 0.42 g Se powder and 14 g $Li_2SO_4 \cdot H_2O$ in a flat bottomed boiling flask. Concentrated $H_2SO_4$ (420 ml) was added carefully with swirling and cooling.

Plant samples (0.5 g) were weighed into 100 ml round bottom-long neck reflux flasks; 5 ml of digesting mixture were added, and the samples digested on electric heaters for 3 hours. At the end of the digestion, the solutions were allowed to cool and were then diluted to 35 ml with 1000 ppm LiCl.

For nitrogen analysis, a 1.0 ml aliquot of sample solution was pipetted into a 100 ml micro-Kjeldal flask. Ten ml of 1.0 N NaOH and 15 ml distilled water were added and the solution was distilled until 30 ml was collected in a flask containg 5 ml of boric acid (2%) and methyl purple indicator. The samples were titrated with standardized $H_2SO_4$.

Determination of P, K, Ca, Mg, Fe, Zn, Mn, Cu, and Al concentrations were made with a SMI IIIA direct current plasma emmission unit. A one to ten dilution of the digested samples was necessary for the K, Ca and Mg analysis.

## Soil Physical Properties

### Soil Temperature and Moisture

Soil temperature measurements were made in both studies on May 17. Four measurements were made in each tillage whole plot. All measurements were made at 10 cm in depth between 14:00 and 15:00 P.M.

Tensiometers and a neutron probe were used to monitor soil moisture content in each of the 8 tillage whole plots in each study. Tensiometers were installed in the row at a depth of 30 cm and were read 3 times per week. Neutron probe access tubes were installed in the row to a depth of 61 cm. Soil moisture was determined using a Campbell Pacific Nuclear Corporation neutron probe (Model 503 hydroprobe). Readings were taken once a week at 15.2, 30.5 and 45.7 cm depths.

### Percent Residue Cover

Surface residue cover in the soybean study was estimated by the photographic method outlined by Mannering (54). A wood frame with inside dimensions of 76 cm by 51 cm was placed on the soil surface in 6 locations in the no-till areas. Pictures of the frame and residue were taken at each location. The images were projected over a grid and the percent cover was estimated by an intersection procedure.

### Bulk Density and Air-Filled Porosity

Bulk density and air-filled porosity were determined by the methods described by Blake (12) and Vomocil (96). Five undisturbed soil cores were taken from the surface 7.62 cm of soil in each of the tillage whole plots in the corn study on July 1. The cores were saturated, weighed and then placed in a pressure plate apparatus. The soil was subjected sequentially to .01, .02, .03, .04, .06, .1, .33 and 1.0 bar pressure. When water was no longer moving out at a given pressure, the cores were weighed and moved to the next higher pressure. After exposure to 1.0 bar pressure, the cores were oven dried (104 C for 24 hours) and then weighed. Air filled porosity at a given pressure was determined using the equation

$$P_p = \frac{(W_s - W_p) \times 100}{V_b}$$

where

$P_p$ = percent air filled pore space at pressure p

$V_b$ = bulk volume of the core in milliliters

$W_s$ = mass of saturated sample in grams

$W_p$ = mass of sample in grams after drainage at pressure p

## Root Distribution

Root samples were taken on September 14 to determine the effect of tillage system on corn root distribution. A mechanical sampler was used to extract undisturbed soil samples (7.6 cm wide by 25.4 cm long by 61.0 cm deep). One core was taken from each tillage whole plot. Each large sample was divided into 18 subsamples (7,6 by 7.4 by 7.6 cm) with a fractionating cutter. This made it possible to analzye corn root lengths at 6 depths and 3 distances away from the row. The sampling method is described in detail by Srivastava et al. (83).

Subsamples were dispersed by soaking them in water containing 50 g per liter of $(NaPO_3)_6$ for a period of 16 hours. Roots were seperated from the soil by the hydropneumatic elutriation system described by Smucker et al. (80). Root length density was determined for each subsample by the intersection method described by Newman (66).

## Statistical Analysis

Statistical analysis was performed as described by Steel and Torrie (85). Analysis of variance of experimental data was done with a Cyber 750 computer using the Genstat statistical package (1).

# RESULTS AND DISCUSSION

## Field Conditions and Soil Physical Properties as Affected by Tillage

### Field Conditions at Planting

The 1982 growing season was characterized by an extremely warm, dry Spring followed by average temperatures and rainfall in the Summer and Fall. Total rainfall for the corn growing season was 40 cm.

At planting, field conditions varied considerably between tillage systems. In the corn study, the conventional plots were cloddy at planting due to Spring plowing and inadequate secondary tillage. Poor seed-soil contact and extremely dry, compact soil conditions hindered germination in these plots. Better moisture conditions existed in the no-till plots at planting resulting in uniform germination. The percent of late germinating plants in the conventionally tilled plots was more than double that of no-till plots (Table 3). The final plant population and percent barren stalks, however, were not significantly different between the two tillage systems.

In the soybean study, dry, compact soil conditions at planting and an uneven soil surface created by the corn stubble led to non-uniform seed and fertilizer placement in no-till plots. Some seeds remained on the soil surface. As a result, final populations were significantly lower in no-till plots (Table 4). No-till plots averaged 17 percent fewer plants than conventional plots. The loss in population was observed for both varieties. The problem of inadequate seed and

Table 3. Effect of tillage on germination, final corn population and percentage of barren stalks.

| | Late germination | Final corn population | Barren stalks |
|---|---|---|---|
| | % | plants/ha | % |
| Conventional | 16.3 | 77,140 | 3.6 |
| No-till | 7.2 | 79,410 | 2.9 |
| LSD (.05) | (5.0) | (NS) | (NS) |

Table 4. Soybean plant population as affected by tillage and variety.

| | Variety | | | |
|---|---|---|---|---|
| Tillage method | Corsoy 79 | SRF-200 | Mean | LSD (.05) |
| | --plants per hectare-- | | | |
| Conventional | 340,000 | 344,000 | 342,000 | (34,000) |
| No-till | 287,000 | 282,000 | 284,500 | |
| Mean | 313,000 | 313,000 | | |
| LSD (.05) | (NS) | | | |

fertilizer placementcould have been reduced by using a heavier planter equiped with more effective coulters and by planting parallel to the corn rows. Cloddy field conditions could have been avoided by plowing in the Fall when the soil was drier.

## Soil Temperature

Surface residue in the no-till plots did not reduce soil temperatures enough to affect emergence in either study. In the soybean study, 60 percent of the surface of the no-till plots was covered with corn residue; however, soil temperature at planting was only slightly lower in no-till plots (22 C) than in the conventional plots (24 C). Because of the unseasonably high soil temperatures, no differences in time of emergence were observed between the two tillage systems. In the corn study, very little surface cover remained on the no-till plots after the rye cover crop was killed. Unseasonably warm conditions at planting allowed for rapid germination and emergence in the no-till corn plots. In years with cooler Spring temperatures reduced soil temperatures under the surface residue have been found to delay germination and emergence in no-till plots (13,49).

## Soil Moisture

In nonirrigated studies the presence of a surface mulch has been found to significantly affect the soil moisture content and distribution (13,14,35,99). In these irrigated studies, differences in soil water content between the two tillage systems were not evident. Tensiometer readings for the corn and soybean studies are shown in Figure 1 and 2. Only slight differences in tensiometer readings occurred between the two

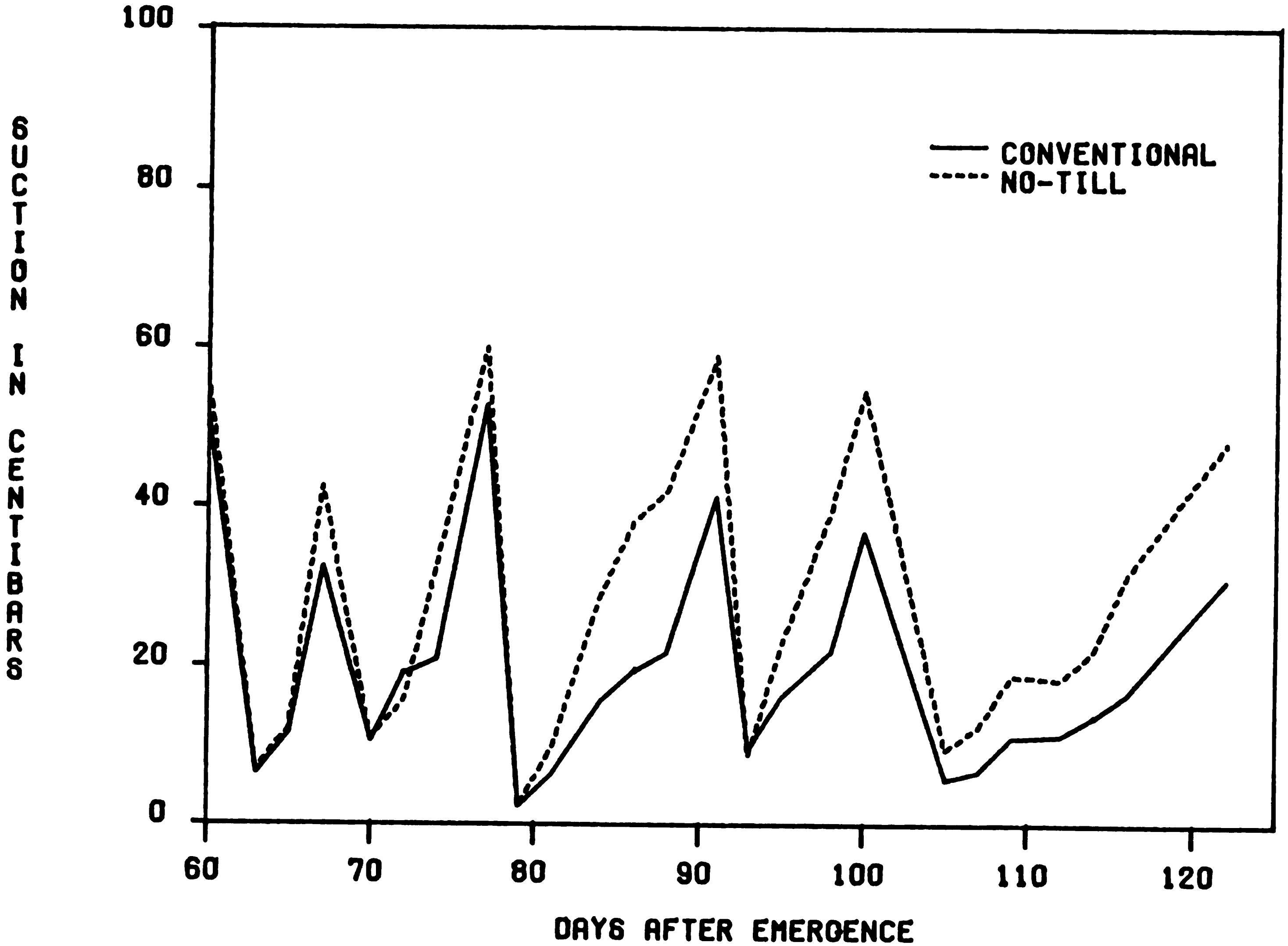


Figure 1. Corn study tensiometer readings at 30 cm as affected by time and tillage.

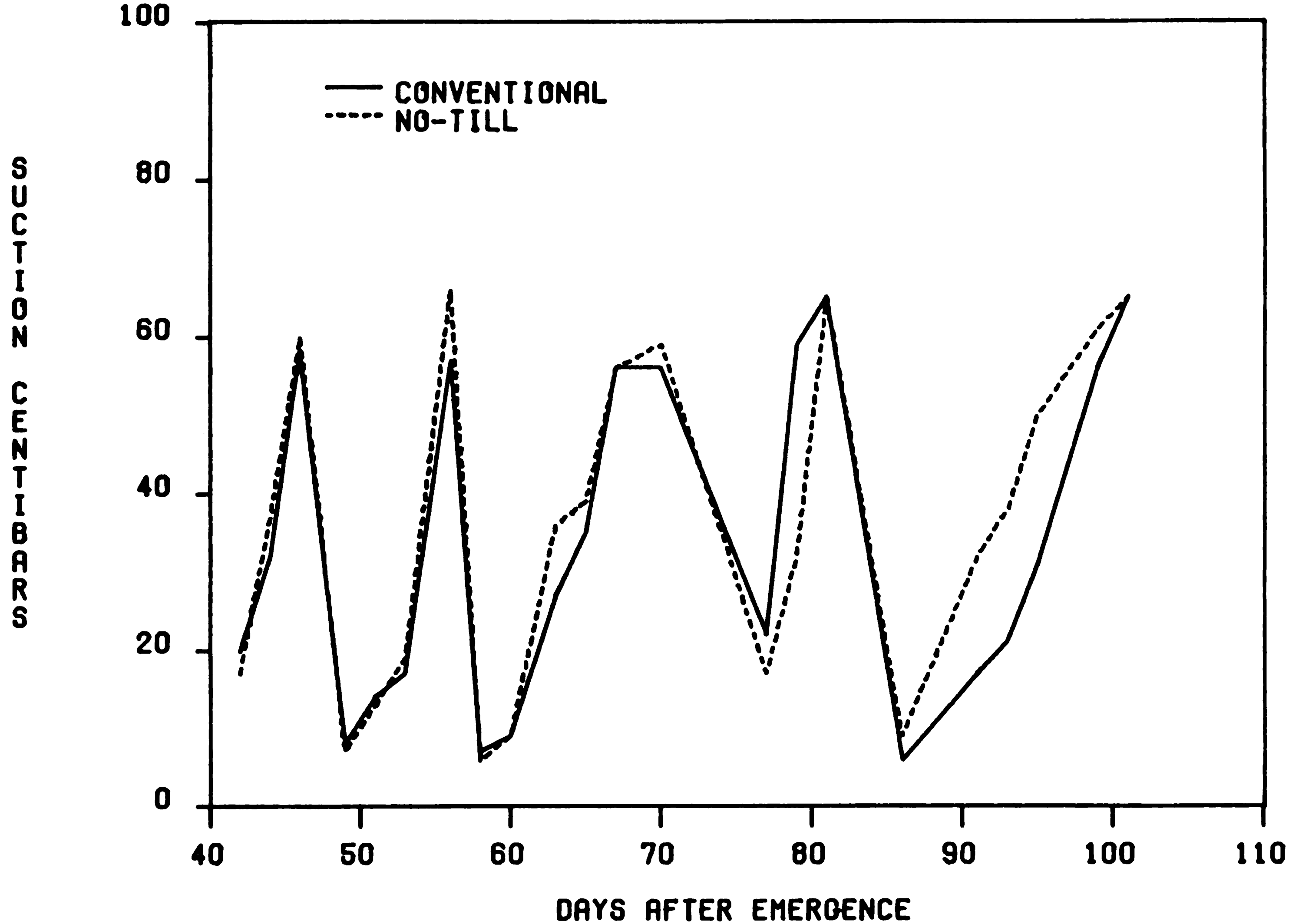


Figure 2. Soybean study tensiometer readings at 30 cm as affected by time and tillage.

tillage systems. Peaks on these figures represent periods of low soil moisture contents. Low suction values occurred after rainfall or irrigation. Tensiometer readings seldom exceeded 60 centibars suction indicating that rainfall and/or irrigation was adequate to avoid extended periods of water stress.

Soil water content as measured by the neutron probe at 15, 30 and 46 cm in depth are shown in Figures 3-8. Fluctuations in soil water content as measured by the neutron probe correspond well to tensiometer readings (Figure 1 and 2). Greater fluctuations in soil water content occurred at the 15 cm depth than at 30 or 46 cm. Soil water content was not significantly affected by tillage method in either study at any of the depths measured.

In both the corn and soybean study, there was a significant interaction between tillage and depth in soil water content. In the corn study (Figure 9) the average soil water content at 15 cm was similar for the two tillage treatments. In conventional plots, the soil moisture at 30 and 46 cm was less than at 15 cm. In no-till plots soil moisture was higher at 46 cm than at 15 and 30 cm. In the soybean study, moisture content in both tillage systems increased slightly with increasing depth (Figure 10) This increase was more pronounced in the conventional treatment than in the no-till treatment. These differences in moisture distribution may be due to differences in root distribution, infiltration, soil variability or water holding capacity in the two tillage systems (6,13).

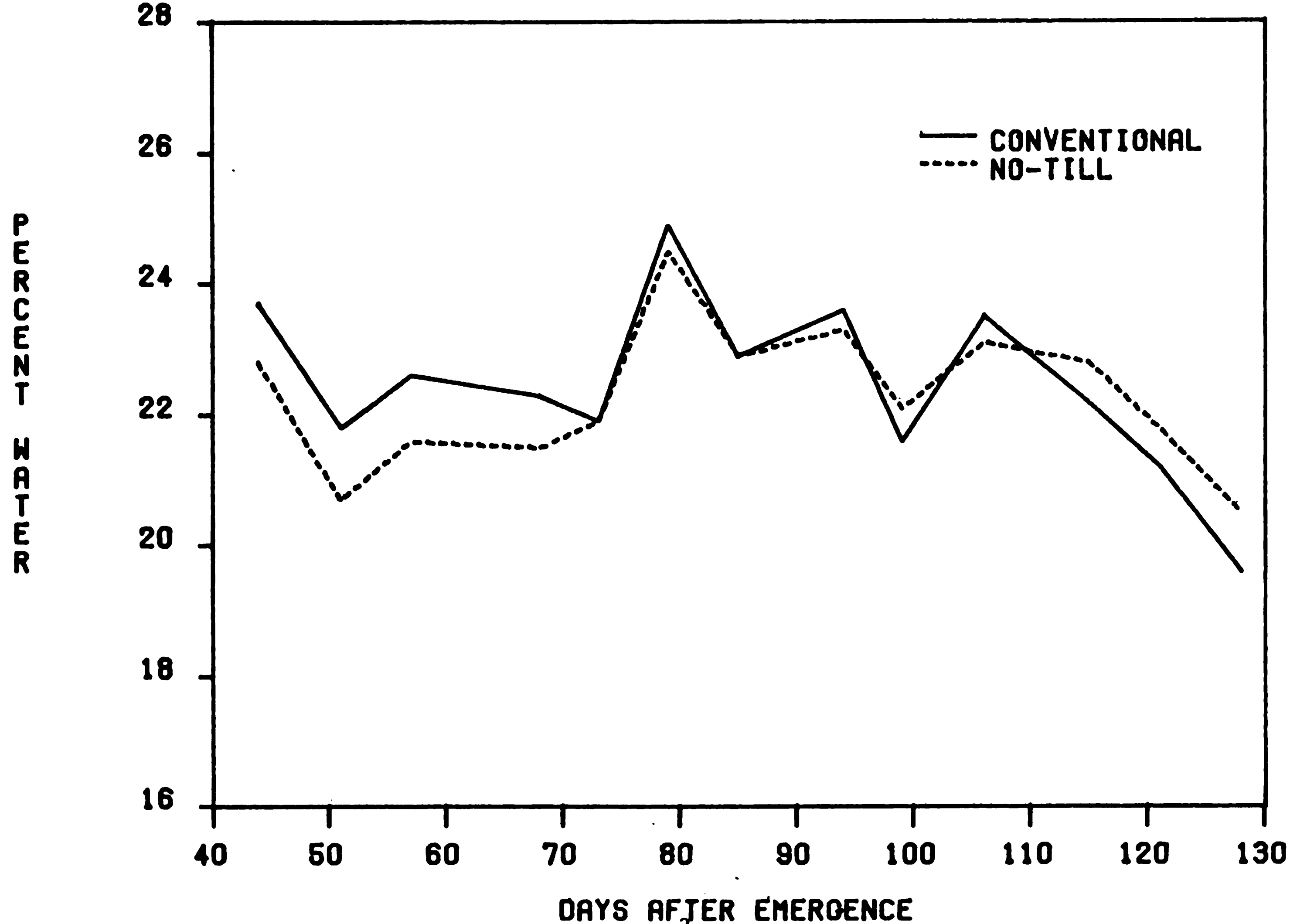


Figure 3. Volumetric water content of soil (g/cm$^3$) at 15 cm depth as affected by tillage; corn study.

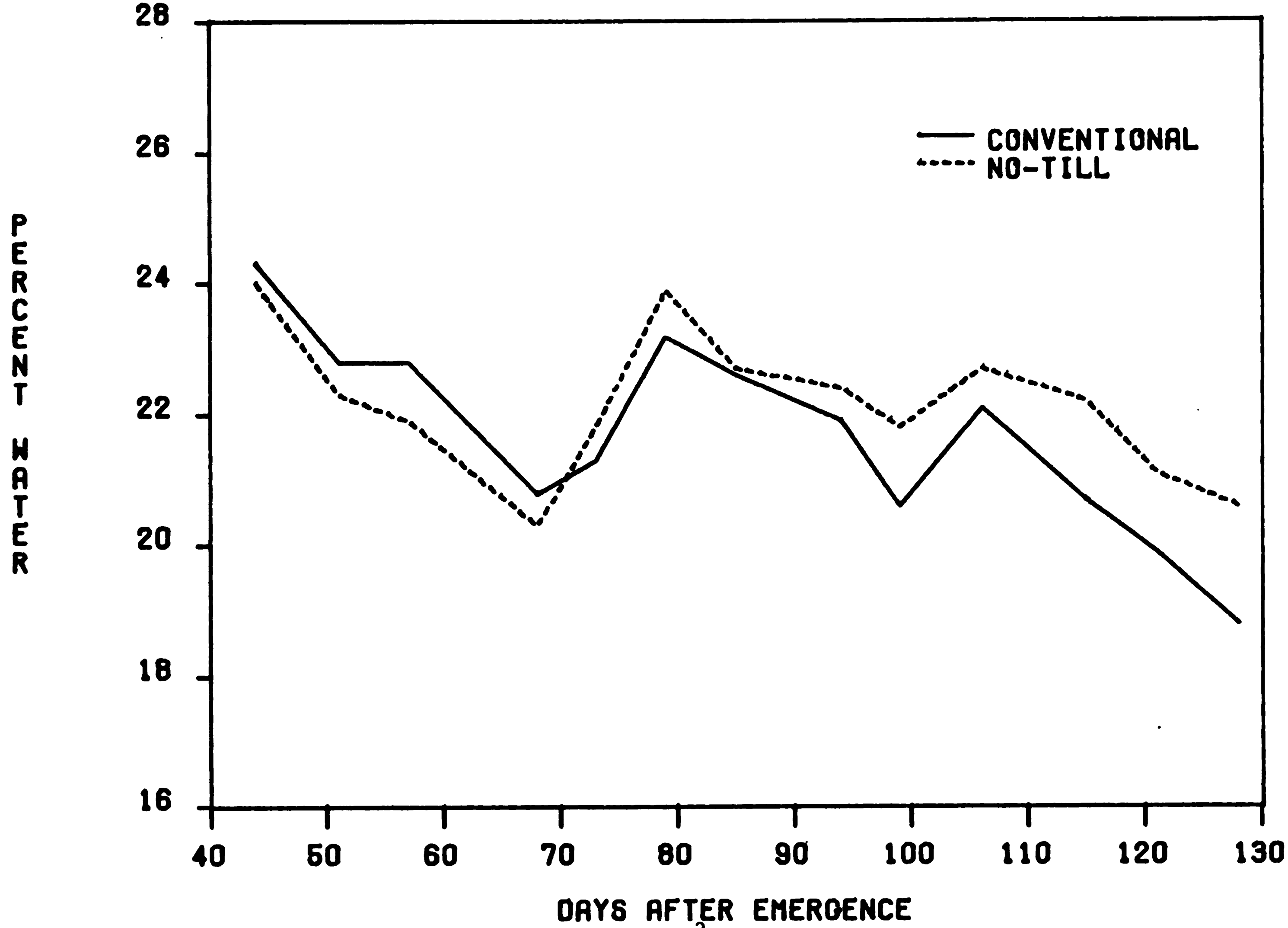


Figure 4. Volumetric water content of soil (g/cm$^3$) at 30 cm depth as affected by tillage; corn study.

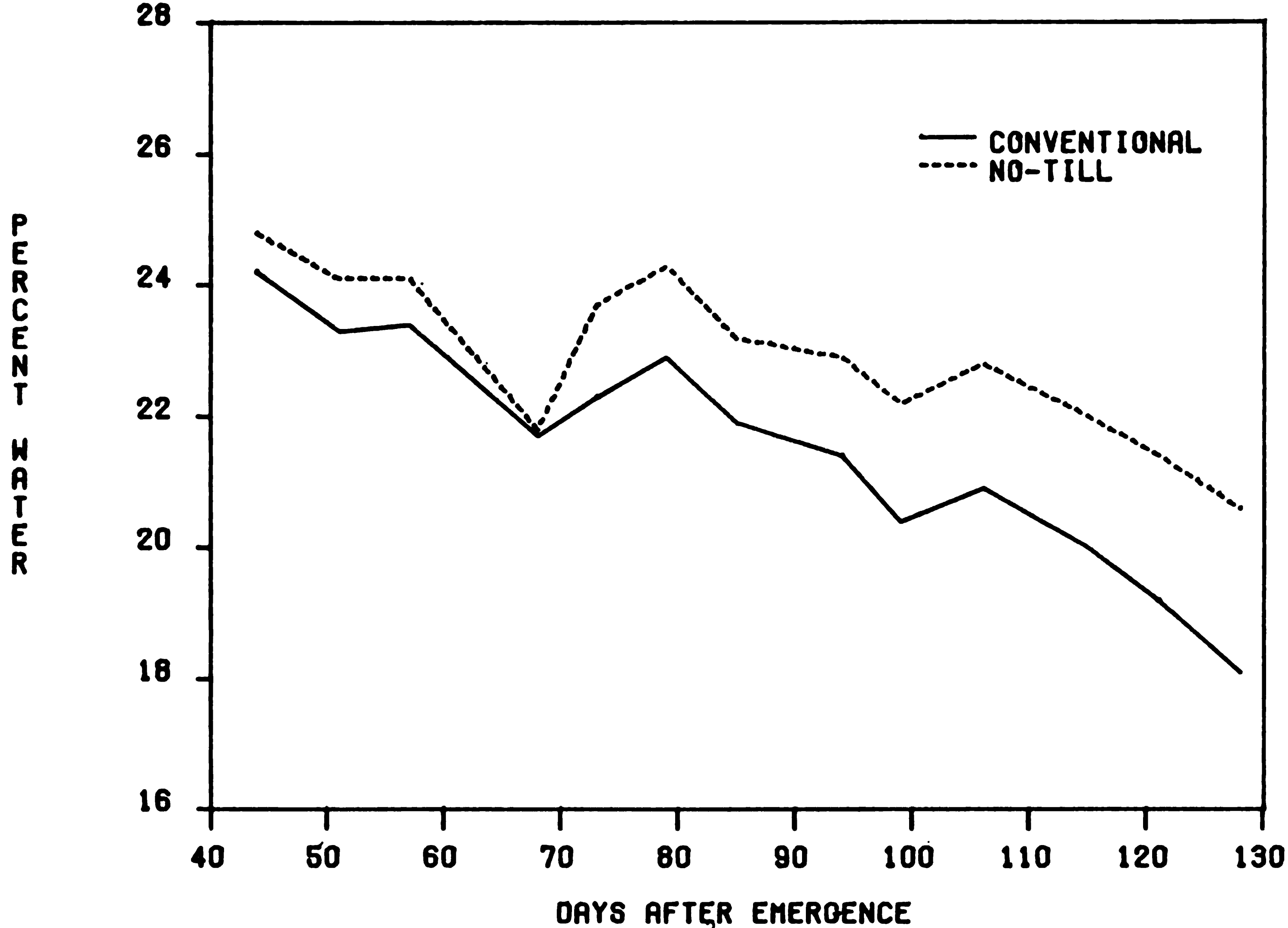


Figure 5. Volumetric water content of soil (g/cm$^3$) at 46 cm depth as affected by tillage; corn study.

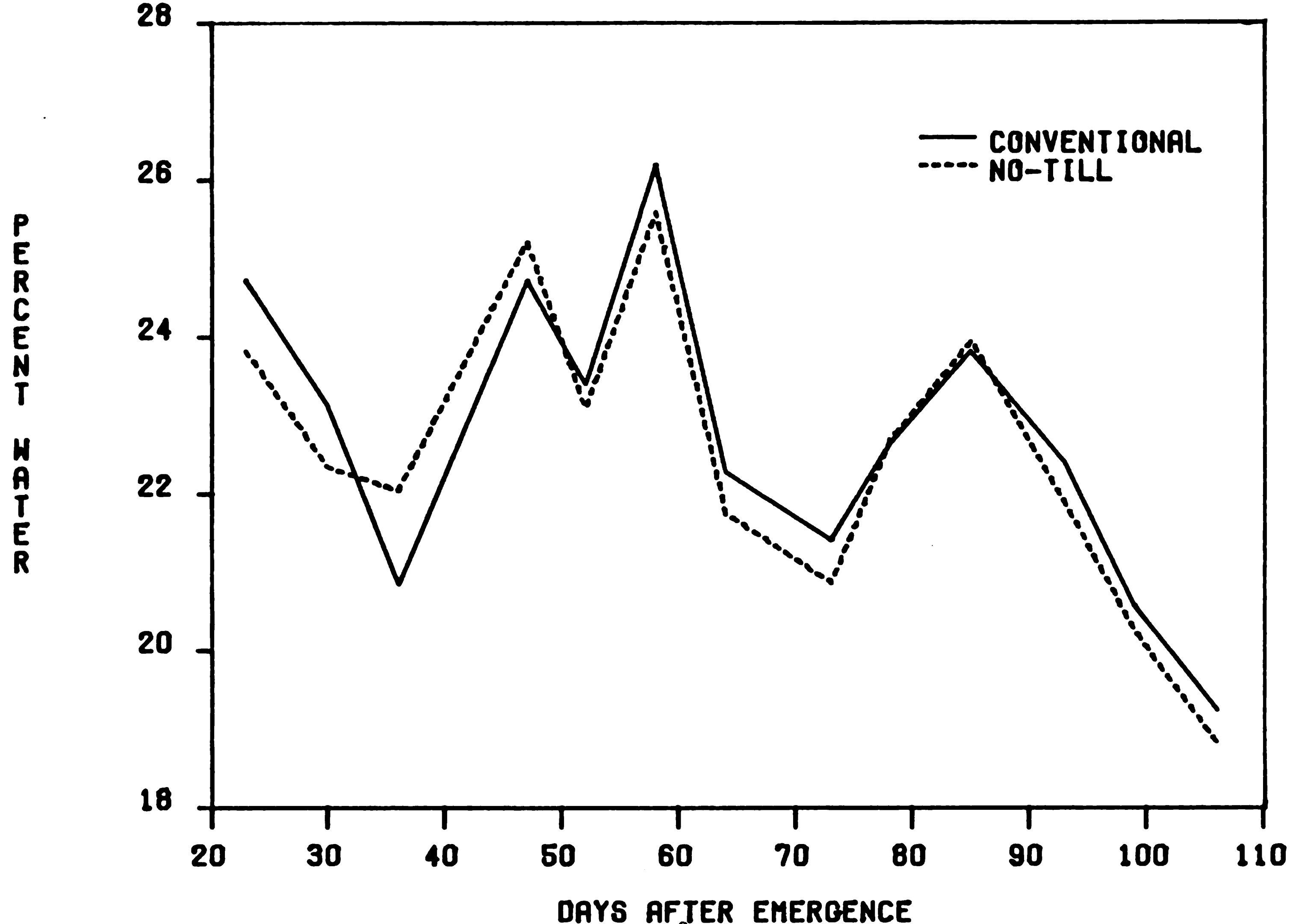


Figure 6. Volumetric water content of soil (g/cm$^3$) at 15 cm depth as affected by tillage; soybean study.

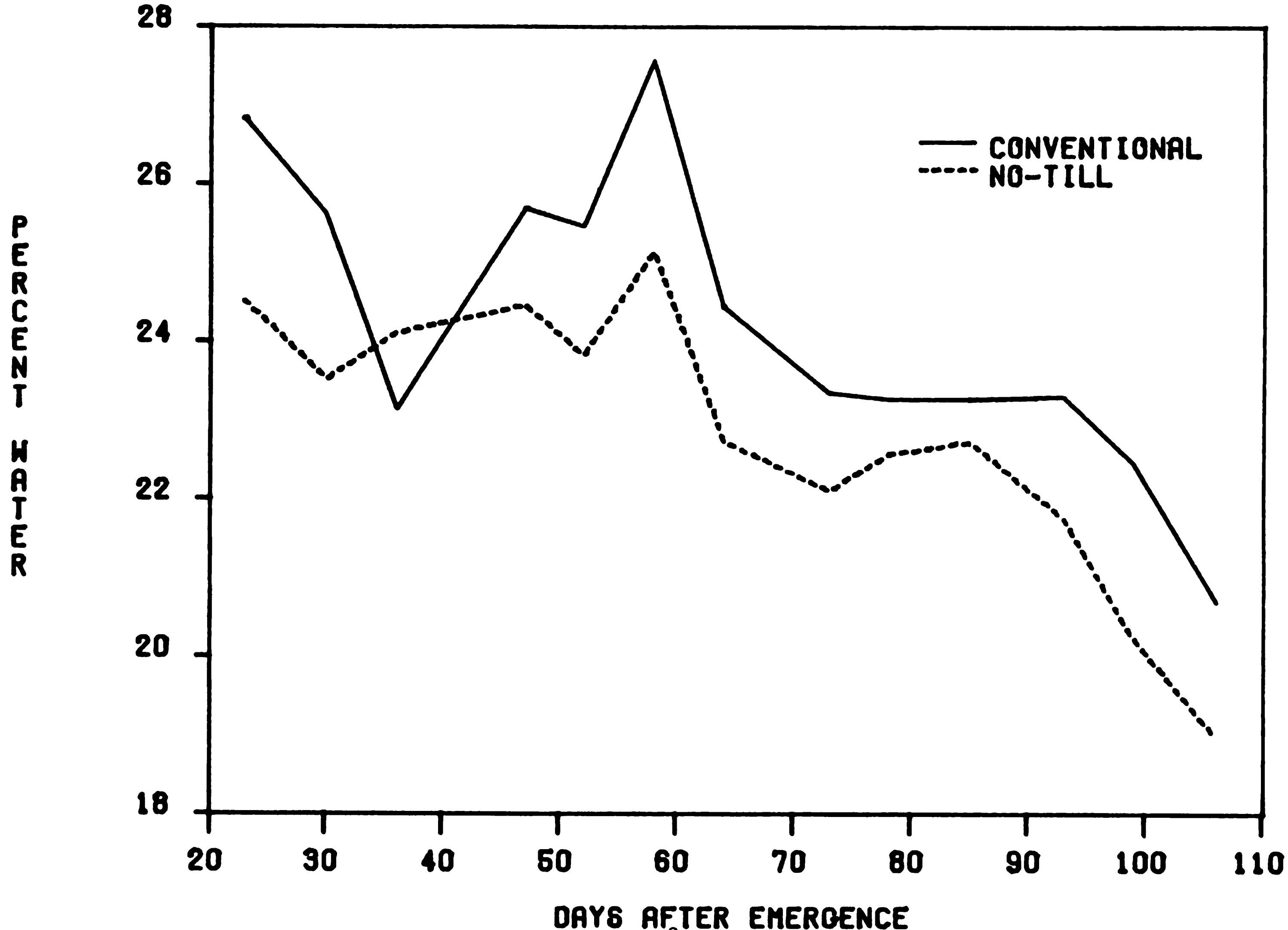


Figure 7. Volumetric water content of soil (g/cm$^3$) at 30 cm depth as affected by tillage; soybean study.

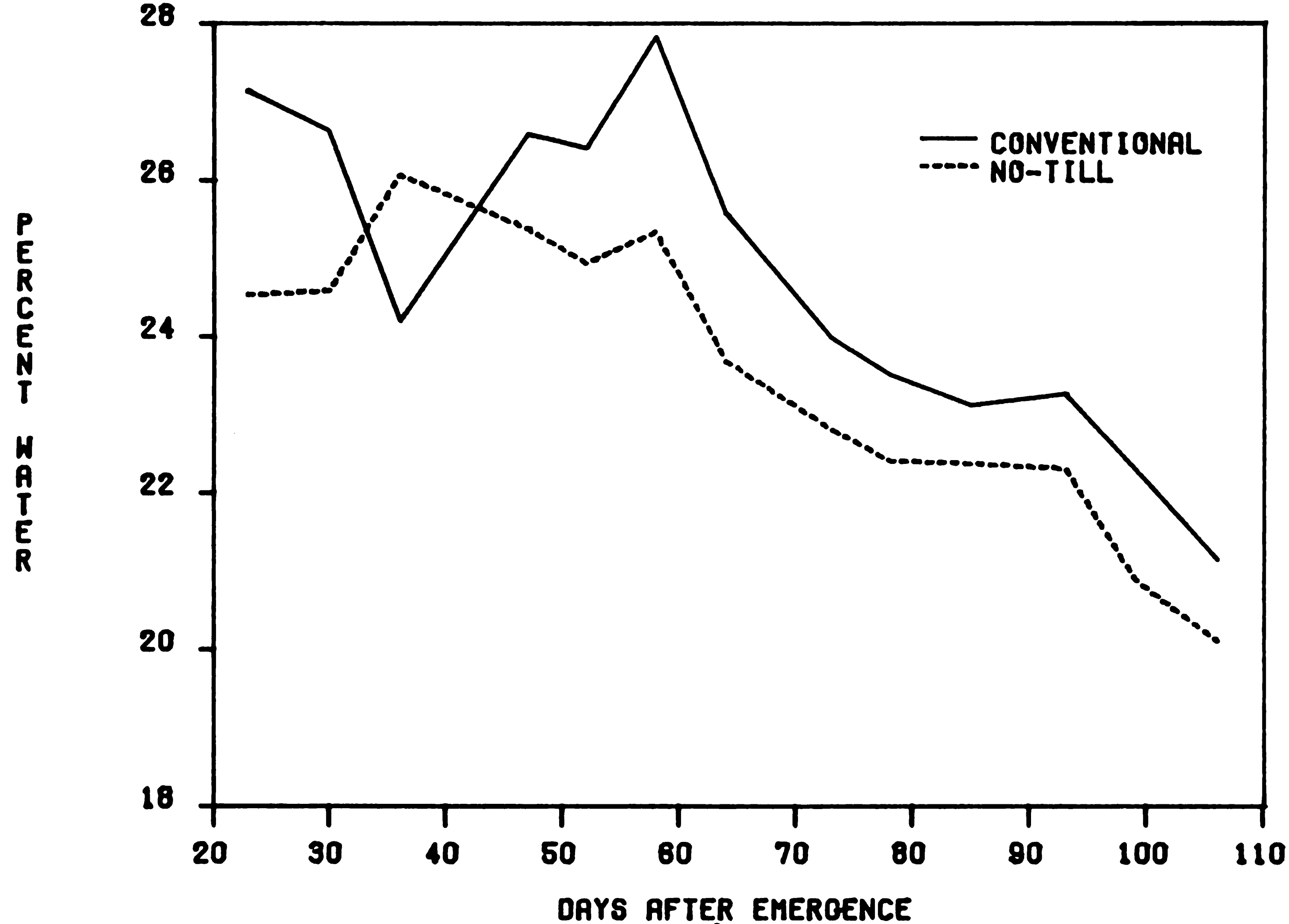


Figure 8. Volumetric water content of soil ($g/cm^3$) at 46 cm depth as affected by tillage; soybean study.

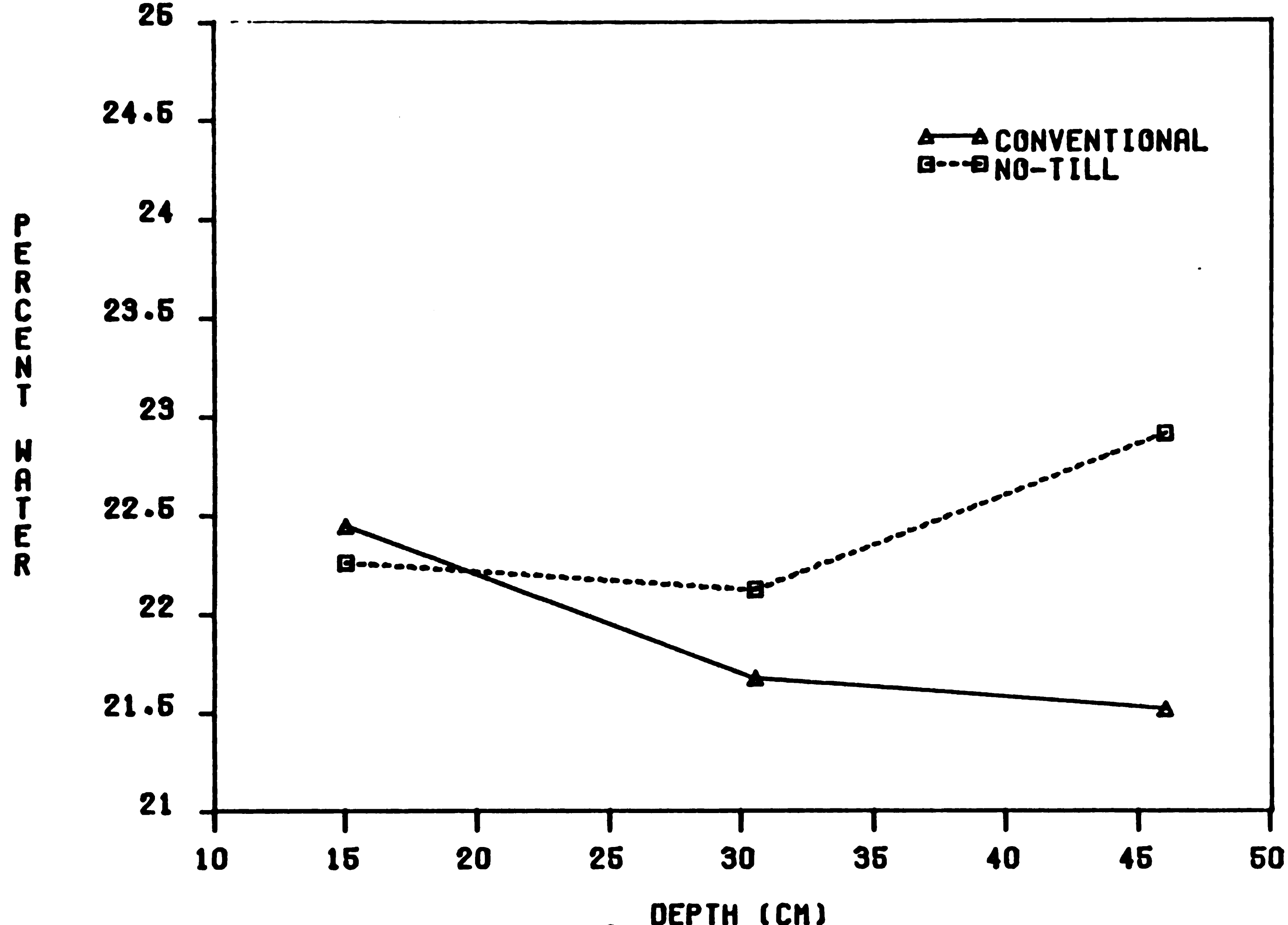


Figure 9. Distribution of soil water ($g/cm^3$) with respect to depth as affected by tillage; corn study.

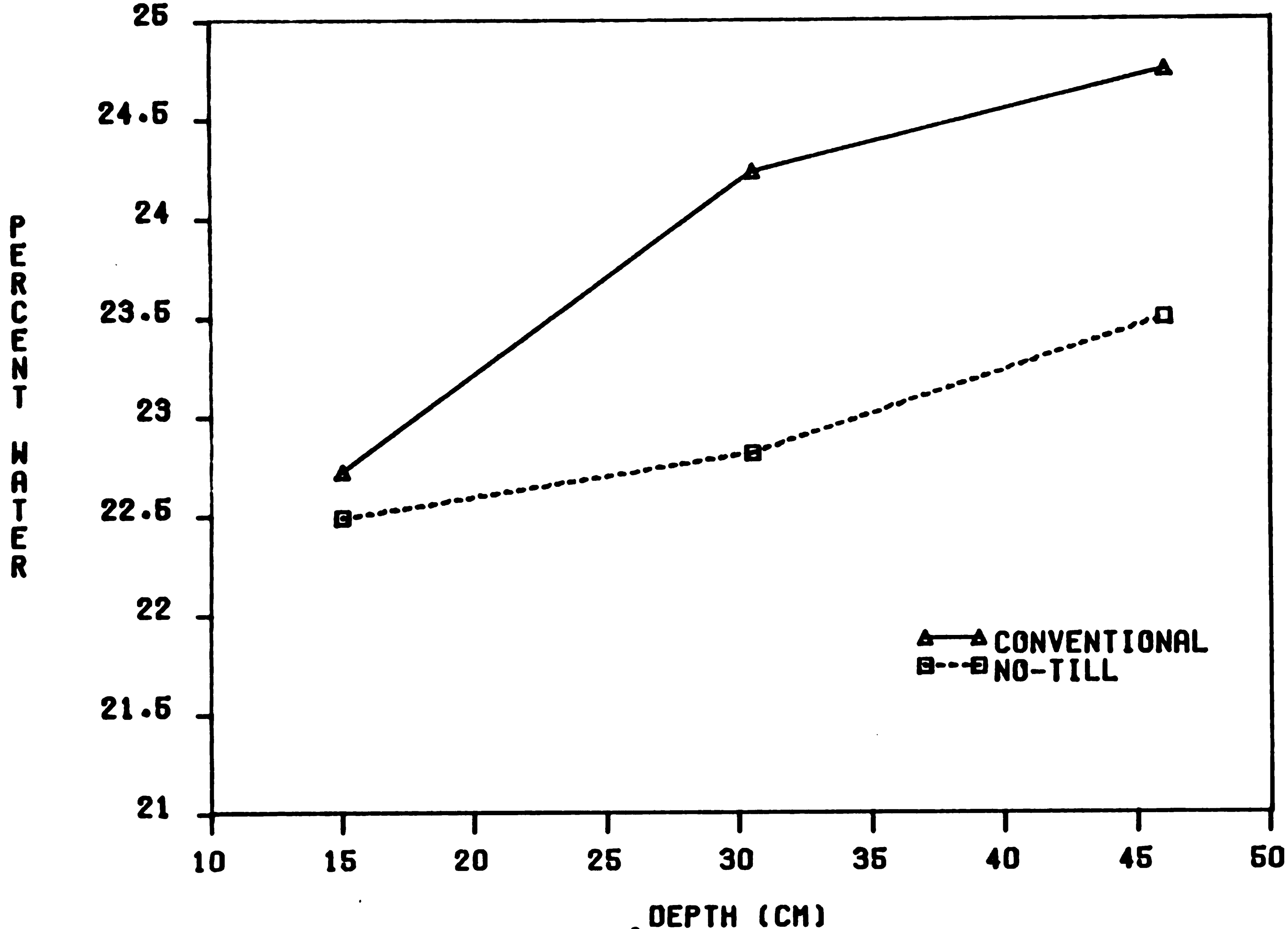


Figure 10. Distribution of soil water (g/cm$^3$) with respect to depth as affected by tillage; soybean study.

Bulk Density and Soil Aeration

Tillage method significantly affected both bulk density and air-filled porosity in the corn study. Bulk densities of the surface soil (0-8 cm) averaged 1.18 $g/cm^3$in the conventional tillage treatment and 1.33 $g/cm^3$ in the no-till treatment. These results support the findings of Gantzer (30) and others (15,21,60,81).

Aeration porosity of surface samples (0-8 cm) taken from the two tillage treatments is shown in Figure 11. A consequence of the increased soil bulk density in no-till plots was that air-filled porosity in no-till plots was less than in conventional plots at all potentials measured. These results are in agreement with the works of Gantzer (30) and A. E. Erickson (personal communication). The aeration porosity results indicate that there are fewer large pores in the untilled soil (81,99). The air-filled pore space exceeded 10 percent at all but the 10 cm suction; therefore, according to the findings of Wesseling and van Wijk (100), aeration was probably not a problem in either system in this study.

## Yields

Corn

Corn grain yields, averaged over the two harvest dates, are shown in Table 5. Only the main effects of tillage method and nitrogen rate were found to be significant at the 95 percent confidence level. The highest yields were obtained in the no-till treatments which received 336 kg N/ha. Lower yields in the conventional treatments are attributed mainly to later germination. Final plant populations and the percentage of barren stalks were similar for the two tillage systems, but plants in

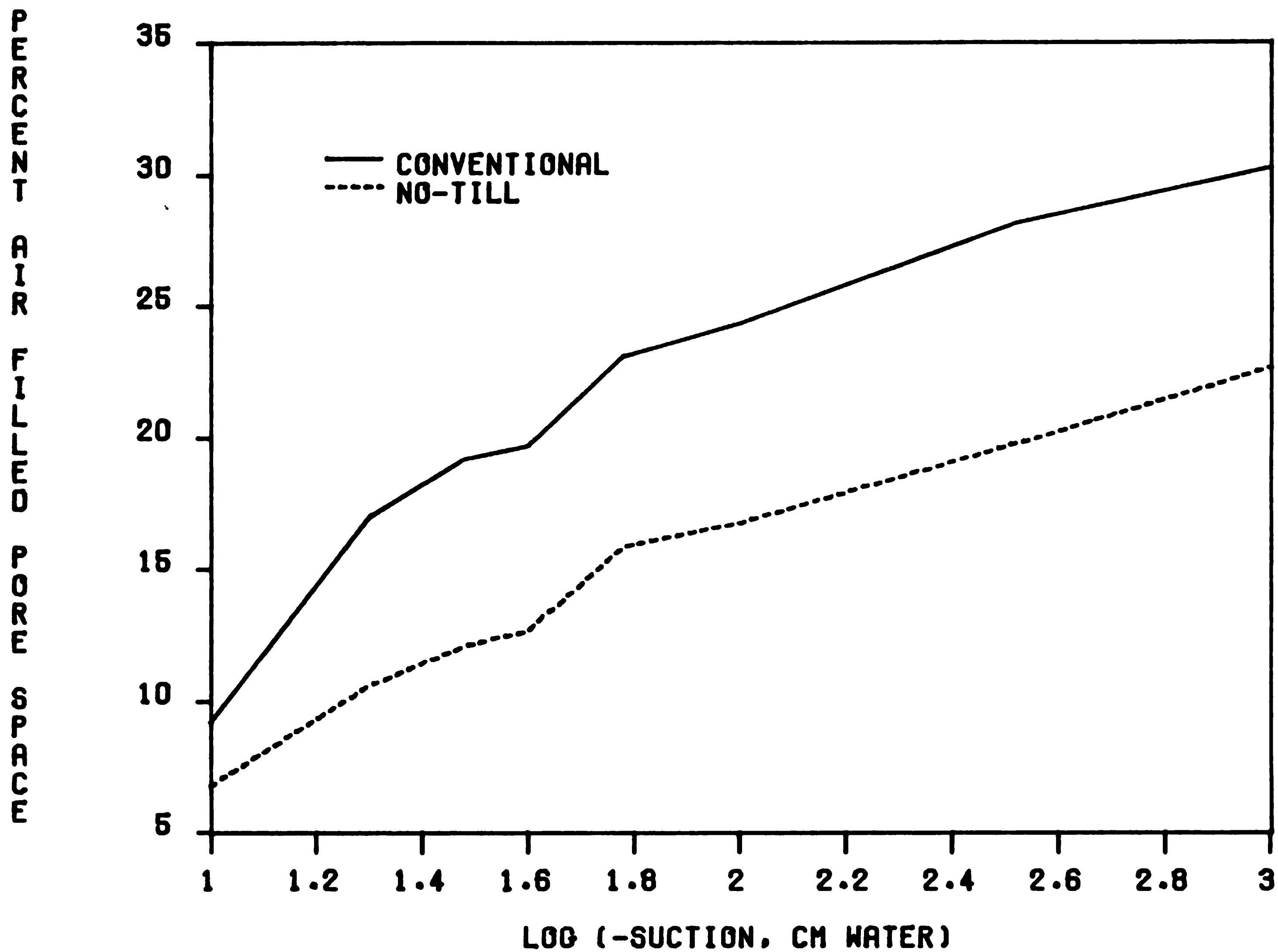


Figure 11. Tillage effects on aeration porosity of surface soil (0-8 cm) in corn tillage study.

Table 5. Corn grain yield as affected by tillage method, nitrogen and potassium rate and phosphorus placement.

| N rate | P placement[1] | K rate | Tillage method: Conventional | Tillage method: No-till | Mean | LSD (.05) |
|---|---|---|---|---|---|---|
| kg/ha | | kg/ha | --------kg/ha[2]-------- | | | |
| 168 | Broadcast | 56 | 12,030 | 12,310 | 12,170 | |
| 168 | | 168 | 11,640 | 12,100 | 11,870 | |
| 336 | | 56 | 12,200 | 12,560 | 12,380 | |
| 336 | | 168 | 12,040 | 12,920 | 12,480 | |
| 168 | Banded | 56 | 11,700 | 12,190 | 11,940 | |
| 168 | | 168 | 12,010 | 12,840 | 12,430 | |
| 336 | | 56 | 12,160 | 13,140 | 12,650 | |
| 336 | | 168 | 12,130 | 12,550 | 12,340 | |
| Overall means | | | | | | |
| Tillage | | | 11,990 | 12,580 | | (390) |
| Nitrogen rate | | 168 kg N/ha | | | 12,100 | (230) |
| | | 336 kg N/ha | | | 12,460 | |
| Phosphorus placement | | Broadcast | | | 12,220 | (NS) |
| | | Banded | | | 12,340 | |
| Potassium rate | | 56 kg $K_2O$/ha | | | 12,290 | (NS) |
| | | 168 kg $K_2O$/ha | | | 12,280 | |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

[2]Adjusted to 15.5% moisture.

conventional tillage plots, which had emerged several weeks late, were tall and spindly compared to early emerging plants. The late germinating plants in the conventional plots were also subject to silk pruning by corn rootworm beetles (Diabrotica virgifera Le Conte).

Good yields were obtained with 168 kg N/ha, and only a moderate yield increase occurred with an additional 168 kg N/ha. Grain yield was not affected by the placement of phosphorus or the addition of potassium; this was probably due to the high initial levels of these nutrients in this field (Table 1).

Grain moisture at harvest was significantly lower in no-till plots (Table 6). Nitrogen rate did not appear to affect grain moisture in the no-till plots; however, in conventional plots, the high nitrogen treatments had significantly lower grain moisture than the low nitrogen treatments. Neither phosphorus placement nor potassium rate had any affect on the moisture content of grain.

Stover yields were not affected by tillage method, phosphorus placement or potassium rates (Table 7). The high N rate (336 kg/ha), however, significantly increased stover yield.

Soybean

Soybean yield data is presented in Table 8. Excellent yields were obtained even though severe lodging occurred in all plots as a result of a heavy shower on July 26 and high intensity irrigation. Despite the severe lodging, harvest losses were small. Phytophthora root rot (Phytophthora megaspermavar sojae) caused some yield reduction in the SRF-200 variety in low lying areas, but did not appearto be related to a particular tillage treatment. Grain yields were not affected by tillage

Table 6. Corn grain moisture at harvest (October 18) as affected by tillage method and nitrogen rate.

| Tillage method | Nitrogen rate (kg/ha) 168 | 336 | Mean | LSD (.05) |
|---|---|---|---|---|
| | -----% moisture------ | | | |
| Conventional | 28.5 | 27.3 | 27.9 | (1.4) |
| No-till | 25.0 | 25.0 | 25.0 | |
| Mean | 26.8 | 26.2 | | |
| LSD (.05) | (0.6) | | | |

Table 7. Corn stover yield as affected by tillage method, nitrogen and potassium rate and phosphorus placement.

| N rate | P placement[1] | K rate | Tillage method: Conventional | Tillage method: No-till | Mean | LSD (.05) |
|---|---|---|---|---|---|---|
| kg/ha | | kg/ha | --------kg/ha--------- | | | |
| 168 | Broadcast | 56 | 9,380 | 8,789 | 9,085 | |
| 168 | | 168 | 8,975 | 8,909 | 8,942 | |
| 336 | | 56 | 9,898 | 9,118 | 9,458 | |
| 336 | | 168 | 9,963 | 9,826 | 9,895 | |
| 168 | Banded | 56 | 9,593 | 8,724 | 9,159 | |
| 168 | | 168 | 9,316 | 9,132 | 9,224 | |
| 336 | | 56 | 9,493 | 9,402 | 9,447 | |
| 336 | | 168 | 10,554 | 9,455 | 10,004 | |
| Overall means | | | | | | |
| Tillage | | | 9,634 | 9,169 | | (NS) |
| Nitrogen rate | | 168 kg N/ha | | | 9,102 | (363) |
| | | 336 kg N/ha | | | 9,701 | |
| Phosphorus placement | | Broadcast | | | 9,345 | (NS) |
| | | Banded | | | 9,459 | |
| Potassium rate | | 56 kg $K_2O$/ha | | | 9,287 | (NS) |
| | | 168 kg $K_2O$/ha | | | 9,516 | |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

Table 8. Soybean yield as affected by tillage method, variety, phosphorus placement and potassium fertilization.

| Variety | P placement[2] | K rate | Tillage method: Conventional | Tillage method: No-till | Mean | LSD (.05) |
|---|---|---|---|---|---|---|
| | | kg/ha | --------kg/ha[1]-------- | | | |
| Corsoy 79 | Broadcast | 0 | 4,409 | 4,543 | 4,476 | |
| Corsoy 79 | | 56 | 4,460 | 4,303 | 4,381 | |
| SRF-200 | | 0 | 4,354 | 4,258 | 4,306 | |
| SRF-200 | | 56 | 4,163 | 4,070 | 4,117 | |
| Corsoy 79 | Banded | 0 | 4,479 | 4,452 | 4,465 | |
| Corsoy 79 | | 56 | 4,497 | 4,409 | 4,403 | |
| SRF-200 | | 0 | 4,132 | 4,043 | 4,087 | |
| SRF-200 | | 56 | 4,156 | 3,876 | 4,016 | |
| Overall means | | | | | | |
| Tillage | | | 4,319 | 4,244 | | (NS) |
| Variety | | Corsoy 79 | | | 4,431 | (136) |
| | | SRF-200 | | | 4,131 | |
| Phosphorus Placement | | Broadcast | | | 4,320 | (NS) |
| | | Banded | | | 4,243 | |
| Potassium rate | | 0 kg $K_2O$/ha | | | 4,334 | (NS) |
| | | 56 kg $K_2O$/ha | | | 4,229 | |

[1]Adjusted to 13% moisture.

[2]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

method. These results support the observation that soybeans can compensate for poor initial stands. The yield of Corsoy 79 was significantly higher than SRF-200. Yield was unaffected by the placement of phosphorus or the addition of potassium; this was probably due to the high initial levels of these nutrients in this field (Table 2).

Grain moisture at harvest, although not reported here, was unaffected by any of the treatments.

## Plant Analysis

### Corn

The main effects of tillage and fertilizer treatments on the elemental composition of whole corn plants taken at the early whorl stage, ear leaf samples taken at silking and grain and stover sampled at harvest are presented in Tables 9-12. Significant treatment interactions are presented in Tables 13-15. Tables 2a-5a in the appendix show the elemental analysis for the individual treatments.

At the early whorl stage, N content of the whole corn plants was significantly higher in the no-till plots than the conventional plots (Table 9). After this sampling, the additional 168 kg N/ha was applied to the high N treatment. The topdressing of additional nitrogen resulted in higher ear leaf, grain and stover N content (Tables 10, 11 and 12). No-till ear leaf, grain and stover samples had lower N content than samples from conventional treatments (Tables 10, 11 and 12). Corn grain from no-till plots had significantly lower levels of N than grain from conventional plots at the low N rate, but about the same concentration as conventional plots at the high N rate (Table 13).

Table 9. Elemental composition of whole plants (early whorl stage) as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| Tillage: | | | | | | | | | | |
| Conventional | 3.98 | .39 | 3.97 | .74 | .35 | 116 | 1,580 | 45 | 12 | 2,330a |
| No-till | 4.26 | .46 | 3.86 | .71 | .40 | 74 | 850 | 37 | 13 | 1,250b |
| LSD (.05) | (.21) | (.04) | (NS) | (NS) | (NS) | (28) | (239) | (NS) | (NS) | (137) |
| Phosphorus placement[1]: | | | | | | | | | | |
| Broadcast | 4.10 | .42 | 3.90 | .74 | .38 | 98 | 1,250 | 41 | 13 | 1,860 |
| Banded | 4.13 | .43 | 3.95 | .72 | .38 | 92 | 1,170 | 41 | 12 | 1,720 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Potassium rate: | | | | | | | | | | |
| 56 kg $K_2O$/ha | 4.16 | .43 | 3.90 | .74 | .39 | 95 | 1,220 | 41 | 13 | 1,790 |
| 168 kg $K_2O$/ha | 4.09 | .42 | 3.94 | .71 | .36 | 95 | 1,200 | 41 | 12 | 1,790 |
| LSD (.05) | (NS) | (NS) | (NS) | (.03) | (.02) | (NS) | (NS) | (NS) | (NS) | (NS) |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

Table 10. Elemental composition of corn ear leaf (early silking) as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| Tillage: | | | | | | | | | | |
| Conventional | 3.18 | .33 | 2.8 | .75 | .23 | 45 | 256 | 43 | 13 | 66 |
| No-till | 3.10 | .33 | 2.5 | .83 | .28 | 39 | 242 | 35 | 12 | 42 |
| LSD (.05) | (.03) | (NS) | (NS) | (.04) | (.04) | (NS) | (14) | (NS) | (NS) | (NS) |
| Nitrogen rate: | | | | | | | | | | |
| 168 kg N/ha | 3.08 | .33 | 2.6 | .77 | .26 | 38 | 244 | 39 | 13 | 54 |
| 336 kg N/ha | 3.19 | .33 | 2.7 | .80 | .25 | 45 | 254 | 40 | 13 | 55 |
| LSD (.05) | (.08) | (NS) | (NS) | (NS) | (NS) | (3) | (NS) | (NS) | (NS) | (NS) |
| Phosphorus placement[1]: | | | | | | | | | | |
| Broadcast | 3.19 | .34 | 2.7 | .80 | .26 | 43 | 256 | 41 | 13 | 52 |
| Banded | 3.08 | .33 | 2.6 | .78 | .25 | 41 | 241 | 38 | 13 | 57 |
| LSD (.05) | (.08) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Potassium rate: | | | | | | | | | | |
| 56 kg $K_2O$/ha | 3.12 | .33 | 2.6 | .80 | .26 | 41 | 233 | 38 | 12 | 53 |
| 168 kg $K_2O$/ha | 3.15 | .34 | 2.7 | .78 | .24 | 42 | 264 | 41 | 13 | 56 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (.01) | (NS) | (25) | (NS) | (NS) | (NS) |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

Table 11. Elemental composition of corn grain as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | N | P | K | Mg | Mn | Fe | Zn | Cu | Al |
|---|---|---|---|---|---|---|---|---|---|
| | % | | | | ppm | | | | |
| Tillage: | | | | | | | | | |
| Conventional | 1.44 | .34 | .50 | .22 | 5.7 | 37 | 23 | 2.4 | 46 |
| No-till | 1.40 | .35 | .49 | .21 | 8.3 | 37 | 24 | 2.8 | 48 |
| LSD (.05) | (.03) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Nitrogen rate: | | | | | | | | | |
| 168 kg N/ha | 1.39 | .35 | .50 | .21 | 5.7 | 35 | 23 | 2.5 | 49 |
| 336 kg N/ha | 1.46 | .34 | .50 | .22 | 8.3 | 38 | 23 | 2.8 | 46 |
| LSD (.05) | (.01) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Phosphorus placement[1]: | | | | | | | | | |
| Broadcast | 1.41 | .34 | .49 | .21 | 7.9 | 37 | 23 | 2.3 | 50 |
| Banded | 1.43 | .35 | .51 | .22 | 6.1 | 37 | 24 | 3.0 | 44 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Potassium rate: | | | | | | | | | |
| 56 kg $K_2O$/ha | 1.43 | .35 | .50 | .22 | 6.2 | 38 | 23 | 2.2 | 50 |
| 168 kg $K_2O$/ha | 1.41 | .35 | .50 | .21 | 7.8 | 36 | 23 | 3.0 | 44 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

Table 12. Elemental composition of corn stover as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| Tillage: | | | | | | | | | | |
| Conventional | .84 | .082 | 1.75 | .60 | .28 | 24 | 283 | 18 | 6.5 | 164 |
| No-till | .74 | .097 | 1.48 | .59 | .29 | 26 | 322 | 15 | 6.3 | 194 |
| LSD (.05) | (.06) | (NS) | (.22) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Nitrogen rate: | | | | | | | | | | |
| 168 kg N/ha | .69 | .090 | 1.56 | .56 | .27 | 22 | 324 | 16 | 6.3 | 176 |
| 336 kg N/ha | .90 | .090 | 1.66 | .62 | .29 | 28 | 282 | 18 | 6.6 | 182 |
| LSD (.05) | (.03) | (NS) | (NS) | (.03) | (.02) | (2) | (29) | (2) | (NS) | (NS) |
| Phosphorus placement[1]: | | | | | | | | | | |
| Broadcast | .77 | .086 | 1.60 | .58 | .29 | 25 | 291 | 16 | 6.3 | 176 |
| Banded | .80 | .093 | 1.63 | .60 | .28 | 25 | 314 | 18 | 6.6 | 182 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (2) | (NS) | (NS) |
| Potassium rate: | | | | | | | | | | |
| 56 kg $K_2O$/ha | .81 | .094 | 1.55 | .61 | .30 | 25 | 309 | 16 | 6.5 | 196 |
| 168 kg $K_2O$/ha | .77 | .086 | 1.68 | .58 | .26 | 24 | 296 | 17 | 6.4 | 162 |
| LSD (.05) | (.03) | (.007) | (.10) | (NS) | (.02) | (NS) | (NS) | (NS) | (NS) | (NS) |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

Table 13. Effect of tillage and nitrogen fertilizer on the elemental composition of corn grain (interaction effects).

| Tillage | N-rate | N | P | K | Zn |
|---|---|---|---|---|---|
| | | Concentration | | | |
| | kg/ha | % | | | ppm |
| Conventional | 168 | 1.41 | .332 | .484 | 21.7 |
| | 336 | 1.47 | .353 | .520 | 23.8 |
| No-till | 168 | 1.34 | .368 | .515 | 24.8 |
| | 336 | 1.46 | .329 | .472 | 22.8 |
| LSD (.05) | | (.03) | (.024) | (NS) | (NS) |

Table 14. Effect of nitrogen and potassium fertilization on the elemental composition of corn grain (interaction effects).

| N-rate | K-rate | P | K |
|---|---|---|---|
| | | Concentration | |
| kg/ha | | % | |
| 168 | 56 | .339 | .486 |
| 168 | 168 | .362 | .512 |
| 336 | 56 | .352 | .512 |
| 336 | 168 | .331 | .481 |
| LSD (.05) | | (.030) | (NS) |

Table 15. Effect of tillage and potassium fertilization on the elemental composition of corn stover (interaction effects).

| Tillage | K-rate | Concentration Mn |
|---|---|---|
| | kg/ha | ppm |
| Conventional | 56 | 23 |
| | 168 | 25 |
| No-till | 56 | 27 |
| | 168 | 23 |
| LSD (.05) | | (NS) |

These results are similar to those observed by Moschler and Marten (62) and Moncrief and Schulte (60). Higher levels of N were observed in ear leaf samples from the broadcast phosphorus treatments when compared to banded, but the data cannot be explained.

No severe deficiency symptoms, however, occurred in any plots. Nitrogen deficiency symptoms late in the season were more apparent in no-till plots particularly at the low N rate. These results are similar to those of Bandel et al. (7) who observed that at suboptimal N rates, N deficiency symptoms were more severe on no-till plots than on plowed plots.

Phosphorus levels in whole plant samples were significantly higher in no-till plots than conventional tilled plots, but the differences were not present in the ear leaf at silking or in the grain and stover at harvest. Greater P concentration in no-till plants at early samplings have been noted by several researchers (65,78,89). These researchers concluded that better moisture conditions in no-till plots may enhance P uptake. In this study, soil moisture measurements were not made early enough in the growing season to substantiate this conclusion. The method of P placement had no effect on the P composition of any plant tissues or grain in either tillage system. The high rate of K fertilization appeared to decrease the P content in corn stover, but K rate had no affect on the P content in early whole plant, ear leaf or grain samples. A significant nitrogen by tillage interaction was observed for the P content of grain (Table 13). Nitrogen topdressing increased the P content of corn grain in conventional treatments but decreased P content of corn grain in no-till treatments. There was also a significant N by K rate interation on P content of grain (Table 14). At the low N rate, P content was higher at the high K rate than at the low K rate. At the high N rate, P content was higher at the low K rate.

The K concentration of stover was found to be significantly lower in the no-till plots than in conventional plots (Table 12). The stover appeared to dry down faster in the no-till treatments. Therefore, the lower levels of K in stover in no-till treatments may reflect higher amounts of K leaching from the senescing plant tissue. The high rate of K fertilization resulted in increased K content of corn stover (Table 12). The K content of early whole plants and ear leaf samples was not affected by tillage. A significant N rate by tillage interaction for K in grain was observed (Table 13). Nitrogen topdressing increased the K content of corn grain in conventional treatments but decreased K content of corn grain in no-till treatments. The N by K rate interaction for K content of corn grain was significant (Table 14). At the low N rate, K content was higher at the high K rate than at the low K rate. At the high N rate, K content was higher at the low K rate.

Calcium and Mg content of ear leaf samples at early silking was significantly higher in the no-till treatment than in the conventional treatment (Table 10). The differences did not carry through to grain and stover at harvest. The treatments with high rates of K fertilization had significantly lower levels of Ca and Mg at the early whorl stage and significantly lower Mg in ear leaf samples at silking and in stover at harvest.As the K concentration in the plant or grain increased Ca and Mg concentrations decreased. This is a well known occurrence due to the competitive effect which K exhibits on Ca and Mg uptake.

The levels of micronutrients in all treatments were well above the critical concentrations required for optimum corn production (38,95). Differences in micronutrient composition between tillage methods were significant at the first sampling with no-till treatments having lower aoncentpations of Mn, Fe and Al than conventional treatments (Table 9). No-till treatments also had lower Fe concentrations in leaf tissue at early silking (Table 10). When N was topdressed higher levels of Mn, Zn and Cu and lower levels of Fe were observed in corn stover (Table 12). The increase in Mn uptake with increasing N rate has also been observed by Lal (48) and Lutz and Lillard (53). The method of P placement and K rate had little influence on the concentration of trace elements. Zinc content of corn stover was higher with banded P than with broadcast P. The Fe content of ear leaf samples at silking were lower at the low K rate than at the high K rate. A significant nitrogen by tillage interaction was observed for Zn in grain (Table 13). Nitrogen topdressing increased the Zn content of corn grain in conventional treatments but decreased Zn content of grain in no-till treatments. A significant K rate by tillage interaction was observed for Mn in corn stover (Table 15). In conventional plots Mn content was higher at the high K rate than at the low K rate. In no-till plots Mn content of stover was higher at the low K rate.

## Soybean

Elemental composition of soybean leaf and grain are presented in Tables 16 and 17. Tables 7a and 8a in the appendix give the elemental analysis for the individual treatments. Nitrogen composition of leaf samples taken at early bloom was greater in no-till treatments than

Table 16. Elemental composition of soybean leaf (early bloom) as affected by tillage method, variety, phosphorus placement and potassium fertilization.

| Treatment | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| | Element | | | | | | | | | |
| | % | | | | | ppm | | | | |
| Tillage: | | | | | | | | | | |
| Conventional | 5.10 | .46 | 2.25 | 1.21 | .52 | 51 | 196 | 37 | 14 | 99 |
| No-till | 5.28 | .47 | 2.31 | 1.27 | .55 | 60 | 192 | 43 | 14 | 75 |
| LSD (.05) | (.15) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Variety: | | | | | | | | | | |
| Corsoy 79 | 5.21 | .47 | 2.27 | 1.29 | .55 | 52 | 187 | 39 | 13 | 81 |
| SRF-200 | 5.18 | .46 | 2.30 | 1.19 | .52 | 60 | 200 | 41 | 15 | 94 |
| LSD (.05) | (NS) | (NS) | (NS) | (.09) | (NS) | (4) | (NS) | (NS) | (NS) | (NS) |
| Phosphorus placement[1]: | | | | | | | | | | |
| Broadcast | 5.22 | .48 | 2.29 | 1.25 | .54 | 56 | 197 | 40 | 14 | 89 |
| Banded | 5.18 | .46 | 2.27 | 1.23 | .53 | 55 | 191 | 39 | 14 | 85 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Potassium rate: | | | | | | | | | | |
| 0 kg $K_2O$/ha | 5.15 | .48 | 2.27 | 1.27 | .55 | 55 | 191 | 40 | 13 | 82 |
| 56 kg $K_2O$/ha | 5.22 | .46 | 2.29 | 1.21 | .51 | 56 | 197 | 39 | 14 | 92 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (.03) | (NS) | (NS) | (NS) | (NS) | (NS) |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

Table 17. Elemental composition of soybean grain as affected by tillage method, variety, phosphorus placement and potassium fertilization.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| Tillage: | | | | | | | | | | |
| Conventional | 6.36 | .74 | 1.95 | .11 | .19 | 21 | 77 | 40 | 14 | 22 |
| No-till | 6.33 | .71 | 1.93 | .10 | .18 | 22 | 77 | 40 | 14 | 14 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Variety: | | | | | | | | | | |
| Corsoy 79 | 6.46 | .73 | 1.93 | .11 | .18 | 21 | 75 | 40 | 14 | 19 |
| SRF-200 | 6.22 | .72 | 1.94 | .11 | .19 | 22 | 80 | 40 | 13 | 16 |
| LSD (.05) | (.07) | (.01) | (NS) | (NS) | (.01) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Phosphorus placement[1]: | | | | | | | | | | |
| Broadcast | 6.36 | .72 | 1.93 | .11 | .18 | 21 | 77 | 40 | 14 | 19 |
| Banded | 6.33 | .73 | 1.94 | .11 | .19 | 22 | 77 | 40 | 14 | 17 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (.01) | (NS) | (NS) | (NS) | (NS) | (NS) |
| Potassium rate: | | | | | | | | | | |
| 0 kg $K_2O$/ha | 6.37 | .73 | 1.93 | .11 | .19 | 21 | 80 | 40 | 14 | 20 |
| 56 kg $K_2O$/ha | 6.32 | .72 | 1.94 | .11 | .19 | 22 | 75 | 40 | 14 | 15 |
| LSD (.05) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) | (NS) |

[1]Phosphorus rate = 56 kg $P_2O_5$ per hectare.

conventional treatments. These differences did not carry through to the grain at harvest. Corsoy 79 had significantly more nitrogen in the grain than SRF-200.

Phosphorus and potassium concentrations were not affected by tillage or fertilizer treatments. The P content of grain was significantly higher in the Corsoy 79 than in the SRF-200. Leaf Ca at early bloom was significantly higher in the Corsoy-79 variety. Leaf Mg content was higher in the SRF-200 variety than in the Corsoy 79. The Mg content of grain was also higher in the treatment receiving no K fertilizer than in the treatment that received K fertilizer. Micronutrient levels in soybean leaves at early bloom and grain at harvest were similar regardless of tillage or fertilizer treatment. The SRF-200 had a significantly higher level of Mn than Corsoy 79 in the leaf tissue at early bloom.

## Root Density

Corn root densities were not altered by tillage (Figure 12, Table 18). In both tillage systems, highest root densities occurred in the surface 7.6 cm of soil. Root densities decreased with increasing depth and with increasing distance away from the row. These result contradict the findings of Barber (6), Phillips et al. (69) and Kang and Yunusa who found that tillage significantly affected the distribution of corn roots with respect to depth. Rooting patterns were probably similar for both tillage treatments in this study because of similar moisture regimes under the two tillage treatments. During sampling, roots were observed at depths below those taken for analysis (45.7 cm). Many of these deep roots were growing through worm channels.

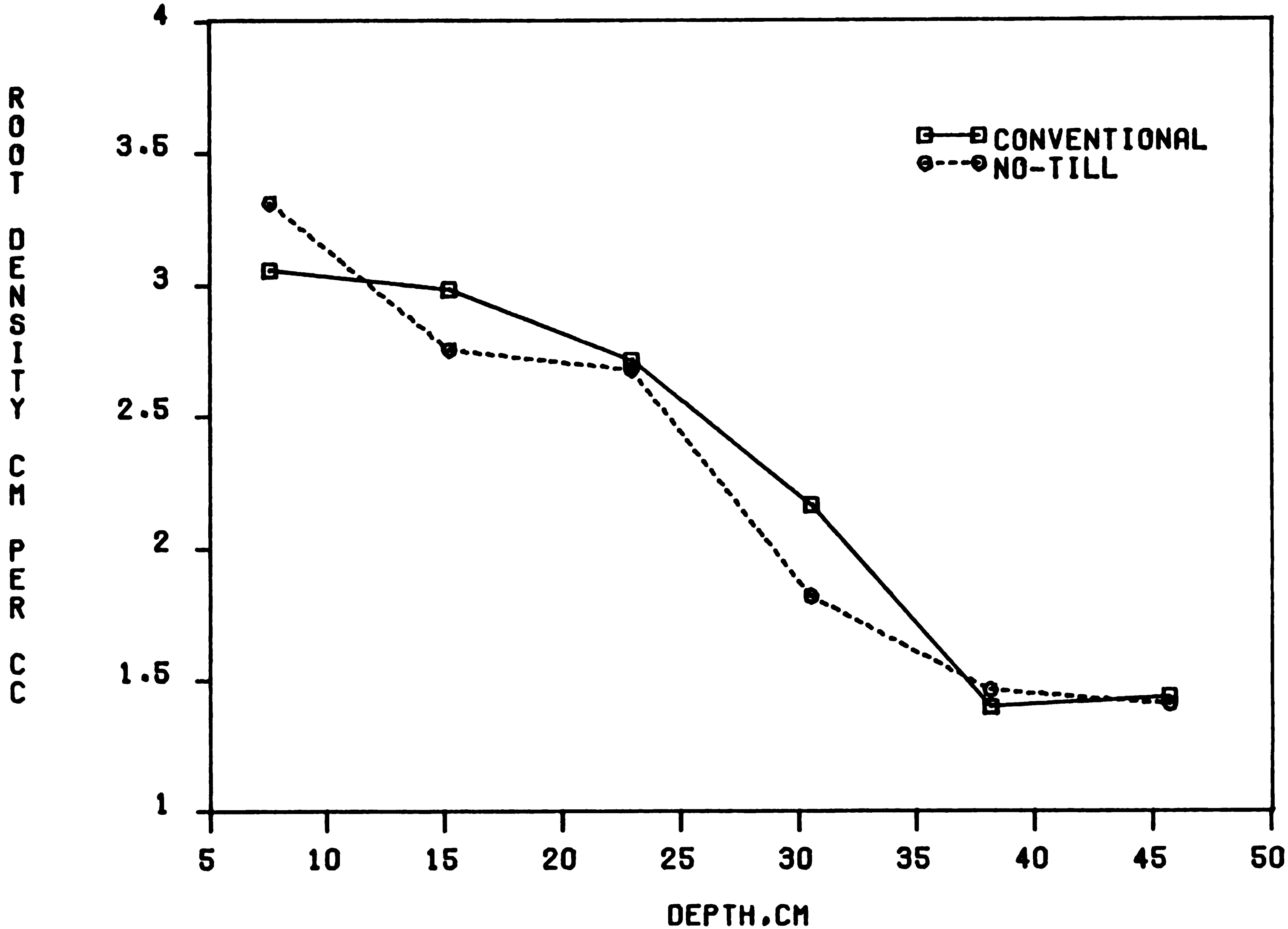


Figure 12. Influence of tillage and depth on corn root length per unit soil volume.

Table 18. Corn root length density as affected by tillage, depth and distance from row.

| | Distance from row (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 7.6 | | 15.2 | | 22.8 | | |
| Depth | Conventional | No-till | Conventional | No-till | Conventional | No-till | LSD (.05)[1] |
| cm | cm/cc | | | | | | |
| 7.6 | 4.5 | 4.6 | 2.8 | 2.9 | 1.9 | 2.4 | (1.8) |
| 15.2 | 4.6 | 3.2 | 2.4 | 2.7 | 2.0 | 2.3 | (1.8) |
| 22.8 | 3.1 | 2.8 | 2.3 | 2.2 | 2.8 | 3.0 | (NS) |
| 30.5 | 3.3 | 1.8 | 1.7 | 1.9 | 1.5 | 1.7 | (NS) |
| 38.1 | 1.7 | 2.3 | 1.5 | 1.3 | 1.0 | .8 | (NS) |
| 45.7 | 1.9 | 2.0 | 1.5 | 1.1 | 0.9 | 1.1 | (NS) |
| LSD (.05) | (1.8) | (1.8) | (NS) | (NS) | (NS) | (NS) | |

[1]For comparing densities at different distances with the same tillage treatment.

## Summary and Conclusions

High corn and soybean yields were obtained in no-till systems on medium textured soils. The climatic conditions of the 1982 growing season were nearly ideal for no-till crop production. The warm, dry Spring allowed for early planting and uniform seed germination and plant emergence. During a cooler Spring, reduced temperatures under the surface mulch may delay emergence and reduce yields in no-till systems.

Lower corn yields occurred in conventionally tilled plots because of dry moisture conditions at planting which delayed germination. This problem was eliminated in the soybean study by irrigating shortly after planting. Soybean stands were lower in no-till plots because of nonuniform seed depth at planting, but yields were not affected by the tillage method.

In previous research, reduced nutrient availability in no-till has been attributed to the low mobility of surface applied P and K. In these studies, however, macro and micronutrient availability appeared to be similar in both tillage systems as evidenced by yield and nutrient composition data. Nitrogen and P uptake early in the season was be higher under no-till than under conventional tillage. The method of P placement and the K rate had little influence on corn or soybean yields or nutrient compostion. These findings are probably a result of (1) the high initial fertility levels of the soils and (2) the fact that P, K and pH stratification was probably not significant during the first year of no-till production.

In the corn study, the higher N rate significantly increased corn grain and stover yields in both the conventional and the no-till plots. Nutrient analysis and visual deficiency observations support the findings of others showing that at suboptimal N levels, N uptake is less in no-till than in conventional tillage systems. Previous research has suggested that decreased N efficiency in no-till may be due to an increased potential for leaching, immobilization, denitrification and volatilization and less mineralization of N in no-till systems as compared to conventional tillage systems.

Corsoy 79 significantly outyielded SRF-200. As the use of minimum tillage practices increases variety trials under no-till conditions will become more important. Early season vigor and disease resistance are two characteristics that corn and soybean varieties will need to be well-suited to use with no-till.

The effect of the surface mulch on soil moisture and soil temperature was small in these irrigated studies. Bulk density was significantly higher and air-filled porosity was significantly less in no-till plots compared to conventional plots, but these differences did not appear to affect corn yield, nutrient composition or root length density.

As these tillage studies become more established, the differences in soil physical and chemical properties between the conventional and no-till plots are likely to become more evident. These differences may become great enough to affect root growth, nutrient availability and yield.

## Recommendations

I. The corn and soybean tillage studies established in East Lansing in 1982 are proposed to continue for a ten year period to allow for a thorough evaluation of the treatments. Several changes in the management practices may make the results from these studies more applicable to farm situations.

A) Ammonium nitrate should be discontinued as the main N fertilizer broadcast in these studies since it is an expensive and little used source in Michigan. Injecting anhydrous ammonia should be considered as an alternative.

B) Hand weeding should be eliminated because mechanical weed control is not practical in no-till crop production and because hoeing leads to incorporation of surface applied nutrients.

C) The benefits of irrigation on soybean yields and nutrient uptake in this study need to be evaluated.

D) Plowing in the Fall instead of the Spring could improve seedbed conditions at planting.

II. Soil chemical and physical properties should be evaluated several times over the duration of the project.

A) Soil testing of samples taken at several depth increments (including a shallow surface sample) is needed to monitor the movement of surface applied P and K and to determine the rate of surface acidification due to the surface application of N.

B) Undisturbed soil cores for bulk density and air-filled porosity measurements should be taken at several depths in each tillage system in order to determine the extent of the soil compaction in the two tillage systems.

III. Research indicates that there are many alternatives to consider when developing a nitrogen management program for no-till corn. In addition to rate, source and placement studies, research is needed to study the use of split application techniques, the timing of N fertilization and the use of nitrification and urease inhibitors.

# APPENDIX A

## PLANT AND GRAIN ANALYSIS FOR INDIVIDUAL TREATMENTS

# APPENDIX

Table 1a. Corn tillage study treatments.

| Treatment | Tillage | P-Placement[1] | N-Rate | K-Rate |
|---|---|---|---|---|
| | | | kg N/ha | kg $K_2O$/ha |
| 1 | Conventional | Broadcast | 168 | 56 |
| 2 | Conventional | Broadcast | 168 | 168 |
| 3 | Conventional | Broadcast | 336 | 56 |
| 4 | Conventional | Broadcast | 336 | 168 |
| 5 | Conventional | Banded | 168 | 56 |
| 6 | Conventional | Banded | 168 | 168 |
| 7 | Conventional | Banded | 336 | 56 |
| 8 | Conventional | Banded | 336 | 168 |
| 9 | No-till | Broadcast | 168 | 56 |
| 10 | No-till | Broadcast | 168 | 168 |
| 11 | No-till | Broadcast | 336 | 56 |
| 12 | No-till | Broadcast | 336 | 168 |
| 13 | No-till | Banded | 168 | 56 |
| 14 | No-till | Banded | 168 | 168 |
| 15 | No-till | Banded | 336 | 56 |
| 16 | No-till | Banded | 336 | 168 |

[1]Phosphorus rate = 56 kg $P_2O_5$/ha.

Table 2a. Elemental composition of corn plants (early whorl) as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| 1 | 3.84 | .36 | 3.88 | .80 | .37 | 132 | 1,980 | 43 | 12 | 3,020 |
| 2 | 3.66 | .35 | 3.92 | .70 | .32 | 122 | 1,680 | 42 | 11 | 2,580 |
| 3 | 4.08 | .40 | 3.90 | .74 | .37 | 110 | 1,500 | 45 | 14 | 2,190 |
| 4 | 4.10 | .39 | 4.01 | .76 | .35 | 121 | 1,550 | 48 | 12 | 2,230 |
| 5 | 3.95 | .40 | 3.82 | .71 | .35 | 118 | 1,440 | 46 | 12 | 1,970 |
| 6 | 4.15 | .42 | 4.10 | .75 | .35 | 99 | 1,340 | 51 | 12 | 2,020 |
| 7 | 4.10 | .41 | 4.14 | .74 | .35 | 104 | 1,410 | 43 | 12 | 2,170 |
| 8 | 4.01 | .40 | 4.02 | .72 | .37 | 119 | 1,710 | 38 | 11 | 2,470 |
| 9 | 4.38 | .47 | 4.00 | .76 | .42 | 74 | 910 | 37 | 13 | 1,370 |
| 10 | 4.26 | .44 | 3.87 | .73 | .40 | 77 | 830 | 38 | 13 | 1,230 |
| 11 | 4.27 | .46 | 3.72 | .70 | .41 | 71 | 750 | 35 | 12 | 1,090 |
| 12 | 4.26 | .47 | 3.84 | .69 | .38 | 75 | 780 | 39 | 14 | 1,170 |
| 13 | 4.45 | .49 | 4.02 | .78 | .43 | 74 | 800 | 37 | 13 | 1,150 |
| 14 | 4.06 | .45 | 3.89 | .65 | .36 | 75 | 860 | 38 | 12 | 1,260 |
| 15 | 4.20 | .45 | 3.69 | .72 | .42 | 77 | 950 | 38 | 13 | 1,360 |
| 16 | 4.19 | .45 | 3.88 | .66 | .38 | 69 | 890 | 37 | 13 | 1,360 |

Table 3a. Elemental composition of corn ear leaf as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| 1 | 3.18 | .34 | 2.82 | .77 | .24 | 40 | 247 | 42 | 13 | 68 |
| 2 | 3.24 | .34 | 2.69 | .76 | .23 | 46 | 253 | 46 | 14 | 65 |
| 3 | 3.22 | .33 | 2.87 | .81 | .25 | 51 | 256 | 42 | 13 | 57 |
| 4 | 3.38 | .33 | 2.80 | .74 | .20 | 49 | 333 | 54 | 13 | 63 |
| 5 | 3.14 | .32 | 2.67 | .73 | .22 | 40 | 236 | 38 | 12 | 55 |
| 6 | 3.00 | .32 | 2.73 | .70 | .22 | 40 | 246 | 42 | 15 | 65 |
| 7 | 3.03 | .32 | 2.70 | .73 | .22 | 43 | 221 | 42 | 12 | 77 |
| 8 | 3.28 | .35 | 2.87 | .76 | .23 | 48 | 254 | 41 | 13 | 81 |
| 9 | 3.04 | .33 | 2.43 | .80 | .30 | 33 | 210 | 34 | 12 | 36 |
| 10 | 3.01 | .34 | 2.54 | .82 | .29 | 37 | 249 | 38 | 12 | 46 |
| 11 | 3.22 | .33 | 2.66 | .87 | .29 | 44 | 228 | 34 | 12 | 56 |
| 12 | 3.24 | .35 | 2.62 | .83 | .26 | 41 | 271 | 35 | 13 | 28 |
| 13 | 3.04 | .33 | 2.55 | .81 | .29 | 39 | 259 | 35 | 12 | 58 |
| 14 | 3.00 | .33 | 2.58 | .81 | .27 | 33 | 248 | 34 | 12 | 37 |
| 15 | 3.11 | .32 | 2.47 | .86 | .29 | 40 | 210 | 36 | 12 | 19 |
| 16 | 3.11 | .34 | 2.49 | .82 | .26 | 42 | 257 | 35 | 13 | 60 |

Table 4a. Elemental composition of corn grain as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | Element | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | ppm | | | | |
| 1 | 1.41 | .32 | .47 | .21 | 4.8 | 39 | 20 | 2.0 | 39 |
| 2 | 1.40 | .33 | .46 | .19 | 5.1 | 28 | 22 | 2.3 | 50 |
| 3 | 1.47 | .37 | .54 | .24 | 6.9 | 50 | 24 | 2.0 | 61 |
| 4 | 1.47 | .33 | .50 | .20 | 5.8 | 28 | 23 | 2.3 | 36 |
| 5 | 1.44 | .33 | .50 | .21 | 4.9 | 30 | 21 | 1.9 | 42 |
| 6 | 1.41 | .35 | .51 | .21 | 5.4 | 44 | 23 | 4.1 | 50 |
| 7 | 1.47 | .37 | .55 | .25 | 6.6 | 39 | 26 | 2.5 | 48 |
| 8 | 1.44 | .35 | .49 | .21 | 6.0 | 35 | 23 | 2.4 | 47 |
| 9 | 1.33 | .32 | .45 | .18 | 5.8 | 30 | 23 | 2.6 | 57 |
| 10 | 1.34 | .39 | .54 | .22 | 5.8 | 30 | 24 | 2.5 | 47 |
| 11 | 1.46 | .33 | .49 | .22 | 7.1 | 34 | 23 | 2.1 | 58 |
| 12 | 1.46 | .32 | .45 | .19 | 22.0 | 55 | 24 | 2.6 | 53 |
| 13 | 1.34 | .28 | .54 | .22 | 7.8 | 51 | 28 | 2.3 | 67 |
| 14 | 1.39 | .38 | .54 | .23 | 6.0 | 31 | 24 | 2.0 | 40 |
| 15 | 1.48 | .33 | .47 | .20 | 5.9 | 29 | 22 | 2.4 | 32 |
| 16 | 1.43 | .33 | .48 | .21 | 6.0 | 38 | 22 | 6.1 | 33 |

Table 5a. Elemental composition of corn stover as affected by tillage method, nitrogen and potassium fertilization and phosphorus placement.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| 1 | .76 | .079 | 1.64 | .57 | .29 | 19 | 287 | 16 | 5.8 | 177 |
| 2 | .71 | .076 | 1.72 | .57 | .25 | 20 | 287 | 16 | 6.5 | 169 |
| 3 | .91 | .076 | 1.61 | .61 | .31 | 28 | 248 | 16 | 6.5 | 146 |
| 4 | .91 | .078 | 2.00 | .57 | .25 | 27 | 249 | 21 | 6.9 | 137 |
| 5 | .81 | .094 | 1.64 | .60 | .28 | 21 | 273 | 18 | 6.7 | 149 |
| 6 | .74 | .083 | 1.81 | .54 | .25 | 24 | 321 | 19 | 5.9 | 189 |
| 7 | .97 | .087 | 1.73 | .69 | .30 | 25 | 297 | 21 | 6.9 | 165 |
| 8 | .90 | .086 | 1.83 | .62 | .27 | 29 | 301 | 20 | 7.1 | 181 |
| 9 | .62 | .104 | 1.37 | .55 | .29 | 23 | 355 | 14 | 5.8 | 307 |
| 10 | .60 | .083 | 1.43 | .55 | .27 | 20 | 309 | 15 | 6.1 | 163 |
| 11 | .90 | .104 | 1.51 | .62 | .32 | 32 | 292 | 14 | 6.3 | 161 |
| 12 | .83 | .092 | 1.53 | .61 | .30 | 29 | 298 | 16 | 6.4 | 148 |
| 13 | .64 | .105 | 1.34 | .59 | .30 | 27 | 445 | 16 | 6.7 | 240 |
| 14 | .62 | .098 | 1.58 | .52 | .24 | 19 | 303 | 15 | 5.4 | 150 |
| 15 | .87 | .102 | 1.56 | .63 | .29 | 29 | 274 | 17 | 7.0 | 225 |
| 16 | .84 | .093 | 1.53 | .62 | .28 | 26 | 301 | 16 | 6.7 | 159 |

Table 6a. Soybean tillage study treatments.

| Treatment | Tillage | Variety | P-Placement[1] | K-Rate |
|---|---|---|---|---|
| | | | | kg $K_2O$/ha |
| 1 | Conventional | Corsoy 79 | Broadcast | 0 |
| 2 | Conventional | Corsoy 79 | Broadcast | 56 |
| 3 | Conventional | Corsoy 79 | Banded | 0 |
| 4 | Conventional | Corsoy 79 | Banded | 56 |
| 5 | Conventional | SRF-200 | Broadcast | 0 |
| 6 | Conventional | SRF-200 | Broadcast | 56 |
| 7 | Conventional | SRF-200 | Banded | 0 |
| 8 | Conventional | SRF-200 | Banded | 56 |
| 9 | No-till | Corsoy 79 | Broadcast | 0 |
| 10 | No-till | Corsoy 79 | Broadcast | 56 |
| 11 | No-till | Corsoy 79 | Banded | 0 |
| 12 | No-till | Corsoy 79 | Banded | 56 |
| 13 | No-till | SRF-200 | Broadcast | 0 |
| 14 | No-till | SRF-200 | Broadcast | 56 |
| 15 | No-till | SRF-200 | Banded | 0 |
| 16 | No-till | SRF-200 | Banded | 56 |

[1]Phosphorus rate = 56 kg $P_2O_5$/ha.

Table 7a. Elemental composition of soybean plants (early bloom) as affected by tillage method, variety, phosphorus placement and potassium fertilization.

| Treatment | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| 1 | 5.17 | .45 | 2.12 | 1.27 | .57 | 50 | 182 | 36 | 10 | 89 |
| 2 | 5.15 | .47 | 2.27 | 1.24 | .50 | 47 | 199 | 37 | 12 | 80 |
| 3 | 5.22 | .56 | 2.33 | 1.17 | .52 | 64 | 243 | 45 | 13 | 149 |
| 4 | 5.11 | .44 | 2.29 | 1.12 | .50 | 51 | 204 | 36 | 19 | 114 |
| 5 | 4.96 | .44 | 2.24 | 1.36 | .57 | 41 | 176 | 33 | 11 | 89 |
| 6 | 5.22 | .47 | 2.23 | 1.20 | .52 | 57 | 196 | 38 | 14 | 82 |
| 7 | 4.86 | .44 | 2.35 | 1.16 | .47 | 50 | 169 | 35 | 13 | 59 |
| 8 | 5.11 | .42 | 2.21 | 1.18 | .51 | 50 | 196 | 34 | 18 | 132 |
| 9 | 5.35 | .50 | 2.25 | 1.31 | .61 | 57 | 187 | 42 | 15 | 79 |
| 10 | 5.24 | .48 | 2.45 | 1.37 | .54 | 52 | 178 | 39 | 12 | 79 |
| 11 | 5.20 | .45 | 2.31 | 1.41 | .59 | 63 | 197 | 45 | 15 | 66 |
| 12 | 5.34 | .48 | 2.33 | 1.09 | .51 | 66 | 186 | 44 | 12 | 56 |
| 13 | 5.18 | .48 | 2.23 | 1.32 | .57 | 56 | 191 | 43 | 16 | 58 |
| 14 | 5.37 | .48 | 2.35 | 1.25 | .52 | 52 | 189 | 43 | 14 | 88 |
| 15 | 5.32 | .49 | 2.33 | 1.14 | .54 | 61 | 182 | 43 | 13 | 65 |
| 16 | 5.21 | .44 | 2.22 | 1.26 | .52 | 72 | 226 | 44 | 14 | 107 |

Table 8a. Elemental composition of soybean seed as affected by tillage method, variety, phosphorus placement and potassium fertilization.

| | Element | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | N | P | K | Ca | Mg | Mn | Fe | Zn | Cu | Al |
| | % | | | | | ppm | | | | |
| 1 | 6.57 | .75 | 2.00 | .11 | .18 | 21 | 68 | 40 | 14 | 32 |
| 2 | 6.44 | .74 | 1.92 | .11 | .17 | 21 | 87 | 41 | 14 | 22 |
| 3 | 6.29 | .72 | 1.93 | .11 | .19 | 21 | 69 | 39 | 13 | 24 |
| 4 | 6.12 | .71 | 1.91 | .12 | .19 | 20 | 74 | 38 | 13 | 11 |
| 5 | 6.46 | .77 | 1.95 | .12 | .18 | 20 | 73 | 42 | 15 | 12 |
| 6 | 6.36 | .72 | 1.91 | .11 | .19 | 22 | 80 | 40 | 13 | 36 |
| 7 | 6.33 | .73 | 1.98 | .11 | .19 | 22 | 94 | 41 | 14 | 29 |
| 8 | 6.28 | .76 | 1.99 | .11 | .21 | 21 | 74 | 40 | 14 | 8 |
| 9 | 6.46 | .72 | 1.93 | .11 | .17 | 21 | 79 | 39 | 15 | 16 |
| 10 | 6.58 | .73 | 1.95 | .10 | .17 | 21 | 65 | 37 | 15 | 12 |
| 11 | 6.25 | .70 | 1.89 | .10 | .19 | 22 | 103 | 41 | 13 | 23 |
| 12 | 6.14 | .70 | 1.95 | .10 | .19 | 22 | 69 | 41 | 13 | 11 |
| 13 | 6.40 | .73 | 1.90 | .10 | .18 | 22 | 76 | 42 | 14 | 11 |
| 14 | 6.42 | .72 | 1.92 | .11 | .18 | 21 | 69 | 38 | 14 | 13 |
| 15 | 6.21 | .69 | 1.89 | .10 | .19 | 21 | 75 | 38 | 13 | 15 |
| 16 | 6.18 | .72 | 2.00 | .11 | .20 | 23 | 78 | 42 | 13 | 11 |

# BIBLIOGRAPHY

# BIBLIOGRAPHY

1. Alvey et. al. 1980. Genstat: a general statistical program. Lawes Agricultural Trust. Rothamsted, England.

2. Anon. 1978. Glossary of soil science terms. Soil Science Society of America. Madison, Wisc. pp 36.

3. Anon. 1982. The history of no-tillage: Modern man comes a full circle. Ag. Chem. Age. 26(4): 10,38.

4. Anon. 1982. Michigan conservation tillage survey. Soil Conservation Service. Mimeograph 2388b.

5. Baeumer, K., and W. A. P. Bakermans. 1973. Zero-tillage. Adv. Agron. 25:77-12.

6. Barber, S. A. 1970. Effect of tillage practices on corn root distribution and morphology. Agron J. 63:724-726.

7. Bandel, V. A., S. Dziernia, G. Stanford, and J. O. Legg. 1975. N behavior under no-till and conventional corn culture. First-year results using unlabeled N fertilizer. Agron. J. 67:782-786.

8. Bandel, V. A., S. Dziernia, and G. Stanford. 1980. Comparison of N fertilizers for no-till corn. Agron. J. 72:337-341.

9. Beale, O. W., G. B. Nutt, and T. C. Peele. 1955. The effect of mulch tillage on runoff, erosion, soil properties, and crop yields. Soil Sci. Soc. Am. Proc. 19:244-247.

10. Belcher, C. R. and J. L. Ragland. 1972. Phosphorus absorption by sod planted corn (Zea mays L.) from surface-applied phosphorus. Agron. J. 64:754-756.

11. Bennett, O. L., G. Stanford, E. L. Mathias, and P. E. Lundberg. 1975. Nitrogen conservation under corn planted in quackgrass sod. J. Environ. Qual. 4:107-110.

12. Blake, G. R. 1965. Bulk density. In: Methods of soil analysis part 1. Physical and mineralogical properties, including statistics of measurement and sampling. Agronomy 9:374-390.

13. Blevins, R. L., and D. Cook. 1970. No-tillage, its influence on soil moisture and soil temperature. Ky. Agr. Exp. Sta. Prog. Rep. 187.

14. Blevins, R. L., D. Cook, S. H. Phillips, and R. E. Phillips. 1971. Influences of no-tillage on soil moisture. Agron. J. 63:593-596.

15. Blevins, R. L., G. W. Thomas, and P. L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after 5 years of continuous corn. Agron. J. 69:382-383.

16. Box, J. E., Jr., S. R. Wilkinson, R. N. Dawson, and J. Kozachyn. 1980. Soil-water effects on no-till corn production in strip and completely killed mulches. Agron. J. 75:797-802.

17. Carson, P. L. 1980. Recommended potassium test. In: Recommended chemical soil test procedures for the North Central region. North Central Reg. Publ. 221:17-18.

18. Costamagna, O. A., R. K. Stivers, H. M. Galloway, and S. A. Barber. 1982. Three tillage systems affect selected properties of a tiled, naturally poorly-drained soil. Agron. J. 74:442-444.

19. Crabtree, J. J., and R. N. Rupp. 1980. Double and monocropped wheat and soybeans under different tillage and row spacing. Agron. J. 72:445-448.

20. Davidson, J. H., and K. C. Barrons. 1954. Chemical seedbed preparation-new approaches to soil conservation. Down to Earth. Winter.

21. Doran, J. W. 1980. Microbial changes associated with residue management with reduced tillage. Soil Sci. Soc. Am. J. 44:518-524.

22. Doran, J. W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44:765-771.

23. Eckert, D. J. 1983. Phosphorus fertilization of no-tillage corn. Ohio State Soil Fertility Research Report, 1982.

24. Estes, G. O. 1972. Elemental composition of maize grown under no-till and conventional tillage. Agron. J. 64:733-735.

25. Fedewa, D. J. 1982. Michigan agricultural statistics: 1982. Michigan Agricultural Reporting Service. Lansing, Mich. 80pp.

26. Fink, R. J., and D. Wesley. 1974. Corn yield as affected by fertilization and tillage system. Agron. J. 66:70-71.

27. Fox, R. H., and L. D. Hoffman. 1981. The effect of N fertilizer source on grain yield, N uptake, soil pH, and lime requirements in no-till corn. Agron. J. 73:891-895.

28. Free, G. R. 1970. Minimum tillage for corn production. Bull. 1030. Cornell Agr. Exp. Sta., Ithaca, N.Y.

29. Frye, W. W., R. L. Blevins, L. W. Murdock, K. L. Wells, and J. H. Ellis. 1981. Effectiveness of nitrapyrin with surface-applied fertilizer nitrogen in no-tillage corn. Agron. J. 73:287-289.

30. Gantzer, C. J., and G. R. Blake. 1978. Physical characteristics of LeSueur clay loam soil following no-till and conventional tillage. Agron. J. 70:853-857.

31. Graff, O. 1969. Activity of earthworms under natural organic materials estimated by sample castings. Pediologia. 9:120-127.

32. Griffith, D. R., J. V. Mannering, H. M. Galloway, S. D. Parsons, and C. B. Richey. 1973. Effect of eight tillage-planting systems on soil temperature, percent stand, plant growth and yield of corn on five Indiana soils. Agron. J. 65:321-326.

33. Hallmark, W. B., and S. A. Barber. 1981. Root growth and morphology, nutrient uptake, and nutrient status of soybeans as affected by soil K and bulk density. Agron. J. 73:779-782.

34. Hargrove, W. L., J. T. Touchton, and R. N. Gallaher. 1982. Influence of tillage practices on the fertility status of an acid soil double-cropped to wheat and soybeans. Agron. J. 74:684-687.

35. Hill, J. D., and R.L. Blevins. 1973. Quantitative soil moisture use in corn grown under conventional and no-tillage methods. Agron. J. 65:945-949.

36. Hovermale, C. H., H. M. Camper, and M. W. Alexander. 1979. Effects of small grain stubble height and mulch on no-tillage soybean production. Agron. J. 71:644-647.

37. Johnson, J. W. 1983. Response of no-till corn to N, P or K. Ohio State Soil Fertility Research Report, 1982.

38. Jones, B. J., and H. V. Eck. 1973. Plant analysis as an aid in fertilizing corn and grain sorghum. In: L. M. Walsh and J. D. Beaton (ed.). Soil testing and plant analysis. Soil Sci. Soc. Amer., Inc. Madison, Wisc.

39. Jones, N. J., J. E. Moody, G. M. Shear, W. W. Moschler, and J. H. Lillard. 1968. The no-tillage system for corn (Zea mays L.). Agron. J. 60:17-20.

40. Juo, A. S. R., and R. Lal. 1979. Nutrient profile in a tropical alfisol under conventional and no-till systems. Soil Sci. 127:168-173.

41. Kang, B. T., and M. Yunusa. 1977. Effect of tillage methods and phosphorus fertilization on maize in the humid tropics. Agron. J. 69:291-294.

42. Kapusta, G. 1979. Seedbed tillage and herbicide influence on soybean (Glycine max) weed control and yield. Weed Sci. 27:520-526.

43. Kaul, J. N., and H. S. Sekhon. 1975. Effects of straw mulch on the performance of soybeans. Indian J. Agric. Sci. 45:291-293.

44. Ketcheson, J. W. 1980. Effect of tillage on fertilizer requirements for corn on a silt loam soil. Agron. J. 72:540-542.

45. Knavel, D. E., J. Ellis, and J. Morrison. 1977. Effects of tillage systems on performance and elemental absorption by selected vegetable crops. J. Am. S. Hort. 102:323-327.

46. Knudsen, D. 1980. Recommended phosphorus tests. In: Recommended chemical soil test procedures for the North Central region. North Central Reg. Publ. 221:14-16.

47. Lal, R. 1976. No-tillage effects on the soil properties under different crops in western Nigeria. Soil Sci. Soc. Am. Proc. 40:762-768.

48. Lal, R. 1979. Influence of 6 years of no-tillage and conventional plowing on fertilizer response of maize (Zea mays L.) on an alfisol in the tropics. Soil Sci. Soc. Am. Proc. 43:399-403.

49. Larson, W. E., G. B. Triplett, Jr. 1970. Problems with no-till crops. Crops and Soils. 23:14-20.

50. Lawton, K. 1946. The influence of soil aeration on the growth and adsorption of nutrients by corn plants. Soil Sci. Soc. Am. Proc. 10:263-268.

51. Legg, J. O., G. Stanford, and O. L. Bennett. 1979. Utilization of labeled-N fertilizer on silage corn under conventional and no-till culture. Agron J. 71:1009-1115.

52. Lindemann, W. C., G. E. Ham, and G. W. Randall. 1982. Soil compaction effects on soybean nodulation, $N_2(C_2H_2)$ fixation and seed yield. Agron. J. 74:307-311.

53. Lutz, J. A., Jr., and J. H. Lillard. 1973. Effect of fertility treatments on the growth, chemical composition and yield of no-tillage corn on orchardgrass sod. Agron. J. 65:733-736.

54. Mannering, J. V. Estimating surface cover photographically. Unpublished report. West Lafayette, Indiana.

55. McKibben, G. E. 1976. O-till soybean culture. Illinois Agric. Exp. Stn. DSAC 4:66.

56. McKibben, G. E. 1978. O-till soybean culture. Illinois Agric. Exp. Stn. DSAC 6:33-45.

57. Meints,V. W., and L. S. Robertson. 1983. Soil sampling for no-till and conservation tillage crops. Michigan State University Ext. Bull. E-1616.

58. Mengel, D. B., D. W. Nelson, and D. M. Huber. 1982. Placement of nitrogen fertilizers for no-till and conventional till corn. Agron. J. 74:515-518.

59. Mitchell, W. H., and M. R. Teal. 1977. Winter-annual cover crops for no-tillage corn production. Agron J. 69:569-573.

60. Moncrief, J. F., and E. E. Schulte. The effect of tillage and fertilizer source and placement on nutrient availability to corn. Unpublished data. 1981.

61. Moschler, W. W., and G. D. Jones. 1974. Nitrogen for no-tillage corn in Virginia-sources and time of application. Comm. Soil S. 5(6):547-556.

62. ________, and D. C. Martens. 1975. Nitrogen, phosphorus and potassium requirements in no-tillage and conventionally tilled corn. Soil Sci. Soc. Amer. Proc. 39:886-891.

63. ________, D. C. Martens, C. I. Ritch, and G. M. Shear. 1973. Comparitive lime effects on continuous no-tillage and conventionally tilled corn. Agron J. 65:781-783.

64. ________, D. C. Martens, and G. M. Shear. 1975. Residual fertility in soil continuously cropped to corn by conventional tillage and no-tillage methods. Agron. J. 67:45-48.

65. ________, G. M. Shear, D. C. Martens, G. D. Jones, and R. P. Wilmouth. 1972. Comparitive yield and fertilizer efficiency of no-tillage and conventionally tilled corn. Agron. J. 64:229-231.

66. Newman, E. L. 1966. A method of estimating the total length of root in a sample. J. Appl. Ecol. 3:139-145.

67. Olsen, T. R., and L. S. Schoeberl. 1970. Corn yields, soil temperature, and water use with four tillage methods in the western corn belt. Agron. J. 62:229-231.

68. Parkinson, J. A., and S. E. Allen. 1975. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. Commun. Soil Sci. and Plant Analysis. 6(1):1-11.

69. Phillips, R. E., et al. 1971. Agronomy Research Univ. Ky. Misc. Publ. 394:36-38.

70. Phillips, R. E., R. L. Blevins, G. W. Thomas, W. W. Frye, and S. H. Phillips. 1980. No-tillage agriculture. Science. 208:1108-1113.

71. Phillips, S. H., and H. M. Young. 1973. No-tillage farming. Reiman Associates, Milwaukee, Wisc. 224pp.

72. Rice, W., and M. Smith. 1982. Denitrification in no-till and plowed soils. Soil Sci. Soc. Am. Proc. 46:1168-1173.

73. Richey, C. B., D. R. Griffith, and S. D. Parsons. 1977. Yields and cultural energy requirements for corn and soybeans with various tillage-planting systems. Adv. Agron. 29:141-182.

74. Robertson, L. S., D. R. Christenson, and D. D. Warnke. 1976. Essential secondary elements: calcium. Mich. Ext. Bull. E-996.

75. ________. 1979. Essential secondary elements: magnesium. Mich. Ext. Bull. E-994.

76. Sanford, J. O., D. L. Myhre, and N. C. Merwine. 1973. Double cropping systems involving no-tillage and conventional tillage. Agron J. 65:978-982.

77. Schwerdtle, F. 1969. Untersuchungen zur populationsdichte von regenwurenbe herkommlicher bodenbearleitung und bei "Direktsaat." Z. Pflanzenkr. Pflazenpathol. Pflazenshutz. 76:635-641.

78. Shear, G. M., and W. W. Moschler. 1969. Continuous corn by the no-tillage and conventional tillage methods: a six year comparison. Agron. J. 61:524-526.

79. Singh, T. A., G. W. Thomas, W. W. Moschler, and D. C. Martens. 1966. Phosphorus uptake by corn (Zea mays L.) under no-tillage and conventional practices. Agron. J. 58:147-148.

80. Smucker, A. J. M., S. L. McBurney, and A. K. Srivastava. 1982. Quantitative seperation of roots from compacted soil profiles by the hydropneumatic elutriation system. Agron. J. 74:500-503.

81. Soane, B. D., J. D. Pidgeon. 1975. Tillage requirements in relation to soil physical properties. Soil Sci. 119:376-384.

82. Sprague, M. A. 1952. Substitution of chemicals for tillage in pasture renovation. Agron. J. 44:405-409.

83. Srivastava, A. K., J. M. Smucker, and S. L. McBurney. 1981. An improved mechanical soil-root sampler. Unpublished report.

84. Stanford, G., O. L. Bennett, and J. F. Powers. 1973. Conservation tillage practices and nutrient availability. In: Conservation tillage, proceedings of a national conference of soil conservation service of America. p.54-62.

85. Steel, R. G. B., and J. H. Torrie. 1980. Principles and procedures mf statistics: a biometric approach. Second edition. McGraw-Hill, N. Y. pp 611.

86. Terman, G. L. 1979. Volatilization of nitrogen as ammonia from surface applied fertilizers, organic amendments and crop residues. Adv. Agron. 31:189-223.

87. Thomas, G. W., R. L. Blevins, R. E. Phillips, and M. A. McMahon. 1973. Effect of a killed sod mulch on nitrate movement and corn yield. Agron. J. 65:736-739.

88. Touchton, J. T., and W. L. Hargrove. 1982. Nitrogen sources and methods of application for no-tillage corn production. Agron. J. 74:823-826.

89. Triplett, G. B., Jr., and D. M. Van Doren, Jr. 1969. Nitrogen, phosphorus and potassium fertilization of non-tilled maize. Agron. J. 61:637-639.

90. ________. 1977. Agriculture without tillage. Sci. Am. 236(1):28-33.

91. ________, and B. L. Schmidt. 1968. Effects of corn (Zea mays L.) stover mulch on no-tillage corn yield and water infiltration. Agron. J. 60:236-239.

92. Tyler, D. D., and J. R. Overton. 1982. No-till advantages of soybean seed quality during drought stress. Agron. J. 74:344-347.

93. Unger, and T. M. McCalla. 1980. Conservation tillage systems. Adv. Agron. 33:1-58.

94. Vitosh, M. L., and D. D. Warncke. 1981. No-till corn: 2. Fertilizer and liming practices. Mich. State Univ. Ext. Bull. E-905.

95. Vitosh,M. L., D. D. Warncke, B. D. Knezek and R. E. Lucas. 1981. Secondary and micronutrients for vegetable and field crops. Mich. Ext. Bull. E-486. pp 19.

96. Vomicil, J. A. 1965. Porosity. In: Methods of soil analysis part 1: Physical and mineralogical properties, including statistics of measurement and sampling. Agronomy 9:299-314.

97. Walker,W. M., J. C. Siemens, and T. R. Peck. 1970. Effect of tillage treatments upon soil tests for soil acidity, soil P, and soil K at three soil depths. Commun. Soil Sci. Plant Anal. 1(6):367-375.

98. Warncke, D. D., and D. R. Christenson. 1981. Fertilizer recommendations: vegetable and field crops in Michigan. Mich. Ext. Bull. E-550.

99. Weatherly, A. B., and J. H. Dane. 1979. Effect of tillage on soil-water movement during corn growth. Soil Sci. Soc. Am. Proc. 43:1222-1225.

100. Wesseling, J., and W. R. van Wijk. 1957. Land drainage in relation to soils and crops. I. Soil physical conditions in relation to drain depth. In: J. N. Luthin (ed.). Drainage of agricultural lands. Agronomy 7:466-472.

101. Whitney, D. A. 1980. Micronutrient soil tests-zinc, iron, manganese and copper. In: Recommended chemical soil test procedures for the North Central region. North Central Reg. Publ. 221:18-21.