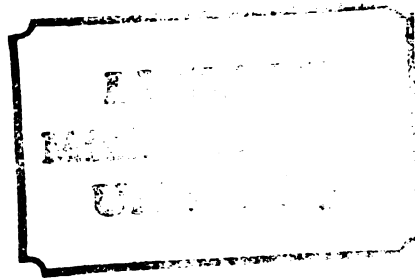




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ALLEVIATING A DENSE SOIL PROBLEM
USING ALFALFA AND DEEP CHISELING

presented by

Sally Logsdon

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M.S. degree in Crop and Soil Sciences

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ALLEVIATING A DENSE SOIL PROBLEM
USING ALFALFA AND DEEP CHISELING

By

Sally Logsdon

A THESIS

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

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ABSTRACT

ALLEVIATING A DENSE SOIL PROBLEM USING ALFALFA AND DEEP CHISELING

By

Sally Logsdon

Compaction is a problem on fine-textured lake-bed soils in Michigan, hindering root growth and function. Limited root growth leads to decreased yields of navy beans (Phaeolus vulgaris), especially when the plants are stressed by inadequate water or nutrients. To correct this problem alfalfa was grown for one year and then killed. Then the soil was deep chiseled in the fall and navy beans were planted in the following spring. The alfalfa had dried out the soil so that deep chiseling would be more effective in shattering the compact layer. Deep chiseled soil had increased air porosity and decreased bulk density compared with conventionally fall plowed and compacted soils. This allowed more root proliferation at deeper levels. Water drained faster which led to less oxygen stress after a heavy rain. Yields were increased due to greater root proliferation.

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TABLE OF CONTENTS

List of Tables.....	iv
List of Figures.....	v
LITERATURE SEARCH.....	1
MATERIAL AND METHODS.....	9
Field Description.....	9
Tillage Treatments.....	9
Soil Physical Properties.....	10
Root Distribution.....	14
Yield of Beans.....	17
RESULTS AND DISCUSSION.....	18
Soil Physical Properties.....	18
Root Distribution.....	38
Yields of Beans.....	46
CONCLUSIONS.....	50
BIBLIOGRAPHY.....	52

LIST OF TABLES

Table

1	Percent Accumulated Air-filled Porosity for Deep Chiseled Soil.....	31
2	Percent Total Porosity for Various Treatments.....	32
3	Analysis of Variance for Moisture Data.....	36
4	Rainfall for the 1980 Season.....	37
5	Analysis of Variance for Oxygen Diffusion Rates.....	40
6	Root Length of Navy Beans at Each Depth....	42
7	Analysis of Variance for Root Data (Log Transformed).....	43
8	Analysis of Variance for Bean Yield Data..	47
9	Yields of Beans in 1980 Compared to Total Root Length.....	48

LIST OF FIGURES

Figure

1	Location of Samples in Relation to Bean Roots.....	15
2	Pore Distribution vs. Depth of a Deep Chiseled Soil.....	20
3	Pore Distribution vs. Depth of a Conventionally-Tilled Soil.....	21
4	Pore Distribution vs. Depth of a Compacted Soil.....	22
5	Pore Distribution vs. Depth of a Deep Chiseled Soil Under a Tire Track.....	23
6	Pore Distribution vs. Depth of a Conventionally-Tilled Soil Under a Tire Track.....	24
7	Air Porosity at 100 cm Tension for Various Treatments.....	26
8	Pore Distribution for Cultivated, Virgin, and Deep Chiseled Soils.....	28
9	Bulk Density vs. Depth for Various Treatments.....	33
10	Moisture Percent by Volume at Two Depths..	35
11	Oxygen Diffusion Rates vs. Days After Flooding for Various Treatments.....	39
12	Root Density of Profiles.....	45

LITERATURE SEARCH

Yields for navy beans have been reduced due to soil compaction problems. A 1974 survey of 99 navy bean fields revealed that 67 fields had restricted root growth and reduced yields. Yields from conventional tillage plots (4 passes with a tractor over the plots before planting beans) were only a little over half of those with less tillage (Robertson, Erickson, and Christenson, 1976).

Soil compaction is caused by excess traffic with heavy machinery which compacts the soil by vibration and pressure (De Roo, 1968). When the soil is wet, machinery may cause puddling, smearing, and sealing. Monoculture corn on clay soil may also cause compaction because of limited rooting depth (Bolton, 1979).

Compaction often indirectly decreases crop yields. Compacted soil has a high bulk density (Eavis, 1968) which increases mechanical impedance to root penetration. Bulk densities above 1.5 g cm^{-3} limited root penetration which limited the amount of moisture available for the plant (Martin, Cassel and Kamprath, 1979). The main root branched profusely just above the compacted layer (Greacen, Barley, and Farrell, 1968).

Gooderham (1977) found that wet plowing increased the bulk density by 4% to an 8 cm depth and reduced yields of kale and barley.

Compaction decreases air-filled pore space and the proportion of larger pores is reduced (Eavis, 1968). Roots must grow into pores that are at least their size or larger. The soil pores must enlarge with the roots or further root growth will be hindered. Because of smaller pores in compacted soils, roots grow around and between aggregates instead of through them (Greenland, 1978).

Compaction leads to smaller and discontinuous pores which slow water infiltration (Gooderham, 1977). Water-logged soils slow gas diffusion into and out of the soil and oxygen diffusion rates are slowed. Root growth is limited if oxygen levels fall below 10% (Tackett and Pearson, 1964). At low oxygen concentrations, roots tend to grow shorter and broader with lower fresh weights, volumes, and dry weights (Eavis, 1968). Without enough oxygen the plant accumulates ethanol which is injurious to the plant (Fulton and Erickson, 1964). Reduced aeration slows the decomposition of organic matter preventing it from contributing to better soil structure. The accumulated organic matter may inhibit root growth (Bolton, 1971).

Not only is the diffusion of oxygen into the soil slowed, but also the diffusion of ethylene out of the

soil. Ethylene accumulation may inhibit root growth (Gooderham, 1977).

Compaction decreases the total yield of roots and slows root growth. The rate of absorption by the root system depends on the total amount of absorbing roots, on the absorption per unit amount of root, and on the rate of expansion of the root (Eavis, 1968). Because of limited root growth, the roots absorb less nutrients and water. If either is limited, yields will be reduced.

Compaction affects other factors: 1. it may decrease the earthworm population for months (Gooderham, 1977), 2. it inhibits potassium uptake, and 3. it requires more nitrogen fertilizer (Bolton, 1979).

Compaction problems have been corrected by various methods of mechanical modification of the profile or by crop rotation. Some producers using profile modification have reported significant increases in yields. Burnett and Jackett (1968) improved yields both by rototilling two feet deep and by profile modification four feet deep. The soil was a Houston Black clay (Udic Pellistert) - a deep, dense, very slowly permeable montmorillonite clay that benefitted from shattering when the soil was dry. Roots could proliferate and use water more efficiently. Doty and Reicosky (1978) obtained comparable yields with nonirrigated chiseled plots and irrigated nonchiseled plots. The soil was Varina sandy loam with a compact sandy A₂ horizon

starting about 25 or 30 cm below the surface. Profile modification broke up the compact sandy layer which allowed roots to proliferate deeper and moisture to penetrate deeper which alleviated moisture stress. Gooderham (1977) found an increase in barley yields of 14% by hand double-digging which reduced mechanical impedance. Kaddah (1976) reported that yields of wheat were 14% higher for subsoil chiseling one way, 25% higher for subsoil chiseling two ways, 27% higher for slip plowing one way, and 40% higher for slip plowing two ways. The surface layer of the soil was Rositas loamy fine sand overlying Imperial silty clay soil. Breaking up the clay horizon resulted in greater root proliferation. Sandoval (1978) reported an average increase in yield of 46% by deep plowing sodic claypan soils (Natriboroll) of western North Dakota. Deep plowing brought up natural gypsum from below the sodic claypan. Martin et al. (1979) found yields for non-irrigated subsoiled soybeans to be 47% higher than for non-irrigated conventionally-tilled soil. This Atlantic coastal plain soil was a Wargram loamy sand (Arenic Palendulf). The A horizon before deep chiseling was sandy loam to loamy sand. The B horizon was clay loam with a plowpan. Deep chiseling broke up the plowpan and allowed roots to grow deeper.

Deep chiseling lifts and shatters the compacted layer and breaks down stratification (Kaddah, 1976). This reduces bulk density (Gooderham, 1977, Pidgeon and

Soane, 1977, Webster, 1980). Mech et al. (1967) reported that the normal bulk density had been 1.31 g cm^{-3} in the top foot of the profile and 1.63 g cm^{-3} from two to five feet deep. The soil which was plowed and mixed to 48 inches had a bulk density of 1.45 g cm^{-3} throughout. The treatment backhoed to 18 inches had a bulk density of 1.36 g cm^{-3} .

Deep chiseling increases the air-filled pore space. Dug pits increased porosity (Webster, 1980). Diffusion of gases is not hindered and lack of oxygen does not inhibit the plant.

Because of these factors, root yield was increased (Sandoval, 1978). Before deep chiseling, not many roots were found in the B horizon or lower. After deep chiseling there was deeper and greater proliferation of roots (Mech et al., 1967). Tap roots of cotton went deeper (Tompkins, McCutchen, and Buntley, 1979). Roots were more efficient in water and nutrient uptake (Eck and Davis, 1971). Roots from the deep chiseled treatment obtained more water from below 25 cm than did the roots from the conventional treatment (Martin et al., 1979).

Profile modification does not always work. Hand double digging had no effect if done under wet, sticky conditions (Gooderham, 1977). Under-row subsoiling did not significantly alter the yields (Tompkins et al., 1979). The lowest yields from their subsoiled

plots were obtained in a wet growing season.

Root yields were not always increased. Eck and Davis (1971) reported lower total root yields for the deep plowed treatments than for rototilled treatments for sudangrass, sugarbeets, and soybeans. The soil was Pullman clay which has a dense horizon of montmorillonite clay 20 to 60 cm below the surface. The fields were irrigated to maintain stress-free plants. If there was no soil physical stress to overcome, improving soil physical properties would not increase yields. Barber (1971) reported no significant difference for various tillage treatments (conventional, chiseled, rototilled, and no-till) on Raub silt loam for which soil physical properties did not need to be corrected.

The soil must be dry when it is deep chiseled or the results will be poor. Compact soil breaks apart because of tensile failure under compression, but the soil must be dry or this will not work (Gooderham, 1977). Under wet conditions the soil may end up more compacted than it was before. Later traffic (secondary tillage, fertilization, pest control, harvesting, and disposing of residues) may repack the soil (De Roo, 1968).

Bolton (1979) used a crop rotation to correct compaction problems. He had five rotation treatments:

1. corn, oats, alfalfa, alfalfa, 2. corn, oats, alfalfa,
3. corn, oats, seedling alfalfa, 4. corn, oats,

5. continuous corn. The yield for fertilized continuous corn was the same as for unfertilized corn after two years of alfalfa. Treatment 1 had more pore space than the other treatments.

The purpose of the study reported here was to measure various soil physical properties and plant parameters and to correct the determined soil physical properties which limit deeper roots proliferation and associated nutrient and water uptake.

I hypothesize that spring traffic on this soil leads to compaction which hinders root growth. If moisture or nutrients are limiting, decreased root growth will lower yields. Low oxygen diffusion rates might stress the plant resulting in lower yields.

I hypothesize that alfalfa will help dry out the soil so deep chiseling can be beneficial. Alfalfa will contribute organic matter to stabilize the new structure formed by deep chiseling. Recompaction can be reduced by reusing the same tire track. On this soil, deep chiseling will decrease bulk density and increase air porosity allowing roots to proliferate deeper. If moisture or nutrients are limited, increased roots in soil from this treatment will lead to an increase in yields. Lack of oxygen stress will help the plant to approach its potential yield.

The objectives of this study were:

1. To study the effect of compaction on soil

physical properties, root growth, and crop yield.

2. To see if alfalfa and deep chiseling would correct a soil compaction problem by improving soil physical properties and thereby increasing root growth and crop yield.

MATERIAL AND METHODS

Field Description

Field study was done at the Beet and Bean branch experimental station in Saginaw County in Michigan. The soil was Charity clay classified as a fine illitic Calcareous Mesic Aeric Haplaquept. It was naturally a very poorly drained lake-bed soil which had been artificially drained. The crop of interest was navy beans (Phaeolus vulgaris) grown in 1980.

Tillage Treatments

Three treatments were of interest. One treatment grew alfalfa in 1979. This was to add organic matter and to dry out the soil so deep chiseling would be successful. The alfalfa was not harvested but was killed with Roundup prior to deep chiseling which was done in the fall with a single-chisel type subsoiler. The furrows were three feet apart plowed in two directions. The depth of tilling was about 46 cm before chiseling, fluffed up to about 61 cm after chiseling. After this it was fall plowed. To prevent recompaction, the same tire track was reused all season in 1980. The second treatment was corn in 1979. It was conventionally fall plowed. The third treatment also grew

corn in 1979 and was fall plowed. In the spring it was purposely compacted with a tractor.

Soil Physical Properties

Various soil physical properties were studied. Undisturbed soil cores were used to determine pore distributions and bulk densities. Undisturbed soil cores show the pore distribution of the natural soil better, especially for the larger pore sizes important in infiltration. A double cylinder hammer driven core sampler (Jamison, Weaver, and Reed, 1950) was used for getting the samples from the compacted and the conventionally-tilled soil, but it compressed the samples from the deep chiseled profile due to the loose unconsolidated condition. To obtain less disturbed cores from this treatment, thin-sided aluminum soil cores were carefully pushed into the soil. Ten cores were taken at each depth of each treatment. In the deep chiseled profile cores were taken from 0 to 7.6 cm, 15 to 23 cm, 30 to 38 cm, 46 to 53 cm, and 51 to 56 cm. In the conventionally-tilled treatment, cores were taken from 0 to 7.6 cm, 7.6 to 15 cm, and 23 to 30 cm. In the compacted soil, cores were taken from 0 to 7.6 cm, 7.6 to 15 cm, 15 to 23 cm, and 23 to 30 cm. Cores were also taken from tire tracks in the deep chiseled and the conventionally-tilled soil at depths of 0 to 7.6 cm and 7.6 to 15 cm. These were all taken in 1980. In

1981 cores were taken where it had previously been deep chiseled. The cores were taken at depths of 30 to 38 cm and 46 to 53 cm. These were taken to see if the deep chiseling had any residual effect. Cores were taken from the B horizon of virgin soil to see what effect continuous cultivation had on the soil.

The cores were prepared by placing a filter paper and cheesecloth at the bottom secured with a rubber band. After being saturated and weighed, the cores were subjected to increasing tensions. A tension table (Leamer and Shaw, 1941) was used for applying the lower tensions (10 cm, 20 cm, 30 cm, and 40 cm) and pressure cookers and Coors ceramic pressure plates with rubber backs (Richards, 1956) were used for the higher tensions (60 cm, 100 cm, 1/3 bar, and 1 bar). Water between the rubber back and the pressure plate drained to the outside of the pressure cooker. The cores were kept on the tension table or pressure plates until mostly equilibrated (most of the water had drained). Gravi-metric moisture determinations were made at each tension.

The air-filled pore space at each tension was calculated by this equation: (saturated weight of soil-weight of soil at a particular tension)/total volume of soil core. This equation is fairly accurate as long as there is no trapped air in the saturated cores. The cores from the compacted soil and some from the conventionally-tilled profile had trapped air and would not

saturate after being placed in water for several days. They were individually covered with plastic and put in a vacuum desiccator. After the air had been removed from the desiccator, it was replaced with water. This allowed the cores to become better saturated.

A graph was made for each treatment showing percent air-filled pore space at 100 cm tension vs. depth; 100 cm was chosen arbitrarily because there is no distinct point called field capacity.

Three dimensional graphs were made of pore distributions (accumulated percent air-filled pore space vs. log pore radius) at each depth. The pore radius was calculated from the capillary rise equation $h = 2\gamma \cos \alpha / g(P_l - P_g)r$, where h = height of capillary rise, γ = surface tension of the liquid, α = the contact angle, g = acceleration due to gravity, P_l = density of the liquid, P_g = density of the gas, and r = capillary pore radius). This assumes pore size is related to water retained at a tension. Larger pores drain at a lower tension while smaller pores drain only at higher tensions.

Bulk densities were determined from a known volume of soil that had been oven-dried. They were calculated from the equation oven dry weight of soil/volume of soil.

Soil moisture determinations in the field were made with a neutron moisture meter. The probe was placed

at depths of 15 and 30 cm and measured a sphere with a radius of around 15 cm (depending on the moisture content of the soil). The determinations were taken in the 1980 growing season starting in late July. The standard count/active count ratio was used to determine density and percent moisture by volume according to a calibration equation. Analysis of variance was carried out on the data as a split block within a split plot. The whole plot was treatment and the split plots were time and depth. These measurements gave an indication of infiltration and soil water retention.

Oxygen diffusion rates were only measured during the period after a heavy rain that had caused flooding on 7/27/80. At other times there would have been no differences among the treatments. Oxygen diffusion rates were measured with a platinum microelectrode (Lemon and Erickson, 1952) which has a reducing surface similar to a root. Voltage is applied between the microelectrode and a large calomel cell ground glass joint, both pressed into the soil. As oxygen reaches the microelectrode, it is reduced (consumed) so the rate of oxygen diffusing to the microelectrode is measured. Ten subsample readings were taken from four random samples for each treatment at a depth of 10 cm. Analysis of variance as a split plot was carried out on the data with treatment as the whole plot and date as the split plot.

Root Distribution

Root distributions were measured to determine proliferation at different depths. Root samples were collected mechanically in late summer (8/19/80) by the method of Srivastava, Smucker, and McBurney (1981). A cutter-sampler attached to a tractor was used to obtain large undisturbed soil samples measuring 7.6 x 25 x 46 cm. These samples were taken at the edge of a bean plant (Figure 1). The cutter sampler had three parts: an outer frame with the cutting edge, two inner liners, and a driving post. The two inner liners were U-shaped with one fitting within the other to form a rectangular box. The driving post was a modified fence post driver. A hydraulic ram raised the hammer, and a control valve caused it to fall. A soil sample extraction frame attached to the back of a tractor was used to remove the sampler and sample by hydraulic power. The sample was removed from the sampler and divided into eighteen cubes (Figure 1) nine at a time by a fractionator. The cubes each measuring 7.6 x 7.6 x 7.6 cm were placed in labelled freezer boxes.

The cubes were manually broken up and chemically dispersed with sodium hexametaphosphate to prepare them for washing by the hydropneumatic elutriation system. The root washer consisted of nine hydroelute systems. Each unit was made of a polyvinyl chloride drainage



Figure 1. Location of Samples in Relation to Bean Roots

pipe, couplers, and reducers all welded together. Each hydroelute chamber was joined to an elutriation tube. Each transfer tube assembly was welded together consisting of one reducer, two couplers, and one transfer tube. Three sprayer nozzles were attached to the wall of the high kinetic energy washing chamber. The high energy water whirlpool caused the soil to separate from the roots and other organic debris. The soil, roots, and debris were washed up through the transfer tube and over into the primary sieve (840 μ). Roots and other organic debris were retained by the submerged low kinetic energy primary sieve while the soil was washed away. This primary sieve allowed even the smaller roots to be retained. After this, the contents of the primary sieve were washed into the secondary sieve (420 μ). The secondary sieve had to be fine enough to save all the roots. Finally the roots were washed into leakproof freezer bags with formaldehyde to preserve them.

Root length was determined by the method of Tennant (1975) using a grid and counter. Root density (roots per unit area) was determined for each depth by dividing the root length by the volume of the soil sample. Total root length for the plant to a depth of 46 cm was determined by adding the eighteen subsamples for each plant (Figure 1) and multiplying by two. (This of course did not include the total length of the root hairs.)

The plants and rows were spaced so that only 2.5 cm between rows was not considered in this determination. Total root length and density at each depth was determined. Analysis of variance was carried out on log transformed data with treatments as the whole plot and depth as the split plot. The data were transformed to achieve a more homogenous variance.

Yields of Beans

Small representative samples were measured by weight to determine yield in tons/hectare. Yields were measured to see how they were affected by soil physical properties and root distribution. Analysis of variance was carried out on yield data.

RESULTS AND DISCUSSION

Soil Physical Properties

The treatments (alfalfa followed by deep chiseling, conventionally-tilled, and compacted) affected the soil physical properties which consequently affected root growth and crop yield. Porosity was affected as shown in Figures 2 through 6. After the first few inches the deep chiseled profile (Figure 2) had more air-filled pore space through its plow layer than did the conventionally-tilled soil (Figures 3 and 7). This was especially true for the larger pores. These larger pores allowed water to drain faster and helped prevent oxygen stress. Roots had a less tortuous path and larger pores in which to grow and could proliferate at deeper depths.

The compacted soil had a distinct zone of compaction extending down over 20 cm (Figure 4). Even the surface soil did not have much air-filled porosity. A heavy rain caused flooding because water did not drain very fast. This caused low oxygen diffusion rates for several days afterwards. Many cores of the compacted plots and even some of the conventionally-tilled plots had trapped air preventing saturation of cores. This trapped air probably slowed infiltration even more.

Figure 2. Air-filled pore space was determined from undisturbed soil cores collected in 1980 from various depths. After being saturated the cores were subjected to increasing tensions. Moisture content of the cores was measured after equilibration at each tension. Air-filled pore space was calculated from this. The log of the radius of the pores correlates with tension since larger pores drain at lower tensions and smaller pores drain at higher tensions. From this graph accumulated air-filled vs. depth of various pore sizes (or tension levels) can be compared. Also the pore distributions (accumulated air-filled pore space vs. log pore radius) of various depths can be compared.

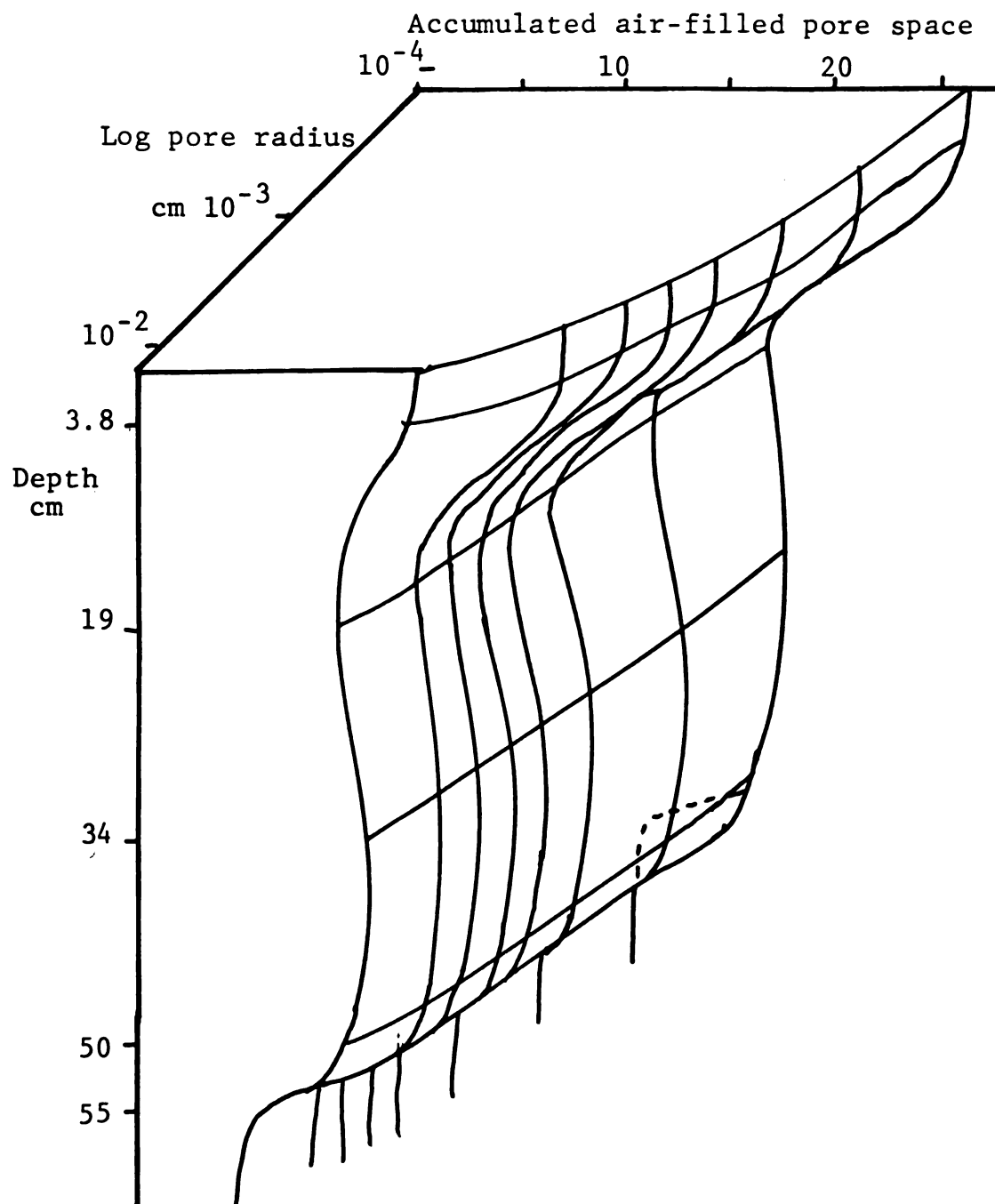


Figure 2. Pore Distribution vs Depth of a Deep Chiseled Soil

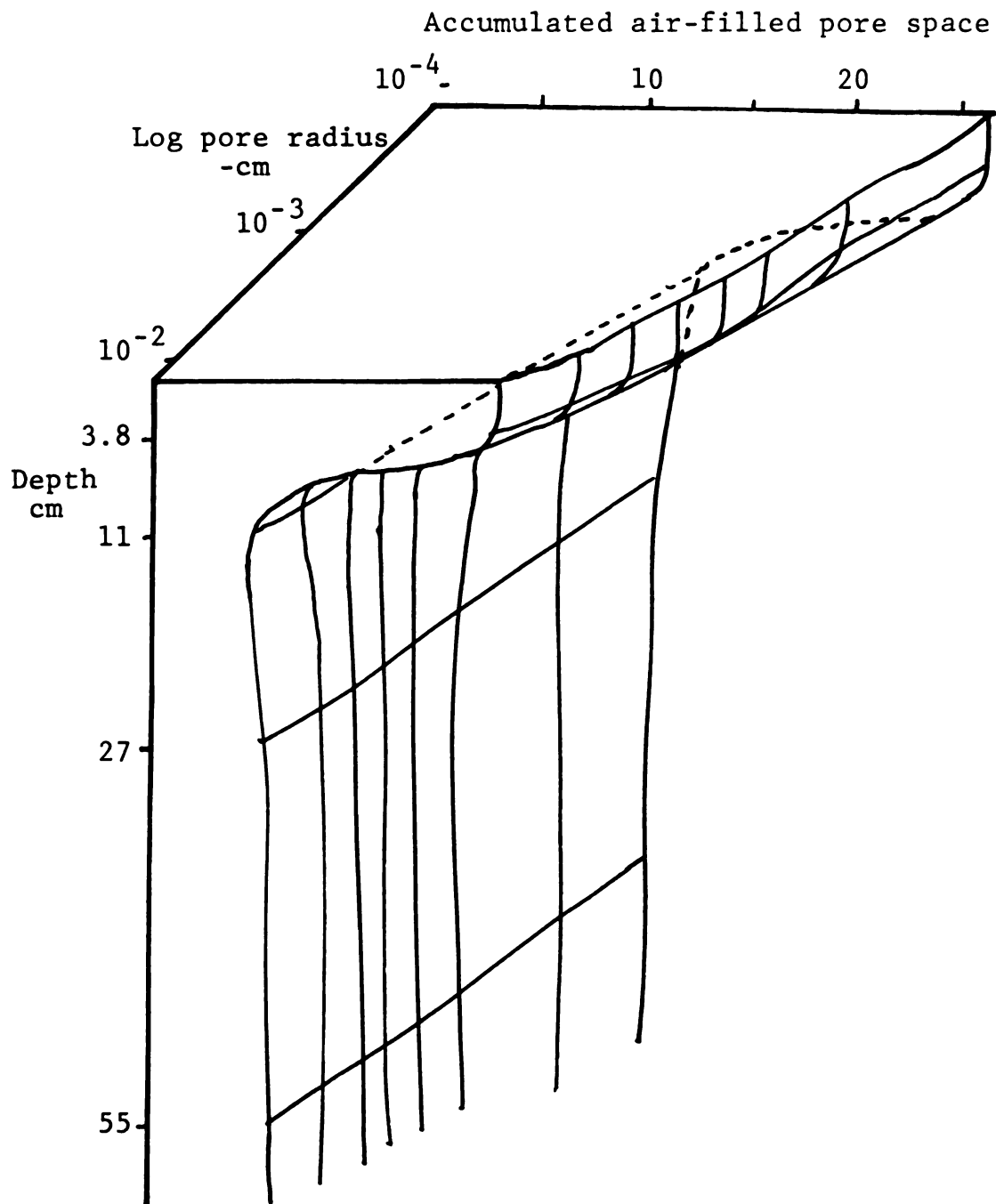


Figure 3. Pore Distribution vs. Depth of Conventionally-Tilled Soil

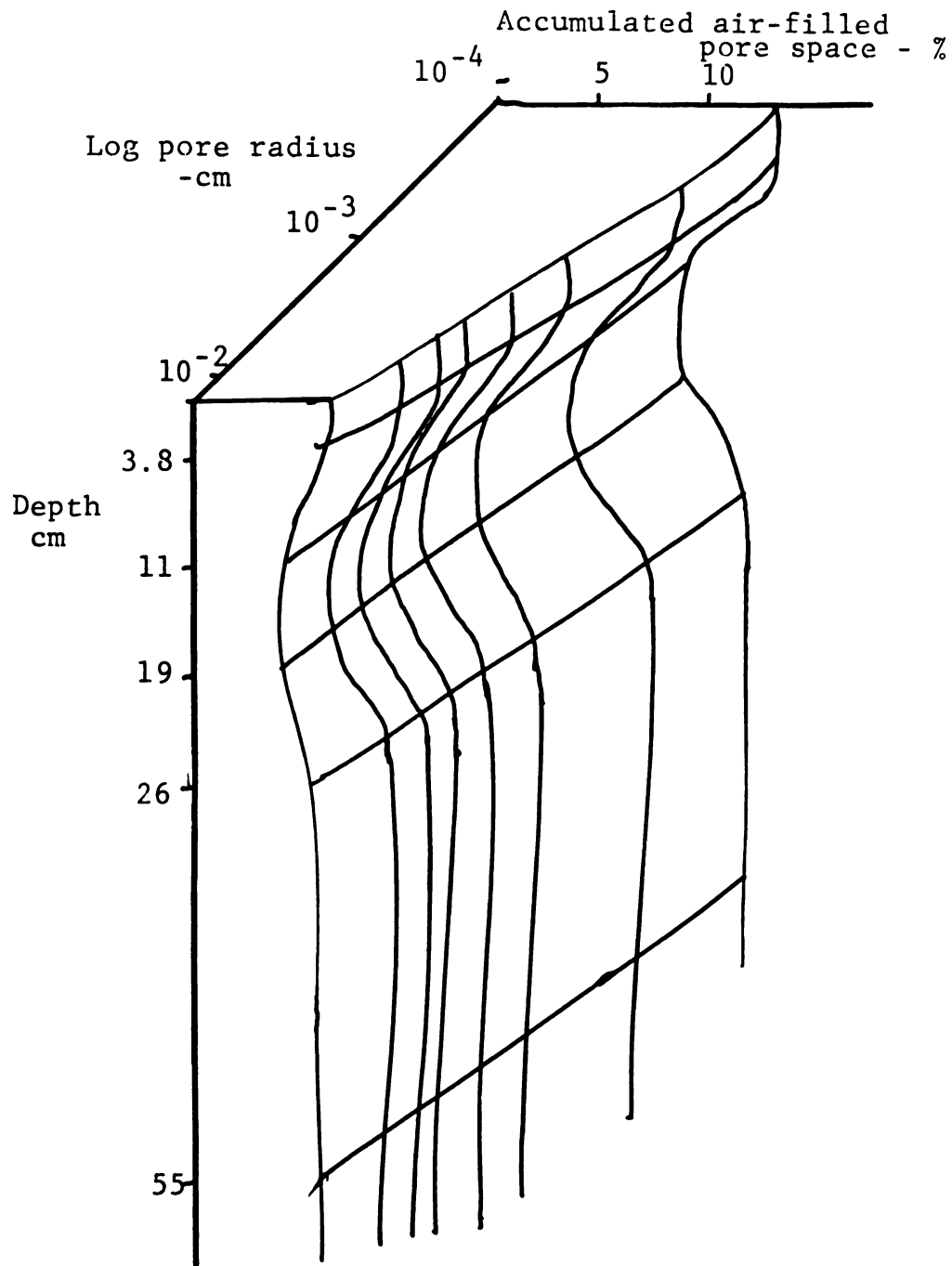


Figure 4. Pore Distribution vs. Depth of Compacted Soil

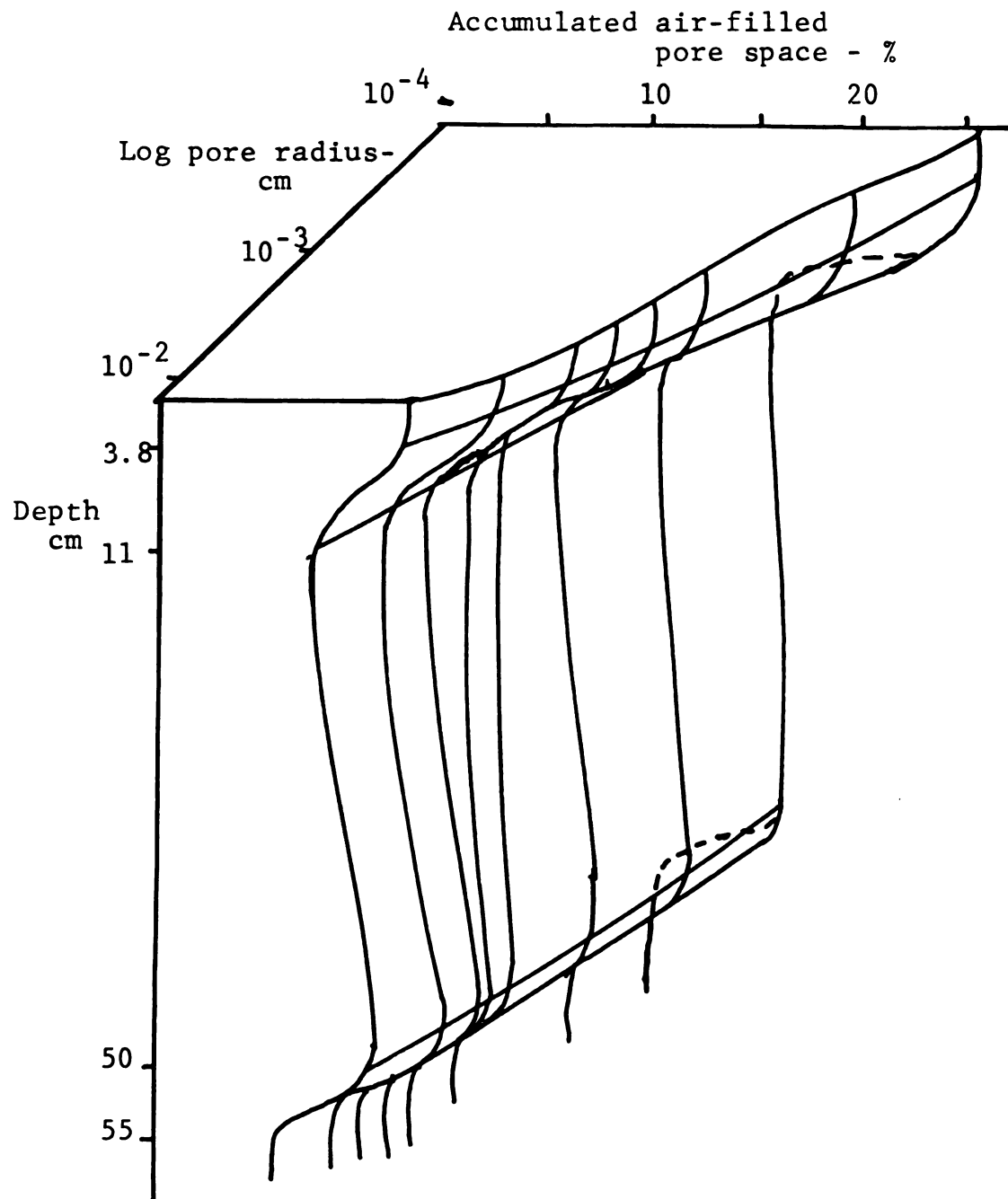


Figure 5. Pore Distribution vs. Depth of Deep Chiseled Soil Under a Tire Track

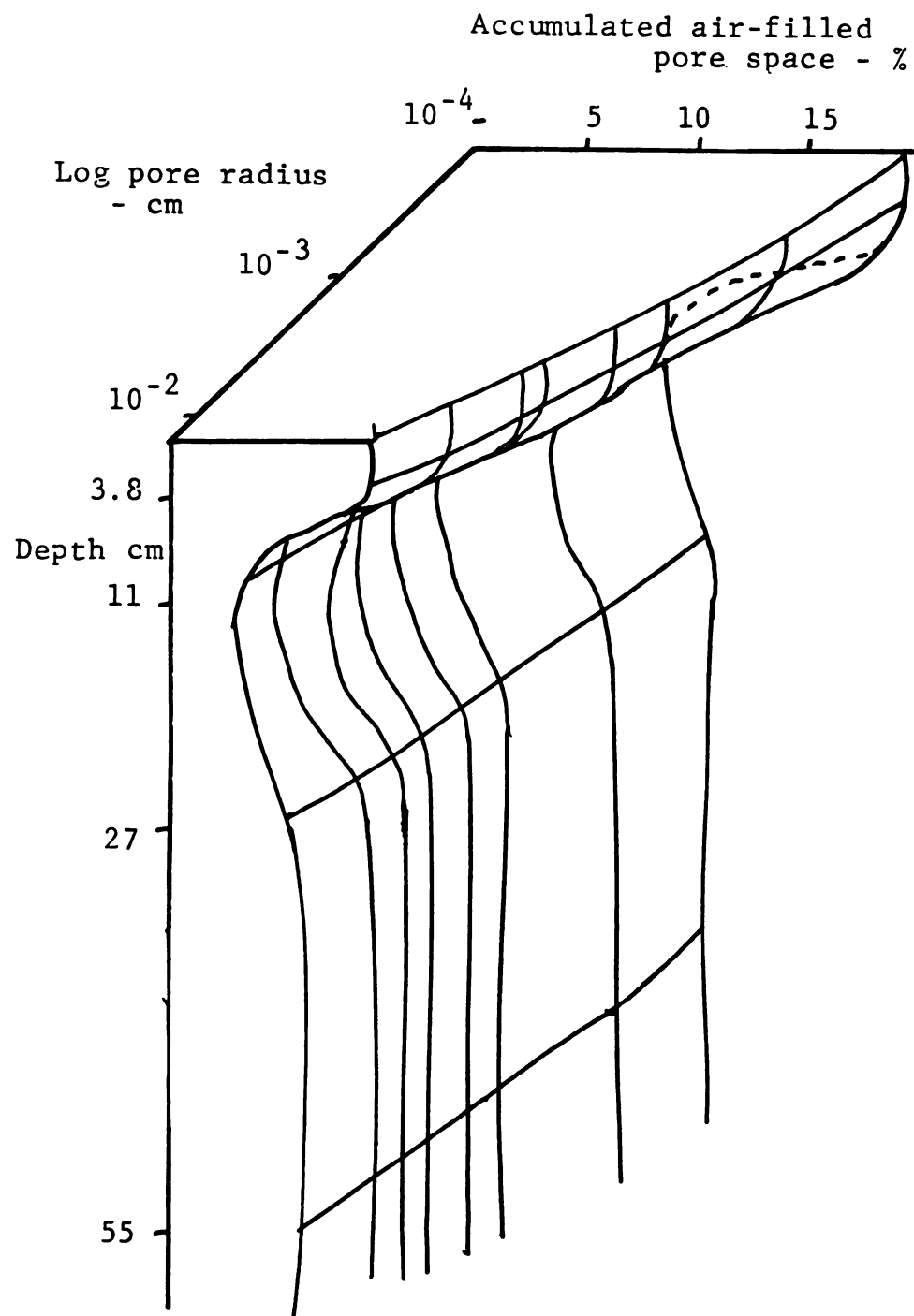


Figure 6. Pore Distribution vs. Depth of a Conventionally-Tilled Soil Under a Tire Track

Figure 7. Air-filled porosity was determined from undisturbed soil cores collected in 1980 from various depths. After being saturated the cores were subjected to increasing tensions and moisture content of the cores were measured after equilibrium at each tension. Air-filled pore space was calculated from this. From this graph the air-filled pore space at 100 cm tension vs. depth of various treatments can be compared.

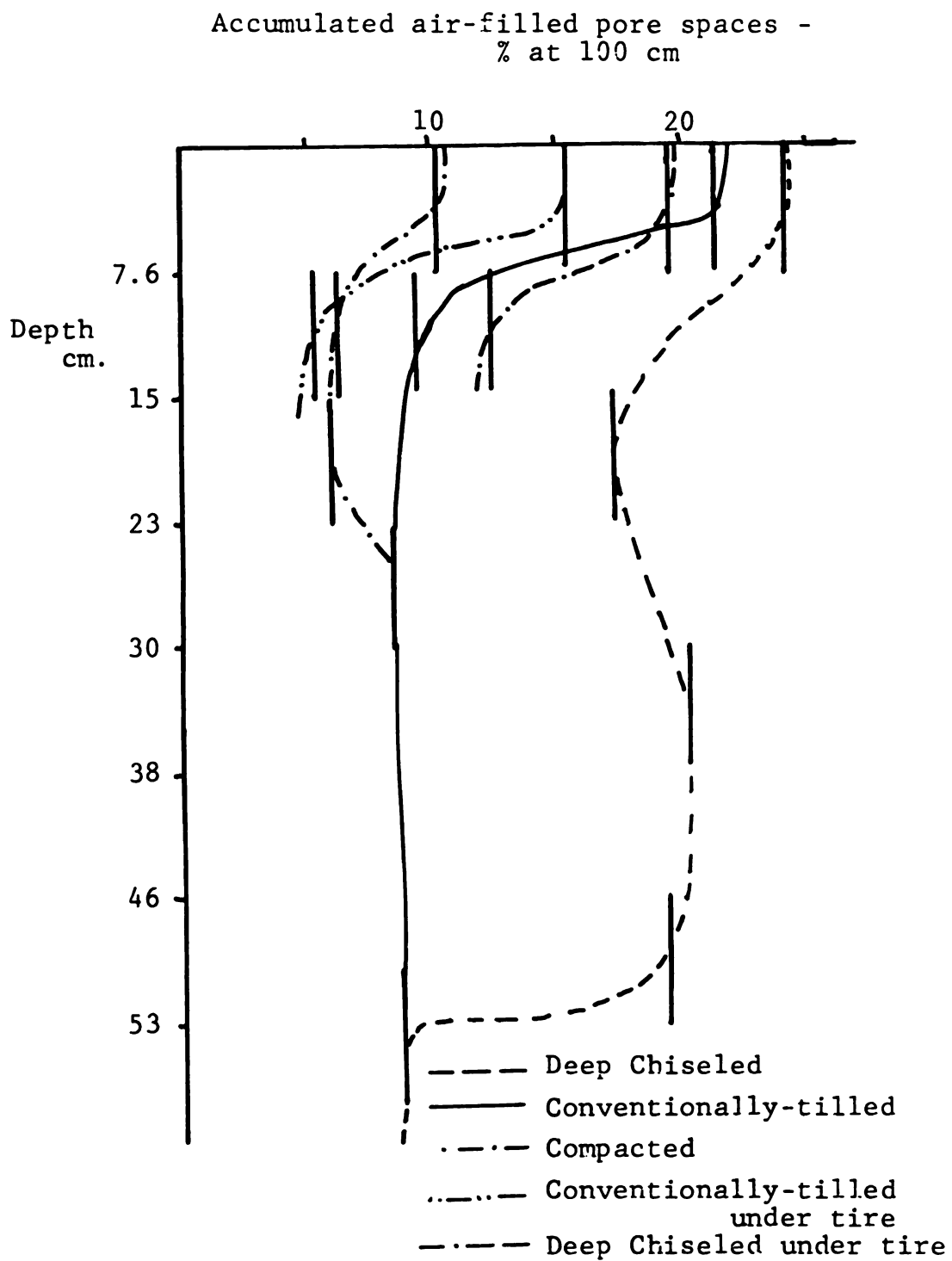


Figure 7. Air Porosity at 100 cm Tension for Various Treatments

Figure 8. Air-filled porosity was determined from undisturbed soil cores collected in 1980 and 81. After being saturated the cores were subjected to increasing tensions and moisture content of the soil cores was measured after equilibration at each tension. Air-filled pore space was calculated from this. The log of the radius of the pores correlates with tension since larger pores drain at lower tensions and smaller pores drain at higher tensions. From this graph, the pore distributions (accumulated air-filled pore space vs. log pore radius) of cultivated, virgin, and deep chiseled soils can be compared.

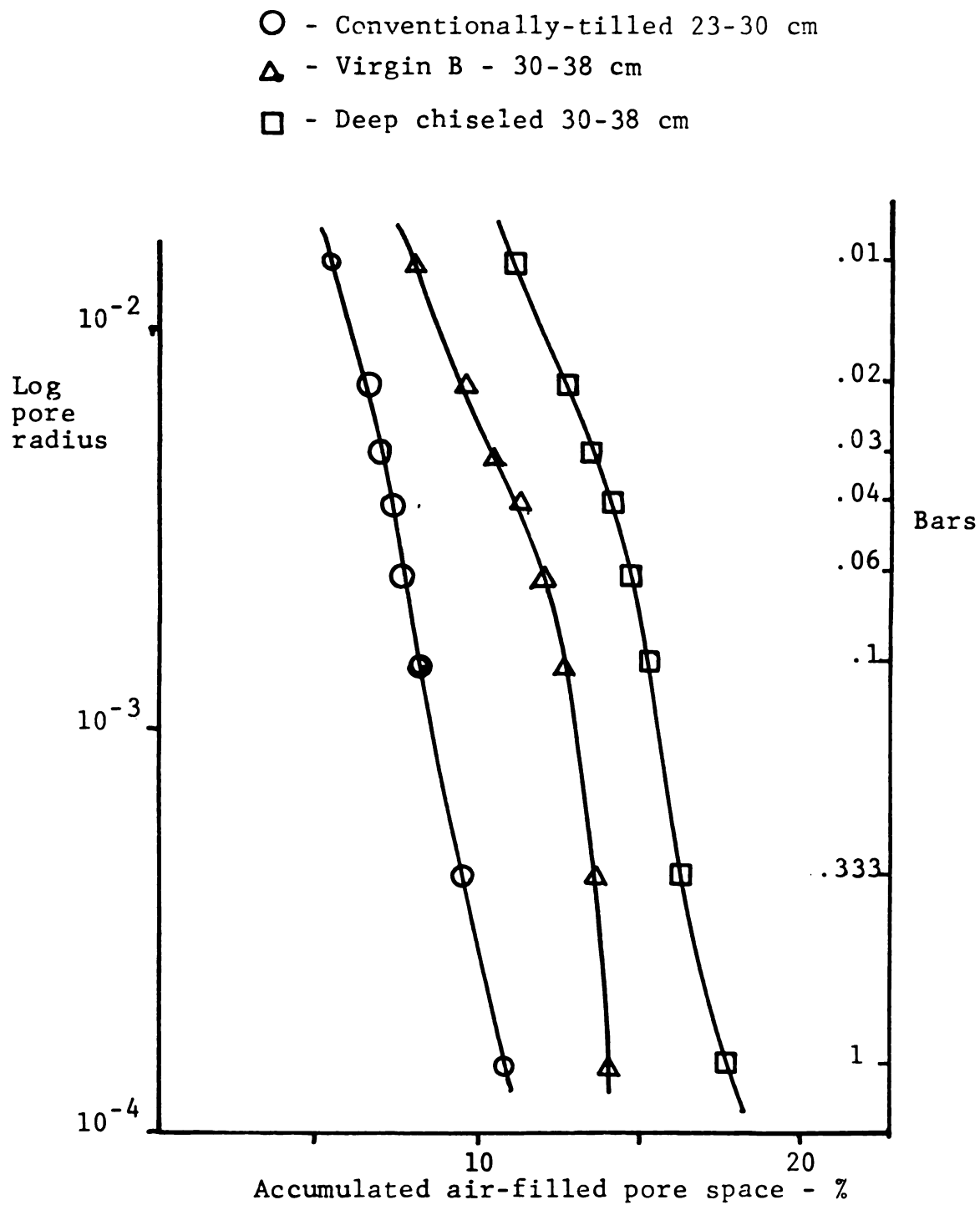


Figure 8. Pore Distributions for Cultivated, Virgin and Deep Chiseled Soils

Soil under a tire track on the deep chiseled plots had fewer large pores and generally more intermediate size pores than did the deep chiseled soil (Figures 5 and 7) which showed how easily deep chiseled soil can be compressed. Also the soil of the conventionally-tilled treatment under a tire track had fewer larger pores and more intermediate-size pores than did the conventionally-tilled (Figures 6 and 7) showing that tractor traffic compacts this soil.

Several of the pore distributions were similar and represented soil that had been cultivated for several years. This included the deep chiseled soil under its plow layer (51 to 56 cm), the conventionally-tilled soil 23 to 30 cm, and the compacted soil 0 to 7.6 cm and 23 to 30 cm (above and below the compacted zone). However, even these representative pore distributions were denser than the B horizon of virgin soil which had more larger-size pore spaces and fewer intermediate-size pores (Figure 8). Deep chiseling increased the air-filled pore space to an even greater volume than was found in the virgin B horizon. The virgin B horizon was redder and less gleyed than the corresponding horizon of cultivated soil, indicating better aeration. It broke easily into smaller peds (2 to 3 cm diameter).

The results of deep chiseling did not continue into the next year because the easily compressed soil had been disturbed (Table 1). It still is not known

whether the benefits of deep chiseling can continue for more than one season if the soil is left undisturbed and is not recompacted by traffic.

Total porosity did not seem to be affected by the treatments (Table 2). The total porosity calculated would not be accurate for the cores that did not saturate well. The soil cores from the deep chiseled area were still compressed some and this may have affected the total porosity.

The treatments did have an effect on bulk densities (Figure 9). The deep chiseled profile had lower bulk densities all the way through its plow layer compared to the conventionally-tilled and compacted treatments. The bulk densities of the conventionally-tilled soil were lower than those of the compacted profile only at the surface. Soil under a tire track of the deep chiseled area had larger bulk densities than the deep chiseled not under a tire track. The bulk densities of the conventionally-tilled soil under a tire track were not increased greatly from those of the conventionally-tilled soil not under a tire track. The bulk density of the virgin B horizon was 1.43 gm/cm^3 which was just as high as that of cultivated soil. High bulk densities in the conventionally-tilled and in the compacted soils might have contributed to decreased root yield.

The treatments affected the moisture content of

Table 1. Percent Accumulated Air-Filled Porosity
for Deep Chiseled Soil

Tension	Pore Size cm	1980 depths			1981 depths		
		30-38 cm	46-53 cm	51-56 cm	30-38 cm	46-53 cm	
10 cm of H ₂ O	1.5×10^{-2}	11.01	10.26	5.80	4.15	4.45	
20 cm	7.4×10^{-3}	12.61	12.10	6.87	5.40	5.80	
30 cm	4.9×10^{-3}	13.36	12.61	7.36	5.89	6.61	
40 cm	3.7×10^{-3}	14.05	13.42	7.76	6.47	7.04	
60 cm	2.5×10^{-3}	14.54	13.88	8.05	6.81	7.36	
100 cm	1.5×10^{-4}	15.32	14.66	8.62	7.53	7.87	
1/3 bar	4.4×10^{-4}	16.15	15.63	10.03	8.74	9.14	
1 bar	1.5×10^{-4}	17.61	16.87	10.92	9.66	10.00	

Table 2. Percent Total Porosity for
Various Treatments

Treatments	0-7.6	7.6-15	15-23	23-30	30-38	46-53	51-56
1980 - Alfalfa, Deep Chiseled	54.1		47.5		52.2	49.7	49.0
1980 - Conventionally-tilled	61.2	51.9		50.9			
1980 - Compacted	53.2	52.6	52.2	53.9			
1980 - Alfalfa, Deep Chiseled under tire track	59.9	49.9					
1980 - Conventionally-tilled under tire track	59.7	52.2					
1981 - Deep Chiseled					48.4	46.4	
Virgin B - 1981					50.5		

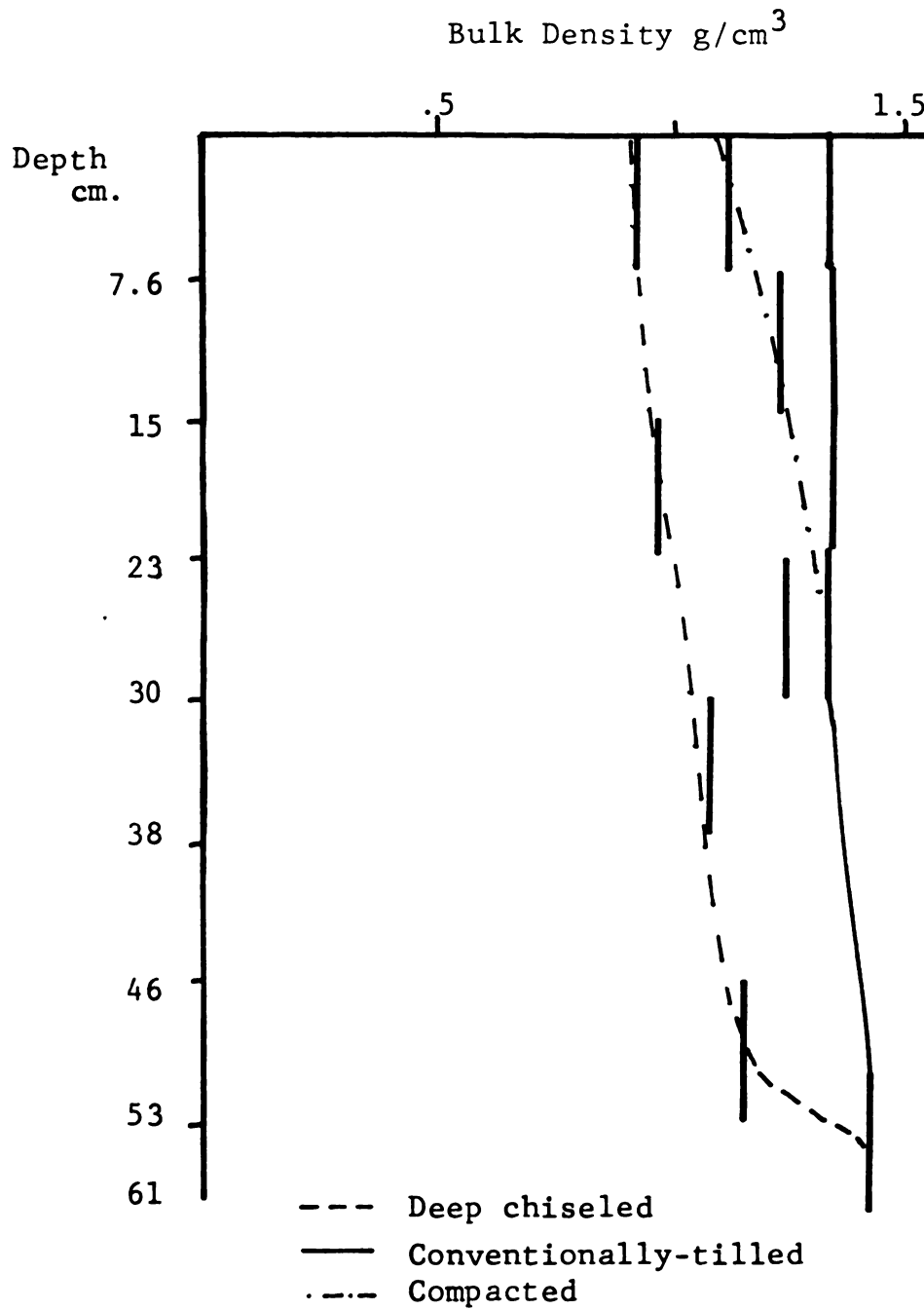


Figure 9. Bulk Density vs. Depth for Various Treatments

Bulk density was determined from undisturbed soil cores collected in 1980 from various depths.

the soil (Figure 10). Analysis of variance showed highly significant differences in moisture content among the treatments (Table 3). Duncan's multiple range test showed highly significant differences between the treatments (Table 3). The deep chiseled treatment was driest and the compacted soil was the wettest. The treatment-time interaction was highly significant indicating that the compacted soil dried the slowest and the deep chiseled soil the fastest. The highly significant treatment-depth interaction showed that the soil in the compacted treatment did not dry out as deep as the soil in the other treatments (Figure 10). More roots at deeper depths helped dry the deep chiseled soil. Starting from the middle of July the season was wet (Table 4), and all the moisture percentages were high. Because of all the rain it was beneficial for crops to have soil that drained quickly. Pore space not occupied by water could be occupied by air.

Larger pores in the deep chiseled profile allowed water to drain faster. Trapped air and smaller pores slowed infiltration in the compacted and in the conventionally-tilled plots. Excess moisture limits air and oxygen diffusion can be greatly slowed. Moisture had been high (7/24/80) right before heavy rains caused flooding on 7/27/80 (Figure 10).

Flooding on conventionally-tilled and compacted plots lowered oxygen diffusion rates (Figure 11). Oxygen

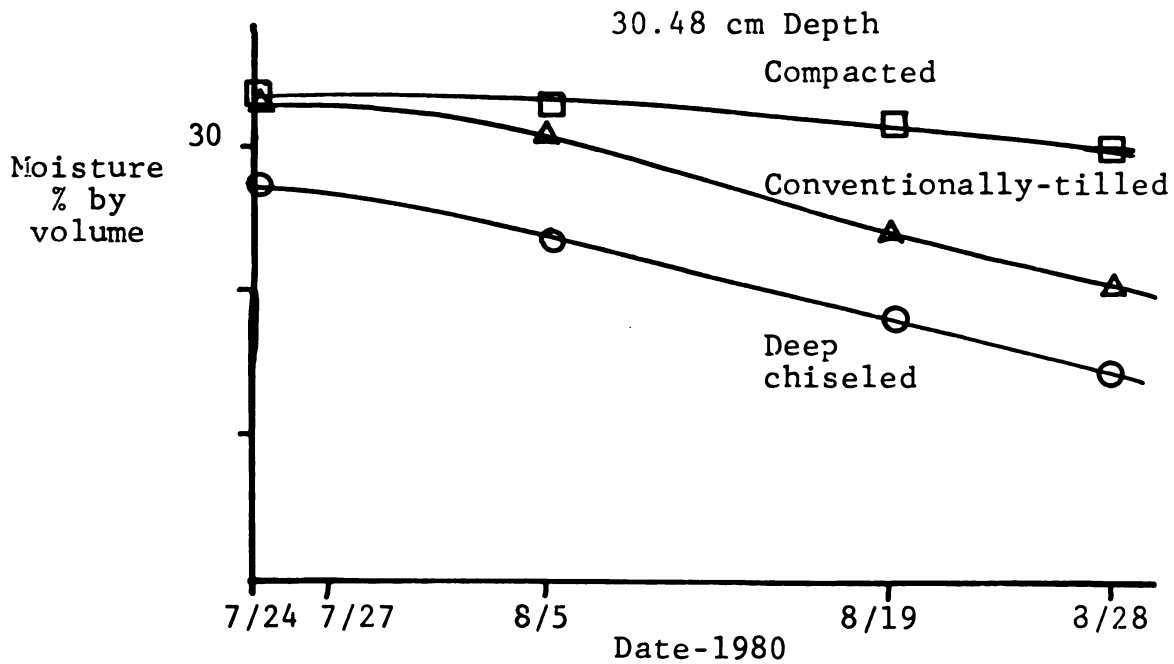
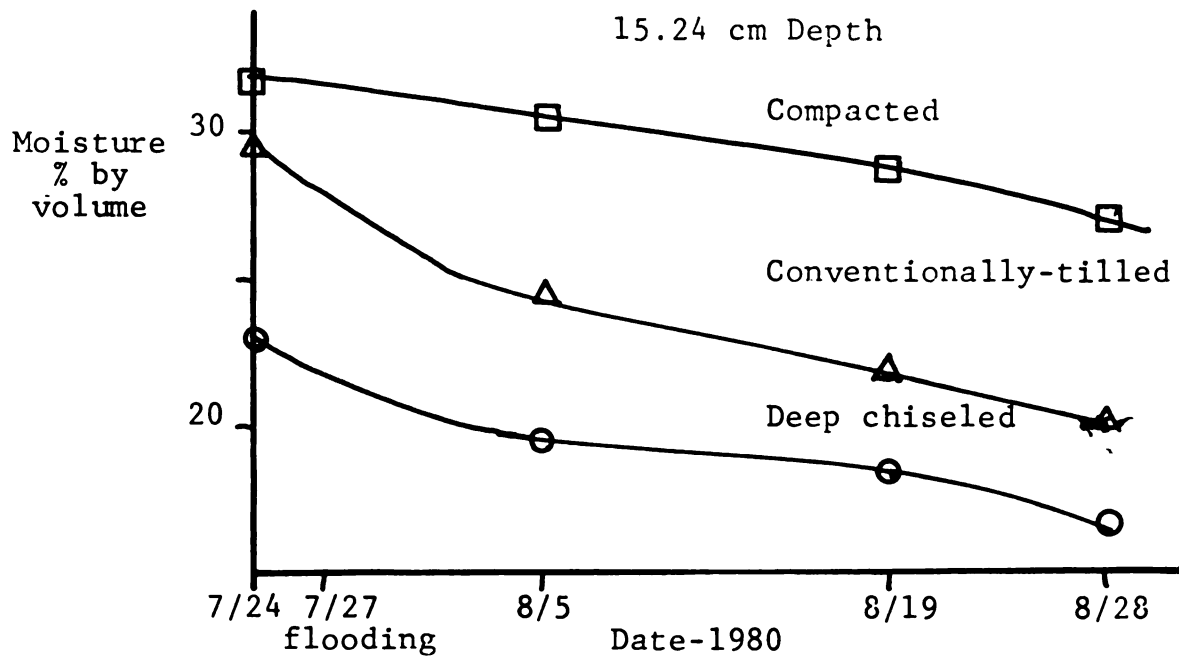


Figure 10. Moisture Percent by Volume at Depths
The moisture percentages were determined with a neutron moisture meter.

Table 3. Analysis of Variance
for Moisture Date

<u>Treatment</u>	<u>*Average - % by Volume</u>	
Compacted	30.23	a
Conventional	26.36	b
Deep Chiseled	22.62	c

*Averages followed by the same letter are significantly different at the 1% probability level according to Duncan's multiple range test.

<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>F</u>
rep	7	7.82	
treatment	2	928	316***
error ^a	14	2.94	
time	3	306	106***
treatment-time	6	21.2	7.38***
error ^b	63	2.88	
depth	1	740	127***
treatment-depth	2	97.6	16.8***
error ^c	21	5.82	
time-depth	3	4.98	1.53n.s.
tmt-time-depth	6	2.89	n.s.
error ^d	63	3.25	

Table 4. Rainfall in Cm for the
1980 Season

<u>Date</u>	<u>Rainfall</u>	<u>Date</u>	<u>Rainfall</u>
May 29	1.57	Aug. 5	.46
30	.46	8	2.26
June 1	.71	10	2.03
6	1.08	11	1.22
7	2.49	20	.84
9	.18	21	.25
14	.13	31	.13
19	1.80	Sept. 1	1.32
26	.97	2	1.52
28	1.80	9	1.52
July 5	.30	12	.20
8	2.62	13	1.22
12	1.04	14	.05
14	.05	15	.03
15	.43	17	2.95
16	.74	20	.08
20	5.61	22	2.39
21	.28	25	.43
22	1.78		
27	3.73		
31	.03		

diffuses about 10^4 times slower through water than through air. Oxygen does not readily diffuse into and through water saturated soil. Analysis of variance showed highly significant differences among the treatments and Duncan's multiple range test showed highly significant differences between treatments (Table 5). Treatment-time interactions were also highly significant. The time required for the soil to return to a safe oxygen diffusion rate ($0.35 \mu\text{g cm}^{-2} \text{ min}^{-1}$) is of primary importance. It took the deep chiseled treatment only two days to return to this level compared to over six days for the compacted soil (Figure 11). Even short periods of oxygen deficiency can damage plants if light intensity is high and oxygen is much in demand (Erickson and Van Doren, 1960). Short periods of oxygen stress can decrease crop yields due to ethanol accumulation (Fulton and Erickson, 1964). In the compacted soil oxygen diffusion rates actually decreased for a short period to an extremely dangerous level (below 0.20 - see Figure 11).

Low oxygen levels were evident in the gleyed soils of the lower horizons of the cultivated soil. The virgin B horizon was much redder (better oxidized).

Root Distribution

These soil physical properties affected root growth and distribution (Table 6). Analysis of variance of log transformed root length showed no significant

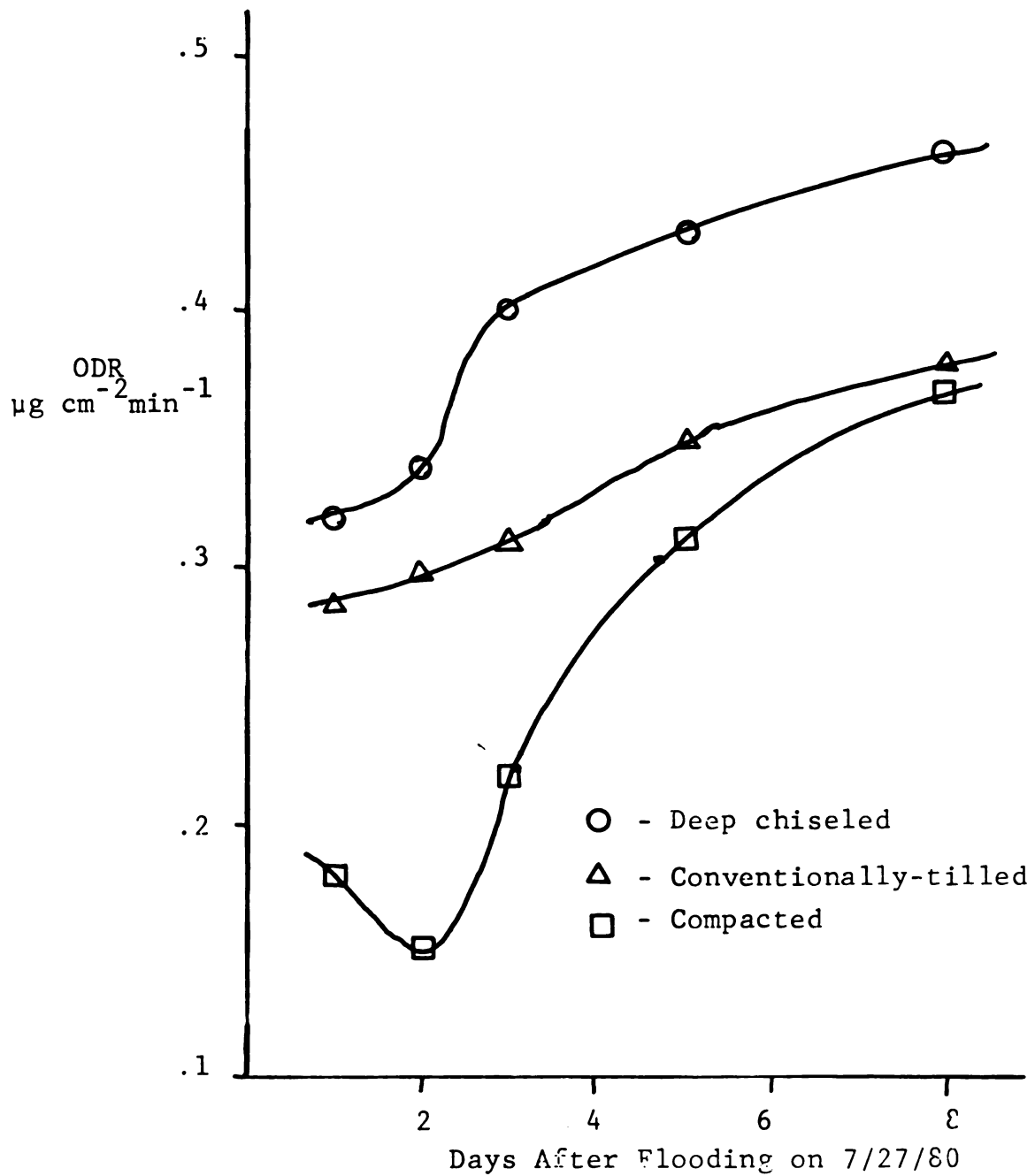


Figure 11. Oxygen Diffusion Rates vs Days After Flooding for Various Treatments

ODR's (oxygen diffusion rates) were measured with a platinum microelectrode (Lemon and Erickson - 1952) at a depth of 10 cm.

Table 5. Analysis of Variance for
Oxygen Diffusion Rates

<u>Treatment</u>	<u>*Average $\mu\text{g cm}^{-2} \text{min}^{-1}$</u>	
Compacted	30.23	a
Conventional	26.36	b
Deep Chiseling	22.61	c

*Averages followed by the same letter are significantly different at the 1% probability level according to Duncan's multiple range test.

<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>F</u>
treatment	2	0.510	107***
error ^a	8	0.00477	
date	11	0.123	30.6***
date-treatment	22	0.0113	3.54***
error ^b	99	0.00318	

difference among treatments (Table 7). This was due to natural variation and to lack of completely homogenous variances even after log transformation. Also in some samples large clumps of undecomposed cornstalks prevented proper analysis of root length. These samples were taken from the bottom of the plow layer in some of the compacted plots and conventionally-tilled plots where compaction had slowed decomposition due to poor aeration. Even though the differences were not significant, the deep chiseled treatment had 16.6% more roots than the conventionally-tilled profile and 64.4% more than the compacted soil. The treatment-depth interaction was very highly significant. The deep chiseled treatment did not have more roots at the surface, but it did have consistently more roots at the deeper depths in the profile (Figure 12). The roots of the conventionally-tilled soil proliferated only in the surface 6 to 10 cm. The roots of the compacted plots were limited. Comparing roots with air porosity (Figures 7, 12), the roots grew where there was more air. In the compacted treatment roots decreased in the compacted layer and below while in the corresponding depths of the deep chiseled profile, the roots proliferated.

In the conventionally-tilled treatment reps 3, 4, 5, and 6 appeared root bound (Table 6). In the compacted treatment rep 5 seemed root bound and reps 2 and 3 had very limited root growth.

Table 6. Root Length of Navy Beans at Each Depth

Depth	Rep 1	2	3	4	5	6	7	8
	Root Length - cm/442.5 cm ³							
	Alfalfa - Subsoiled							
0 - 7.6 cm	5680	2620	3170	3360	4060	2460	3250	4860
7.6-15.2	3970	2150	4850	6150	3170	1580	4310	3540
15.2-22.9	4850	3050	3560	4910	2620	1540	3870	2510
22.9-30.5	3480	2900	2650	2520	2210	1420	2220	2970
30.5-38.1	1930	1570	1960	1910	1680	800	1260	1840
38.1-45.7	1490	950	1290	1410	840	1020	1040	1320
	Conventional							
0 - 7.6 cm	4720	4560	3820	5540	5260	6860	4160	4230
7.6-15.2	3530	3490	1960	2780	1630	4010	3120	3970
15.2-22.9	3930	3280	1820	1280	872	1410	2400	3460
22.9-30.5	2640	1450	430	933	312	646	3280	3290
30.5-38.1	1480	1150	471	585	267	797	2520	2950
38.1-45.7	845	742	521	454	112	228	434	1640
	Compacted							
0 - 7.6 cm	3570	2590	1440	3580	1580	3270	4180	7380
7.6-15.2	2750	1270	544	118	1440	1290	1620	4730
15.2-22.9	2170	1430	139	125	1600	846	1580	4910
22.9-30.5	1100	562	83	73	728	756	1480	3870
30.5-38.1	1066	726	134	39	497	974	1840	2160
38.1-45.7	1310	988	80	13	281	1670	2260	1360

Table 7. Analysis of Variance for
Root Data (Log Transformed)

<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>F</u>
rep	7		
treatment	2	2.01	2.07 n.s.
error ^a	12	0.971	
depth	5	0.966	6.52***
depth-treatment	10	0.646	4.36***
error ^b	101	0.148	

Figure 12. Root-soil samples were collected in late summer (8/19/80). The roots were washed by the hydropneumatic elutriation system and root length was measured by an intersection method (Tennant - 1975). Root density is root length divided by the volume of soil in which the roots were contained. This graph compares root density vs. depth for the various treatments.

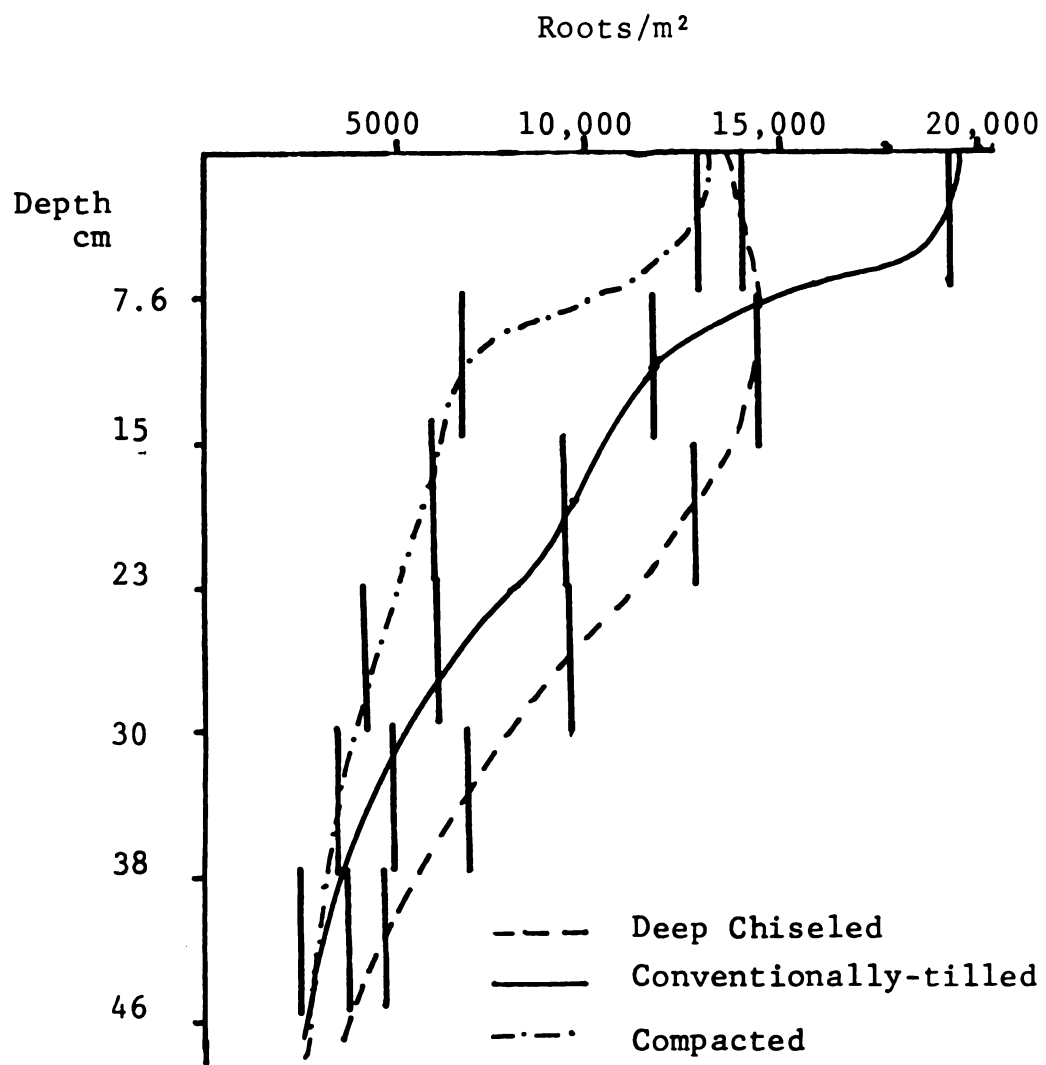


Figure 12. Root Density Profiles

Factors that contributed to poor root growth included low air-filled porosity in the soil, low oxygen diffusion rates after flooding and high bulk densities.

Yield of Beans

Root growth and oxygen stress affected yields of beans. Yields for the deep chiseled treatment were 14.3% higher than for the conventionally-tilled treatment and 100.9% higher than for the compacted treatment. Analysis of variance showed very highly significant differences in yield among the treatments (Table 8). Duncan's multiple range test showed highly significant differences between treatments (Table 8).

Root growth might have affected bean yields. In several reps (2 through 6) of the compacted soil, decreased total root length to 46 cm contributed to decreased yields (Table 9). Limited root growth might have decreased nutrient uptake, lowering yields. Bolton (1979) reported correlations between porosity and nutrient uptake. In some of the deep chiseled plots (reps 1, 3, 4, and 8) increased total root length was associated with an increase in yield.

In other plots (rep 8 of the compacted treatment and rep 4 of the deep chiseled profile) total root length to 46 cm did not seem to correlate well with yield. Root distribution was probably a more important factor

Table 8. Analysis of Variance for
Bean Yield Data

<u>Treatment</u>	<u>*Averages q/ha</u>	
Compacted	12.46	a
Conventional	21.94	b
Deep Chiseled	24.96	c

*Averages followed by the same letter are significantly different at the 1% probability level according to Duncan's multiple range test.

<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>F</u>
rep	7	4.55	
treatment	2	340	779***
error	14	0.437	

Table 9. Yields of Beans in 1980 Compared to Total Root Length

Reps	Yields q/ha			Total Root Length (m)		
	Treatments			Treatments		
	Deep Chiseled	Conventional tilled	Compacted	Deep Chiseled	Conventional tilled	Compacted
1	24.62	19.56	13.73	2120	1710	1190
2	22.83	22.22	14.20	1320	1470	760
3	26.86	18.45	9.01	1750	900	240
4	26.43	21.00	14.30	2030	1160	400
5	24.04	23.28	13.03	1460	840	610
6	22.90	22.03	12.28	880	1400	880
7	25.67	22.47	9.25	1590	1590	1300
8	26.30	26.48	13.85	1700	1950	2440

Reps	Rank					
1	19	10	5	23	19	10
2	15	13	7	12	15	4
3	24	9	1	20	8	1
4	22	11	8	22	9	2
5	18	17	4	14	5	3
6	16	12	3	6.5	13	6.5
7	20	14	2	16.5	16.5	11
8	21	23	6	18	21	24

than total root length to 46 cm.

CONCLUSIONS

Compacted charity clay had less air-filled porosity, higher bulk densities, and lower oxygen diffusion rates for a longer time after flooding than conventionally-tilled and deep chiseled soils. These factors led to decreased root growth especially at deeper depths which limited the absorption of water and nutrients from the lower depths. Thus nutrients and possibly water uptake were limited to the upper soil horizon which stressed the plant and contributed to reduced yields. Small soil pores and trapped air slowed drainage and led to flooding resulting in lower oxygen diffusion rates which stressed the plants and reduced yields.

Deep chiseling this soil increased the air-filled pore space and decreased bulk densities resulting in faster drainage with no indication of flooding and oxygen diffusion rates did not stay low as long. Because of these factors, root growth was not restricted. These bean plants absorbed more water and nutrients from lower depths of the soil than did the plants from the conventionally-tilled and compacted plots. Lack of stress (due to limited oxygen, nutrients, or water) allowed the plants from the deep chiseled plots to approach potential yields.

Charity clay under continuous cultivation was compact compared to virgin soil which had a higher frequency of larger pores. The soil was easily compacted by tractor traffic which reduced air-filled porosity. The deep chiseled soil was very fragile and compressed easily under a tractor track resulting in less air-filled pore space.

Charity clay would benefit from deep chiseling if the soil is dry when deep chiseled. Alfalfa, if established, would help dry out the soil so it could be deep chiseled in the fall. Minimum tillage, controlled traffic and other management considerations for minimizing compaction would be beneficial.

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