ABSTRACT

THE INFLUENCE OF DEEP MIXING A KALAMAZOO SANDY LOAM ON SEVERAL PHYSICAL SOIL FACTORS AND CORN ROOT DEVELOPMENT AND YIELD

by Curtis Dean Piper

A research project was conducted over an eight year period to determine the feasibility of using a deep-mixing process to alter the physical properties of a dense soil layer that acted as a barrier to root development and reduced yields.

The deep-mixing did improve the physical properties of the dense soil layer, by redistributing the soil separates. Increases were obtained in the total pore space and macro-pores, with a corresponding decrease in the density of this soil layer. These improvements were of short duration as they soon reverted back to, or in most cases beyond their original state. The deep-mixing increased the oxygen diffusion recovery rate and also improved the soil water utilization. The over-all influence of the deep-mixing was to increase the corn grain yields every year but one (1962) and resulted in an eight year average increase of 30.4 bushels per acre. For this particular soil the increase in yields were sufficient to warrant the expense of the deep-mixing operation.

Supplemental organic matter in the form of chopped alfalfa hay, used as a stabilizing agent in the soil, increased the water retention capacity of the soil, as indicated by the neutron moisture probe. It also increased the phosphorus, potassium, calcium and magnesium content of the soil. The alfalfa treatment decreased the amount of root development, however, it did increase the corn grain yields every year but one.

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INTRODUCTION

Many soils are agriculturally unproductive because they have natural barriers which restrict plant root development. These soils produce inferior crop yields, yet many of them can be mechanically manipulated so as to improve their physical properties and increase the yields of crops.

The root system of a plant bears the characteristics of the species but is greatly influenced in its development by the prevailing soil physical conditions, such as moisture, aeration, compaction (bulk density), and temperature, as well as the soil chemical properties, such as pH, fertility and salinity.

Bonner and Galston (8) aptly describe the soil-plant relationship in their discussion of, "The soil as a medium for plant growth," as follows:

> The mineral and water resources of the soil are tapped by the plant through a prodigiously ramified system of roots and root hairs, which bring the plant into intimate contact with many of the soil particles beneath it. This thorough exploitation of the soil is achieved not only by repeated branching of the root as it penetrates downward, but also by the production of the root hairs which develop in enormous numbers in the roots of many species.

If then the plant is depending on such a complete ramification of the soil by the root system, to supply its needed water and nutrients, any restriction placed on root development will tend to be followed by a reduction in vegetative growth and eventually a reduction in crop yield.

With the powerful equipment available today, it is possible to modify soils that are presenting difficulties to the rooting of certain plants. This modification should allow a suitable depth of root penetration and total proliferation within the soil mass. The modification procedure used in this research to break up the barrier layer existing below normal plow depth, was to thoroughly mix the surface soil to the depth of 22 inches with a disc plow that had been adjusted for maximum mixing.

This study includes both laboratory and field measurements to determine the following:

A. The influence of a deep-soil-mixing process on the physical properties of specific soils.

B. The effects of the alteration of the soil physical properties on the development of plant roots within the given area.

C. The duration of the alteration of the soil physical properties, brought about by the deep-soil-mixing process.

D. The effects of supplemental organic matter as a stabilizing agent, on the physical properties of the soil.

E. The influence of supplemental plowdown fertilizer, incorporated into the soil by the soil-mixing process, on crop yield response.

F. The feasibility of using deep-soil-mixing to modify problem soils as a means of increasing crop production.

REVIEW OF LITERATURE

In the past few years a considerable number of investigations have been carried out to determine the effects of the soil physical properties on plant root development. Various methods of soil modification have been tried in order to increase the productive capacities of certain soils that limit normal root development.

I. Mechanical Impedance and Root Development

Soils having high bulk densities have been observed to restrict root growth. For this reason the effect of mechanical impedance of dense soil layers have received much attention. Veihmeyer and Hendrickson (87) observed that plants growing on soils with a dense subsoil layer, tended to be as shallow rooted as those growing on hardpan soils. In their investigations to determine the threshold density for root penetration, they concluded that it was not necessarily the same for all soils, but instead covered a wide range, from 1.46 grams per c.c. to 1.9 grams per c.c., depending on the soil texture. It was their impression that roots failed to penetrate compact soil layers due to the small pore size, rather than from the lack of oxygen (87).

Wiersum et al. (90) in an experiment to determine the effect of size and rigidity of pores on root penetration, found that young growing roots would only pass through pore sizes exceeding the diameter of the root tip. They were also able to demonstrate that the rigidity of the pore structure influenced root penetration. One may ask the question as to the amount of pressure a young growing root does exert in forcing its way through the soil? Pfeffer in his "Studies of Root Growth Pressures Exerted by Plants," as reviewed by Gill et al. (32) has provided the answer to this question. This review indicates that Pfeffer was able to demonstrate that plants vary as to the root pressures exerted, according to the species. However, using one species for an example, Pfeffer determined that Zea Maise roots could exert an axial pressure varying from 9.53 atm. to 24.94 atm. depending on the distance from the root tip. The radial pressure was found to be 6.59 atm. Needless to say, the total force exerted by the radial pressure was much greater than for the axial pressure.

Fehrenbacher and Snider (21) were able to determine that for a Cisne soil, corn roots were highly developed throughout the compact claypan, due to the well developed prismatic structure which permitted corn roots to penetrate. However, they found the A 2-2 horizon, having a dense platy structure, to be most limiting to root branching. Fehrenbacher et al. (22), reporting on further studies, state that the Cisne soil showed that with proper fertilization and liming the amount of root penetration into the "claypan" B horizon, was very good for all crops.

In an experiment to determine the influence of soil compaction on root penetration, Meredith and Patrick (58) were able to show that as artificial soil compaction increased bulk density, there was a decrease in non-capillary porosity, water permeability and root penetration. They also obtained a linear relationship between soil root penetration and bulk density, emphasizing the fact that there appears to be no critical bulk density stopping root penetration. However, Edwards, et al. (17) found a bulk density of about 1.80 grams per c.c. to be a threshold density above which discrete soil peds are not penetrated by corn roots.

Phillips and Kirkham (65) also working with artificially compacted soils, obtained a definite correlation between, (1) root penetration and bulk density, and (2) between the amount of root penetration and corn yields. They concluded that probably the mechanical impedance set up by the high bulk density soil was more restrictive to root penetration than any other factor. Tackett and Pearson (80) also assumes that mechanical impedance is more detrimental to root growth than are low oxygen concentrations in subsoils with bulk densities above 1.5 grams per c.c. Taylor and Gardner (81) found a highly significant negative correlation to exist between the relationship of soil strength and root penetration. Their conclusion was that soil strength, not bulk density was the critical impedance factor controlling root penetration.

In a study of the effect of mechanical stress on the growth of roots, Barley (2) found that a stress of 1.1 to 1.8 atm. would greatly reduce the length of growth of corn radicles. He was also able to show an interaction between mechanical stress and oxygen supply on root growth. Cannon and Free (12) were the first to conclude that a certain level of oxygen must be maintained within the soil atmosphere for proper root development.

Using a device to adjust mechanical impedance and oxygen concentrations on a root system, Gill and Miller (33) were able to show that a mechanical impedance would restrict root growth, even at optimum oxygen concentrations. They also demonstrated that the ability of the root to enlarge in spite of the mechanical resistance is greatly impaired by modest reductions in oxygen concentrations.

II. Oxygen Diffusion in the Soil System and Root Growth

In 1955 Lemon and Erickson (47) introduced the platinum microelectrode method for the measurement of oxygen diffusing through the soil solution to the plant roots. These researchers concluded that the concentration of oxygen in the soil atmosphere was not the controlling factor in the supplying of oxygen for root growth, but that the rate of diffusion of oxygen across the soil solution phase surrounding each plant root was much more critical. Their findings have stimulated a considerable volume of research in the area of soil aeration and mechanical impedance on root growth.

Bertrand and Kohnke (5) found that corn roots did not penetrate subsoils compacted to a bulk density of 1.5 grams per c.c., but that they grew profusely in a subsoil having a bulk density of 1.2 grams per c.c. They also determined that the oxygen diffusion rate was much slower for the more dense subsoil than for the looser subsoil, and that high moisture contents intensified the restricting effect of the dense subsoil on both the oxygen diffusion rate and root growth. They suggested that an oxygen diffusion rate of less than 20 to 30 x 10^{-8} $g.cm^{-2}.min^{-1}$ would limit root growth.

Erickson and VanDoren (18) have shown that oxygen deficiencies for a one day period can have a great influence on the yield of the plants. The magnitude of the influence will be determined by the specie and variety of the plant, its stage of development, soil fertility as well as some other factors.

Birkle et al. (6), Letey et al. (48,49,50,51,52 and 53) and Stolzy et al. (76) have conducted a considerable number of experiments applying the platinum microelectrode method of measuring the oxygen diffusion rate to root response. Their work has centered around the use of a controlled and varied oxygen supply and its influence on diffusion rates, and has further substantiated the initial findings of Lemon and Erickson (47). Their investigations could be summarized briefly as follows: (1) Oxygen diffusion rather than oxygen concentration of the soil atmosphere is the more critical factor in root growth, (2) The shoot growth responses of many plants are influenced by the oxygen supply in the root zone, (3) Plant species vary in their limiting value of oxygen diffusion rate and root response, (4) The concentration of potassium, nitrogen and phosphorus increases in the plant tissue as the oxygen supply to the plant root increases, where as the sodium concentration decreases, (5) Water consumption by the growing plant is reduced under low oxygen supply, (6) Corn roots can show restricted growth where the oxygen diffusion rate is greater than $10^{-8}g.cm^{-2}.min^{-1}$, while a rate of $40 \times 10^{-8}g.cm^{-2}{\cdot}min^{-1}$ provides for a maximum growth.

Jensen et al. (40) and Jensen and Kirkham (39) indicate that the reason corn roots are able to continue growing at such low oxygen diffusion rates, is that there is apparently a self-diffusion of oxygen from the shoot down through to the root, thereby supplying the corn roots with a portion of their required oxygen supply. Birkle et al. (6) and Waddington and Baker (88) have also shown that other members of the grass family can produce as well under conditions of lower oxygen diffusion rates, probably because they too have self-diffusion of oxygen within their root systems.

The conclusions of Letey and his associates seem to bear out the findings of Hopkins et al. (36), in that the accumulation of the major plant nutrients, with the exception of magnesium, was dependent upon the oxygen supplied to the roots and that the sodium content decreased as the oxygen supply increased. Van Diest (85) found that the oxygen diffusion rates were greatly depressed in compacted soils and that the ability of the plant roots to absorb nutrients supplied by fertilizers, varies more with compacted soils than with the more normal aerated soils.

Wiersum (91) has found a good correlation to exist between measurements of oxygen diffusion rates and soil characteristics also with root penetration. Scott and Erickson (72) have also shown that there is a definite interaction between oxygen availability and root penetration brought about by high bulk density layers. Kristensen and Lemon (44) explain that the rate of oxygen diffusion is governed by the "apparent diffusion path length," that the oxygen must move across to enter the plant root. This would substantiate the findings of the other researchers whereby oxygen diffusion rates have decreased as bulk densities have increased. This would be accounted for by the increase in the capillary porosity, lengthening the mean diffusion path of oxygen through the soil solution.

Williamson (92) using lysimeters installed in the field, was able to show a direct relationship between the oxygen diffusion rate and a controlled water table. He was also able to obtain a very good relationship between the relative yields of corn and the rates of oxygen diffusion.

The interaction of reduction of diffusion rates due to increase in moisture content of the soil has stirred some controversy about the possibility of increased CO_2 concentrations reducing root growth due to the toxicity of the CO_2, rather than the lack of oxygen causing the reduction. Geisler (30) using solution cultures found that CO_2 concentrations such as those found in the soil system stimulated root growth in the pot cultures. However, Tackett and Pearson (80) were able to show that at low bulk densities the root elongation rate decreased progressively with increasing CO_2 concentrations, although moderate to good growth did occur even at 24% CO_2 concentrations. At high subsoil density, CO_2 concentrations had little effect on root penetration.

III. Soil Water Use by the Plant Root Systems as Influenced by Soil Compaction

Gardner and Ehlig (28) found that any impedance to water movement in the soil limits water availability in dry soils and is greater than the impedance to water movement into the plant roots, even in the relatively moist soils. Gardner (27) also indicates that the relative distribution of roots with depth and the water retaining and transmitting properties of the soil determine the main features of the water uptake

pattern and that the total number of roots were relatively unimportant.

However, Stevenson and Boersma (75) concluded that the water absorption process, which appears to be related to the water content of the soil, should be interpreted in terms of amount of root growth as affected by the water content of the soil. Russell and Danielson (71) were able to determine that corn can utilize water to a depth of five feet or more in a deep Brunizem soil and that the total water used was proportional to grain yields.

The effect of soil moisture stresses at different stages of growth on the development and yield of corn have been shown by Denmead and Shaw (14). A moisture stress prior to silking reduced grain yields as much as 25%, while a moisture stress at silking time reduced grain yields by 50%, and moisture stresses after silking reduced grain yields by only 21%. They assume that the early stress may reduce the total root assimilation surface, while a later stress reduces direct assimilation of essential nutrients.

IV. Soil Modification and Root Growth

Kohnke and Bertrand (42) found an increase in corn root growth due to subsoil fertilization, while subsoiling alone increased root growth only slightly. The subsoil fertilized area maintained a higher porosity for over two years, resulting in a greater water supply for the growing crop.

Linscott et al. (54) determined that moisture use was related to corn root growth and that the efficiency of the moisture use, as measured by grain production, was increased by the application of nitrogen fertilizers. It was assumed that the increased root production, due to the fertilization, increased subsequent moisture utilization during a critical period of plant development prior to and during tasseling, resulting in higher yields. Woodruff and Smith (95) found that only in a few cases did the increased yields pay for the power requirement for subsoil shattering and liming on a Putnum silt loam.

Patrick et al. (62) were able to demonstrate an increased corn root development in the subsoil due to deep plowing, subsoiling and deep placement of fertilizers, on soils having a traffic pan. They found that the increased root growth enabled the crop to better withstand dry periods. Fehrenbacher et al. (22) ascertained that deep-soil-mixing alone did not increase corn root penetration. However, when fertilizer was placed throughout the entire tilled zone, root penetration did increase.

Harper and Brensing (35) summarized their findings on "Deep Plowing to Improve Sandy Land," as follows: (1) experiments have shown that on some types of loose, sandy soil deep plowing will; (a) increase crop yields and (b) reduce wind erosion, (2) the research has also shown that deep plowing will not; (a) improve the physical conditions of all types of land, nor (b) improve crop yields permanently unless followed by proper use of rotations, fertilizers, and soil-improving crops. They further explain that their increased yields were obtained on loose sandy soils which had subsoils containing 10% to 25% clay lying near enough to the surface to be reached by the special plows used. They also stipulated that the method would not be satisfactory for soils having a sandy subsurface. These researchers assume the effects of the deep-plowing operation to be permanent, that is for a period of at least 50 to 100 years.

V. Soil Modification and Water Infiltration Rates

The water infiltration rate of a soil has been defined by Richards (68) as the maximum rate at which a soil, in a given time, can absorb rain. It has also been defined by Parr and Bertrand (61) as the maximum rate at which a soil will absorb water impounded on the surface at a shallow depth when adequate precautions are taken regarding border or fringe effects.

The double-ring infiltrometer has been used extensively to study the movement of water into the soil. Haise et al. (34) have presented general information as to selection of site, equipment, installation, operation, computations and plotting of data obtained from the use of the ring infiltrometers to determine the intake characteristics of soils.

Marshall and Stirk (57) have studied the effects of buffered and unbuffered rings on the lateral movement of water in soil. They found the buffered rings do yield more consistent results. However, Burgy and Luthin (11) were not able to determine any appreciable differences in the values obtained from the buffered and unbuffered ring infiltrometers. The differences in the observations of Marshall and Stirk and those of Burgy and Luthin comes from the use of two different types of soil profiles. The former group were studying the effects of water movement into a well developed soil profile, which presented an impedance to water movement, resulting in a considerable amount of lateral movement. The soil studied by Burgy and Luthin showed no profile development and was freely permeable, hence a minimum amount of lateral movement of water.

Swartzendruber and Olsen (78) have made extensive studies in the use of the double-ring infiltrometer as affected by size of rings and soil texture. They recommended the use of larger rings than were generally accepted as sufficient for most studies. They suggested an inner ring of 20 inches in diameter and an outer ring of 24 inches in diameter, to minimize the influence of the double-ring flow system. However, Aronovici (1) concluded from his studies on the influence of ring size on the infiltration rate, that the decrease in flow velocity was only 0.05 centimeters per hour for each inch of increase in ring diameter beyond four inches, while the rate

of change was 1.3 centimeters per hour for every inch increase from one-half inch up to four inches in diameter.

Slater (73) has suggested using 15 replications of the double ring infiltrometers to insure an accuracy within 20% of the true mean, while Burgy and Luthin (11) found that an average of six replications came within 30% of the true mean, for a soil having no restricting layers.

The FA infiltrometers or rain simulators have also received considerable use in determining the amount of infiltration and runoff from research plots. Wilm (93) has used this method to determine the effect of and measurement of artificial rainfall on the water intake rates of soil. Whereas the double ring infiltrometer employs a constant head of water imponded on the surface of the soil, the FA type infiltrometer employs the use of a sprinkler system spraying the water into the air in such a fashion as to simulate water droplet sizes close to the size of rain drops. The FA type infiltrometer also uses a wetted buffer zone around the area of actual measurement. In comparing the infiltration velocities of the two types of infiltrometers, Slater (73) found that the unbuffered ring velocities exceeded that of the sprinkler velocities by a factor of four. Swartzendruber and Olsen (77) using rings of considerably larger diameters than Slater used, obtained a ring velocity that exceeded the sprinkler velocities by a factor of only three.

DESCRIPTION OF FIELD EXPERIMENTS

I. Description of Soil

Indications from previous studies on the Kalamazoo sandy loam soil had shown slight increases in crop yields due to subsoiling or subsoil fertilization treatments. One of the characteristics of this soil is the dense B 2 horizon, having a sandy loam texture. This horizon is 13 to 15 inches thick and lies 11 to 12 inches below the surface, which is just below the depth ordinarily reached by a conventional moldboard plow. It has a high bulk density and has a consistency somewhat plastic when wet, firm when moist and hard when dry.

The Kalamazoo sandy loam is a Gray-Brown Podzolic soil developed on a coarse textured outwash material underlain by acid sands and gravel at depths of 24 to 66 inches. It is well drained and is one of the more droughty agricultural soils in the southern part of Michigan. The mechanical analysis and the bulk density measurements of this soil are shown in Tables 2, 3 and 4.

II. Description of Field Plots and Treatments

Field plots were established in the fall of 1956 on a uniform area of this soil type, located on the Ewald Fick

farm, approximately four miles south and three miles east of Battle Creek, Michigan.

The total area, measuring 244 by 320 feet, was divided into four main blocks, each measuring 61 by 320 feet. Two of these blocks were plowed with the conventional moldboard plow to a depth of 9 to 10 inches. The remaining two blocks were tilled to a depth of 20 to 22 inches using a giant disc plow that had been adjusted for maximum soil mixing.

Prior to the deep mixing, four additional treatments were superimposed at right angles to the direction of plowing. These treatments were replicated two times on each plowed area and were as follows: (1) control or crop residue treatment, (2) five tons per acre of chopped alfalfa hay, (3) five tons per acre of a partially decomposed oak sawdust, and (4) subsoiling to a depth of 27 to 28 inches.

Each of the areas originally designated for depth of tillage, were again subdivided for three rates of plowdown fertilizer, to be applied along with the plowing operation. These rates were: (1) no fertilizer, (2) 500 pounds per acre of a 12-5.22-10 (12-12-12) granulated fertilizer, and (3) 1000 pounds per acre of the same grade of fertilizer.

An early maturing variety of hybrid corn, M-250 was planted in the spring of 1957, using minimum tillage. All of the plots received 500 pounds per acre of the same grade of fertilizer at planting time as that used for plowing down. The corn also received supplemental nitrogen applied as a

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side-dressing at the rate of 150 pounds of N per acre, when the corn was cultivated.

All of the above treatments were repeated for the springs of 1958 and 1959. However, during the 1958-60 seasons each of the plowdown fertilizer treatment areas were further subdivided for two varieties of corn. One was the early maturing hybrid M-250. The other was a late maturing hybrid variety, M-480. The late maturing M-480 was the only variety grown during the 1961 and 1962 growing seasons.

In 1960, 1961 and 1962 the entire plot area was plowed to a depth of 9 to 10 inches with the conventional moldboard plow. During these three years, no further additions of supplemental organic matter or plowdown fertilizer were made, nor was the subsoiling operation performed.

In the spring of 1963 it was decided to alter the tillage treatments to determine the influence of a one time, three time and four time deep-soil-mixing process, on the physical properties of the soil. The previously shallow plowed and the deep tilled areas were split in half by another deep tillage operation. This resulted in one-fourth of the total plot area remaining as a control area, receiving only the tillage operation of the conventional moldboard plow, to a depth of nine to ten inches. One-fourth of the area was deep-tilled to a depth of 22 to 24 inches for the first time, while another fourth of the area received the fourth deep tillage treatment. The remaining one-fourth of the plot area which had previously been deep tilled three times was plowed with the conventional moldboard plow. The giant disc plow was again used to accomplish the deep-tillage operation and was set to operate to a depth of 20 to 22 inches.

Prior to the tillage operations in 1963, the supplemental organic matter and subsoiling treatments were repeated as they were in the previous years. A blanket application of 500 pounds per acre of the 12-5.22-10 (12-12-12) granulated fertilizer was applied to the entire area for a plowdown treatment.

In 1964 the entire area was plowed with the conventional moldboard plow to a depth of 9 to 10 inches. Two moderately early maturing hybrid varieties, M-250 and M-300 were grown during the 1963 and the M-300 only for the 1964 seasons.

Each year the following procedures were follow on all plots: (1) planting time fertilizer was applied at the rate of 500 pounds per acre, using the 12-5.22-10 (12-12-12) granulated fertilizer, (2) supplemental nitrogen was applied at the rate of 150 pounds of N per acre, (3) corn was planted according to the minimum tillage principle, (4) the previous years crop residue was returned to its respective area, (5) all plots received a pre-emmerge weed spray treatment and were cultivated only once during the growing season, and (6) grain yields were taken and recorded in bushels of shelled corn per acre.

With the above experimental design all treatments were replicated four times each year. Figure 1 and Figure 2 give detailed designs for the entire plot area for the 1956 to 1962 and for 1963 and 1964, respectively.

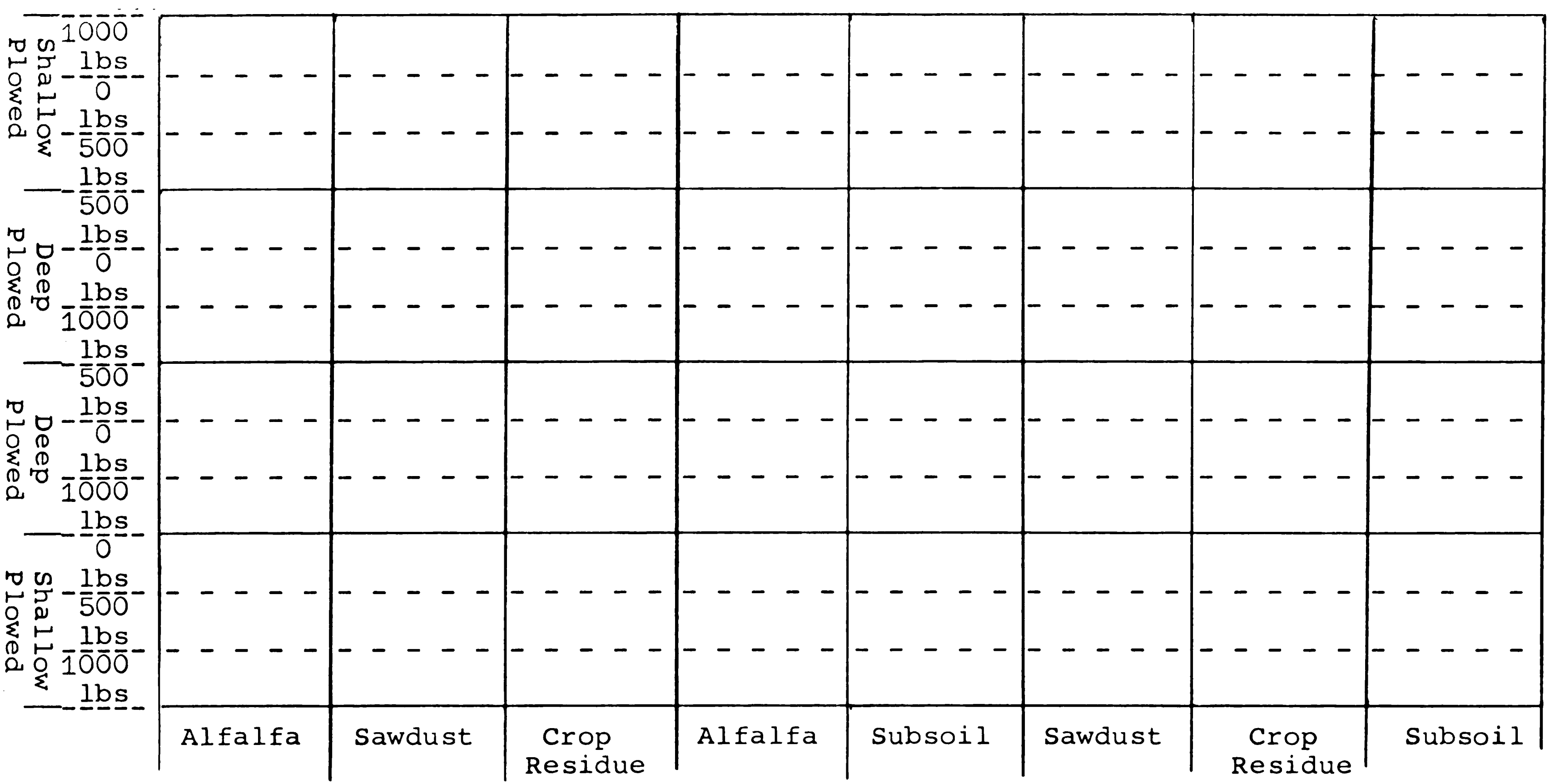


Figure 1. Fick Farm plot diagram for 1956 through 1962, showing (1) tillage treatments, (2) organic matter and subsoil treatments, and (3) plowdown fertilizer treatments. (Each plot area outlines measures 21 feet by 40 feet.)

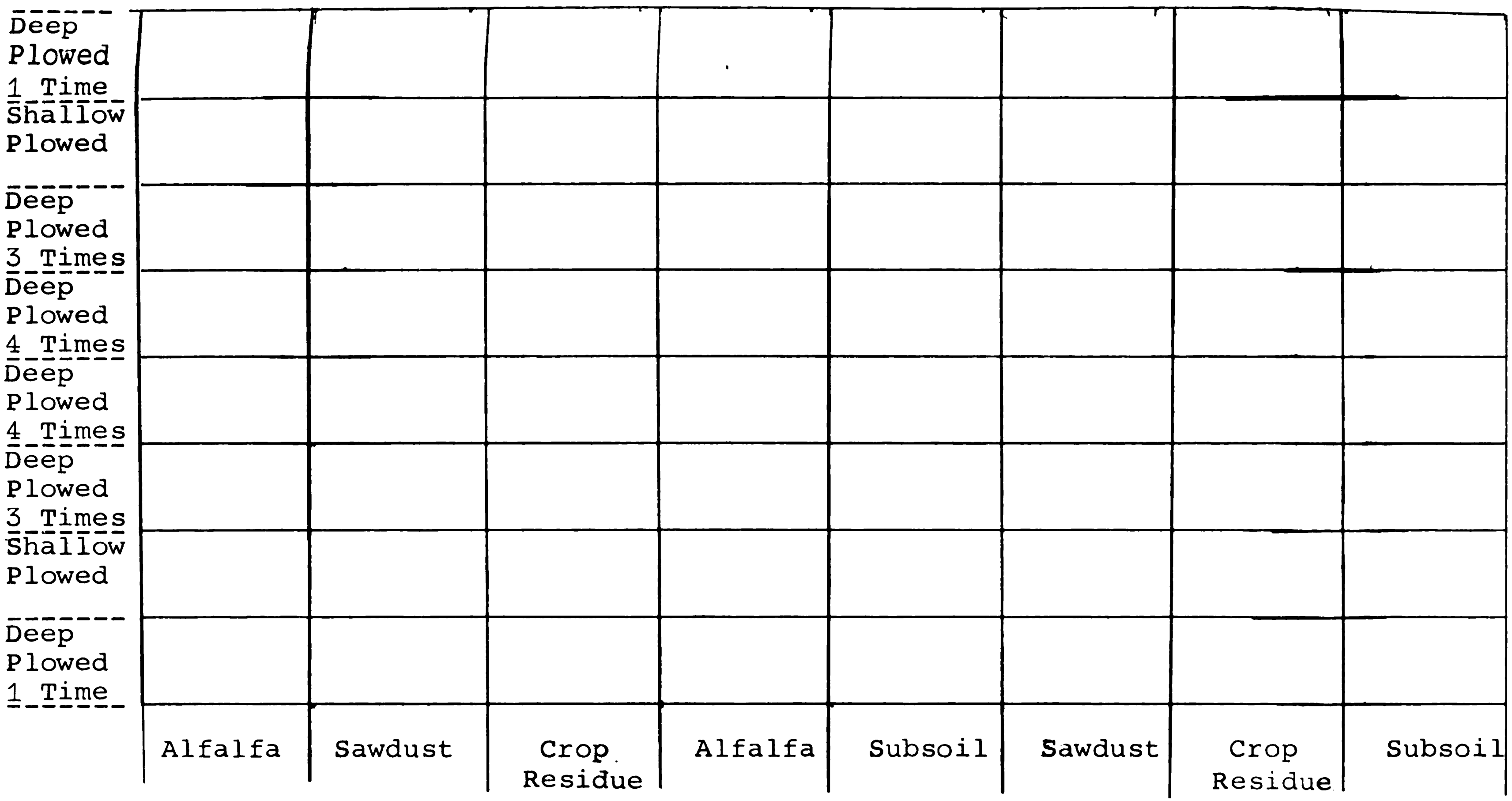


Figure 2. Fick Farm plot diagram for 1963 and 1964, showing (1) tillage treatments, (2) organic matter and subsoil treatments. All plots are receiving 500 lbs of plow down fertilizer. (Each plot area outlined, measures 31.5 feet by 40 feet.)

METHODS OF STUDYING SOIL PHYSICAL PROPERTIES

I. Methods of Analysis

1. Soil Nutrient Status

Before the deep tillage operation was performed in 1956, composite soil samples were taken at the 0 to 9 inch depth and at the 27 to 28 inch depth, to determine the nutrient status of the soil. The soil was again sampled in 1961 on both the shallow plowed and the deep-tilled areas that had received a total of 500 pounds of fertilizer per year. The depth of sampling in 1961 was 0 to 9 inches. A routine soil analysis was carried out by the Michigan State University Soil Testing Laboratory using the following methods of analysis: (a) in 1956 the phosphorus and potassium was determined by the Spurway reserve test using an extracting solution of 0.13 N HCl, and the calcium and magnesium were determined by the Spurway active test employing an extracting solution of 0.018 N HAc. (b) The 1961 phosphorus was determined by the Bray P_1 test, which employs a 0.25 N HCl plus a 0.03 N NH_4F extracting solution in a 1 to 8 soil to solution ratio. The exchangeable potassium, calcium and magnesium were determined by using a 1 N NH_4Ac extracting solution buffered at a pH of 7.0. The results of the soil test analysis are reported in Table 1.

2. Soil Particle Size Analysis

To determine the extent of the change in soil texture brought about by the deep-soil-mixing process, soil samples were taken from the shallow plowed and from the deep tilled areas, at four depths in the profile. A particle size analysis was made of each sample to determine the percent sand, silt and clay within each layer sampled.

The pipette method was used to analyze the soil samples taken in 1959. This method is widely used and is considered to be the most accurate yet devised for the particle size analysis of soils. This method was developed independently by Krauss in Germany (43), Robinson in Wales (70), and Jennings et al. in the United States (38). The accepted procedure for making a pipette analysis is described in the "Methods of Soil Analysis" (7). The results of the pipette analysis are presented in Table 2.

After the deep-soil-mixing process in 1963, soil samples were again obtained from three depths of the soil profile, for a particle size analysis to determine the effect of the soil-mixing process on the textural makeup of this soil. The hydrometer method developed by Bouyoucos (9) was used to obtain the clay fraction of each sample. This procedure consisted of weighing a 100 gram sample of soil, treating with a dispersing reagent, a sodium hexametaphosphate solution, and stirring 10 minutes with a modified malted milk blender. The sample was then transferred to a sedimentation cylinder and brought to volume and then allowed to reach a constant temperature of 20°C. The soil solution was agitated thoroughly to bring the soil particles into suspension, then it was allowed to sediment. Two hours after the solution was agitated the hydrometer was inserted to determine the amount of clay particles remaining in suspension. The soil solution was then washed through a 300 mesh sieve which retained all of the sand fraction. The sand particles were then transferred to a drying dish and placed in an oven set at 105°C. After drying, each sand fraction was weighed to determine its percentage of the soil sample weight. The silt size components of the soil sample were then obtained by subtracting the sum of the clay and sand fractions from the original weight of the soil sample. Table 2 shows the results of the 1963 particle size analysis.

3. Porosity and Bulk Density Measurements

The Uhland type core sampler (83) was used to obtain undisturbed soil samples from each plot area, at three specific depths in the soil profile, for the years 1959, 1960, 1962, and 1963. The soil cores measured three inches in diameter and three inches in length. After their removal from the field plots the soil cores were further prepared in the laboratory for total and non-capillary porosity and for bulk density measurements.

The soil cores were saturated with water, weighed, then placed on tension tables, constructed after the method described by Leamer and Shaw (46). The soil cores were allowed to reach equilibrium to a tension of 60 cm. of water, over a 48 hour period. They were removed from the tension tables, reweighed and placed in an oven adjusted to 105°C. After drying for 48 hours the cores were removed from the oven, cooled and again reweighed. From the weights of water lost from the cores between saturation and 60 cm. of water tension and from saturation and oven dry weight, the volume of the non-capillary or macro pore spaces and total porosity of the respective soil cores were determined. A total of 10 soil cores were taken at each depth, for each plot area. The values expressed in Tables 3 and 4 are the averages of four replications for each treatment.

4. Infiltration Studies

In 1958 and 1959 studies were undertaken to determine the effect of tillage processes and organic matter treatments on the infiltration rate of water through this soil. Two types of infiltrometers were used to obtain the infiltration rates.

One type, the double-ring infiltrometer, consists of two six inch long, concentrically placed cylinders, measuring five inches and nine inches in diameter respectively, were driven two or three inches into the soil with the least amount of soil disturbance as possible. Water was then imponded to a shallow depth in the inner compartment through the use of a reservoir system, which enabled the maintaining of a constant head of water and also provided a means of measuring the volume of water delivered over a period of time. Water was also imponded to a one inch depth in the outer compartment by manual application, to buffer the lateral flow of water from the inner compartment.

Ten of the double-ring infiltrometers were used on each replication of each plot area in this study in an effort to obtain a value as close to the mean as possible. The infiltration rates were obtained for the soil at the existing soil moisture content by applying water to the soil for a period of about two to three hours, or until the rate of water intake remained the same over a period of one hour. The rings were allowed to remain in the soil after this series of readings and the soil was allowed to drain for twenty-four hours and the process was repeated. The data presented in Table 9 are the equilibrium infiltration values.

The FA type infiltrometer or rain simulator was the second type of infiltrometer used to obtain the infiltration rates for this soil. This method has also been used to a considerable extent to determine both the infiltration and runoff rates for research plots. Wilm (93), Fischback and Duley (23), Duley and Domingo (16) and others have used the FA infiltrometer to determine the water intake rates of various soils. This method consists of driving a seven inch high metal frame, measuring one foot in width by two and one-half feet in length, three inches into the soil, again with the minimum amount of disturbance to the natural soil structure. The entire area bounded by the metal frame and also a border area of one and one-half feet were wetted by a sprinkler system. The wetted border area provided moisture for buffering the lateral flow from the pan area. The simulated rainfall was applied by a spray nozzle positioned so that the water was sprayed up into the air and would then fall back to the soil similarly to rain drops. The drops of water produced by these nozzles were relatively large sized.

The entire mechanism of the sprinkler and metal frame were enclosed by a tent, to reduce the amount of wind disturbance on the falling water. The water was supplied to the sprinkler at a constant pressure of 15 p.s.i. by a centrifugal pump from a large mobile water supply tank.

Rainfall intensities were determined from a 10 to 15 minute calibration run made either prior to or after each soil infiltration determination. The amount of runoff water was measured volumetrically and the difference between the applied rainfall and the amount of runoff was assumed to be the infiltration rate for that soil. After the initial runs were made under the prevailing soil moisture conditions the metal frames were allowed to remain in the same location and a second determination was made at the end of 24 hours which was called the wet run. The application of water to these areas continued until the runoff rate remained constant for a period of thirty to forty-five minutes. The values presented in Table 10 are the infiltration rates obtained under the above described conditions.

5. Soil Moisture Measurements

With the introduction of the neutron scattering probe for measuring soil moisture "*in situ*," a relatively large number of measurements can be made over a short period of time. The theory and application of this method for use in soil moisture measurements have been presented by Gardner and Kirkham (29), Van Bavel (84), McHenry (58) and others.

The use of the Nuclear Chicago P-19 depth probe to determine soil moisture on this project began in 1959 and was used each successive year through the 1964 season. Each spring after the corn was planted, two aluminum access tubes, measuring two inches in diameter and 45 inches in length were placed in the corn row within each plot area. Placing of the access tubes in the corn row allowed for cultivation without disruption of the tubes. Each tube was inserted into the soil by augering out a hole the size of the tube with the minimum amount of disturbance of the soil around the hole. The tubes were stoppered to prevent evaporation and possible plugging by foreign objects.

Moisture measurements were taken within each tube at six inch intervals to a depth of 36 inches, periodically during each growing season, to trace the moisture depletion by the corn crop. The access tubes were removed from the plot area each fall and reused the following year.

The P-21 Surface Moisture Probe was used to obtain the moisture content of the top 12 inches of soil during the 1961 to 1964 growing seasons.

The compiled moisture data are presented in Tables 11, 13, 15, 17, 19, and 21, and are averages of eight determinations for each treatment.

6. Oxygen Diffusion

The use of the platinum microelectrode as a method to determine the rate that oxygen diffuses through the water film surrounding the plant roots was first introduced by Lemon and Erickson (47). In the years following its introduction, this method has become very popular for characterizing the soil aeration status.

Oxygen diffusion readings were taken at varying depths on both the shallow plowed and the deep tilled areas to determine the effect of depth of tillage on the rate of oxygen diffusion to the plant root system within the depth sampled for the 1959 and 1961 growing seasons. Tables 23, 24, and 25, show the results of these determinations.

7. Root Studies

Preliminary studies were undertaken in 1960 to determine the effect of depth of tillage on the penetration and proliferation of the corn root system within the soil profile.

A metal frame, measuring 4 inches by 21 inches by 24 inches was constructed to remove a slice of soil from the wall of a pit dug perpendicular to the corn row. The metal frame was adjusted so that one side split the corn stalk in half and the other side extended into the center of a 42 inch row spacing. The top of the frame was placed directly at the soil surface and the bottom extended to a depth of 24 inches, which was just below the depth attained by the giant disc plow. It is assumed that inasmuch as the corn plants were spaced at 8 inch intervals, the samples obtained represented one-fourth of the total root system to a depth of 24 inches.

Each slice of soil was sectioned vertically at 3, 9, and 15 inches from the center of the corn stalk. It was then sectioned laterally at 6, 12 and 18 inches from the soil surface. Each individual soil section of the total slice was then placed in a wire screen basket and washed free of all soil particles. The corn roots remained on the screen during the washing process and were then removed, oven-dried and then weighed. The same procedure was used in 1961 to obtain root sample weights from the respective treatments.

A modified procedure employing the same method used by Foth (26) was used in 1962 and 1963 to obtain the root samples. This method employs the use of a smaller steel frame, measuring four inches by 12 inches by 24 inches. The slice of soil was taken from the wall of a pit dug between two rows of corn. The metal frame was centered between the two adjacent corn plants to assure an even distribution of roots within the sampling area. After removing the block of soil and roots from the pit, the slice of soil was sectioned vertically in half and laterally at 6, 12 and 18 inches. Each section of soil was then washed free of soil, the roots were removed and oven-dried then weighed. This method of sampling reduced the total number of samples to be washed, however, it did give sufficient information to characterize the effect of the tillage operations on the amount of root proliferation into each soil layer sampled.

The root samples were taken after the corn plants had reached the tasseling stage. According to Foth (25), the density of corn roots in the lower soil depths sampled did not increase to any extent after the corn plant had reached this state of maturity.

II. Methods of Statistical Analysis of Data

Over the period of years that this research was conducted, a considerable volume of data was obtained that was influenced by many variables. The data were therefore subjected to analysis of variance to determine if any significant differences existed due to the various treatments.

The analysis of variance was done by the Control Data Corporations 3600 computer in the Michigan State University Computer Laboratory. Each analysis was made on the basis of a split plot design. The number of splits ranged from a one-way split up to a three-way split according to the number of treatments and samplings involved. Inasmuch as the plowing depths were of primary interest, they were always considered as the main plots. The supplemental organic matter treatments were usually considered as the first sub-treatment, with the depth of sampling or fertilizer treatment acting as the second split of the main plot area. The third split of the main treatments usually entered in the number of determinations obtained for each second sub areas.

The analysis of variance is given in table form for all determinations as F-values and the values for least significant differences are given where applicable.

Additional analysis of variance analyses were made on the yield data, after close observation of these yields gave indication that the depth of plowing did increase crop yields, though not verified by the analysis of variance using the split plot technique. Error variance within years was pooled for testing interactions between plowing depth and years. The plowing depth by year interaction mean square was used to test effects of years and the long term effects of plowing depth, as described in Snedecor (74). The results of this analysis are included with the other results in their respective tables.

RESULTS AND DISCUSSION

Soil Test Results as Influenced by the Tillage Depth, Supplemental Organic Matter and Rate of Plow Down Fertilizer

Before the first deep-mixing operation was performed in 1956, soil samples were obtained at the 0-9 inch and 27-28 inch depth to determine the nutrient status. The analysis were made in the Michigan State University Soil Testing Laboratory using the following extracting procedures: (1) phosphorous and potassium were extracted by the Spurway Reserve test, using a 0.13 N HCl extracting solution, (2) calcium and magnesium were extracted with the Spurway Active Test, employing a 0.018 N HAc extracting solution. The results of the 1956 soil test are presented in Table 1 as pounds per acre. The pH values are also presented in the same table.

In 1961 the soil was again sampled at the 0-9 inch depth to determine if the various treatments had influenced the nutrient status of the soil. The analyses were again made in the Michigan State University Soil Testing Laboratory, however, the extracting procedures were changed as follows: (1) phosphorus was determined by the Bray P_1 test, employing a 0.25 N HCl plus a 0.03 N NH_4F extracting solution, in a 1:8 soil to water ratio, and (2) potassium, calcium and magnesium were determined with an extraction solution of 1.0 N NH_4Ac buffered at a pH of 7.0. The results of the 1961 soil test are presented in Table 1.

Table 1. The 1956 and 1961 soil test results for the Kalamazoo sandy loam soil, showing the effects of plowing depth, organic matter treatment and plowdown fertilizer rates. All values are averages of four determinations for each treatment.

Plow Depth	Organic Matter	Fert. Rate (lbs/A)	Pounds per acre of available P	K	Ca	Mg	pH
1956 Soil Test*							
0-9 inches			48	84	<320	16	6.1
28 inches			30	64	<320	0	5.0
1961 Soil Test** (0-9 inch soil depth)							
	Alfalfa	0	104	316	1824	104	5.9
	Crop Residue	0	99	182	1716	96	5.9
Shallow	Alfalfa	500	122	358	1644	92	5.7
	Crop Residue	500	110	230	1644	98	5.6
	Alfalfa	1000	139	414	1812	68	5.6
	Crop Residue	1000	131	326	1751	60	5.6
	Alfalfa	0	71	220	1872	120	5.7
	Crop Residue	0	68	152	1691	107	5.5
Deep	Alfalfa	500	75	246	1908	127	5.7
	Crop Residue	500	75	184	1716	127	5.6
	Alfalfa	1000	101	320	1788	115	5.5
	Crop Residue	1000	89	248	1648	107	5.4

*1956 Soil Test
P and K determined by Spurway reserve (0.13 N HCl extracting solution).
Mg and Ca determined by Spurway active (0.018 N HAc extracting solution).

**1961 Soil Test
P determined by "Bray P_1 test" (0.25 N HCl plus 0.03 N NH_4F extracting solution in a 1:8 soil to solution ratio).
K, Ca and Mg determined using a 1.0 N NH_4Ac extracting solution buffered at a pH of 7.0.

The deep mixing process decreased the concentration of phosphorus and potassium in the surface soil and influenced the amount of calcium and magnesium very little. However, the mixing process did decrease the pH values slightly. The decrease in the phosphorus, potassium and pH were brought about by a dilution effect, through the mixing of the subsoil and the surface soil.

The addition of a total of 15 tons of chopped alfalfa hay per acre for the most part increased the amount of phosphorus, potassium, calcium and magnesium in the soil and at the same time increased the pH values slightly, especially on the deep-tilled areas. The amount of nutrients contained in alfalfa hay have been listed in Millar, Turk and Foth (60) as: 2.45% nitrogen, 0.5% phosphorus, 2.1% potassium, 1.39% calcium and 0.355% magnesium, per ton of dry material. The total amount added to this soil on the acre basis by the alfalfa treatment would amount to: 735 pounds of nitrogen, 150 pounds of phosphorus, 630 pounds of potassium, 417 pounds of calcium and 106.5 pounds of magnesium.

As the fertilizer rate increased, the amount of phosphorus and potassium in the soil increased, and at the same time the pH values decreased. The fertilizer rate had little influence on the calcium content of the soil, however, it did have a considerable influence on the magnesium content in the soil. As the fertilizer rate increased the amount of magnesium in the soil decreased. This was especially true where the high rates of fertilizer were applied to the surface soil on the shallow plowed areas, where it decreased the magnesium content as much as 37%. This decrease could have occurred due to two or more factors: (1) the additional potassium ions added to the soil by the fertilizer may have replaced the magnesium on the exchange sites of the clay and organic matter, allowing the magnesium to be leached from the soil, or (2) the magnesium could have been trapped as interlayered material between the illite or montmorillonite crystals, as the potassium ions caused a collapsing of these structures, as the soils dried out. Inasmuch as the fertilizer added to the deep-tilled areas was incorporated throughout the entire mixing depth, the influence of the potassium in the fertilizer on the magnesium content was not as great.

Effects of Deep-Soil-Mixing on the Particle Size Composition of the Soil

In 1959 the plowing treatments were sampled at four depths. These soil samples were then subjected to a pipette particle size analysis in the laboratory to determine how effective the soil-mixing process had been in developing a uniform soil mixture. Table 2 presents these data for the 1959 (and also includes the 1963 results) pipette analysis indicating the effectiveness of the soil-mixing procedure.

The natural soil had a nearly uniform texture to the eight inch depth, due to the yearly manipulation of this soil layer for agricultural purposes. The clay content of this

Table 2. Summary of the particle size analysis of the Kalamazoo sandy loam soil. Each value given is an average of four determinations for the shallow and deep-mixed treatments.

Plow Depth	Year	Depth of Sample (inches)	Percent Sand	Percent Silt	Percent Clay
Shallow Plowed	1959*	0-3	60.4	28.5	10.9
		5-8	59.5	29.6	10.9
		11-14	63.7	21.9	14.4
		18-21	76.1	11.2	12.6
	1963**	3-6	55.2	31.7	13.1
		12-15	59.8	24.7	15.5
		18-21	72.8	13.9	13.3
Deep Mixed	1959*	0-3	60.2	26.5	13.1
		5-8	60.3	26.2	13.5
		11-14	62.5	24.5	12.8
		18-21	69.2	19.1	11.7
	1963**	3-6	56.9	29.1	14.0
		12-15	59.5	25.8	14.7
		18-21	63.4	22.3	14.3

*1959 Data are averages of four determinations using the pipette method of analysis.

**1953 Data are averages of four determinations using the modified Hydrometer method of analysis.

soil increased 3.5% below the normal tillage depth. The deep-soil-mixing, which was repeated three times was successful in obtaining a nearly uniform textural composition throughout the tilled portion of the soil.

After the deep-soil-mixing process was repeated in 1963, the soil was again sampled at three depths for a laboratory analysis of their particle size composition. The analysis employed a modification of the Bouyoucous Hydrometer Method of soil analysis as described in the experimental procedure.

The results of the 1963 particle size analysis are presented in Table 2 and again indicate that the deep-mixing process was able to obtain a nearly uniform texture throughout the depth of mixing.

Effects of Deep-Soil-Mixing and Supplemental Organic Matter Treatments On the Laboratory Analysis of Soil Cores for Soil Moisture Holding Capacities, Pore Space Relationships and the Soil Bulk Density

Soil core samples (three inches in diameter and three inches high) were obtained from three depths in the soil profile during the 1959, 1960, 1962 and 1963 growing seasons. These cores were then subjected to laboratory analyses to determine the amount of macro, micro and total porosity and the bulk density of the soil. The summaries of all of these data obtained from these soil cores are presented in Tables 3 and 4. The results of the analysis of variance of each year's data are presented in Tables 5, 6, 7, and 8, respectively.

Although there were considerable variations in the data obtained from the soil cores, these variations were not significantly related to treatment until 1962 when the analysis showed significance for all determinations except on the amount of water held in the soil at 60 cm. of water suction. Only the bulk density determinations were statistically significantly different in 1963. With the exception of the 1962 data the variability was so great between cores taken within a treatment that small differences due to treatment could not be detected.

The influence of the depth of tillage on the pore space relationships, water holding capacities and bulk density measurements varied considerably from year to year and with sampling depth. As the primary interest of this research was to determine the influence of deep mixing on the dense B horizon, the major portion of the discussion will deal with the 12 to 15 and 18 to 21 inch sampling depths.

Changes in Soil Properties at the 12 to 15 Inch Depth

The 1959 soil mixing process increased the macro pore space 39% by volume, which showed high significance, and at the same time increased the amount of total pore space by 10.0% and decreased the bulk density of the soil, although neither of the latter two changes were statistically significant. However, in 1960 the bulk density measurements of this soil indicated a slight increase due to the deep tillage and in 1962 there was a significant increase of 0.1 g/cc over that of the same depth on the shallow plowed area. During these two years the tillage treatments had little or no influence on the pore space relationships. After the 1963 revision in the tillage treatments, the 1X and 4X deep tilled areas were found to have: (1) significantly increased, (a) the total pore space by 9.0% over that of the shallow plowed areas, and by 15.9% over the 3X deep tilled areas, (b) the macro pore space by 36.0% over the shallow plowed area and 66.0% over the 3X deep tilled areas, and (2) significantly decreased the bulk density of this soil by 0.17 g/cc from those obtained on the shallow plowed areas and by 0.22 g/cc in comparison to the 3X deep tilled areas. Although the shallow plowed areas did contain the highest amount of micro pore spaces, followed by the 3X deep tilled area then by the 4X and the 1X deep tilled areas, the differences were not significant.

Changes in Soil Properties at the 18 to 21 Inch Depth

In 1959 the deep tillage showed no consistent influence on the pore space relationships and even though the bulk density was reduced by 0.1 g/cc it was not a statistically significant reduction. In 1960 the deep tilled areas contained 2.7% and 14.0% more total and micro pore spaces respectively than did the corresponding shallow plowed areas. There was little or no influence on the macro pore spaces and bulk density values. In 1962 the deep tillage increased the micro pore space by 9.8% and significantly increased the

(1) total pore space by 4.0% and (2) the bulk density of the soil by 0.04 g/cc, resulting in a corresponding decrease of 8.0% in the macro pore spaces. The 1963 results indicated that the total pore space was significantly increased by 5.4% on all of the deep tillage treatments to that in the shallow plowed treatment. The 4X deep tilled area contained 4.4% more micro pore spaces than did the 1X deep tilled area and 11.0% more micro pore spaces than both the 3X deep tilled and shallow plowed areas. All treatments contained approximately the same amount of macro pore spaces. The bulk density determinations prove to be the same for the 1X and 4X deep tilled areas and both were 0.04 and 0.08 g/cc less than those obtained on the 3X deep tilled and shallow plowed areas, respectively.

Although the supplemental organic matter treatment showed trends of increasing the total pore spaces in the soil, these increases were only significant for 1960. The organic matter treatment did however increase the amount of micro pore spaces and the water held in the soil under 60 cm of water suction for the years 1960 and 1963. There were indications that these increases were existing during the other two years, however, they were not statistically significant. The alfalfa treatment did show less macro pore spaces than the control area in 1962 and the indications were the same for the other years, especially for the 18 to 21 inch sampling depth. The organic matter treatments did not have any influence on the bulk density measurements of the soil.

The depth at which the soil cores were obtained proved to display a significant influence on all determinations for each year except in 1963 when the amount of macro pore spaces were not significantly influenced by sampling depth. In general the amount of total and micro pore spaces decreased with increasing depth of sampling as did the moisture holding capacities of the soil. The macro pore spaces were usually lower in the 12 to 15 inch depth of sampling than in the 18 to 21 inch depth, with the 3 to 6 inch depth having the highest amount of macro pores of the three layers sampled.

The bulk density of the soil displayed a definite increase as the depth of sampling increased to 12 to 15 inches and then decreased slightly at the 18 to 21 inch depth, in respect to that of the preceding layer.

The immediate effect of the deep tillage operation in the lower portion of the soil was to increase the amount of total pore space as well as the macro pore space, and at the same time decrease the bulk density of the soil. However, the long term effect of this tillage process, resulted in a reduction of the total porosity, as well as the macro and micro porosity and also increased the bulk density of the soil, in comparison to the values obtained for the natural soil.

The addition of the chopped alfalfa hay did not have too much influence on the porosity and bulk density of this soil. There were indications that the alfalfa was increasing the amount of micro pore spaces.

Table 3. Summary of the soil core data obtained for various years at various depths in the soil on the Alfalfa organic matter treatment. All values are averages of 40 cores taken at each depth, except for the year 1959, which are the averages of 20 cores.

Sample Depth (inches)	Plow Depth	Year	H_2O Sat.	H_2O 60 cm	Macro P.S.	Micro P.S.	TPS	B.D. gm/cc
			Percent					
3-6	Shallow	1959	33.9	20.8	16.6	27.2	44.1	1.31
		1960	31.3	19.4	15.6	26.9	42.5	1.39
		1962	31.5	20.8	14.2	28.1	42.3	1.38
		1963	29.2	18.5	15.8	27.3	43.1	1.48
	Deep 1X	1963	29.6	18.5	16.3	27.6	44.0	1.49
	Deep 3X	1959	24.9	16.8	14.9	24.9	39.8	1.49
		1960	29.1	17.3	17.5	25.3	42.8	1.47
		1962	29.7	18.7	15.9	27.2	43.1	1.46
		1963	26.3	17.5	13.7	27.6	41.3	1.59
	Deep 4X	1963	27.4	18.2	14.1	28.2	42.3	1.55
12-15	Shallow	1959	26.1	17.5	12.6	25.5	38.1	1.46
		1960	24.8	16.9	12.3	26.6	38.9	1.58
		1962	27.8	18.2	14.0	27.0	41.0	1.49
		1963	24.4	16.9	12.2	28.7	40.9	1.65
	Deep 1X	1963	29.6	17.3	18.2	25.6	43.8	1.48
	Deep 3X	1959	27.9	18.1	14.4	26.9	41.3	1.48
		1960	24.3	16.7	11.9	26.7	38.6	1.60
		1962	24.5	17.0	12.6	26.7	39.3	1.60
		1963	23.2	16.2	11.8	26.4	39.2	1.69
	Deep 4X	1963	30.1	18.4	17.3	27.2	44.5	1.48
18-21	Shallow	1959	25.5	20.6	9.2	32.7	41.9	1.58
		1960	25.1	16.2	13.8	25.4	39.2	1.57
		1962	26.0	14.8	17.3	22.0	39.0	1.52
		1963	22.5	15.0	12.5	25.3	37.8	1.68
	Deep 1X	1963	25.7	15.9	15.4	25.3	40.7	1.58
	Deep 3X	1959	33.4	20.8	17.5	23.4	40.9	1.43
		1960	25.1	16.2	13.8	25.4	39.2	1.57
		1962	26.7	16.1	16.1	24.8	40.9	1.54
		1963	25.0	16.2	14.5	26.4	40.9	1.64
	Deep 4X	1963	25.1	17.0	13.0	27.5	40.5	1.62

Table 4. Summary of the soil core data obtained for various years at various depths in the soil on the Crop Residue organic matter treatment. All values are averages of 40 cores taken at each depth, except for the year 1959 which are the averages of 20 cores.

Sample Depth (inches)	Plow Depth	Year	H_2O Sat.	H_2O 60 cm	Macro P.S.	Micro P.S.	TPS	B.D. gm/cc
			Percent					
3-6	Shallow	1959	29.4	18.1	16.6	26.7	43.3	1.48
		1960	29.4	18.5	15.5	26.3	41.8	1.43
		1962	28.3	19.7	12.5	28.6	41.0	1.47
		1963	30.5	17.8	18.5	25.8	44.3	1.45
	Deep 1X	1963	29.3	16.7	17.6	26.2	43.6	1.49
	Deep 3X	1959	29.0	16.8	17.9	24.6	42.5	1.46
		1960	27.2	17.3	14.5	25.2	39.7	1.46
		1962	28.7	17.6	16.4	25.9	42.3	1.47
		1963	27.1	16.0	17.1	24.7	41.8	1.55
	Deep 4X	1963	26.7	15.6	15.9	24.7	40.6	1.59
12-15	Shallow	1959	24.0	17.1	11.1	27.7	38.8	1.62
		1960	23.4	15.2	12.7	24.0	36.7	1.58
		1962	25.0	15.9	14.0	24.4	38.3	1.54
		1963	24.3	15.6	14.3	25.3	39.7	1.63
	Deep 1X	1963	30.4	17.4	19.1	25.4	44.5	1.46
	Deep 3X	1959	30.4	17.6	18.5	25.3	43.8	1.46
		1960	22.8	15.4	11.9	25.0	36.9	1.62
		1962	24.5	15.9	13.4	25.2	38.6	1.63
		1963	21.4	14.9	11.0	25.2	36.1	1.69
	Deep 4X	1963	29.3	16.5	18.8	24.4	43.2	1.47
18-21	Shallow	1959	24.7	10.9	21.3	17.1	38.4	1.56
		1960	23.8	9.4	23.4	13.1	36.5	1.54
		1962	25.7	13.6	18.4	20.6	39.0	1.52
		1963	22.8	12.5	17.0	20.7	37.7	1.66
	Deep 1X	1963	25.2	15.0	16.2	23.8	39.9	1.61
	Deep 3X	1959	27.3	14.9	18.9	22.4	41.1	1.51
		1960	25.8	13.4	19.1	20.4	39.5	1.53
		1962	24.7	13.9	16.7	22.1	38.8	1.58
		1963	23.8	13.6	16.4	22.1	38.5	1.62
	Deep 4X	1963	26.1	15.4	16.5	23.7	40.2	1.55

Table 5. Analysis of variance of the 1959 soil core data.

	F- Values					
	Percent					
Treatments	H_2O at Sat.	H_2O at 60 cm	Macro P.S.	Micro P.S.	TPS	B.D. (gm/cc)
Plow	0.78	0.52	797*	1.06	1.65	0.93
Organic	1.8	2.19	1.42	1.27	3.88	10.7
P XOM	94.1*	7.77	0.03	4.39	31.2*	32.0*
Depth	34.9**	10.1**	16.2**	6.9**	21.8**	29.3**
P x D	7.1**	1.82	3.5*	1.01	3.56*	8.5**
OM x D	0.62	2.29	2.09	3.42	0.63	0.92
P x OM x D	3.5*	0.52	5.2	2.44	1.28	4.8*
Number	0.37	1.17	0.41	1.24	0.56	0.27
P x N	0.75	1.19	0.43	0.86	0.59	1.13
OM x N	1.21	1.48	0.97	0.85	1.54	1.18
P x OM x N	0.63	0.67	0.57	0.60	0.64	0.70
D x N	0.73	0.98	0.80	1.01	1.14	0.64
P x D x N	0.72	0.48	1.01	0.76	0.90	0.60
OM x D x N	0.68	0.83	0.90	1.17	1.01	0.74
PxOMxDxN	0.76	0.48	0.74	0.44	0.83	0.77
L S D values						
Plow			1.14			
Organic	0.97				1.13	0.039
Depth	1.89	1.77	2.14	2.41	1.74	0.048

Plow = plowing depth; Organic = organic matter treatment; Depth = depth of samping, and Number = number of core samples taken at each depth, Sat. = saturation; 60 cm = 60 cm of water tension, Macro PS = macro pore spaces; Micro PS = micro pore spaces; TPS = total pore spaces, and B.D. = bulk density or weight/ volume of soil.

Table 6. Analysis of variance of the 1960 soil core data.

Treatments	F- Values: Percent: H_2O at Sat.	H_2O at 60 cm	Macro P.S.	Micro P.S.	TPS	B.D. (gm/cc)
Plow	1.41	0.00	4.97	1.34	0.21	4.68
Organic	5.61	18.9**	5.61	23.3**	14.0*	0.12
P x OM	0.03	0.72	2.22	0.70	0.13	0.14
Depth	77.6**	58.3**	19.9**	33.4**	57.4**	85.7**
P x D	8.7*	10.3**	0.58	7.4**	10.4**	3.2*
OM x D	1.82	3.46*	9.24**	6.6**	1.60	1.91
P x OM x D	0.17	0.41	0.07	0.67	0.92	0.35
Number	1.23	0.57	1.46	0.98	1.39	0.79
P x N	0.77	0.98	0.57	0.34	0.69	1.16
OM x N	1.98*	0.75	1.38	0.87	0.95	1.34
P x OM x N	0.64	1.22	1.49	1.60	0.79	0.67
D x N	0.89	1.03	0.97	0.74	0.87	1.10
P x D x N	1.61*	1.11	1.37	0.68	1.53	1.55*
OM x D x N	0.77	1.29	0.92	1.44	0.82	0.70
PxOMxDxN	1.37	0.77	1.10	0.92	1.03	1.11
L S D Values						
Organic		1.08		1.44	1.11	
Depth	1.15	0.95	1.58	1.35	1.02	0.029

Plow = plow depth; Organic = organic matter; Depth = depth of core sampling; Number = number of core samples taken at each depth; Sat. = saturation; 60 cm = 60 cm of water tension; Macro PS = macro pore spaces; Micro PS = micro pore spaces, TPS = total pore space, and B.D. = bulk density or weight/volume of soil.

Table 7. Analysis of variance of the 1962 soil core data.

Treatment	F- Values					
	Percent					
	H_2O at Sat.	H_2O at 60 cm	Macro P.S.	Micro P.S.	TPS	B.D. (gm/cc)
Plow	1.74	1.28	0.01	0.02	0.03	11.4*
Organic	2.35	1.59	0.08	0.81	1.65	3.74
P x OM	0.01	0.11	0.10	0.44	0.34	0.20
Depth	27.2**	21.0**	26.5**	16.3**	22.2**	35.8**
P x D	0.34	1.80	2.37	2.47	0.49	0.59
OM x D	0.07	0.50	0.60	1.57	0.18	0.32
P x OM x D	0.76	1.00	0.29	1.02	1.56	0.42
Number	3.3**	0.91	2.54*	2.45*	2.09*	3.4*
P x N	0.78	0.92	1.35	2.66**	0.46	1.59
OM x N	1.68	1.12	1.58	1.06	2.06	2.00
P x OM x N	1.66	1.66	1.17	1.23	1.47	1.54
D x N	1.15	1.00	1.36	0.94	1.17	1.15
P x D x N	1.25	1.34	1.30	1.44	1.03	1.92
OM x D x N	1.15	1.16	0.93	1.15	1.13	0.88
PxOMxDxN	1.14	0.96	0.95	0.94	1.08	1.36
L S D Values						
Plow						0.018
Depth	2.25	1.32	1.69	1.51	1.68	0.016
Number	0.80		0.74	0.37	0.55	0.006

Plow = plowing depth; Organic = organic matter; Depth = depth of core sampling; Number = number of core samples at each depth; Sat. = saturation; 60 cm = 60 cm water tension; Macro PS = macro pore space; Micro PS = micro pore space; TPS = total pore space; and B.D. = bulk density or weight/volume of soil.

Table 8. Analysis of variance of the 1963 soil core data.

Treatment	F- Values					
	Percent					
	H_2O at Sat.	H_2O at 60 cm	Macro P.S.	Micro P.S.	TPS	B.D. (gm/cc)
Plow	18.8**	4.1*	5.5*	0.30	14.3**	24.8**
Organic	0.07	8.3*	14.3**	13.6**	1.12	1.30
P x OM	0.32	0.53	1.31	0.76	0.77	0.17
Depth	26.2**	26.0**	2.79	8.8**	24.9**	21.3**
P x D	10.3**	2.53*	5.69**	1.09	8.37**	11.2**
OM x D	0.13	0.50	0.69	1.06	0.57	0.33
P x OM x D	0.77	0.71	0.44	0.42	1.01	0.66
Number	1.96	1.02	0.97	0.39	1.89	2.0*
P x N	1.02	0.77	1.06	0.71	1.14	0.92
OM x N	2.19*	0.58	2.34	1.10	2.12*	2.16*
P x OM x N	1.12	1.00	1.00	0.88	0.98	1.14
D x N	1.03	0.39	1.46	0.52	0.78	0.86
P x D x N	1.14	1.25	1.15	1.43	1.32	1.00
OM x D x N	1.70*	1.71*	1.15	1.04	1.64	1.96*
PxOMxDxN	1.27	0.92	1.11	0.59	1.26	1.10
L S D Values						
Plow	1.19	0.96	1.63		1.11	0.030
Organic		0.95	0.99	1.31		
Depth	1.06	0.65		1.01	0.93	0.029
Number						0.018

Plow = plowing depth and number of times plowed deep; Organic = organic matter; Depth = depth of core sampling; Number = number of core samples taken at each depth; Sat. = saturation; 60 cm = 60 cm of water tension; Macro PS = macro pore spaces; Micro PS = micro pore spaces; TPS = total pore spaces; and B.D. = bulk density or weight/volume of soil.

The porosity of the soil decreased with increasing soil depth and at the same time the bulk density showed a definite increase. The tillage treatment did show statistically significant interactions three of the four years between plowing depth and sampling depth. In some years there were increases in the porosity obtained and decreased in others depending on the length of time between sampling and deep tillage, while the reverse was holding true during the same years for the bulk density measurements.

Water Infiltration Rate as Influenced by Deep-Soil-Mixing and Supplemental Organic Matter

The rate at which water enters a soil is governed by the physical properties of that soil and any change in these properties, especially the pore space relationships, should reflect a change in the water infiltration rate. In 1958 and again in 1959, studies were made to determine the influence of the deep-soil-mixing and addition of chopped alfalfa hay on the water intake capacities of the Kalamazoo sandy loam soil.

Two types of infiltrometers, the double-ring and FA type, were used each year in an attempt to characterize the water intake rate of this soil. The values shown in Tables 9 and 10 are averages of 10 double-ring infiltrometer units and two replications of the FA type infiltrometer respectively.

The values presented under the "dry-run" heading for the double-ring units, were obtained under the existing soil moisture conditions, which were well below field capacity. The "wet-runs" were obtained approximately 24 hours later, on the same locations of the "dry-runs." In 1958 a rain storm interrupted the crop residue dry-run and therefore no data was obtained for either the double-ring or FA type infiltrometers. In 1959 no data were obtained for the double-ring wet-runs.

In the comparison of these data obtained from the two methods it should be understood that there should be considerable differences in the infiltration rates obtained due to the methods of applying the water to the soil. The double-ring infiltrometers, of course, maintained a constant head of water, while the FA type is more closely associated to that of actual rainfall. Slater (73) found that the unbuffered ring velocities exceeded that of the sprinkler velocities by a factor of four, while Swartzendruber and Olsen (78) using rings of considerably larger diameters than Slater used, obtained a ring velocity that exceeded the sprinkler velocities by a factor of only three.

An analysis of variance of the 1958 double-ring wet-run data indicates that although the deep tillage process did increase the water intake rate slightly, the increase was not significant. However, the chopped alfalfa hay increased the intake rate significantly on both the shallow and deep tilled areas, with a slightly larger increase existing on the latter of the two. Since the water movement through the soil is governed by the amount of macro pore spaces, one would assume that the alfalfa treatment had increased the macro pore spaces of this soil. However, the information obtained from the 1959, 1960, 1962 and 1963 core data indicates that the reverse was true, in that the macro pore space was reduced, while the micro pore spaces were increased. Therefore the increase in water intake due to the alfalfa treatment was obtained from some other factor than the influence of the alfalfa on the pore space relationships. Without a doubt the greatest influence of the alfalfa treatment was on the stability of the soil aggregates due to the increased amount of microbial gums which were acting as strong cementing agents. The increased soil aggregate stability allowed the water to enter the soil much more rapidly than did the crop residue treatments.

As there were only two replications of the FA type infiltrometer and since the crop residue dry-run was rained out, no statistical analysis of the 1958 data was attempted. The analysis of variance of the 1959 data gave no indications that the water intake rates were being influenced by either the deep-tillage or alfalfa hay. However, the averages of the two determinations do indicate that the water intake rate was greater for the alfalfa treatment than for the crop-residue treatment. Had more replications been run on these treatments the indicated trends may have proven to be significant.

Table 9. Infiltration rates obtained on a Kalamazoo sandy loam soil through the use of double-ring infiltrometers. Each value is an average of 10 units replicated two times for each treatment.

Plow Depth	Organic Matter	1958 Dry Run	1958 Wet Run	1959 Wet Run
		Inches per hour		
Shallow	Alfalfa	5.6	4.8	12.6
	Crop Residue	5.8	1.5	13.8
Deep	Alfalfa	10.1	5.3	10.2
	Crop Residue	xxx	1.7	14.2

xxxCrop Residue dry run rained out.

Table 10. Infiltration rates obtained on a Kalamazoo sandy loam soil, through the use of an FA type infiltrometer. Each value is an average of two replications for each treatment.

Plow Depth	Organic Matter	1958 Dry Run	1958 Wet Run	1959 Dry Run	1959 Wet Run
		Inches per hour			
Shallow	Alfalfa	1.79	1.49	2.16	1.68
	Crop Residue	1.79	1.06	1.69	1.30
Deep	Alfalfa	1.29	0.75	2.89	2.11
	Crop Residue	xxx	1.52	2.02	1.44

xxxCrop Residue dry run rained out.

The Effect of Deep-Soil-Mixing and Supplemental Organic Matter on the Soil Moisture as Measured In Situ Through the Use of the Neutron Moisture Probes

In 1959, aluminum access tubes measuring 2 inches I.D. and 45 inches in length were inserted vertically into the soil within the existing corn rows. On seven dates during the growing season, soil moisture measurements were made at six inch intervals to a depth of thirty-six inches, using the P-19 Neutron Moisture probe. At the end of the growing season, the access tubes were pulled from the soil and were replaced within each treatment every year through the 1964 growing season. In 1961 and each year thereafrer the surface soil moisture (0-12 inches) was determined through the use of the P-21 Neutron Moisture probe in place of the P-19 probe.

The summaries of the moisture measurements for the respective years are presented in Tables 11, 13, 15, 17, 19 and 21. The moisture data were subjected to an analysis of variance each year to test for significance of these data. The results of the analysis of variance are presented in Tables 12, 14, 16, 18, 20 and 22. These tables include both the F and LSD values obtained for each treatment.

The depth of tillage displayed no significant influence on the soil moisture, except for one date in 1960, up until the year 1963 when the moisture readings showed significant differences on each date of that year. The analysis of variance of the 1963 data did indicate that both the depth of tillage and the number of times the soil was mixed deep were exerting significant influences on the soil moisture. Figures 11a, 11b, 12a and 12b indicate that the influences of depth of plowing were somewhat varied for the surface and 12-inch moisture measurements. However, a general pattern did exist throughout these two depths of moisture measurements indicating that the 3X and 4X deep mixed areas were yielding higher moisture values than were the shallow and 1X deep mixed areas. The greatest influence of plowing depth existed at the 18-inch depth of measurement. At this depth, which is below that reached by the conventional moldboard plow, the shallow plowed area showed a considerably higher moisture content than the other areas and the 3X deep mixed area, for the most part, had a higher moisture content than the other two deep plowed areas.

Even though the analysis of variance of the 1964 data gave no indications that the plowing depth was significantly influencing the soil moisture holding capacities, the same moisture pattern exists for this year as for 1963. This is especially true for the 18-inch depth of moisture measurements.

From the 1963 and 1964 data, one can draw the conclusion that especially at the 18-inch depth of moisture measurement, the soil condition of the shallow plowed area was such that it restricted the removal of water by the growing plants. This also held true for the 3X deep mixed area, which had not been remixed to the 22-inch depth since 1959. These moisture data along with the information gained from the soil cores obtained in 1963, would indicate that the soil physical condition had not been maintained as it was the first summer after the 1959 deep plowing treatment. In fact, the soil condition was such that plant root growth was restricted, as was the amount of water removed by the growing plants on this deep plowed area.

The analysis of variance of the yearly moisture data indicated that the supplemental organic matter treatment of alfalfa hay increased the moisture holding capacities of the soil. Although these increases were not significant on every date of the moisture readings, for their respective years, these data for the most part showed significant increase in soil moisture due to the added alfalfa hay, especially at the 12-inch depth of moisture readings and lower. This increase due to the added alfalfa hay was also evident in the moisture holding capacities of the soil cores when placed under 60 cm. of water suction. It was also visible at the time of plowing each spring, inasmuch as the alfalfa treatments were much more moist than were the crop residue treatments and did present some problems in side slippage of the crawler tractor while deep-soil-mixing these areas.

The depths of moisture measurements were highly significant every year. These data indicate that the amount of soil moisture increased with increasing depth of moisture measurements up to the 18-inch depth and in some cases up to the 24-inch depth, then the moisture content decreased with increasing depth of measurement beyond this point. As one considers these moisture readings and the information obtained from the particle size analysis (see Table 2), it is evident that the moisture content of the soil is closely associated with the clay content, as the clay content increased to a maximum around the 15 to 18-inch depth and below this depth the clay decreased with a corresponding increase in the amount of sand. Even though the particle size analysis did not extend below 21 inches, the texture of this soil was observed annually to a depth of 45 inches while augering out holes for inserting the tubing for the moisture measurements. It was very evident from these observations, that the sand content of this soil increased greatly below 22 to 24 inches and at the same time the clay and silt content decreased.

There were considerable amounts of interactions between the plowing depths and depth of moisture sampling as shown in the analysis of variance for the respective years. The 1959 soil moisture readings were consistently lower on the deep tilled plots at the 12 and 18-inch depth, than were the shallow plowed plots. However, the alfalfa deep tilled plots were giving higher moisture contents at the 24 and 30-inch depth than the shallow plowed plots. Assuming that the slope of the lines in Figures 3c and 4a are the result of a greater use of water by the plant root system due to the deep soil mixing, then it also should indicate that the deep mixing has increased the amount of root growth in these areas to increase the water absorption area.

The 1960 moisture data indicated very little interaction with plowing depth and sampling depth, however, there were considerable interactions between the organic matter treatment and sampling depths. These were especially noticeable in the 18 and 24-inch depth, where the alfalfa treatments had consistently higher moisture content on every data of moisture determinations.

The 1961 soil moisture data did show tendencies for the deep-soil-mixing plots to give higher moisture readings than the shallow plowed plots at the 18 and 24-inch depth, however, the greatest influence at these depths was brought about by the alfalfa treatment, which increased the soil water holding capacity greatly.

In 1962 the deep mixing process and organic matter showed a variety of influences at the different depths. The alfalfa deep tilled plots usually had higher moisture readings at the 12, 18 and 24-inch depths than the shallow plowed plots. At the same time the crop residue deep tilled treatments gave lower moisture readings on the 12 and 18-inch depths and higher moisture readings at the 24-inch depths than the shallow plowed plots. Again the alfalfa registered higher moisture values than the crop residue treatments.

Table 11. Percent soil moisture, on a volume basis, obtained on a Kalamazoo sandy loam soil, at 6 depths for 7 dates during the 1959 growing season, using the P 19 Neutron moisture probe Each value is an average of 8 observations at each depth for each treatment.

Plow Depth	Organic Matter	Sample Depth (inches)	Dates of moisture readings 6-17	7-1	7-20	7-29	8-10	8-24	9-13
Shallow	Alfalfa	6	18.0	11.9	17.8	22.6	15.6	9.8	13.1
		12	21.7	16.1	19.1	23.9	19.5	13.3	16.1
		18	22.1	18.9	19.1	21.5	19.5	15.1	16.7
		24	17.6	15.8	15.5	16.1	15.5	13.2	13.5
		30	13.3	12.1	12.5	12.2	12.2	10.1	10.8
		36	12.2	11.4	11.4	11.2	11.7	11.0	10.7
	Crop Residue	6	15.9	10.3	16.6	20.8	13.5	8.5	12.2
		12	20.6	14.7	19.4	22.2	17.5	11.9	15.1
		18	19.3	16.5	17.1	20.8	16.7	12.5	14.1
		24	15.2	13.9	13.8	15.1	14.5	11.4	11.8
		30	13.2	12.5	12.3	12.9	12.9	10.6	10.7
		36	13.3	12.5	11.9	12.4	12.2	10.9	11.3
Deep	Alfalfa	6	17.7	11.7	15.3	22.0	14.5	10.6	12.2
		12	20.9	13.9	13.7	22.1	15.9	12.3	12.9
		18	21.8	15.4	12.7	20.8	16.7	12.9	13.2
		24	21.6	16.1	13.6	18.9	17.2	13.7	13.6
		30	16.4	14.2	12.4	13.8	13.5	12.7	12.2
		36	13.3	12.2	11.4	11.6	11.6	11.9	11.0
	Crop Residue	6	16.7	11.1	17.4	20.6	13.7	9.9	12.5
		12	18.8	11.8	14.9	20.1	14.1	10.5	12.1
		18	18.9	12.1	12.6	18.7	13.9	10.5	11.2
		24	15.8	12.0	11.8	16.2	13.5	10.3	10.8
		30	12.4	10.5	10.6	12.4	11.0	9.7	9.6
		36	11.8	10.7	10.1	11.1	10.6	9.9	9.9

Table 12. Statistical analysis of the 1959 soil moisture data, giving the results of the analysis of variance, by indicating the F and the LSD values for each treatment and the interactions. (**indicates significance at the 1% level and * indicates a significant difference in soil moisture at the 5% level.)

Treatment	F values					
	6/17	7/1	7/20	7/29	8/10	8/24
Plow	0.21	2.49	9.26	0.26	2.90	1.64
Organic	28.1**	17.8**	1.04	4.64	9.7*	8.1*
P x OM	4.45	3.80	0.56	1.24	0.86	0.40
Depth	88.7**	26.9**	16.0**	142.9**	38.4**	24.4**
P x D	3.4**	6.0**	5.2**	3.0*	4.7**	5.8**
OM x D	3.7**	2.36	1.54	1.97	1.76	2.05
PxOMxD	1.99	1.71	1.67	0.37	1.62	1.18
Number	1.31	0.72	0.13	0.30	3.56	1.47
P x N	2.17	1.06	0.91	1.04	7.99**	10.1**
OM x N	0.01	1.34	2.42	4.06	2.83	3.01
PxOMxN	0.03	0.11	0.13	0.08	0.58	1.00
D x N	0.30	0.14	0.41	0.17	0.49	0.15
PxDxN	0.10	0.49	0.86	0.09	0.50	0.33
OMxDxN	0.16	0.15	0.72	0.14	0.10	0.39
PxOMxDxN	0.44	0.17	0.68	1.63	0.05	0.16
	LSD values in percent					
Plow Depth						
Organic	0.96	0.68			1.26	1.05
Depth	0.99	0.95	1.81	1.07	0.99	0.87
Number					0.54	0.56

Plow = plowing depth; Organic = organic matter treatment; Depth = depth of moisture sampling; and Number = number of moisture determinations within each replication.

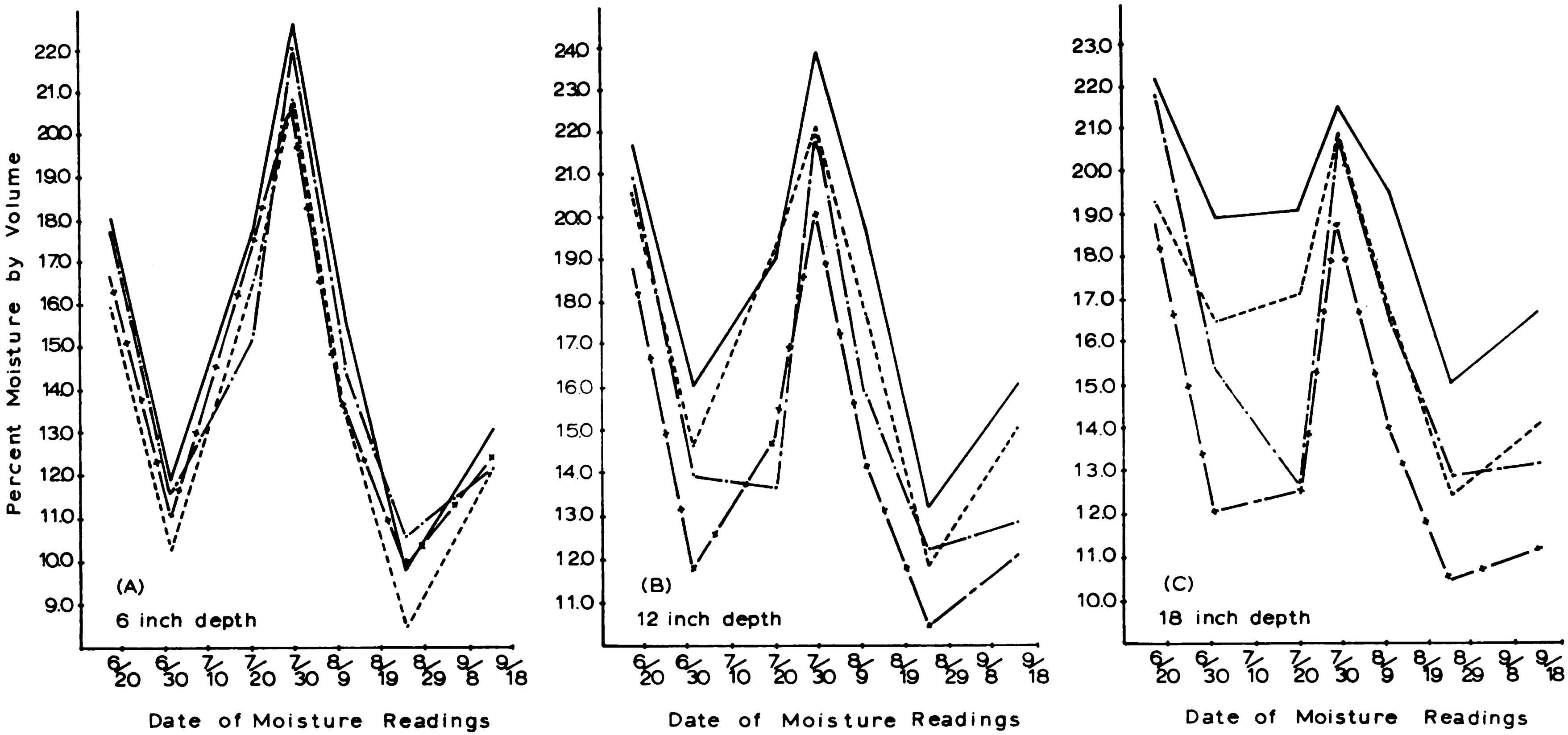


FIG. 3 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON SEVEN DATES DURING THE 1959 GROWING SEASON MEASURED WITH A P-19 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

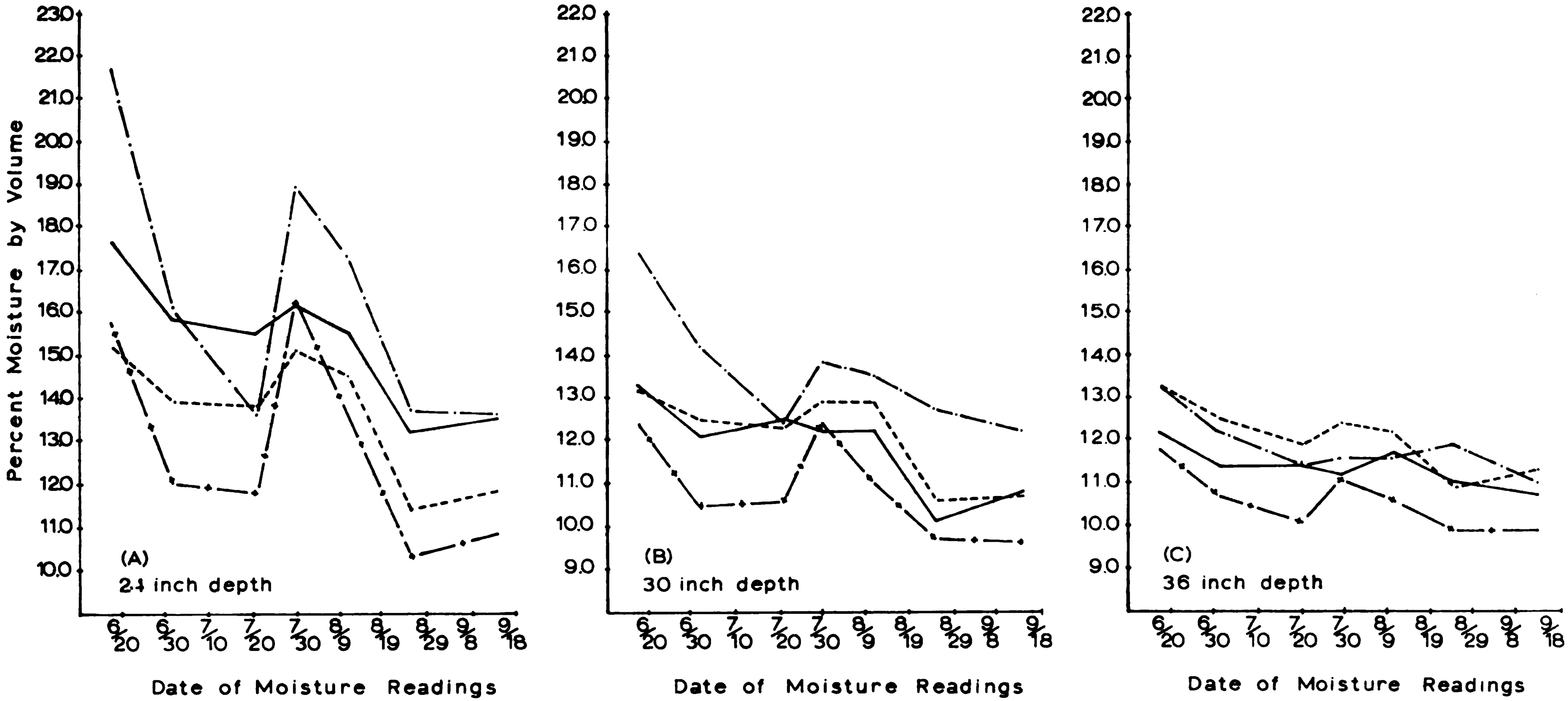


FIG. 4 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON SEVEN DATES DURING THE 1959 GROWING SEASON MEASURED WITH A P-19 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

TREATMENTS

- ——— Alfalfa Shallow Plowed
- - - - - - Crop Residue Shallow Plowed
- —·—·— Alfalfa Deep Plowed
- —•— Crop Residue Deep Plowed

Table 13. Percent soil moisture, on a volume basis, obtained on a Kalamazoo sandy loam soil, at 6 depths on 9 dates during the 1960 growing season, using the P 19 Neutron moisture probe. Each value is an average of 8 determinations for each depth of each treatment.

Plow Depth	Organic Matter	Sample Depth (inches)	Dates of moisture readings 4-3	6-20	7-5	7-18	8-2	8-10	8-18	8-25	9
		6	24.3	14.8	13.8	9.1	11.7	9.3	7.5	8.1	
		12	25.5	23.6	23.4	17.5	16.0	15.3	14.6	15.0	1
	Alfalfa	18	24.2	22.4	22.9	19.3	16.9	15.6	14.7	14.6	1
		24	19.9	19.2	18.5	15.7	13.9	13.9	12.1	11.2	1
		30	17.5	16.0	14.6	12.7	11.6	11.3	10.6	10.4	
		36	17.9	16.3	14.6	13.3	12.0	11.7	11.0	10.7	
Shallow											
		6	23.6	14.2	13.3	8.5	11.2	7.8	9.1	No data obtained	
		12	25.1	23.1	22.6	17.3	15.8	14.4	12.8		1
	Crop Residue	18	22.4	20.9	19.4	15.6	13.6	12.8	11.9		1
		24	19.2	19.1	16.7	14.5	12.7	11.8	10.9		
		30	18.5	18.2	14.7	12.9	11.6	11.0	10.4		
		36	19.1	18.2	14.9	13.6	12.1	11.4	11.1		
		6	22.5	No data obtained	14.6	11.5	15.7	10.6	9.2	10.1	
		12	24.3		23.5	18.3	17.1	15.9	14.7	15.6	1
		18	23.8		23.7	18.2	16.5	15.6	14.4	14.8	1
	Alfalfa	24	23.0		20.0	16.5	14.6	13.6	12.7	12.4	1
		30	18.8		16.3	13.7	12.7	11.9	11.1	10.8	
		36	17.7		15.9	13.8	12.9	12.0	11.4	11.1	
Deep											
		6	21.8		13.2	9.9	14.0	10.0	11.0	No data obtained	
		12	21.8		21.4	16.0	16.4	13.1	13.0		1
	Crop Residue	18	19.8		18.7	15.0	14.7	12.1	11.7		1
		24	17.8		16.2	13.5	12.0	10.6	10.4		1
		30	15.7		16.1	12.6	11.1	10.6	9.9		
		36	15.9		16.1	13.8	12.0	11.4	10.5		

Table 14. Statistical analysis of the 1960 soil moisture data, showing the results of the analysis of variance, giving the F and LSD values for each treatment and the interactions. (**indicates a significance at the 1% level, and * indicates a significant difference in soil moisture at the 5% level.)

Treatment	F values					
	7/5	7/18	8/2	8/10	8/18	9/18
Plow	0.46	0.18	11.9*	0.36	0.50	0.85
Organic	11.4*	8.2*	2.94	10.8*	4.60	1.62
P x OM	1.19	1.06	0.26	0.71	0.26	0.06
Depth	111.0**	85.8**	15.9**	43.0**	24.4**	36.9**
P x D	1.35	2.38	2.03	1.93	0.84	0.18
OM x D	6.5**	4.3**	0.85	2.9*	3.9*	1.15
P x OM x D	0.31	0.56	0.40	0.82	0.40	0.14
Number	0.29	0.49	1.67	0.15	0.37	0.35
P x N	0.68	0.31	0.06	0.36	0.44	0.34
OM x N	0.10	0.43	5.5*	0.08	0.22	0.47
P x OM x N	2.73	2.22	0.37	4.2*	5.5*	2.34
D x N	0.97	0.72	0.73	0.34	0.10	0.34
P x D x N	0.54	0.67	1.17	0.25	0.35	0.12
OM x D x N	0.47	0.32	0.88	0.28	0.18	0.37
PxOMxDxN	1.43	1.12	1.11	0.72	0.47	0.25
	L S D Values in percent					
Plow Depth			0.79			
Organic	1.13	1.18		1.16		
Depth	0.96	0.86	1.29	0.83	0.98	1.68
Number			0.62	0.52	0.44	

Plow = plowing depth; Organic = organic matter treatment; Depth = depth of obtaining moisture determination; Number = number of moisture determinations within each replication.

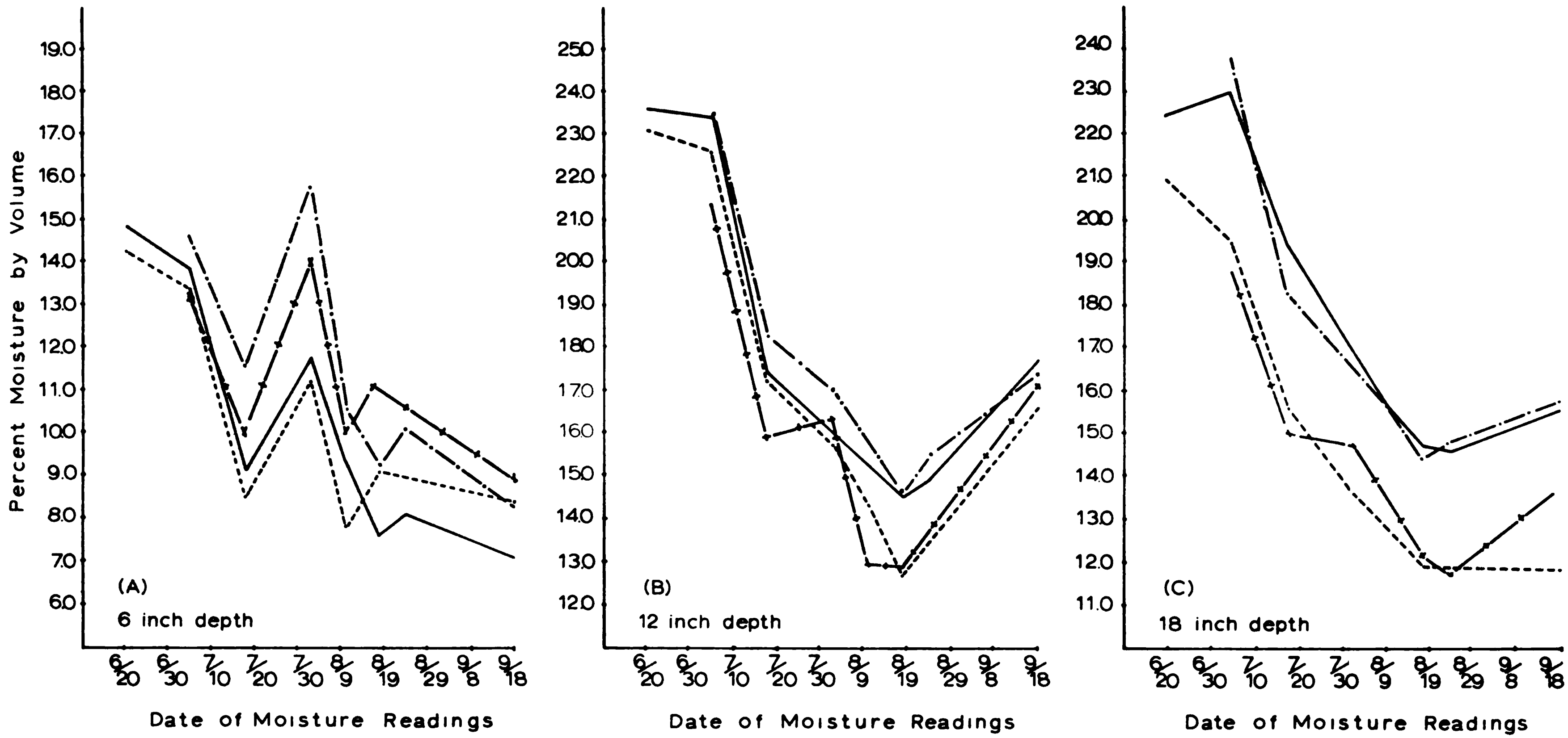
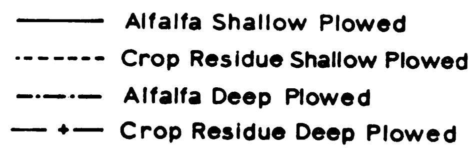


FIG. 5 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON EIGHT DATES DURING THE 1960 GROWING SEASON MEASURED WITH A P-19 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

TREATMENTS



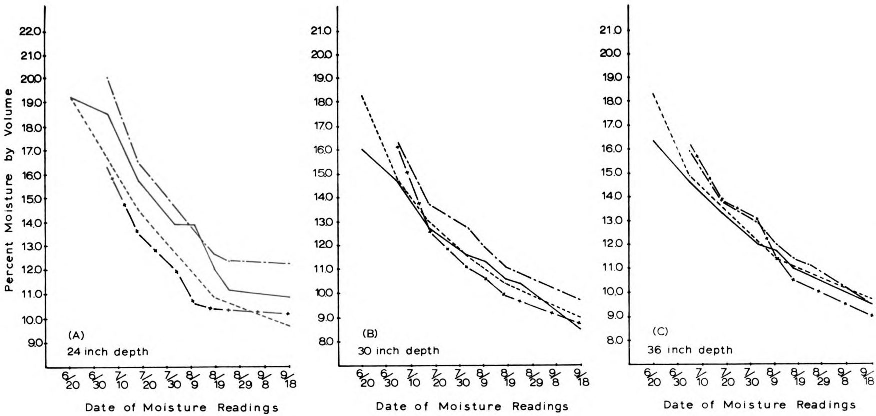


FIG. 6 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON EIGHT DATES DURING THE 1960 GROWING SEASON MEASURED WITH A P-19 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

TREATMENTS

- Alfalfa Shallow Plowed
- Crop Residue Shallow Plowed
- Alfalfa Deep Plowed
- Crop Residue Deep Plowed

Table 15. Percent soil moisture, on a volume basis, obtained on a Kalamazoo sandy loam soil, at 6 depths, on 8 dates during the 1961 growing season, using the P 19 and P 21 Neutron moisture probes. Each value is an average of 8 observations at each depth for each treatment.

Plow Depth	Organic Matter	Sample Depth (inches)	Dates of moisture readings 7-18	7-25	8-1	8-8	8-15	8-29	9-5	9-12
Shallow	Alfalfa	0-12	9.7	13.6	15.8	13.3	7.6	20.7	18.8	17.0
		12	17.2	15.2	14.6	19.4	16.9	21.8	22.4	21.1
		18	17.0	16.7	15.1	16.4	16.2	18.3	19.2	18.3
		24	13.5	13.7	11.9	12.6	12.4	13.7	13.9	13.2
		30	10.4	11.6	10.4	10.6	10.2	11.3	11.4	11.0
		36	11.2	10.4	10.4	10.0	9.8	11.3	10.6	10.2
	Crop Residue	0-12	10.5	12.8	14.5	12.3	7.2	18.1	17.0	15.2
		12	15.6	14.3	13.6	20.2	17.3	22.4	21.2	20.0
		18	13.7	14.4	13.4	16.2	14.7	19.0	16.9	16.0
		24	11.8	11.7	11.0	12.5	11.6	15.9	13.0	12.5
		30	11.8	11.6	10.8	11.8	11.4	15.0	12.3	12.1
		36	11.9	11.7	11.0	11.7	11.4	14.4	12.5	12.1
Deep	Alfalfa	0-12	11.8	15.9	16.8	16.1	10.5	21.5	20.8	17.2
		12	18.4	16.7	15.8	21.4	19.1	24.8	25.0	22.8
		18	18.8	17.1	16.3	19.4	18.4	23.7	25.0	22.1
		24	17.1	17.1	16.0	17.3	17.0	21.7	21.9	19.6
		30	13.8	15.3	13.3	13.7	13.3	18.6	16.6	15.6
		36	12.3	12.7	11.7	11.6	11.5	15.8	14.7	13.9
	Crop Residue	0-12	11.1	15.3	16.4	14.4	9.5	20.1	18.7	15.5
		12	15.9	14.6	13.8	19.9	17.4	22.0	21.9	20.0
		18	14.9	14.4	13.1	16.9	15.8	19.4	19.2	18.0
		24	12.6	12.6	11.4	13.1	12.6	15.6	14.8	14.0
		30	11.0	11.1	10.4	11.6	11.2	14.4	13.0	12.3
		36	11.5	11.0	10.4	11.2	11.1	14.6	13.1	12.3

Table 16. Statistical analysis of the 1961 soil moisture data showing the results of the analysis of variance, giving the F and LSD values for each treatment and the interactions. (** indicates a significance at the 1% level and * indicates a significant difference in soil moisture at the 5% level.)

Treatment	F Values							
	7/18	7/25	8/1	8/8	8/15	8/29	9/5	9/12
Plow	1.93	3.19	1.65	3.75	4.71	2.49	8.69	6.16
Organic	35.7**	25.2**	13.5*	12.3*	18.6**	0.12	8.29*	7.8*
P x OM	13.8**	6.9*	4.79	20.7**	22.8**	3.92	5.32	4.32
Depth	50.8**	26.5**	42.2**	81.7**	108.3**	111.2**	128.5**	102.9**
P x D	0.85	1.94	1.30	1.01	1.56	2.5*	3.7**	4.0**
OM x D	4.8**	3.1*	2.29	1.34	3.0*	2.7*	6.0**	3.4**
P x OM x D	0.91	1.70	1.71	0.62	0.80	6.7**	2.5*	2.2
Number	1.64	1.49	0.07	0.55	0.62	1.04	0.97	0.08
P x N	0.16	0.18	4.4*	9.6*	2.59	4.3*	18.8*	21.8**
OM x N	2.63	8.5**	6.6*	6.5*	2.48	0.00	7.4**	1.83
P x OM x N	0.10	2.00	0.01	5.1*	12.3**	1.70	1.73	6.0*
D x N	0.82	0.34	0.89	1.10	1.11	0.80	1.34	2.25
P x D x N	0.57	0.43	0.45	0.53	0.59	1.08	0.82	0.48
OM x D x N	1.88	0.65	1.28	1.32	1.06	0.05	0.88	0.88
PxOMxDxN	1.15	0.09	0.26	1.11	0.91	0.38	0.11	0.45
	L S D Values in percent							
Plow								
Organic	0.69	0.85	1.01	0.64	0.56		1.87	1.62
Depth	1.00	0.88	0.88	1.08	0.92	0.95	0.97	0.95
Number		0.52	0.49	0.57	0.49	0.99	0.74	0.57

Plow = plowing depth; Organic = organic matter; Depth = depth of obtaining moisture determination; Number = number of moisture determinations on each replication.

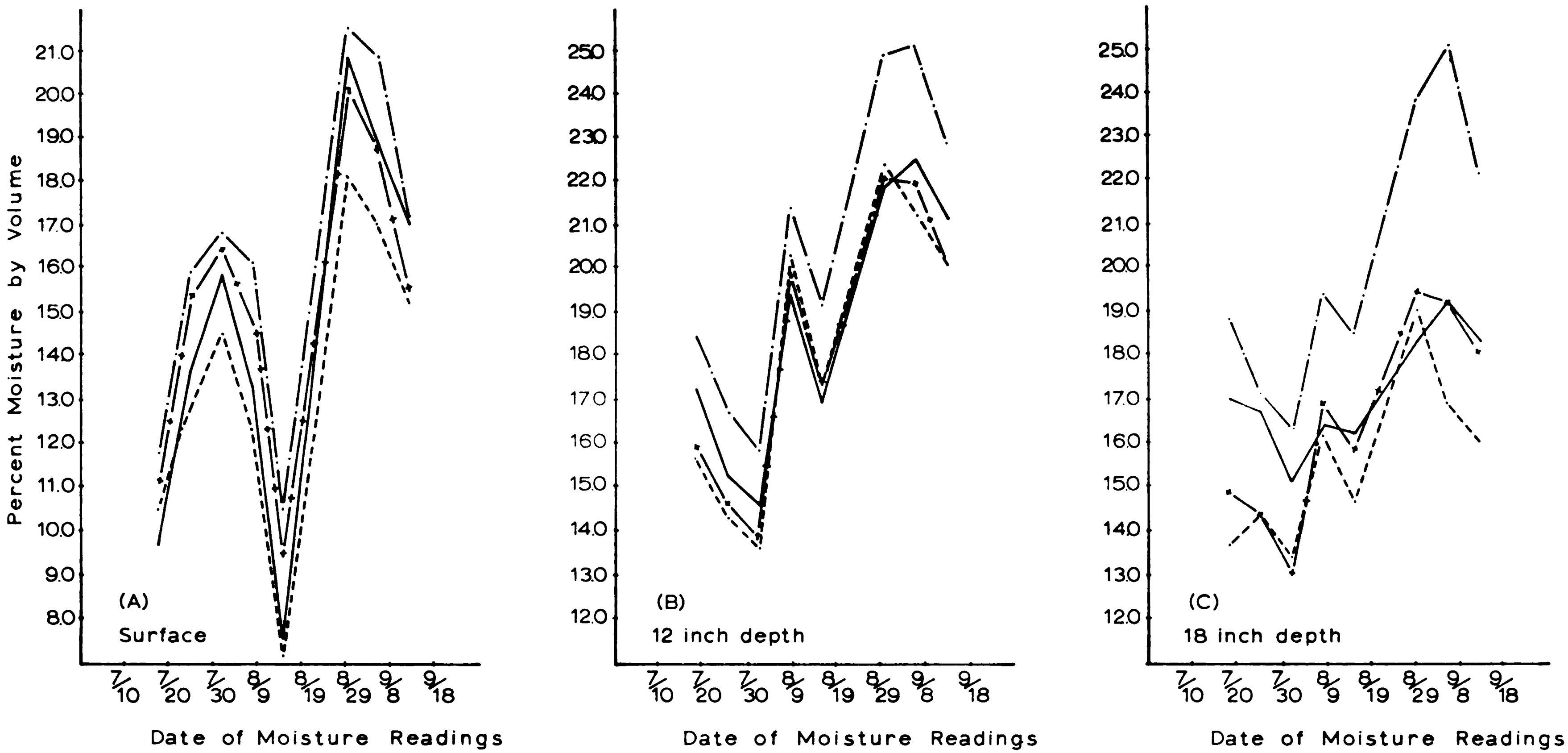


FIG. 7 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON EIGHT DATES DURING THE 1961 GROWING SEASON MEASURED WITH A P-19 AND P-21 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

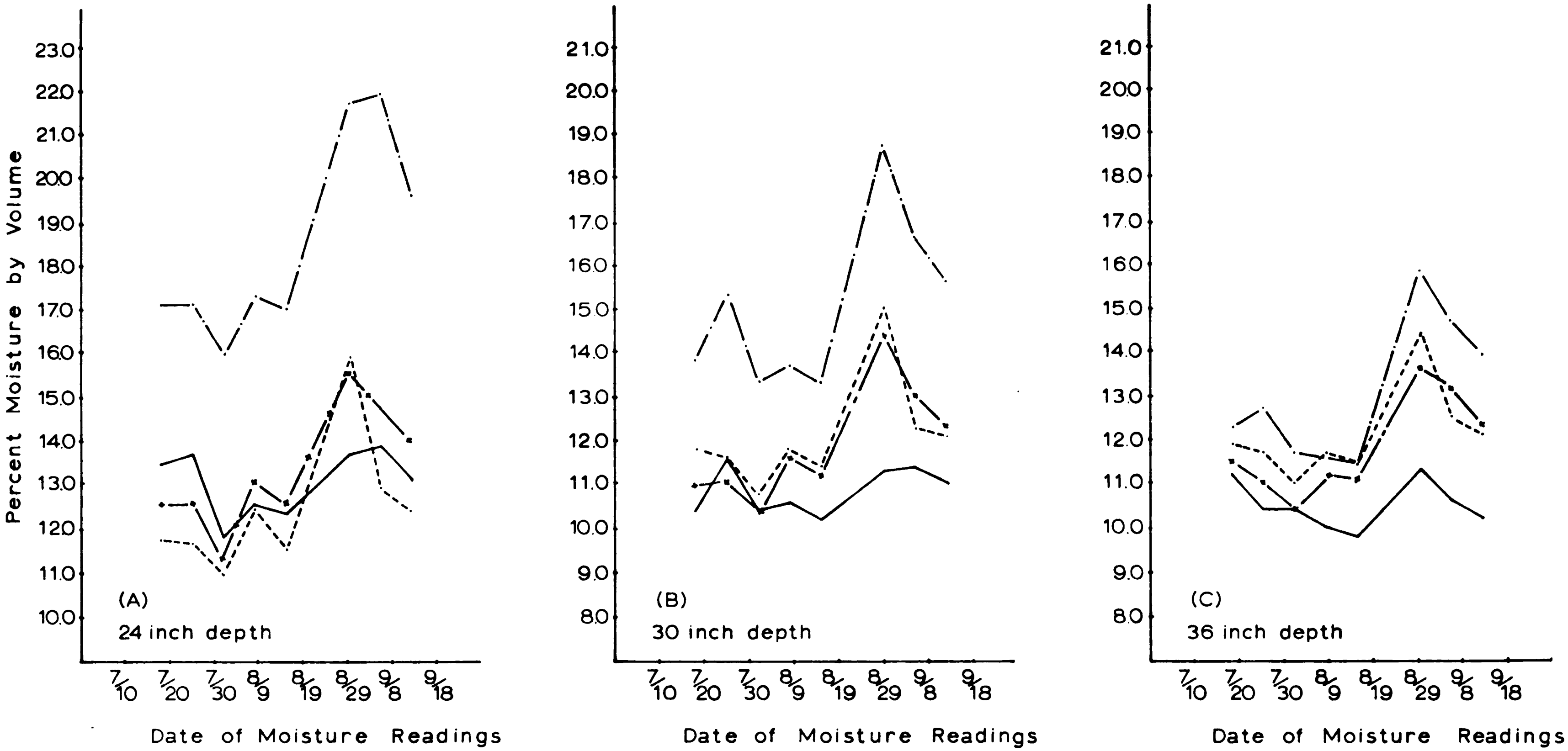


FIG. 8 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON EIGHT DATES DURING THE 1961 GROWING SEASON MEASURED WITH A P-19 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

Table 17. Percent soil moisture, on a volume basis, obtained on a Kalamazoo sandy loam soil, at 6 depths on 11 dates during the 1962 growing season, using the P 19 and P 21 Neutron moisture probes. Each value is an average of 8 observations at each depth for each treatment.

Plow Depth	Organic Matter	Sample Depth (inches)	6-18	6-26	7-3	7-10	7-31	8-6	8-20	8-27	9-3	9-10	9-17
Shallow	Alfalfa	0-12	11.7	11.8	22.3	9.3	11.8	18.7	7.1	6.9	12.5	18.0	20.5
		12	23.2	22.6	22.8	17.4	20.0	14.3	12.0	10.7	12.5	18.0	20.5
		18	20.7	23.1	21.6	20.1	20.2	15.5	14.6	12.7	14.3	15.5	18.1
		24	16.6	19.3	17.8	17.2	17.2	14.9	12.6	13.0	12.4	13.2	14.2
		30	14.1	15.7	14.3	13.7	14.3	12.5	10.8	10.7	10.6	11.0	12.2
		36	13.8	14.5	13.6	12.9	13.5	12.3	11.0	10.5	10.6	10.2	11.9
	Crop Residue	0-12	11.7	11.7	21.4	7.3	8.9	16.3	5.8	6.5			
		12	23.1	22.4	23.2	18.1	18.5	13.6	12.4	12.5	12.9	15.7	18.9
		18	18.9	21.2	20.1	18.5	18.6	14.5	13.6	14.0	13.8	12.8	15.0
		24	16.5	16.8	15.7	15.1	15.0	13.3	11.9	12.1	11.7	10.8	11.4
		30	14.0	14.5	14.0	12.1	13.1	12.0	11.0	10.3	10.8	9.7	10.5
		36	14.0	13.9	13.5	12.1	12.6	10.2	9.4	10.6	10.7	9.9	10.3
Deep	Alfalfa	0-12	12.0	13.3	22.9	10.6	10.8	18.7	8.2	8.2	11.1		
		12	23.7	23.0	23.7	18.8	19.5	14.7	13.7	12.7	13.5	20.0	20.5
		18	23.6	23.8	22.6	20.5	20.1	16.6	14.0	13.6	13.4	17.5	19.2
		24	20.0	21.8	20.7	20.1	18.8	16.1	13.9	12.4	13.1	13.8	15.6
		30	17.2	17.9	17.3	16.2	15.9	14.6	13.0	11.6	11.9	12.1	12.4
		36	15.5	15.3	14.5	13.8	13.6	12.8	11.5	11.1	10.5	10.4	10.7
	Crop Residue	0-12	11.6	13.2	21.6	9.6	9.8	18.3	7.5	7.8	14.5		
		12	21.6	22.1	22.7	17.3	18.3	12.8	12.4	12.1	13.2	18.7	19.8
		18	19.5	20.6	19.4	17.1	17.0	13.8	11.7	11.7	11.9	14.3	16.0
		24	16.3	18.5	17.4	15.9	15.1	12.3	10.9	10.8	10.8	11.3	12.4
		30	15.3	15.1	14.4	13.1	12.9	11.5	10.2	10.3	10.2	10.0	10.7
		36	15.6	14.6	14.2	13.1	13.1	12.0	10.7	10.5	10.5	10.2	10.5

Table 18. Statistical analysis of the 1962 soil moisture data showing the results of the analysis of variance giving the F and LSD values for each treatment and their interactions. (**indicates significance at the 1% level and * indicates a significant difference in the soil moisture at the 5% level.)

Treatment	F Values										
	6/18	6/26	7/3	7/10	7/31	8/6	8/20	8/27	9/3	9/10	9/11
Plow	2.36	2.18	1.34	1.47	0.01	0.09	1.31	2.29	0.28	4.29	0.83
Organic	32.2**	18.6**	20.8**	32.2**	14.3**	4.51	10.7*	10.2*	11.6*	8.5*	17.1**
P x OM	16.6**	1.20	4.41	5.02	0.17	0.21	3.56	8.9*	9.1*	0.01	0.04
Depth	105.5**	114.8**	92.9**	80.6**	83.5**	28.9**	55.9**	95.5**	22.2**	63.7**	151.6**
P x D	1.86	1.18	1.27	1.15	0.71	0.68	2.30	3.7**	2.8*	1.07	1.45
OM x D	1.94	2.30	1.80	1.60	1.00	0.70	0.93	1.21	2.11	1.97	2.66
P x OM x D	0.60	0.18	0.33	0.80	0.91	1.20	1.13	0.58	0.51	0.18	0.34
Number	0.08	0.05	0.15	0.06	0.40	0.25	0.55	2.29	4.4*	0.68	1.04
P x N	0.53	2.55	0.46	0.34	2.61	1.96	0.09	3.63	0.27	6.7*	8.2*
OM x N	2.05	1.08	2.14	1.28	0.34	0.27	2.94	9.1**	7.4**	0.37	0.17
P x OM x N	4.1*	0.77	2.52	5.3*	1.08	2.56	5.2*	3.04	2.14	0.26	0.81
D x N	0.17	0.27	0.06	0.13	0.16	0.18	0.05	0.64	0.23	0.17	0.58
P x D x N	0.21	0.08	0.20	0.34	0.14	0.66	0.21	0.36	0.23	0.40	0.09
OM x D x N	1.26	1.35	1.21	0.71	0.46	0.51	0.49	1.42	0.57	0.20	0.69
PxOMxDxN	0.07	0.66	0.92	1.13	0.59	0.43	0.76	0.43	1.65	0.34	0.98
	L S D values in percent										
Plow											
Organic	0.52	0.84	0.76	0.70	1.25		0.87	0.42	0.46	1.59	1.20
Depth	1.13	1.09	1.11	1.16	1.07	1.10	0.84	0.58	0.73	1.10	0.87
Number									0.43		

Plow = plowing depth; Organic = organic matter; Depth = depth of obtaining moisture determinations; Number = number of determinations per replication.

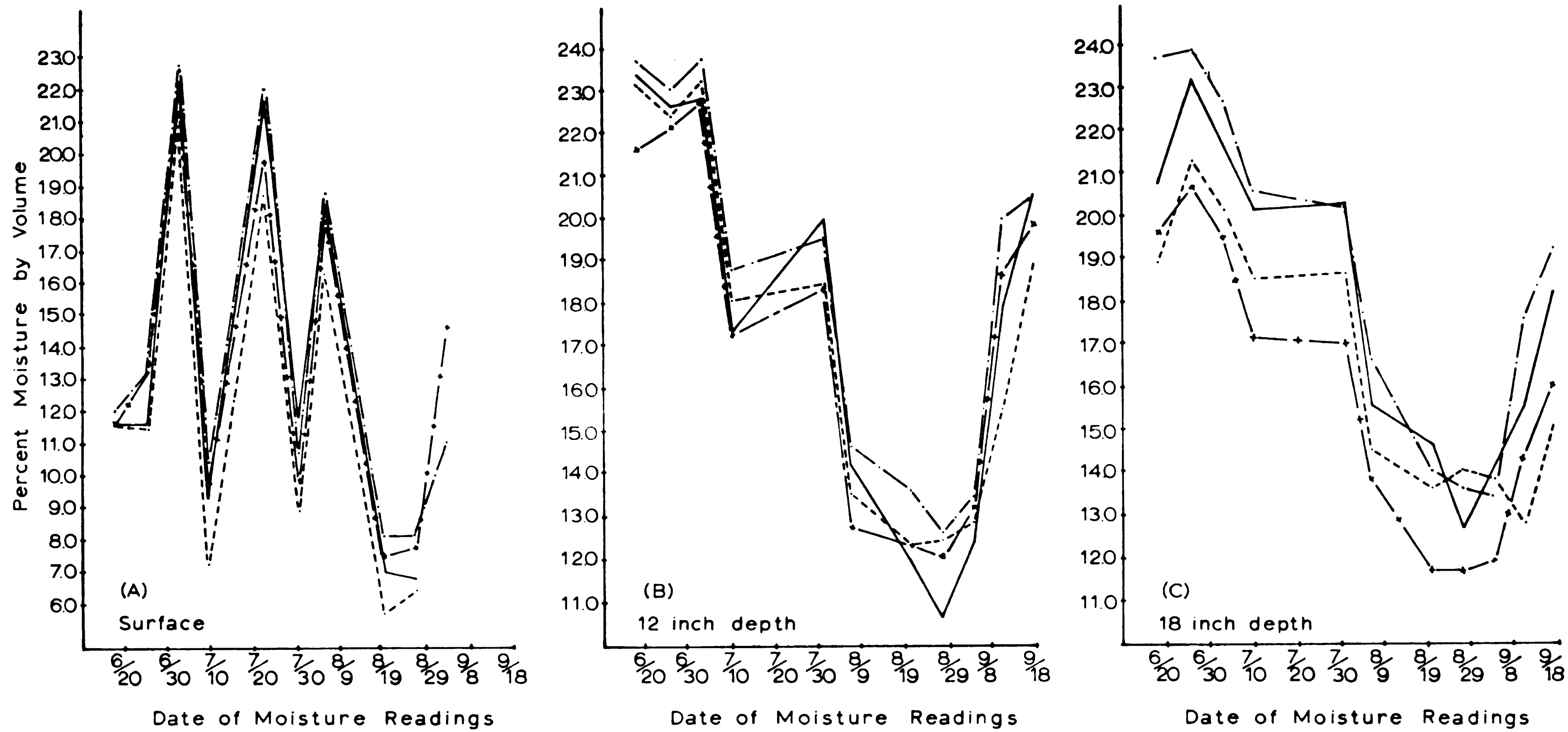


FIG. 9 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON ELEVEN DATES DURING THE 1962 GROWING SEASON MEASURED WITH A P-19 AND P-21 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

TREATMENTS

- ——— Alfalfa Shallow Plowed
- - - - - - Crop Residue Shallow Plowed
- —·—·— Alfalfa Deep Plowed
- —•— Crop Residue Deep Plowed

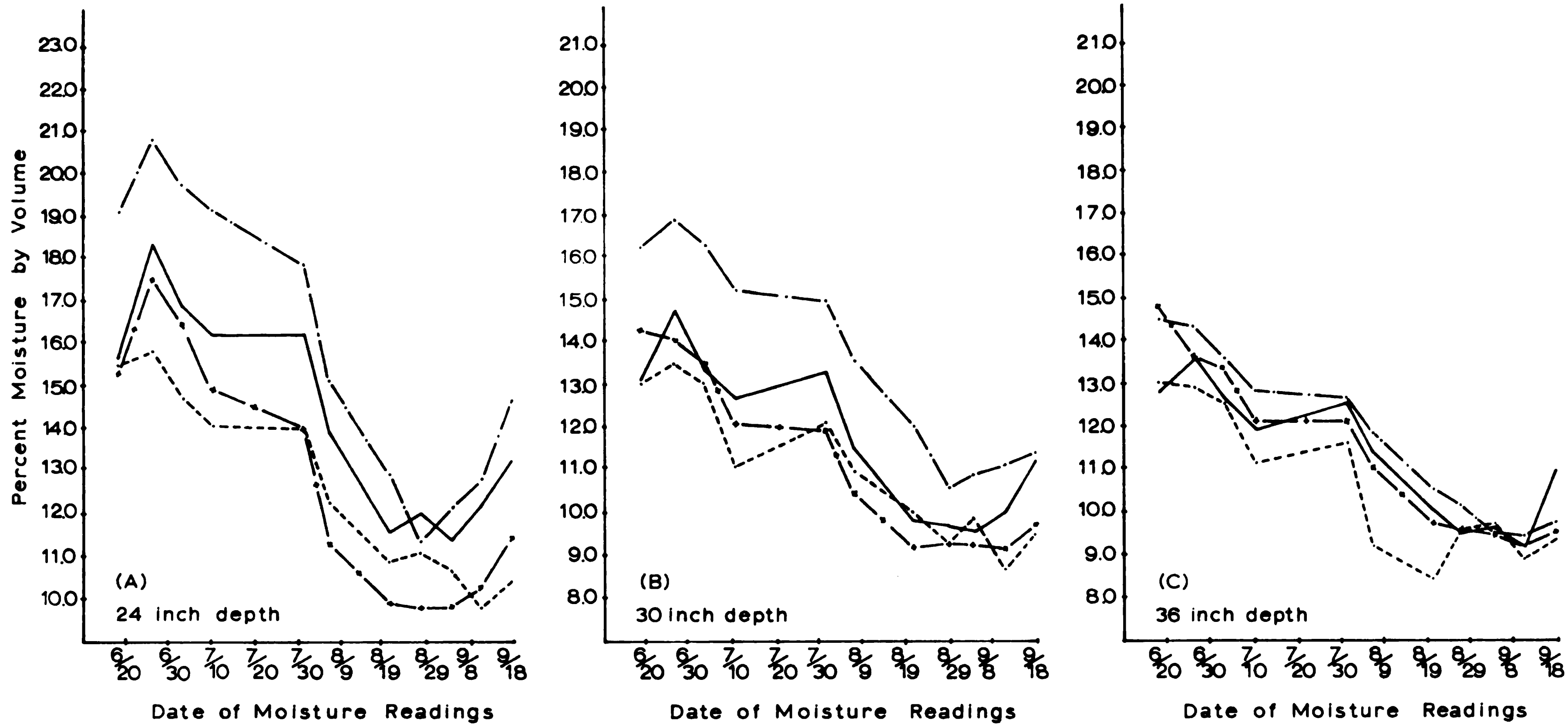


FIG.10 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON ELEVEN DATES DURING THE 1962 GROWING SEASON MEASURED WITH A P-19 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

TREATMENTS

- Alfalfa Shallow Plowed
- Crop Residue Shallow Plowed
- Alfalfa Deep Plowed
- Crop Residue Deep Plowed

Table 19. Percent soil moisture, on a volume basis, obtained on a Kalamazoo sandy loam soil, at 3 depths on 9 dates during the 1963 growing season, using the P 19 and P 21 Neutron moisture probes. Each value is an average of 8 observations at each depth for each treatment.

Plow Depth	Organic Matter	Sample Depth (inches)	7-8	7-22	8-5	8-15	8-22	8-29	9-5	9-11	9-18
Shallow	Alfalfa	0-12	5.6	11.7	12.8	10.3	9.2	11.8	8.9	7.7	8.6
		12	11.6	18.0	18.1	16.0	14.2	14.9	13.6	12.2	12.4
		18	18.5	20.2	20.5	19.7	18.6	18.9	17.8	17.4	17.1
	Crop Residue	0-12	5.0	10.7	11.3	8.2	6.7	9.7	6.9	6.0	7.1
		12	9.3	14.5	15.1	12.8	11.2	11.5	10.5	9.5	9.9
		18	16.0	18.8	18.8	17.4	16.3	16.5	15.8	15.3	15.5
Deep 1 X	Alfalfa	0-12	4.7	11.7	12.7	8.7	7.7	10.8	8.0	6.6	7.2
		12	9.2	14.3	14.8	12.3	11.4	12.2	10.7	10.0	9.9
		18	12.4	14.3	14.5	14.3	13.8	13.4	13.0	12.5	12.5
	Crop Residue	0-12	4.6	10.8	12.1	8.1	7.0	9.8	7.4	6.2	6.9
		12	9.0	14.5	15.1	12.1	10.9	11.9	10.6	9.5	9.6
		18	12.1	13.5	14.3	13.4	12.6	12.8	12.2	11.5	11.4
Deep 3 X	Alfalfa	0-12	6.1	13.6	14.5	11.4	10.4	12.7	9.6	8.4	9.3
		12	14.0	18.3	18.1	16.0	14.4	15.0	14.2	11.0	13.0
		18	18.5	20.1	18.5	17.5	16.1	16.5	15.5	13.3	15.3
	Crop Residue	0-12	4.8	11.1	15.3	7.8	7.0	10.2	6.7	5.7	7.3
		12	11.6	15.4	14.9	12.8	11.0	11.8	11.1	10.4	10.7
		18	15.2	17.8	15.3	14.5	13.5	13.5	13.0	12.5	12.8
Deep 4 X	Alfalfa	0-12	6.7	13.4	13.8	10.4	9.6	12.0	9.0	7.7	9.1
		12	13.3	18.2	17.5	14.4	13.2	14.3	13.1	12.5	12.6
		18	16.6	18.1	16.3	15.1	14.6	14.4	14.0	13.7	13.8
	Crop Residue	0-12	5.4	11.5	11.8	8.2	7.6	10.5	7.3	6.3	7.7
		12	13.6	16.9	16.8	13.5	11.9	14.2	12.2	11.6	11.[illegible]
		18	13.7	16.8	15.8	13.7	12.8	13.9	12.9	12.4	12.5

Table 20. Statistical analysis of the 1963 soil moisture data, showing the results of the analysis of variance, giving the F and LSD values for each treatment and the interactions. (**indicates a significance at the 1% level, and * indicates a significant difference in soil moisture at the 5% level.)

Treatment	F Values								
	7/8	7/22	8/5	8/15	8/22	8/29	9/5	9/11	9/18
Plow	11.4**	73.4**	76.6*	34.3**	27.4**	7.8**	9.5**	9.5**	14.3**
Organic	8.3**	21.2**	9.6**	14.4**	19.3**	12.4**	14.3**	10.0**	14.8**
P x OM	0.44	2.61	1.47	1.35	1.26	1.61	1.33	0.54	0.89
Depth	593**	463**	135**	422**	576**	181**	587**	511**	374**
P x D	12.7**	16.6**	11.7**	9.9**	14.0**	14.2**	16.4**	14.0**	11.0**
OM x D	4.0**	1.59	0.50	0.14	0.08	0.04	0.19	0.44	0.24
P x OM x D	0.94	2.05	0.54	0.75	0.56	1.12	0.92	1.57	0.37
Number	0.40	2.71	0.56	1.43	1.86	0.06	0.30	2.18	1.86
P x N	0.01	0.03	0.13	1.41	3.00*	5.2**	4.5**	5.2**	3.7*
OM x N	0.31	0.06	0.82	0.16	0.10	2.41	0.17	1.73	1.13
P x OM x N	0.11	0.02	4.3**	2.57	1.05	3.5*	1.81	1.76	1.09
D x N	0.99	0.12	0.07	0.56	0.20	0.01	0.17	0.09	0.07
P x D x N	0.90	0.07	0.54	0.46	0.38	0.41	0.62	0.85	0.76
OM x D x N	0.20	1.82	2.18	0.46	0.48	0.47	0.26	0.14	0.19
PxOMxDxN	0.52	0.24	0.47	0.23	0.27	0.64	0.25	0.17	0.27
	LSD Values in percent								
Plow	1.31	0.46	1.07	0.60	0.55	1.02	0.85	0.86	0.81
Organic	0.97	0.72	1.19	1.13	1.02	1.05	1.03	0.93	0.84
Depth	0.58	0.40	0.58	0.46	0.40	0.43	0.37	0.43	0.44

Plow = plowing depth; Organic = organic matter treatment; Depth = depth of obtaining the moisture determination; Number = number of moisture determinations taken per replication.

FIG.11 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON NINE DATES DURING THE 1963 GROWING SEASON MEASURED WITH A P-19 AND P-21 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

TREATMENTS: Alfalfa
- ——— Shallow Plowed
- - - - - - - Deep Plowed 1X
- —·—·— Deep Plowed 3X
- —•— Deep Plowed 4X

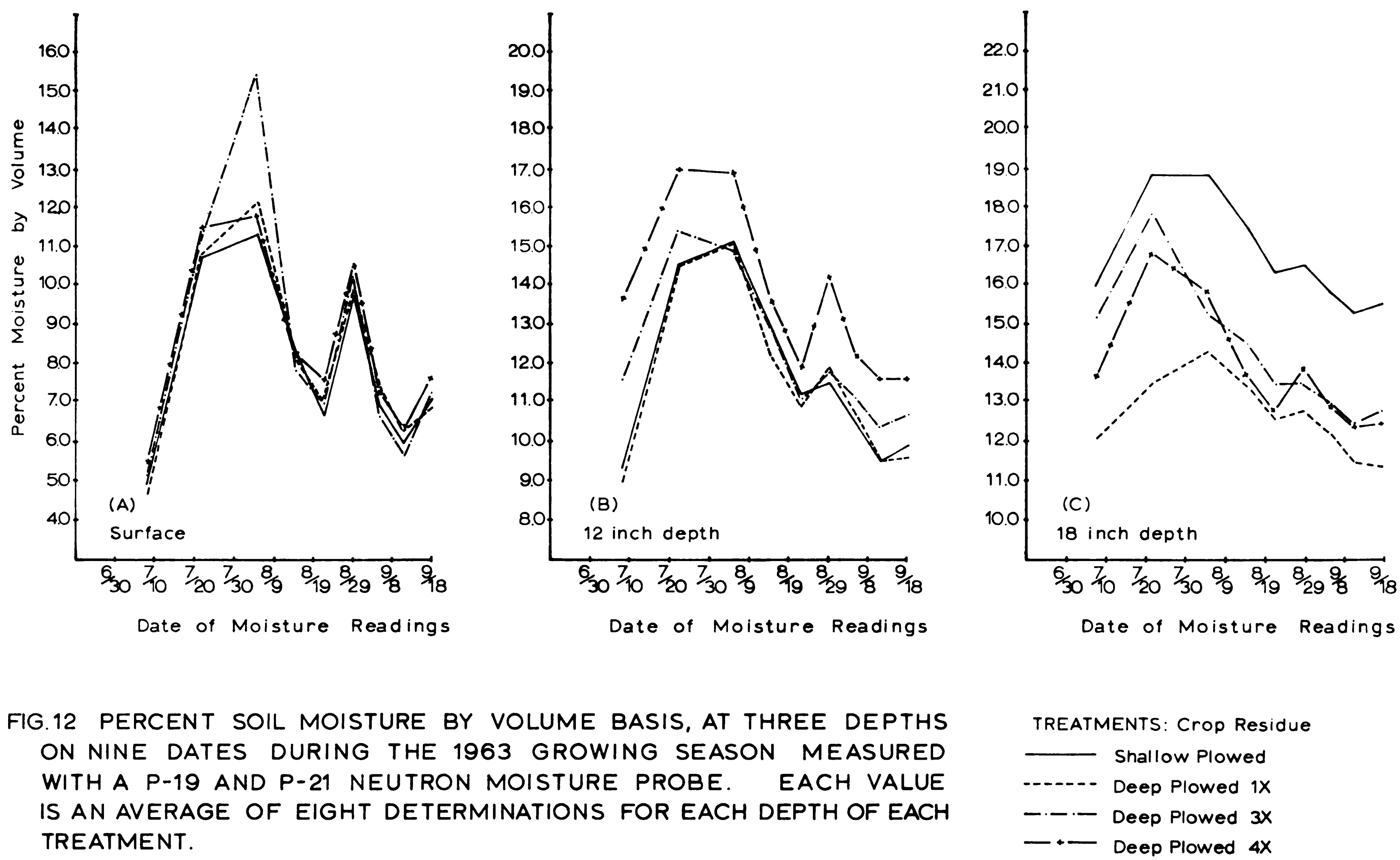


FIG.12 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON NINE DATES DURING THE 1963 GROWING SEASON MEASURED WITH A P-19 AND P-21 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

Table 21. Percent soil moisture on a volume basis, obtained on a Kalamazoo sandy loam soil, at 3 depths, on 6 dates during the 1964 growing season, using the P 19 and P 21 Neutron moisture probes. Each value is an average of 8 observations at each depth.

Plow Depth	Organic Matter	Sample Depth (inches)	Dates					
			7/10	7/27	8/3	8/10	8/17	8/24
Shallow	Alfalfa	0-12	11.9	7.0	6.0	4.9	6.6	1.59
		12	18.2	14.3	15.1	12.6	14.3	35.4
		18	22.9	20.3	18.2	18.2	20.4	38.9
	Crop Residue	0-12	10.1	6.0	5.7	4.3	5.9	13.6
		12	15.9	14.0	13.7	13.2	14.3	30.8
		18	18.8	15.0	13.9	14.5	13.6	26.3
Deep 1 X	Alfalfa	0-12	10.2	6.0	5.9	4.4	6.2	14.9
		12	18.8	14.4	14.1	12.1	13.7	28.3
		18	19.5	17.9	15.9	14.9	15.3	27.5
	Crop Residue	0-12	10.0	5.4	5.8	4.2	6.1	14.3
		12	18.4	14.1	14.1	12.5	13.9	30.8
		18	18.5	15.6	14.1	14.5	14.0	29.2
Deep 3 X	Alfalfa	0-12	12.8	7.3	7.8	5.2	8.4	17.2
		12	20.7	15.6	15.0	13.9	14.3	30.4
		18	24.1	16.5	15.3	14.9	14.5	27.0
	Crop Residue	0-12	11.1	6.4	6.8	5.1	7.9	14.5
		12	19.6	14.4	13.8	12.9	14.2	27.8
		18	21.3	14.0	12.9	13.6	12.7	24.8
Deep 4 X	Alfalfa	0-12	11.8	7.0	7.1	5.2	8.0	16.8
		12	19.4	15.5	14.5	13.3	14.2	33.5
		18	21.8	16.0	14.7	14.2	14.3	31.0
	Crop Residue	0-12	11.8	6.9	7.0	5.0	7.6	14.0
		12	19.5	14.7	13.8	13.2	14.2	29.8
		18	21.0	14.7	13.3	13.4	13.5	25.6

Table 22. Statistical analysis of the 1964 soil moisture data showing the results of the analysis of variance giving the F and LSD values for each treatment and the interactions. (**indicates a significance at the 1% level, * indicates a significant difference in soil moisture at the 5% level.)

Treatment	F Values					
	7/10	7/27	8/3	8/10	8/17	8/24
Plow	4.90	0.18	0.47	1.10	0.92	1.92
Organic	1.16	7.89*	7.42*	3.79	5.70	1.82
P x OM	0.25	0.39	0.48	0.64	0.85	0.68
Depth	124.0**	485.0**	325.0**	1065.0**	272.0**	241.0**
P x D	1.33	3.3**	2.7*	5.9**	5.5**	2.29
OM x D	0.29	7.8**	4.4*	6.2**	8.5**	2.44
P x OM x D	0.30	0.94	0.46	2.3*	2.2	1.69
Number	0.53	0.11	0.03	0.01	1.97	2.55
P x N	0.53	0.89	0.29	0.51	1.96	1.99
OM x N	0.26	2.20	0.55	0.84	0.47	6.0*
P x OM x N	1.10	1.40	1.80	0.95	0.83	1.48
D x N	0.27	0.55	0.04	0.68	0.58	1.06
P x D x N	0.40	0.31	0.45	0.42	0.49	0.74
OM x D x N	0.26	0.61	0.75	0.03	0.12	1.84
PxOMxDxN	0.45	0.81	1.30	0.15	0.68	0.63
	LSD Values in percent					
Plow						
Organic		1.15	0.99			
Depth	1.27	0.68	0.80	0.41	0.47	1.01

Plow = plowing depth; Organic = organic matter treatment; Depth = depth of obtaining individual moisture determinations; Number = number of moisture determinations obtained per each replication.

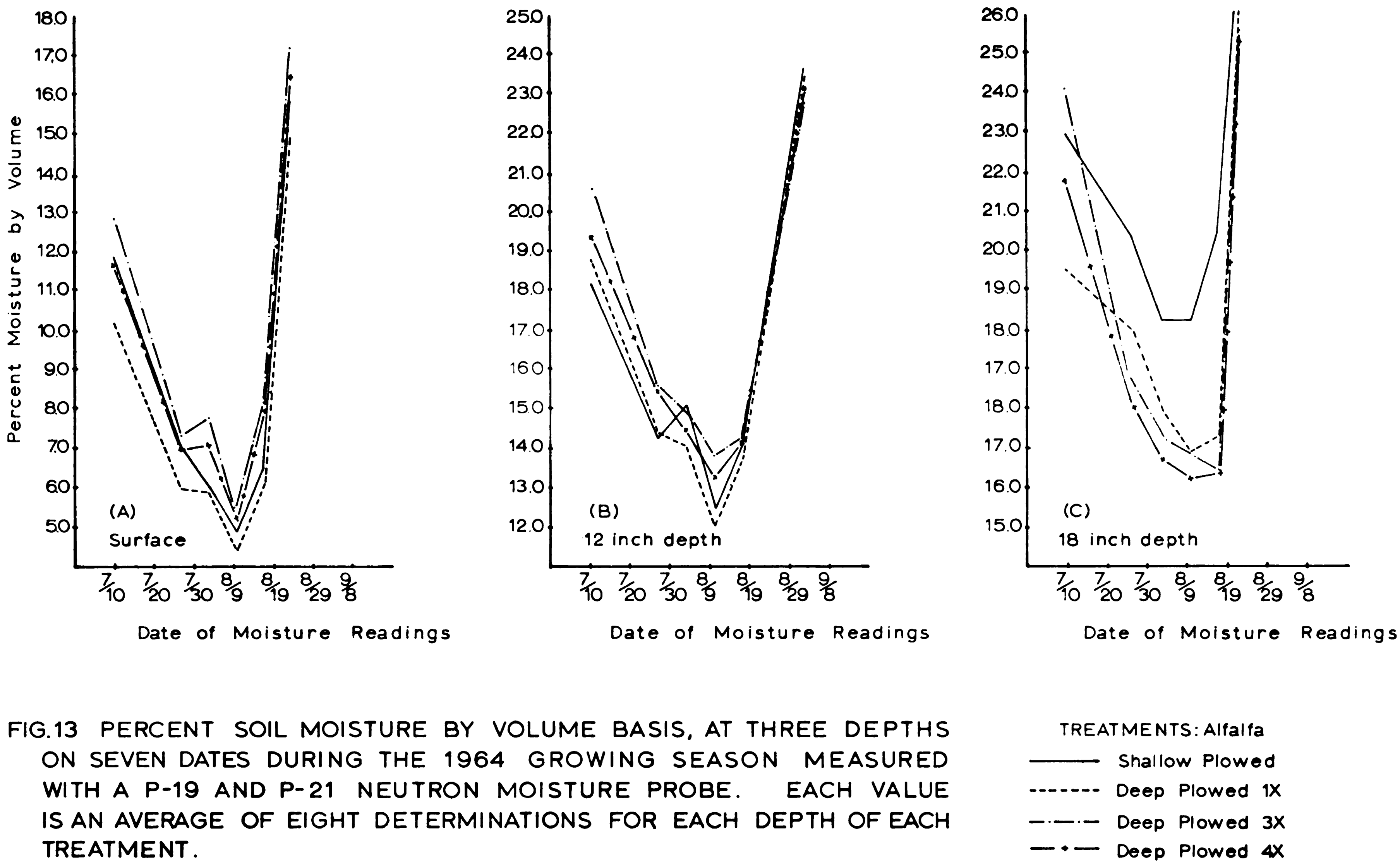


FIG. 13 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON SEVEN DATES DURING THE 1964 GROWING SEASON MEASURED WITH A P-19 AND P-21 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

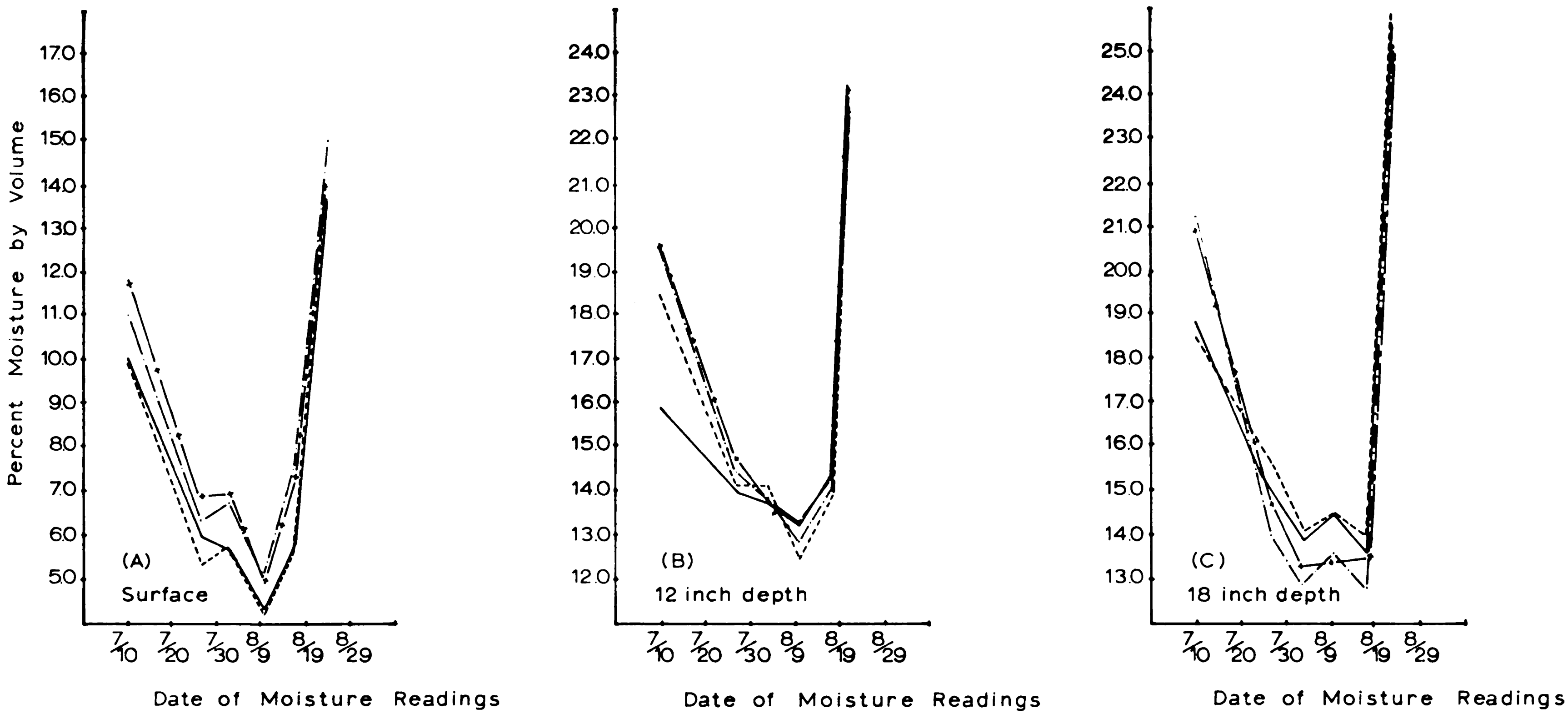


FIG. 14 PERCENT SOIL MOISTURE BY VOLUME BASIS, AT THREE DEPTHS ON SIX DATES DURING THE 1964 GROWING SEASON MEASURED WITH A P-19 AND P-21 NEUTRON MOISTURE PROBE. EACH VALUE IS AN AVERAGE OF EIGHT DETERMINATIONS FOR EACH DEPTH OF EACH TREATMENT.

TREATMENTS: Crop Residue
- ——— Shallow Plowed
- - - - - - - Deep Plowed 1X
- —·—·— Deep Plowed 3X
- —•— Deep Plowed 4X

The revision of the tillage treatments in 1963 resulted in considerable influence on the soil moisture holding capacities. In general the moisture readings at the 18-inch depths followed in the descending order, with the shallow plowed having the highest, then the 3X deep tilled plots, followed by the 4X deep tilled plots and the 1X deep tilled plots giving the lowest readings.

The root weights obtained in 1963 at the 12 to 24-inch soil depth were greatly influenced by the moisture holding capacities of the soil. The total root development in these depths followed the reverse order of the moisture measurements, indicating that the total water use was greatest for the greater amount of root development.

In 1964, the moisture measurements showed little influence due to tillage except at the 18-inch depth, which followed the same pattern as the 1963 moisture measurements.

Oxygen Diffusion Rate as Influenced by Deep-Soil-Mixing and Supplemental Organic Matter

An active growing plant root system requires sufficient oxygen to maintain normal growth rates and any impedance to the oxygen supply for these roots will give a corresponding reduction in root growth. It has been substantiated that the amount of water held in the soil micropores will have a considerable influence on the rate at which oxygen reaches the plant root system. The controlling factors in the diffusion process is the diffusive properties of oxygen in water and the amount of water the oxygen must diffuse through to reach the root system. Since the diffusive properties of oxygen cannot be governed, the only other possible chance of controlling the oxygen diffusion rate is to decrease the mean path of diffusion for the oxygen as rapidly as possible after the soil has been wetted. This could be accomplished by improving the macro-micro pore space relationships in the soil, allowing more air to diffuse into the soil more rapidly.

The platinum micro-electrode oxygen diffusion equipment is widely used to determine the rate of oxygen diffusing through the soil solution to the plant roots. This equipment was used in this research to determine the influence of the tillage and organic matter treatments on the oxygen diffusion rates in this soil.

In 1959 oxygen diffusion rates were obtained within the wetted plot area used for the FA type infiltration studies. The diffusion rates presented in Table 23 are averages of 10 electrodes taken on four separate days following the saturation of the soil by the FA infiltration studies. The oxygen diffusion rates obtained for the surface soil are well above the minimum amount of 40×10^{-8} g $O_2/cm^2/min.$, established to maintain maximum root growth. The diffusion rates did decrease on the fourth day of readings due to a heavy rainfall on the previous day. However, even these readings were only slightly below the minimum requirements for normal root growth.

On the first of September, 1959, additional diffusion rates were obtained from the 14 to 17-inch soil depth. This was accomplished by excavating a pit in the soil of sufficient size and depth for taking the required readings. After the pit was opened, water was ponded on the soil so as to saturate the soil. The first readings were obtained 24 hours after the last visible water had drained away. From the data presented in Table 24, at no time were the plant roots under an oxygen stress of any extent, which would indicate that the dense B horizon of the natural soil was maintaining an oxygen diffusion rate sufficient for plant root growth. However, one must remember that under natural growing conditions the plant roots growing at this depth may be experiencing a lower supply of oxygen than is indicated by these determinations, due to the 14 to 17 inches of soil and water lying above these roots that the oxygen must diffuse through to reach the growing roots. The reduction of oxygen diffusion rates with each increasing depth of determinations has been well established by many researchers. From the information presented by Letey et al. (51) it would seem plausible that the plant roots are receiving less oxygen than the rates obtained indicate by these determinations.

In 1961 additional oxygen diffusion rates were obtained at varying depths in the soil under the alfalfa treatment only. These data are presented in Table 25 and are averages of 10 micro-electrode readings for each replication.

The surface readings were replicated four times, while the others were replicated only two times.

It is apparent from these data that the surface soil drained rapidly after saturation, allowing a sufficient amount of oxygen to diffuse into the soil for both tillage treatments. However, as the depth of determinations increased, the oxygen diffusion rates decreased on both tillage treatments. The oxygen diffusion rates for the 9-inch depths on the shallow plowed areas were always lower than the corresponding depths of the deep tilled areas, with both indicating an oxygen stress for several days. The recovery rate after saturation was much slower for the shallow plowed soil (10 days) than for the deep tilled areas which required a total of only 6 days to return to normal. These data also record a decrease in diffusion rates for the shallow plowed area on the 23rd of June, caused by a light rain shower on the previous day. The shower did not decrease the diffusion rates on the deep tilled areas, however. The effects of the rain shower were also noted in the soil moisture determinations for the same time period (see Table 35), however, they were only sufficiently heavy to moisten the surface layer and did not penetrate to the 12-inch depth.

The differences in the two series of oxygen diffusion rates obtained at the lower soil depth probably were due to the time of the season in which they were obtained. The 1959 diffusion rates were obtained late in the season after the

Table 23. Oxygen diffusion rates obtained on the Kalamazoo sandy loam soil, at a four inch depth, following the FA type infiltration studies. (All values are expressed in grams of oxygen$\cdot$cm$^{-2}\cdot$min^{-1}, and are averages of 10 electrodes.)

Plow Depth	Organic Mater	Date	Rep. 1	Rep. 2	Ave.
Shallow Plowed	Alfalfa	July 20	49.4	54.4	51.9
	Crop Residue	July 20	38.8	43.8	41.3
	Alfalfa	July 21	51.2	49.1	50.2
	Crop Residue	July 21	38.2	40.0	39.1
	Alfalfa	July 22	58.8	41.8	50.1
	Crop Residue	July 22	43.8	48.2	45.9
	Alfalfa	July 24	39.5	43.9	41.7
	Crop Residue	July 24	32.6	38.1	35.3
Deep Plowed	Alfalfa	July 20	46.7	50.0	48.4
	Alfalfa	July 21	42.7	39.4	41.1
	Crop Residue	July 21	41.5	33.9	37.7
	Alfalfa	July 22	48.2	43.6	45.9
	Crop Residue	July 22	45.2	43.0	44.1
	Alfalfa	July 24	37.5	37.7	37.6
	Crop Residue	July 24	31.5	40.7	35.9

Table 24. Oxygen diffusion rates obtained on the Kalamazoo sandy loam soil, taken on four consecutive days at 14 to 17 inch depths after a hole had been filled with water and allowed to drain away. (All values are given in grams of oxygen$\cdot cm^{-2} \cdot min^{-1}$, and are averages of 10 electrodes.)

Plow Depth	Organic Matter	Date	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Ave.
Shallow	Alfalfa	Sept. 1	34.6	42.5	31.9	47.1	39.1
	Crop Residue	Sept. 1	47.1	44.4	65.9	39.3	49.2
	Alfalfa	Sept. 2	34.7	42.7	31.2	30.2	34.7
	Crop Residue	Sept. 2	45.9	31.9	44.7	58.8	45.6
	Alfalfa	Sept. 3	44.9	49.6	50.4	51.2	49.0
	Crop Residue	Sept. 3	75.4	54.4	61.7	48.2	60.2
	Alfalfa	Sept. 4	48.8	53.4	58.7		55.5
	Crop Residue	Sept. 4	50.5	47.9	52.0		50.2
Deep	Alfalfa	Sept. 1	44.7	48.1	41.5	50.0	46.1
	Crop Residue	Sept. 1	55.0	38.8	43.7	38.9	44.1
	Alfalfa	Sept. 2	45.3	30.1	60.7	35.2	42.9
	Crop Residue	Sept. 2	47.0	42.6	43.3	45.4	44.6
	Alfalfa	Sept. 3	47.9	37.1	30.5	37.9	38.3
	Crop Residue	Sept. 3	44.7	44.1	60.9	40.4	47.5
	Alfalfa	Sept. 4	42.9	45.2	46.7		44.9
	Crop Residue	Sept. 4	48.3	43.7	50.3		47.4

Table 25. Oxygen diffusion rates obtained in 1961 on the Kalamazoo sandy loam soil taken at various soil depths and on various dates, after the soil had been saturated with water. (Each value for the 4 inch depth is an average of 4 replications while the other values are averages of 2 replications only, with each replication using 10 electrodes. Each value is expressed in grams of oxygen x $10^{-8}/cm^2/min.$)

Date	Depth (inches)					
	Shallow Plowed			Deep Mixed		
	4	9	12	4	9	18
June 15	50.6	29.5	24.1	52.5	29.5	30.1
June 16	41.6			44.0		
June 20	46.4	28.3	42.4	51.2	35.6	52.5
June 21	42.8	38.4	43.4	48.8	39.8	47.6
June 23	45.2	33.2	43.4	47.0	42.8	47.6
June 24	43.4	35.6	53.7	50.1	43.4	47.6
June 27	59.1	45.2	56.1	59.7	50.0	57.9

soil had experienced a considerable amount of drying during the summer months, which improved the amount of structural development in this clay layer, improving the oxygen diffusion rates. The 1961 diffusion rates were obtained before the soil had an opportunity to dry and therefore the structural arrangement was such that the oxygen diffusion rates were reduced to such a level as to place the growing roots under an oxygen stress, thereby reducing the root development in these soil depths.

The Effect of Deep-Soil-Mixing and Supplemental Organic Matter on the Amount of Corn Root Development

From 1960 to 1963 the root distribution of the corn plants was studied. The method of obtaining the corn root samples is presented in the experimental procedures and was modified somewhat in 1962 and 1963 (see details in the experimental procedures). The weight of corn roots obtained from both methods showed the amount of root development at each sampling depth as they were influenced by the specific plowing and organic matter treatment.

Although the data in Table 26 shows a greater total amount of roots developing in the deep tilled treatments than in the shallow plowed treatment, the increases obtained were not large enough to be statistically significant until 1963 (see Tables 27 and 28). In that year the combination of the deep soil mixing and the number of times the soil had been mixed deep proved to have a significant influence on the amount of root development. The 1X and 4X deep mixed areas increased the amount of root development, especially within the 12 to 24-inch sampling depth. At the same time the 3X deep mixed area increased the root development only in the 18 to 24-inch sampling depth of the crop residue treatment.

The amount of root development at each sampling depth was considerably influenced due to the addition of the chopped alfalfa hay in respect to that of the crop residue treatments. The general pattern was that the alfalfa decreased the amount of root development at all sampling depths, except for a very few instances in 1962 and 1963. However, the decrease was more noticeable in the lower sampling depths (12 to 24 inches) and ranged from a low of 1/6 in 1961 to a high of 1/4 decrease in root weights in 1962 on the shallow plowed areas, while the 1963 results indicated no differences. The decrease was even greater for the 3X deep tilled areas and averaged close to a 50% decrease in root development, except in 1962 when the alfalfa treatment showed a slight increase in root growth. In 1963 the 1X deep tilled areas also decreased the root growth in the 12 to 24-inch sampling depth by approximately 50% and at the same time the 4X deep tilled areas responded in a 2-fold increase in root development. The analysis of variance indicated that the supplemental organic matter had a highly significant influence every year but 1963, when the variability of the various plowing depths removed the significance.

The amount of root growth decreased with increasing sampling depth as one would expect. However, the decrease in root growth was considerably greater at the 12 to 18 and 18 to 24-inch sampling depths on the shallow plowed areas than on the deep tilled areas. The difference in root growth due to the deep mixing process ranged from 1/3 to a 2-fold increase in root growth at the 12 to 18-inch depth on the alfalfa treatment (except for a slight decrease at this depth in 1962), and up to a 3-fold increase in root growth on the crop residue deep mixed areas.

At the 18 to 24-inch depth of sampling the increase was even greater. The alfalfa treatments ranged from a 2-fold increase to a 5-fold increase. The crop residue treatments averaged about a 9-fold increase for 1960, 1961 and 1963, due to the deep tillage process and registered a slight decrease in 1962. The statistical analysis indicated that the decrease in root growth with increase of depth of sampling was highly significant every year. It also indicated that the interactions obtained between plowing depth and organic matter treatments and organic matter and depth of sampling was highly significant every year but 1963. The increase in root growth with depth of sampling due to the deep tillage process gave a significant response in 1960 and 1961. A three way interaction between plowing depth, organic matter treatment and depth of sampling gave significant increases in root development every year but 1961.

In comparing the information obtained from the soil core data and the field moisture measurements with that of the corn root weight data, there appears to be a very close relationship existing between the amount of root development and the amount of water held in the soil by the micropores. Inasmuch as the alfalfa treatments showed a definite increase in the micro pore spaces, resulting in a greater water holding capacity, it also showed a reduction in the amount of root development, especially at the 12 to 24-inch sampling depth, when compared to the same depth on the crop residue treatments.

The increased water holding capacity of the alfalfa hay treatments should have increased the "mean diffusion path" for the oxygen within the soil system, especially at the 12 to 24-inch depths, and in turn would decrease the amount of root development in these depths of soil. However, the oxygen diffusion readings taken in 1959 (see Table 24) indicate that at the 14-inch soil depth there should only be a very short period of time after soil saturation that the corn roots are actually undergoing an oxygen stress. That is if one assumes the oxygen diffusion rate of $40 \times 10^{-8} g/cm^2/min$ to be sufficient for maximum root development. The diffusion rates given in Table 25 are showing the influence of having removed the surface 12 to 14-inches of top soil so that the diffusion readings for the 19-inch soil depth might be obtained. The removal of this surface soil would in itself increase the possibilities of obtaining a higher diffusion rate at the 14-inch soil depth than might be obtained had the soil been left on the surface and diffusion readings taken through the full depth of soil.

Table 26. Grams of corn roots obtained by year from various depths in the soil, representing one quarter of the total root system to depth sampled. All weights are given in grams per 504 in^3 and are averages of 4 replications for each treatment.

Plow Depth	Organic Matter	Sample Depth (in.)	Years 1960	1961	1962	1963
			Grams of corn roots/504 in^3			
Shallow	Alfalfa	0-6			1.42	0.27
		6-12	1.53	1.76	0.90	0.12
		12-18	0.53	0.53	0.38	0.08
		18-24	0.13	0.13	0.36	0.05
		Total	2.19	2.42	3.06	0.52
	Crop Residue	0-6			1.40	0.25
		6-12	2.85	2.85	1.21	0.45
		12-18	0.60	0.60	0.52	0.11
		18-24	0.21	0.19	0.46	0.03
		Total	3.66	3.64	3.59	0.84
Deep	Alfalfa	0-6			0.80	0.07
		6-12	1.44	1.39	0.64	0.42
		12-18	0.99	0.97	0.32	0.12
		18-24	0.61	0.73	0.67	0.11
		Total	3.04	3.09	2.43	0.72
	Crop Residue	0-6			1.75	0.28
		6-12	2.53	2.53	1.93	0.35
		12-18	1.85	1.85	0.54	0.18
		18-24	1.64	1.73	0.29	0.31
		Total	6.02	6.11	4.51	1.12

Table 27. Analysis of variance of the corn root weight yields by years.

	F-- Values 1960	1961	1962	1963
Plowing depth	4.74	5.3	0.5	7.7 **
Organic Matter	120.0**	83.0**	17.3**	0.1
P x OM	14.2**	14.9**	7.7*	0.5
Depth of sample	48.2**	115.9**	28.6**	5.4**
P x D	26.1**	28.9**	0.6	1.5
OM x D	10.6**	6.3**	5.9**	0.7
P x OM x D	6.9**	2.9	4.7**	3.7**
	LSD values (grams)			
Plowing depth				0.04
Organic Matter	0.17	0.18	0.05	
Depth of Sample	0.18	0.21	0.07	0.03

Table 28. Grams of corn roots obtained on the Kalamazoo sandy loam soil at four depths, taken from the center of the corn row (15 to 21 inches from the corn plant), for the year 1963, showing effects of depth of plowing number of times plowed deep and organic matter treatment. Each value is an average of 4 replications for each treatment.

Plow Depth	Organic Matter	Depth of Sample (inches)	Root Weight (gm/144 in^3)	Total Weight	Ave.
Shallow	Alfalfa	0-6	0.077		
		6-12	0.034		
		12-18	0.023		
		18-24	0.014	0.148	
	Crop Residue	0-6	0.070		
		6-12	0.129		
		12-18	0.030		
		18-24	0.008	0.237	0.192
Deep 1 X	Alfalfa	0-6	0.14		
		6-12	0.278		
		12-18	0.099		
		18-24	0.027	0.544	
	Crop Residue	0-6	0.075		
		6-12	0.090		
		12-18	0.157		
		18-24	0.104	0.426	0.485
Deep 3 X	Alfalfa	0-6	0.021		
		6-12	0.121		
		12-18	0.035		
		18-24	0.030	0.207	
	Crop Residue	0-6	0.080		
		6-12	0.100		
		12-18	0.052		
		18-24	0.088	0.320	0.263
Deep 4 X	Alfalfa	0-6	0.015		
		6-12	0.046		
		12-18	0.083		
		18-24	0.093	0.237	
	Crop Residue	0-6	0.078		
		6-12	0.072		
		12-18	0.039		
		18-24	0.039	0.228	0.232

LSD values (see Table 27 for analysis of variance).

Plowing depth	0.038 grams
Depth of sampling	0.030 grams

The 1961 oxygen diffusion determinations do indicate that the corn root systems were undergoing oxygen stresses especially at the 9-inch depth and it also shows that the deep mixed areas made a much faster recovery after the soil had been saturated than were the shallow plowed treatments.

It has been well established that the oxygen diffusion rates will decrease with increasing soil depth even though the soil structure is uniform and that the oxygen concentration above the soil is maintained at a constant high level. The decrease in root growth with respect to depth of sampling can also be explained through the same principle, that is the rate of oxygen diffusion in this soil is decreasing with depth and the root production is also decreasing accordingly with depth.

It is interesting to note that the decrease in root growth is less at the lower depths under the deep plowing treatments than for the shallow plowing treatments during the 1960 and 1961 growing seasons, with the same trend still persisting in 1962 and 1963.

Corn Grain Yields as Influenced by Depth of Plowing Supplemental Organic Matter Treatment, Plowdown Fertilizer Rate and Variety of Corn

Plowing Depth and Grain Yields

The corn grain yields are presented in Tables 29 and 30 as averages of the four replications of each treatment each year. Inasmuch as the original plot areas were revised in 1963, Table 29 just records the results of the original plowing depths over the 8-year period. Table 30 consists of the yields results for the complete revision during 1963 and 1964. Each year the yields were subjected to an analysis of variance to determine if the yield differences brought about by the respective treatments were significantly different from one another. The results of this analysis are presented in Table 31.

The yield response from the deep-tillage operation resulted in an increased yield every year except one, 1962, when the shallow plowed area did outyield the deep tilled areas, but only by 0.9 bushels per acre. The increases obtained from the deep-soil-mixing process proved to be significant in three of the years. In 1963 and 1964 the influence of the number of times the deep-tillage process had been performed were significantly different but were very low yields.

The corn grain yields reached a maximum in 1958 and then maintained a somewhat lower although respectible yield over the next three years, after which they started to decline. The reduction of yields in 1962 were not too drastic, however, the 1963 and 1964 yields were reduced to such an extent that there was a crop failure. The reduction in yields during these two years can be accounted for due to insufficient rainfall during the growing season, and especially during the period of pollination. The rainfall data presented in Table 35, along with the moisture data obtained "in situ" with the neutron moisture probe (see tables 11 through 14) indicate that the growing plants were undergoing serious moisture stress both years during the latter part of July and early part of August.

At the time of harvesting the corn in 1964 it was noted that the plants were quite short and a good percentage of these plants were barren, so a plant and ear count was made of each plot area. The averages of the four replications are presented in Table 33, as is the results of the analysis of variance of these data. As can be seen from these data, there was no significant differences in the plant stand count, although the alfalfa shallow plowed area did have some 2000 plants per acre less than the others. It is also evident that the depth of plowing had a highly significant influence on the number of ears of corn produced on each plot area. The differences between the shallow and 1X deep tilled areas were not significant nor were the differences between the 3 and 4X deep-tilled areas. However, the 3 and 4X deep-tilled areas yielded approximately 48% more than the shallow plowed areas and 38% more than the 1X deep-tilled area.

From the neutron moisture measurements made in 1964 (see Figures 13 and 14), it is evident that the soil moisture content was very low and that the 1X deep plowed areas were registering less moisture than the others. The shallow plowed plots had more moisture than the others at 18 inches deep, which would indicate that the plant root system was not able to penetrate this dense layer of soil sufficiently well to remove the moisture that was there in the soil.

The yield increases from the deep-soil-mixing only averaged 11.8 bushels per acre for all other treatments involved. However, the 8-year average increase due to the deep mixing on the 500 pound per acre plowdown fertilizer rate for the early variety of corn was 30.4 bushels per acre.

Organic Matter and Grain Yields

The supplemental alfalfa hay treatments also produced significant increases in yields every year except in 1962 and 1963, when all treatments are considered. However, if one again uses the yields for the 500 pound per acre plowdown fertilizer rate, the alfalfa increased the yields significantly each year. The 8-year average increase for the shallow plow and deep mixed treatments were 25.8 and 29.0 bushels per acre respectively.

The increase in yields due to the alfalfa treatment can be accounted for in part by the increased amount of water held in the soil at field capacity and also in respect to that held by the crop residue treatments throughout the season. This increased the available water for plant use and was very evident in the 1964 season, when all treatments experienced a considerable shortage of moisture. During that year all treatments maintained the same number of plants (see Table 33), however, the alfalfa treatments produced a considerably larger number of ears of corn per acre than did the crop residue treatments. These increases ranged from 21% on the 1X deep tilled treatments to 54% on the 3X deep tilled treatments.

Another factor that may have helped in increasing the yields, was the additional amounts of available nutrients supplied to the soil through the decomposition of the alfalfa hay.

Plowdown Fertilizer Rates and Corn Grain Yields

The influence of the plowdown fertilizer rates on the corn grain yields was quite variable and showed statistical significance only twice in the first six years of the research project. For all practical purposes the 500 pound per acre fertilizer rate returned the most consistent highest yields. Because of this consistency in providing higher yields, the 500 pound per acre rate was maintained over the entire plot area after the 1963 revision of the tillage treatments.

Variety and Grain Yields

The pollination of corn is greatly influenced by the amount of available moisture in the soil and since the available moisture varies as the rainfall varies during the growing season, an early and a late maturing variety of corn was planted in 1958, 1959 and 1960, to determine if the maturing date and available water would influence the yields. The yield results proved to be significant each year, however, there were interactions between the variety of corn and the plowing depth during 1958 and 1959 that added to the influence on the yields.

The early maturing variety returned higher yields on the shallow plowed areas in 1958 than did the late maturing variety, however, the late maturing variety outyielded the early variety on the deep-tilled area. The reverse of this was true for 1959. As no moisture data is available for 1958, little can be said as to the influence of the moisture on the yields, except that the late maturing variety of corn must have been able to utilize the soil moisture more effectively on the deep tilled areas than was the early variety. According to the moisture determinations in 1959 (see Table 11 and Figures 3 and 4), there was little or not rainfall during the period of the month of August while the corn plants were undergoing pollination, and therefore the plants were required to utilize the available water stored in the soil, with the result that the late variety made better utilization of the water on the shallow plowed areas, as did the early variety on the deep plowed areas.

Table 29. Yearly corn grain yields obtained on a Kalamazoo sandy loam soil as affected by depth of plowing, organic matter, plow-down fertilizer and variety of corn. Each value is an average of 4 replications of each treatment.

Plow Depth	Organic Matter	Fert.	Var.	Years 57	58	59	60	61	62	63*	64*
		0	250	60.7	69.0	69.7	67.9				
			480		61.6	86.5	61.7	78.1	55.0		
	Alfalfa	500	250	64.6	90.9	71.8	68.7			18.9	
			480		62.8	92.3	67.2	79.4	59.1	23.1	10.0
		1000	250	64.1	83.0	68.5	70.8				
Shallow			480		70.5	81.3	65.4	67.6	57.2		
		0	250	46.0	68.4	60.8	65.7				
			480		42.8	72.7	59.2	71.3	54.8		
	Crop Residue	500	250	52.3	78.1	73.0	59.5			27.4	
			480		45.2	82.3	62.4	69.8	56.7	31.4	5.4
		1000	250	51.1	57.4	74.6	67.5				
			480		46.8	78.1	57.4	59.9	54.4		
		0	250	71.2	134.8	98.3	81.4				
			480		133.5	90.0	78.5	89.3	55.3		
	Alfalfa	500	250	71.5	114.0	75.0	78.5			28.8	
			480		118.4	85.6	66.4	85.0	63.2	28.7	23.5
		1000	250	72.0	113.7	107.1	77.0				
Deep Mixed			480		137.8	102.0	71.2	93.0	58.0		
		0	250	54.5	109.5	59.1	66.4				
			480		108.3	53.3	59.5	77.4	51.7		
	Crop Residue	500	250	57.1	111.6	73.8	70.8			38.1	
			480		101.0	83.8	52.2	71.7	52.9	37.2	8.5
		1000	250	54.2	92.3	89.4	61.3				
			480		93.3	81.4	54.4	83.1	48.4		
LSD values in bushels per acre											
Plowing Depth					4.4					2.5	5.4
Organic Matter				7.5	12.4	3.9	3.9	2.4		2.9	4.3
Fertilizer				2.2		6.6					
Variety					6.1	5.2	2.6				

* The 1963 and 1964 yields are given for the Shallow and Deep 3X only and the variety was M-300 instead of the M-480.

Table 30. Corn grain yields obtained on a Kalamazoo sandy loam soil as affected by plowing depth, organic matter, variety of corn and number of times plowed deep. Each value is an average of 4 replications for each treatment.

Plow Depth	Organic Matter	Variety	1963	Ave.	1964	Ave.
				Bushels per acre		
	Alfalfa	M-250	18.9			
		M-300	23.1		10.0	
Shallow				21.0		
	Crop	M-250	27.4			
	Residue	M-300	31.4		5.4	
				29.4		
	Average			25.2		7.7
	Alfalfa	M-250	25.1			
		M-300	33.9		10.6	
Deep 1	X			29.5		
	Crop	M-250	25.3			
	Residue	M-300	29.9		8.0	
				27.6		
	Average			28.5		9.3
	Alfalfa	M-250	28.8			
		M-300	28.7		23.5	
Deep 3	X			28.7		
	Crop	M-250	38.1			
	Residue	M-300	37.2		8.5	
				37.6		
	Average			33.2		16.0
	Alfalfa	M-250	42.9			
		M-300	43.5		24.8	
Deep 4	X			43.2		
	Crop	M-250	38.2			
	Residue	M-300	37.2		10.7	
				37.9		
	Average			40.5		17.7
			LSD values in bushels per acre			
Plowing depth				2.5		5.4
Organic matter				2.9		4.3

Table 31. Analysis of variance of the corn grain yields by year.

Treatment	F Values							
	57	58	59	60	61	62	63	64
Plow	7.5	270**	3.5	6.7	9.7	0.2	68.0**	6.4**
Organic	23.3**	15.0**	59.5**	15.6**	107**	3.0	3.5	24.5**
P x OM	0.2	0.4	21.2**	3.6	4.1	1.2	7.3**	2.3
Fert.	5.0*	0.4	6.6*	0.5	0.5	1.0		
P x F	2.2	2.6	5.3*	1.6	5.9*	0.1		
OM x F	0.8	1.9	6.1**	0.1	0.1	0.4		
PxOMxF	0.3	0.7	2.9	0.9	0.1	0.8		
Variety		7.3*	5.0*	28.8**			3.4	
P x V		13.9**	7.1*	2.8			1.5	
OM x V		2.8	0.7	0.6			0.4	
F x V		0.3	0.6	0.6			0.1	
PxOMxV		2.9	2.1	0.2				
PxFxV		0.4	0.9	5.0*				
OMxFxV		0.1	0.1	0.1				
PxOMxFxV		1.2	0.1	0.8				
	LSD values in bu/acre							
Plow		4.4					2.5	5.4
Organic	7.5	12.4	3.9	3.9	2.4		2.9	4.3
Fert.	2.2		6.6					
Variety		6.1	5.2	2.6				

Plow = plowing depth; Organic = organic matter treatment; Fert. = plowdown fertilizer; Variety = variety of corn.

Table 32. Analysis of error variance within years for pooled testing of interactions between plowing depth and years, treating each organic matter treatment separately.

Treatment		F-values	LSD (5%)	LSD (1%)
Alfalfa	Plowing depth	14.4**	5.32 bu/a	7.87 bu/a
	Years	78.5**	9.81 bu/a	15.78 bu/a
Crop Residue	Plowing depth	2.5		
	Years	10.5	19.7 bu/a	29.1 bu/a

Table 33. Corn plant stand and ear count at the time of harvesting corn on the Kalamazoo sandy loam soil in 1964. Each value given is an average of four samplings for each treatment.

Plow Depth	Organic Matter	Plants per Acre	Ears per Acre	
Shallow	Alfalfa	16956	4637	
	Crop Residue	19980	2268	
			Ave.	3452
Deep 1 X	Alfalfa	19008	4731	
	Crop Residue	19798	3672	
			Ave.	4201
Deep 3 X	Alfalfa	19116	9776	
	Crop Residue	19009	3834	
			Ave.	6805
Deep 4 X	Alfalfa	19656	8370	
	Crop Residue	18900	4914	
			Ave.	6692

Table 34. Analysis of variance of the 1964 corn plant and ear count at time of harvest, giving the F and LSD values for each.

Treatment	F value (plants)	F values (ears)	LSD (ears/a)
Plowing	0.37	9.78**	1765
Organic	0.92	34.13**	1179
Px OM	1.38	3.65*	

Table 35. Amount of rainfall received on the plot areas during the respective growing seasons as measured in inches per rain. Rainfall data for 1961 and 1962 are not available.

1959		1960		1963		1964	
Date	Rain	Date	Rain	Date	Rain	Date	Rain
7-1	.05	5-19	.38	6-28	.18	4-16	.63
7-10	.05	5-24	.30	7-8	1.36	5-1	.95
7-16	1.45	6-7	2.69	7-15	.86	5-8	.77
7-23	.97	6-16	.70	7-22	1.38	5-15	2.64
7-29	.32	6-20	.15	7-30	.76	5-22	.56
7-30	.20	6-27	.37	8-5	.30	5-29	.08
8-3	.30	7-1	2.28	8-14	.03	6-5	.05
8-6	.08	7-7	.43	8-21	.85	6-12	1.06
8-12	.67	7-21	2.08			6-19	.92
8-23	1.10	8-2	.55			6-26	.18
8-27	1.10	8-12	.38			6-30	.59
9-2	.78	8-19	.60			7-10	1.08
		9-16	1.64			7-17	.99
		9-20	2.40			7-24	.14

CONCLUSIONS

The Kalamazoo sandy loam soil has a dense B horizon which restricts root growth and limits crop yields. A giant disc plow was used to break up this horizon and mixed it throughout the tillage zone. The effects of this tillage operation was observed through many types of measurements both "in situ" and in the laboratory. The following conclusions have been drawn in respect to the effect of the tillage operation on the crop yield response as well as the various physical and chemical properties of this soil.

1. Although the deep mixing operation did increase the corn grain yields for the overall treatments, they were not consistently statistically significant. However, after separating many of the variables included in this research, one finds that the deep-mixing did give an average increase for the 8 years of 30.4 bushels per acre for the plowdown fertilizer rate of 500 pounds per acre, and for the early variety of corn.

2. The mixing of the soil with the giant disc plow did alter the mechanical composition of the soil, especially in the dense B horizon, distributing the soil separates evenly throughout the soil profile to a depth of 22 inches.

3. The tillage operation showed very little influence by itself on the water holding capacities of the soil, until

after the 1963 revision of the tillage treatments. At this time the deep tillage treatments increased the amount of water held in the soil at 60 cm. of water suction and also allowed the plant root systems to remove the soil moisture more effectively.

4. The pore space relationships were only slightly influenced by the deep-mixing operation, until after the 1963 revision of treatments. At this time the deep-mixing increased the macro and total pore spaces in the soil, expecially in the 12 to 21-inch depth of sampling the soil profile.

5. The deep-mixing usually resulted in an immediate reduction in the bulk density values in the 12 to 21-inch sampling depth. However, these reductions were of short duration, as the bulk density of this lower portion of the soil returned to the original or even higher values within one year after the tillage operation. At the end of four years these values were considerably higher.

6. Although the deep-mixing operation appeared to decrease the water infiltration rate in 1958, it also increased the water intake rate in 1959. However, neither of these were statistically significant increases or decreases.

7. The 1961 oxygen diffusion rates gave indications that the deep-mixing allowed the oxygen diffusion rate to recover more rapidly in the lower portion of the soil, after the soil had been saturated, than was possible for the natural soil at the same depths.

8. The deep-mixing did reduce the concentration of phosphorus and potassium in the 0-9 inch soil depth, and at the same time reduced the pH value of the soil. It also gave slight increases in the exchangeable magnesium concentrations of this same layer of soil.

9. The amount of corn root development was increased considerably, in some instances the increases were close to 10-fold, in the 12 to 24-inch sampling depth. The increases at these depths due to the deep-mixing were statistically significant.

Supplemental organic matter in the form of chopped alfalfa hay was added to the soil at the time of the deep-mixing operation, to attempt to improve the stability of any changes in the soil physical properties brought about by the deep-mixing process. The following conclusions are drawn in regards to the influence of the alfalfa hay on the crop yield response and on the physical and chemical properties of the soil.

1. The alfalfa hay increased the corn grain yields significantly every year, except in 1962 and 1963.

2. The alfalfa hay did increase the water holding capacities of the soil when placed under 60 cm. of water suction. However, these increases were statistically significant in 1960 and 1963. It also increased the amount of moisture held in the soil as measured "in situ" with the neutron moisture probe.

3. The general trend was that the alfalfa hay decreased the amount of macro pore space and increased the micro pore space in the soil. However, the decreases and increases were statistically significant in 1960 and 1963 only.

4. The alfalfa hay treatment reduced the amount of corn root development considerably in 1960, 1961 and 1962, in comparison to that obtained in the crop residue treatment.

5. There was no influence on the bulk density values brought about by the alfalfa treatment.

6. The water intake rates of the soil, on the wet runs, were generally increased due to the alfalfa hay treatment.

7. The addition of a total of 15 T/A of chopped alfalfa hay to this soil resulted in general increases in the phosphorus, potassium, calcium and magnesium content of the soil and at the same time increased the pH values by 0.1 to 0.2 points, especially on the deep mixed treatments.

The deep mixing operation resulted in a thorough mixing of the soil to a depth of 22 inches and in so doing would tend to dilute the concentration of the essential plant nutrients in the surface soil. Supplemental fertilizer was added to the soil as a plowdown treatment to determine the quantity required for counteracting the dilution process. The following conclusions were obtained from the plowdown fertilizer treatments in respect to their influence on the corn grain yields and on certain chemical properties of the soil.

1. The addition of high rates of plowdown fertilizer to the shallow plowed treatments decreased the amount of magnesium available for plant use.

2. The addition of plowdown fertilizer did increase the acidity of this soil.

3. The 500 pound per acre rate of plowdown fertilizer gave the most consistent higher yields of corn grain, and was therefore maintained as the blanket application for the 1963 tillage revisions.

Two varieties of hybrid corn were used in this research to determine if the maturity date of the corn showed any influence on the yields. They were observed to produce varied yield responses from year to year and were influenced somewhat by the deep-mixing process. In general the early maturing variety seemed to respond better on this soil than the late maturing variety.

The results of this research indicate that the deep-soil-mixing operation alone could increase the production capacities of this soil. However, supplemental organic matter in the form of chopped alfalfa hay and supplemental plowdown fertilizer improved the yield capacities even more.

The changes brought about in the soil structure by the deep mixing, were found to be of short duration, however, the increased yields continued even though the improved soil structure did not persist.

With the yield increases obtained due to the deep-soil-mixing, supplemental organic matter and plowdown fertilizer, one could economically afford to perform this operation on soils such as the Kalamazoo sandy loam to improve the productive capacities of these soils.

General Summary in Retrospect

The Kalamazoo sandy loam soil was chosen for this research project because it did possess a dense B horizon, also due to the fact that previous studies had indicated that any fracturing of this horizon could increase crop yields. Inasmuch as the dense B horizon seemed to act as a natural barrier to root penetration, the decision was made to till the soil to a depth of 22 inches with a giant disc plow, rather than to subsoil, with a chisel type tool, because the shattering of the dense layer with the chisel was known to quickly revert back to its natural condition.

With the thorough mixing of the soil to a depth of 22 inches, the physical properties of the dense horizon should be improved. Therefore the amount of root proliferation in this area should also increase, thereby improving the total absorption area and possibly increase the crop yield. If the deep mixing process was found to be successful for improving crop yields on this soil it could then possibly be used on other soils possessing similar restrictive layers.

Realizing that the mixing of the soil alone might not be the complete answer, additional treatments were also included along with the tillage operation, such as addition of chopped alfalfa hay to improve the stability of any changes in the soil physical properties brought about by the mixing process and the addition of supplemental fertilizer as a plowdown treatment, to reduce the influence of the dilution of essential nutrients in the surface soil brought about by the same mixing process.

A variety of measurements were made on the soil both in the field and in the laboratory to determine the influence of the deep mixing on the soil physical and chemical properties along with the many related factors, such as aeration, water intake rate, moisture holding capacities, etc., and how these changes influenced the crop yield responses.

The immediate response of the deep-mixing operation was to give a very even distribution of the soil separates throughout the depth of tillage and also to improve the physical properties of the dense clay layer, thereby greatly increasing the amount of root development within this same layer, resulting in a corresponding increase in corn grain yields.

Although the improvement of the macro and micro pore space relationships along with the decrease in bulk density was of short duration, as they soon reverted back to or even beyond their original state, the increase in root development brought about by the deep mixing, persisted throughout the duration of this research project, as did the corresponding increase in crop yields.

The question immediately arises as to why the continued increase in root growth, after the soil had reverted back to or beyond its original state? Inasmuch as there are no data available to determine the exact cause of this increase, a possible solution comes from personal observations and from conjectures as to what is occurring in the soil system.

On close inspection of the soil after the third deep-mixing process, one observes that the mixing process did not pulverize the large structural units of the original dense B horizon, but rather broke them into smaller fragments of approximately 1 to $1\frac{1}{2}$ inches in diameter. These smaller units along with the available organic materials, were mixed in a vertical wave like fashion, which produced a somewhat loose porous type of soil structure. However, as time passed there was a certain amount of settling of the finer structural units in and around the larger units, thereby increasing the bulk density and producing a less favorable pore space relationship.

Inasmuch as the bulk density and porosity determinations were made on a 3 x 3 inch round core, one would have to consider these measurements to have been made on a macro scale in comparison to that encountered by the growing roots within the same soil system. It therefore seems plausible that within the sampling area, there were rather large dense units left over from the original B horizon, that were contributing heavily to the bulk density measurements and that these dense units were surrounded by less dense material more easily penetrated by the growing roots. Because of this situation the root development continued to be greater in the deep-mixed areas than that of the natural soil, thereby increasing the total absorption area allowing the plants to more effectively extract the available soil moisture and nutrients resulting in an increase in crop yields.

The alfalfa hay treatment displayed significant influences on such factors as increasing waterholding capacities and crop yields, and at the same time decreased the total amount of root absorption area within the soil system.

At the same time the 500 pound per acre of plowdown fertilizer was found to be sufficient to offset the dilution of the essential nutrients brought about by the deep-mixing process.

If one sorts out the many variables entailed in this research, the conclusion can be drawn that the deep-mixing of this soil was profitable as it did give a 30 bushel per acre increase the production which should have offset the cost of treatment (set at $25.00 per acre in 1956) and would give a good return on the moneys spent for the mixing treatment. However many questions appear to be unanswered by this research project that could possibly have been answered had the design of the original project been different.

The first question that arises is, just how many times should this soil be deep-mixed and was three mixings necessary or would one have been sufficient? The answer to this question could have best been determined by establishing treatments in the beginning to determine the influence of the one time through the three or four time deep-mixing processes on the various soil properties and the related yield response. This would have also given the long term influence of the deep-mixing process. Although there is insufficient data to make concrete conclusions, there are indications that a one or two time deep-mixing would have been sufficient to produce the desired responses. This is substantiated somewhat by the 1958 yield results and had there been more normal years in 1963 and 1964 a stronger conclusion could possibly have been made.

Another question that arises is in regards to the oxygen diffusion rates obtained on this project. Why did the oxygen diffusion rates obtained late in the 1959 season show little or no oxygen stresses in the dense B horizon, yet the 1961 oxygen diffusion rates showed serious stresses in this same horizon? An improved method to determine the influence of the deep-mixing on the oxygen diffusion rates and corresponding rooting capacities, might have been to have started the root studies early in the season and to have continued the study of root development throughout the season and at the same time determined the oxygen diffusion rates for each depth of root sampling. There is a strong possibility that as this soil dries out during the summer months the contraction occurring due to the shrinking properties of the soil clay, is sufficient to allow more oxygen to diffuse through the soil late in the season, than is possible earlier in the season. This in turn could also influence the amount or root development at these specific seasons of the year.

The influence of the chopped alfalfa hay on the water holding capacities and the amount of root development, suggests that possibly more should have been done to determine what was occurring within this treatment. Assuming that there was over 3,000 T/A of this soil to a depth of 18 inches, it seems unlikely that the added organic matter from the alfalfa hay could increase the water holding capacities of this soil as much as it did, in that the total 15 T/A was only 0.5% of the total soil weight. It also seems unlikely that the increased water holding capacity brought about by the alfalfa treatment was responsible for the reduction of root development that was obtained in this research. It is quite possible that the CO_2 released from the decomposition of this organic material helped to reduce the root growth, however, concentrations of CO_2 greater than that found in most of our soils have been found to increase root growth slightly.

A series of measurements to determine the exact influence of the alfalfa on the water holding capacities and on the exact amount of CO_2 released by the decomposing alfalfa would have provided valuable information for understanding the responses obtained from this research.

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