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The relation of subsoiling to water runoff, soil moisture, root distribution and corn yield

William C. Moffitt

To the Graduate Council:

I am submitting herewith a thesis written by William C. Moffitt entitled "The relation of subsoiling to water runoff, soil moisture, root distribution and corn yield." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

Horace C. Smith Jr., Major Professor

We have read this thesis and recommend its acceptance:

L. N. Skold, Joe A. Martin

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

May 13, 1961

To the Graduate Council:

I am submitting herewith a thesis written by William C. Moffitt entitled "The Relation of Subsoiling To Water Runoff, Soil Moisture, Root Distribution and Corn Yield." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

Horace C. Smith Jr.
Major Professor

We have read this thesis
and recommend its acceptance:

Lloyd F. Seatz

Joe A. Martin

Accepted for the Council:

H. E. Spivey
Acting Dean of the Graduate School

THE RELATION OF SUBSOILING TO WATER RUNOFF, SOIL MOISTURE, ROOT DISTRIBUTION AND CORN YIELD

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

William C. Moffitt

June 1961

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Professor L. N. Skold, Dr. L. F. Seatz, Dr. W. L. Parks, Dr. O. H. Long, Mr. T. J. Longwell, Mr. J. N. Odom and Dr. Joe A. Martin for their cooperation and helpful suggestions which made the study possible.

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CHAPTER I

INTRODUCTION

The effect of subsoiling has been the subject of much investigation. However, most of the investigations have been concerned with crop yield relationships. In only a few instances have attempts been made to find the reason for yield differences that sometimes have occurred. This experiment was designed to study the effects of subsoiling a particular soil type on water runoff, soil moisture relationships, root distribution and crop yield. By comparing results of the effects of subsoiling some conclusions may be reached that will aid in the evaluation of subsoiling.

CHAPTER II

LITERATURE REVIEW

The literature relating to the effect of subsoiling on crop yield is extensive. In a few instances crop yields seem to be higher as a result of subsoiling, but in general this is not true.

Mooers (10) reported results of subsoiling experiments on Cumberland loam in East Tennessee, Baxter cherty silt loam in the Highland Rim region of Middle Tennessee, and Olivier and Lintonia silt loams in West Tennessee. Results of crop yields on all of the soils studied clearly indicated that subsoiling was not profitable.

Hume (5) presented data relating crop yield to depth of plowing and subsoiling. Experiments were conducted on Williams silt loam using corn, wheat and sweetclover. The following treatments were included for the experiments: moldboard plowing 7 inches deep; moldboard plowing 4 inches deep; moldboard plowing 6 inches deep plus subsoiling; and subsoiling 8 inches deep without plowing. The yield differences between treatments were not significant.

Olmstead (12) conducted a study of tillage practices on a nearly level terrace soil with a moderate claypan. Fall plowing 8 inches deep and fall plowing 8 inches deep followed by subsoiling 8 inches deep in the bottom of the furrow were the treatments used. Results in favorable and unfavorable growing seasons showed that yields were not increased by subsoiling this particular soil type.

From one years' data on the effects of subsoiling on corn yield, Robertson and Fiskell (15) obtained results different from those of Hume (5), Mooers (10) and Olmstead (12). They found a significant increase in the yield of corn from subsoiling Leon silt loam and Ona silt loam. Both of these soils have hardpans near the surface. Woodruff and Smith (25) obtained similar results from subsoiling a poorly drained soil with a claypan.

Kohnke and Bertrand (7), and Schwantes et al. (16) in several subsoiling experiments found that check plots out-yielded subsoiled plots in more than 50% of the trials. Crops grown were corn for grain, corn for silage, wheat, oats, potatoes, barley and rye.

Odom (11) compared the effects of subsoiling and subsoiling and discing with ordinary turning as a means of initial seedbed preparation for corn. The effects on yields of corn, wheat and red clover and on the moisture and organic matter content of the soil were determined. The crops were grown in a three year rotation on each of 3 ranges. Odom found that subsoiling or subsoiling and discing did not significantly increase the yield of corn or the succeeding crops. He also found that subsoiling or subsoiling and discing did not significantly affect the moisture content or the organic matter content of the surface soil or the subsoil at the time of planting of corn or after 2 cycles of rotation of succeeding crops.

The effects of subsoiling other than on crop yields have not been studied extensively. However, Diebold (3) in a study of different tillage practices reported less water runoff, more water intake, and less soil erosion on subsoiled plots than on plots plowed 6 to 8 inches deep.

Smith (17) stated that subsoiling creates more total space for water in the soil, improves internal drainage, and will therefore reduce the volume of water runoff. He stated that subsoiling a soil with a claypan was not successful in most experiments because the operation of the subsoiler gave a shearing rather than a shattering effect.

Fehrenbacher and Snider (4) conducted experiments on corn root penetration on three soils with somewhat different physical features. They found that fertility, bulk density, structure, aeration and moisture were soil properties which affected corn root penetration. Long (8) stated that soil structure is significant in determining the rooting pattern of corn.

Bertrand and Kohnke (1) reported an increase in the rooting depth of corn as a result of subsoiling. They found that a dense subsoil may act as a barrier to corn roots from not only a mechanical standpoint, but also because of a lack of oxygen. Old corn roots did not freely penetrate a silty clay subsoil which had a bulk density of 1.5 g. per cc., but the roots grew freely in a subsoil with a bulk density of 1.2 g. per cc.

Woodruff and Smith (25) stated that the average moisture content of a soil with a claypan, measured to a depth of 18 inches periodically during the growing season of corn was slightly higher in subsoiled plots than in check plots.

CHAPTER III

MATERIALS AND METHODS

Subsoiling Experiment

An experiment conducted on Wolftever clay loam was designed to study the effects of subsoiling on water runoff, soil moisture relationships, root distribution and crop yield. The experiment was laid out in a modified randomized block design with three replications. The treatments were: plots where no subsoiling was done, plots subsoiled on the contour and plots subsoiled up and down the slope. Plot size was 18.2 feet by 110 feet or 0.046 acre.

The subsoiling was done November 20, 1956 when the plots were in a sod of fescue, orchardgrass, alfalfa, and Ladino clover. The subsoiler, Ford model 10-89, was pulled 18 inches deep with an 18 inch span between subsoiled furrows. The surface had 19.4% moisture and the subsoil had 20.2% moisture at the time of subsoiling.

On the eleventh, sixty-fourth, and ninety-fifth day after subsoiling water was applied with an overhead irrigation system at the rate of 0.75 inches per hour. Soil moisture samples from the surface and subsoil were taken before and after water was applied. Water was collected in cans on each plot to determine the amount of water applied. Time was recorded when runoff started and the runoff was collected and measured in 5 gallon cans. The equipment used in catching and measuring runoff was not constructed to accurately measure runoff from all of the rainfall that fell on the treatments while this experiment was being conducted.

The plots were turned with a moldboard plow May 10, 1957, and corn was planted on the contour with a two-row tractor-drawn corn planter. Rows were 42 inches apart and one kernel was planted every 4 to 6 inches in the row. Fertilizer was applied in the row at the rate of 250 pounds of 6-12-12 per acre. The corn was side-dressed with 81 pounds of nitrogen per acre applied as ammonium nitrate on June 27, 1957. Twenty-six days after planting the plots were hand thinned to one plant every 15 inches or 10,000 plants per acre. The plots were cultivated three times during the growing season.

Soil moisture samples were taken from each plot when the plants were 18 to 24 inches tall and at 1 week intervals thereafter until the corn was mature. The procedure consisted of taking three samples (approximately 300 g. per sample) of soil from both the surface (0 to 6 inches) and the subsoil (6 to 18 inches). Samples were dried in an oven at 105 degrees C. and percent moisture calculated.

Evapotranspiration data was computed according to the procedure as described by van Bavel (23). The initial quantity of available soil moisture in the effective rooting zone of corn was measured by taking 3 samples (approximately 300 g. per sample) of soil from both the topsoil and subsoil. The samples were dried in an oven at 105 degrees C. and percent moisture calculated. The quantity of available soil moisture throughout the last seven weeks of the growing season was computed by adding daily precipitation rates and subtracting daily evapotranspiration rates.

Root distribution studies were conducted when the corn was in the late dent stage. Pits were dug in two check plots and in the two adjoining contour subsoiled plots. Soil was taken from an area one-half the distance between rows and one-half the distance between plants on either side of the plant being sampled. The soil was removed in three successive layers of 8, 10, and 10 inches from the measured area. Each layer of soil was placed in a 55 gallon barrel that had been modified so that roots could be floated away from the soil. Separation of roots from the soil was accomplished by the upward action of water forced through an inlet located near the bottom of the barrel. Roots floated to the top and were caught in a removable screen box located beneath a water outlet at the top of the barrel. The roots were cleaned, dried in an oven at 85 degrees C. and weighed on a Torsion balance.

The corn was harvested November 15, 1957. The area harvested from each plot was 0.0053 acre. Acre yields were calculated on the 15.5% moisture shelled corn basis. The percent moisture of the shelled corn was determined with a Steinlite Moisture Meter.

Soil Characterization

In order to determine the variability of the area being studied three pits were dug, spaced diagonally across the experimental area approximately 45 feet apart. The pits were approximately 36 inches deep. Soil profiles were described from the faces of excavations according to the procedure outlined in the U. S. Department of Agriculture Soil Survey Manual (19). Soil profile descriptions are given in Appendix A.

Bulk samples were taken from each horizon. The soil samples were air dried and crushed to pass through a 2 mm. sieve. Soil pH was determined with the Beckman pH meter. Organic matter content was determined by the modified chromate oxidation method of Walkley and Black (23).

Low moisture tensions were determined by the porous plate method as described by Richards (13); the higher moisture tensions were determined with the pressure membrane method also described by Richards (14). Percentage sand and clay were determined by a modification of the pipette method as described by Kilmer and Alexander (6). Sedimentation times for the clay fraction were calculated using the nomograph of Tanner and Jackson (21). The details of laboratory procedures used in this study are given in Appendix B.

CHAPTER IV

RESULTS AND DISCUSSION

Soil Characterization

Results of particle size distribution given in table 1 and table 10 show that the soil studied has more clay in the A_p, B_{21} and B_{22} horizons than was estimated in the field examination. According to the results of the mechanical analysis, the textural classes for the soil horizons are: A_p-clay loam, B_{21}-clay, B_{22}-clay, B_{31}-clay loam, and C-clay loam. There was little variation in the textures of the three sites studied.

At the beginning of this experiment this soil was thought to have a claypan. Data in table 1 show that the B horizon did not have the required amount of increase in clay content for a claypan soil (20).

The organic matter content and pH of the soil horizons are given in tables 1 and 10. The percent organic matter decreased with soil depth from 2.4 in the A_p horizon, to 0.5 in the B_{21}, and to 0.2 in the C horizon. Soil pH values changed slightly throughout the soil profile. The three upper horizons had higher pH values than the lower two horizons. In general, the reaction of the horizons was very strongly acid (4.2-5.5).

Table 2 shows the bulk density of the different horizons of the soil studied. The bulk density was about the same throughout the soil profile. Very compact subsoils regardless of texture may have bulk

Table 1.--Particle size distribution and organic matter.*

Horizon	Depth	Sand 2.0-0.05mm.	Silt 0.05-0.002mm.	Clay -0.002mm.	Organic matter
	Inches	%	%	%	%
Ap	0-7	28.0	43.4	28.6	2.4
B_{21}	7-16	22.4	31.8	45.8	0.5
B_{22}	16-23	26.4	33.7	40.5	0.4
B_3	23-30	33.1	32.7	34.6	0.2
C	30 +	39.1	30.7	27.8	0.2

* Average of 3 sites.

Table 2.—pH, bulk density and moisture at 1/3 and 15 atmospheres tension.*

Horizon	Depth	pH	Bulk density	Water 1/3 atmosphere	Water 15 atmospheres
	Inches		g./cc.	%	%
Ap	0-7	5.0	1.5	22.0	11.3
B_{21}	7-16	5.3	1.5	27.8	17.7
B_{22}	16-23	5.2	1.5	26.7	16.0
B_3	23-30	4.5	1.5	27.5	15.0
C	30 +	4.3	1.5	26.8	13.8

* Average of 3 sites.

densities in the neighborhood of 2.0 (7). The bulk densities of 1.5 throughout the horizons indicate that this was not a compact soil.

The percent water held at 1/3 atmosphere (approximate field capacity) and 15 atmospheres (approximate permanent wilting percentage) is shown in tables 3 and 11. An examination of these data indicates that the water holding capacity of this soil varies with the content of clay. At 1/3 atmosphere tension the moisture content averaged 22.0% in the A_p horizon. The B horizon average was approximately 27.0% and the C horizon was 26.8% moisture. At 15 atmospheres tension the A_p average was 11.3%, the B horizons around 16.0%, and C horizon 13.8% moisture.

Results of percolation and permeability determinations are shown in tables 3 and 11. Water movement through this soil is relatively unrestricted except for the cores sampled in the B_{21}, B_3, and C horizons of site number 1 (table 11). These results show a wide variation in the percolation and permeability of the different plots on which this experiment was conducted. However, several samples are required before any definite trend can be established regarding percolation and permeability rates of a particular soil (9).

Water Runoff

The average amount of water applied and runoff of water from subsoiled and unsubsoiled plots is given in table 4. The amount of water applied to treatments varied, but the difference was not significant. The soil moisture before the first irrigation was low and the percent of applied water that ran off was almost negligible.

Table 3.--Percolation, permeability, porosity and moisture at pF 1.7.*

Horizon	Depth of cores	Percolation rates	Permeability index	Water drained pF 1.7 15 min.	30 min.	15 hrs.	Moisture pF 1.7
	Inches	In./Hr.		ml./100 g.			Wt. %
Ap	1-4	10.6	7 (very rapid)	6.9	7.6	10.8	24.6
B_{21}	8-11	5.9	6 (rapid)	6.8	7.7	10.2	26.7
B_{22}	16-23	9.1	6 (rapid)	7.9	8.7	10.5	27.4
B_3	24-28	7.1	6 (rapid)	7.3	8.4	10.2	26.2
C	34-37	5.9	6 (rapid)	6.9	7.8	10.3	26.3

* Average of 6 cores at 3 sites.

Table 4.--Application and runoff of water from subsoiled and unsubsoiled plots.

Treatment	First irrigation	Second irrigation	Third irrigation	
	Water applied, inches			
Not subsoiled	3.3	2.8	3.7	
Subsoiled on contour	3.0	2.3	2.4	
Subsoiled up and down slope	3.4	2.9	3.2	
L.S.D. at 0.05	N.S.	N.S.	N.S.	
	Runoff, percent water applied			
Not subsoiled	0.2	14.3	23.3	~~12.6~~/3
Subsoiled on contour	0.2	12.2	17.5	10.0
Subsoiled up and down slope	0.2	13.1	21.2	11.5
L.S.D. at 0.05		2.1	1.4	

Statistical analysis of the data was not computed because runoff did not occur on all of the plots during the first irrigation.

The treatment of no subsoiling had a significantly higher percent of applied water runoff during the second and third irrigations than the treatment of contour subsoiling. The treatment of no subsoiling had a small but significantly higher percent of applied water runoff during the third irrigation then the treatment of subsoiling up and down slope. It was noted that the runoff was slower on contour subsoiled areas than on the other two areas. The runoff was also slower on plots subsoiled up and down slope than on plots not subsoiled. The slowing down of the water runoff allowed more time for water infiltration on subsoiled areas and accounts for the difference in runoff.

Field observations showed that after approximately 13 inches of water fell on the subsoiled area, the channel left by the subsoiler was almost completely filled with soil particles. This probably explains why there was not a greater difference in runoff on the three treatments studied.

Moisture Relationships

There was a direct relationship between the amount of runoff (table 4) and the moisture content of the surface and subsoil (table 5) both before and after irrigations. The average moisture content of the surface increased 14.5% and the average moisture content of the subsoil increased 6.0% during the first irrigation when there

Table 5.--Moisture content of soil before and after irrigations.

Treatment	Moisture					
	First irrigation		Second irrigation		Third irrigation	
	before	after	before	after	before	after
	%	%	%	%	%	%
			Surface Soil			
Not subsoiled	17.7	33.3	20.7	28.9	18.3	22.7
Subsoiled on contour	19.3	33.4	24.5	31.5	19.8	21.5
Subsoiled up and down slope	18.3	31.9	22.9	28.6	20.6	28.4
LSD at 0.05	N.S.	N.S.	1.9	N.S.	1.3	3.6
			Subsoil			
Not subsoiled	21.0	26.2	23.1	30.7	22.3	24.8
Subsoiled on contour	21.7	28.2	25.6	32.9	21.3	26.4
Subsoiled up and down slope	20.8	27.7	20.8	27.1	22.2	26.0
LSD at 0.05	N.S.	N.S.	4.6	1.8	N.S.	N.S.

was almost no runoff from a range of 3.0 to 3.4 inches of applied water. The average moisture content of the surface increased from a range of 4.6% to 7.0% and the average moisture content of the subsoil increased from a range of 4.6% to 7.0% during the second and third irrigations when there was a range of 12.2% to 23.0% runoff from a range of 2.3 to 3.7 inches of applied water.

No significant differences occurred between treatments or horizons before and after the first irrigation.

Before the second irrigation the moisture content of the surface was significantly higher on contour subsoiled plots than on plots subsoiled up and down slope or on plots not subsoiled (table 5). Also, before the second irrigation the moisture content of the surface was significantly higher on plots subsoiled up and down slope than on plots not subsoiled (table 5). Before the second irrigation the moisture content of the subsoil was significantly higher on plots subsoiled on the contour than on plots subsoiled up and down slope (table 5).

After the second irrigation the moisture content of the subsoil was significantly higher on contour subsoiled plots than on plots subsoiled up and down slope or on plots not subsoiled. Also, after the second irrigation the moisture content of the subsoil was significantly lower on plots subsoiled up and down slope than on plots not subsoiled.

Before the third irrigation the moisture content of the surface was significantly higher on plots subsoiled on the contour and plots subsoiled up and down slope than on plots not subsoiled. After the third irrigation the moisture content of the surface was significantly higher on plots subsoiled up and down slope than on plots subsoiled on the contour or on plots not subsoiled.

In most cases these results indicate that the moisture content of the surface soil before and after irrigations was higher on subsoiled plots than on plots not subsoiled. The significant differences between treatments that occurred in the moisture content of the subsoil was before and after the second irrigation. Since these differences occurred only during the second irrigation, no definite conclusions could be drawn.

Average moisture content of surface soils and subsoils during the last seven weeks of the growing season are presented in tables 6 and 7. Table 6 shows the direct measurements calculated after taking a soil sample from the field to the laboratory. These measurements showed that there was only one critical period for the growing crop. This was a brief interval during the open tassel-early dent stage when the soil moisture was close to the permanent wilting percentage in the surface and subsoil.

There was only one time during this period when a significant difference in the soil moisture content occurred. This was in the surface when the stage of corn growth was shoulder high. The moisture content of the surface was significantly higher on treatments of subsoiling up and down slope and no subsoiling than on the treatment of contour

Table 6.--Moisture content of surface and subsoil at various stages in growth of corn.

Treatment	Moisture, Stage of corn: 30 In. high	Waist high	Shoulder high	Tassel emerging	Tassel open	Early dent	Late dent
			Topsoil				
Not subsoiled	15.2	19.2	17.8	13.3	13.0	13.0	16.7
Subsoiled on contour	17.9	21.1	15.0	15.0	14.0	14.8	16.4
Subsoiled up and down slope	16.4	20.9	17.7	13.7	13.7	12.3	15.6
LSD at 0.05	N.S.	N.S.	1.9	N.S.	N.S.	N.S.	N.S.
			Subsoil				
Not subsoiled	21.1	23.0	20.7	20.6	19.1	18.2	18.7
Subsoiled on contour	21.6	23.2	19.9	20.4	18.6	20.8	21.4
Subsoiled up and down slope	22.2	23.0	21.6	19.2	18.1	19.4	20.0
LSD at 0.05	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

subsoiling. Table 6 shows that from the time the corn was waist high until it was shoulder high there was an average of 6.1% moisture loss on contour subsoiled treatments compared to 3.2% loss on the treatment of subsoiling up and down slope and 1.4% loss on the treatment of no subsoiling. For an unexplainable reason, or reasons, there seems to have been a higher evapotranspiration rate on contour subsoiled treatments during the shoulder high stage of corn growth. Generally speaking, an insolated case such as this has little meaning statistically.

Available soil moisture using available climatological data is shown in table 7. Data collected using this method show that there was available moisture throughout the last seven weeks of the growing season. Results using this method are similar to results obtained by direct moisture readings from soil samples taken throughout the last seven weeks of the growing season.

Root Distribution

The percent total roots and calculated root weights on an acre basis are presented in table 8. The total weight of dry roots per acre on the four plots sampled ranged from 643 pounds to 1,372 pounds.

Plots number 2 and 9 which had been subsoiled had similar percentages of roots in the 0-10 inch and 10-18 inch layers. Plot number 2 had 82.4% of the total amount of roots in the 0-10 inch layer and 8.6% of the total amount of roots in the 10-18 inch layer. Plot number 9 had 89.6% of the total amount of roots in the 0-10 inch layer and 9.5% of the total amount of roots in the 10-18 inch layer.

Table 7.--Available moisture in soil computed from climatological data.

Date	Corn growth stage	Evapotranspiration	Precipitation	Amount of available soil moisture in root zone (28 inches)
		Inches	Inches	Inches
		Amount from previous month 2.80		
July				
11-17	30 Inches high	1.05	1.72	3.47
18-24	Waist high	1.05	0.58	3.00
25-31	Shoulder high	1.05	0.03	1.98
August				
1-7	Tassels emerging	.91	1.13	2.20
8-14	Tassels open	.91	0.00	1.29
15-21	Early dent	.91	1.51	1.89
22-30	Late dent	.91	.37	1.35

Table 8.--Weight and distribution of roots at different depths on selected plots receiving different treatments.

	Subsoiled				Not subsoiled			
	Plot 2		Plot 9		Plot 3		Plot 8	
Depth	Weight, lbs.	Percent	Weight, lbs.	Percent	Weight, lbs.	Percent	Weight, lbs.	Percent
0-10"	1130	82.4	992	89.6	469	73.0	1014	86.1
10-18"	119	8.6	104	9.5	102	15.8	136	11.5
18-28"	123	9.0	10	0.9	72	11.2	27	2.4
Total Weight	1372	100.0	1106	100.0	643	100.0	1177	100.0

In the 18-28 inch layer of plot number 2 had 9.0% of the total as compared to 0.9% in the 18-28 inch layer of plot number 9.

Plots number 3 and 8 which had not been subsoiled also had similar root percentages in the first two layers. Plot number 3 had 73.0% of the total amount of roots in the 0-10 inch layer and 15.8% in the 10-18 inch layer. Plot number 8 had 86.1% in the 0-10 inch layer and 11.5% in the 10-18 inch layer. In the 18-28 inch layer plot number 3 had 11.2% as compared to 2.4% found in plot number 8.

Subsoiled treatments compared to treatments not subsoiled show no wide variation in the percent of the total amount of roots found in 0-10, 10-18 inch layer. However, there is a variation in the percent of the total amount of roots in the 18-28 inch layers of the sites sampled. Since adjoining samples had approximately the same root percentages, this variation is probably due to the range in permeability in the subsoil where the experiment was conducted.

In plot number 2 which was subsoiled there was 1,130 pounds of roots per acre in the 0-10 inch layer as compared to 469 pounds per acre in the 0-10 inch layer of plot number 3 which was not subsoiled. In the 10-18 inch layer plot number 2 had 119 pounds per acre as compared to 102 pounds per acre in plot number three. Comparing plot number 2 with plot number 3 there was considerably more roots in the subsoiled treatment.

Plot number 9 (subsoiled) compared to plot number 8 (not subsoiled) shows no wide variation in total amount of roots per acre in the 0-10 inch layer and the 10-18 inch layer. However, in the

18-28 inch layer of plot number 9 there was 10 pounds per acre as compared to 27 pounds per acre in plot number 8. Several samples would be required before any definite conclusions could be drawn regarding root distribution.

Yield

Corn yield data are summarized in table 9. These data were subjected to statistical procedures outlined by Cochran and Cox (2) and Snedecor (18).

Plots subsoiled up and down slope averaged 64.5 bushels per acre, plots subsoiled on contour averaged 62.7 bushels per acre and plots not subsoiled averaged 59.8 bushels per acre. Subsoiling did not significantly affect yields. The lack of response of corn yield to subsoiling in this experiment is similar to the conclusion made in a previous study by J. N. Odom (11).

Table 9.--Corn yields as influenced by subsoiling.

Treatment	Bu./Acre
Not subsoiled	59.8
Subsoiled on contour	62.7
Subsoiled up and down slope	64.5
LSD 0.05	N.S.

CHAPTER V

SUMMARY AND CONCLUSION

The study was made in an attempt to establish more definite relationships among some of the effects of subsoiling. The effects studied were: water runoff, soil moisture relationships, root distribution, and crop yield. The experiment was conducted on Wolftever clay loam which is a moderately well drained Red-Yellow Podzolic soil.

Results of mechanical analyses showed the textural classes to be: Ap-clay loam, B_{21}-clay, B_{22}-clay, B_{31}-clay loam, and C-clay loam. Laboratory data and field examination showed that the soil did not have the required increase in clay content in the B_2 horizon to be a claypan Planosol. The water holding capacity of the soil was relatively high. Percolation and permeability studies indicated that water movements through this soil were relatively unrestricted.

The amount of water runoff varied directly with the percent moisture in the soil. When the soil was low in moisture a low percent of the applied water was lost by runoff; when the soil was high in moisture a higher percent was lost.

Runoff was less from subsoiled plots than from plots not subsoiled. It appeared that this difference was the result of better permeability of the subsoil on subsoiled areas. There was a slightly smaller amount of runoff from contour subsoiled plots than from plots subsoiled up and down slopes. The runoff from contour subsoiled areas was also slower than on plots subsoiled up and down slope or from plots not subsoiled. This allowed more time for water infiltration on contour subsoiled plots and accounts for the difference in runoff.

The channel left by the subsoiler was almost completely filled with soil particles after 13 inches of applied water and rainfall fell on the area.

In most cases the moisture content of the surface soil was higher before and after irrigations on subsoiled areas than on areas not subsoiled. The moisture content of the surface was higher before and after irrigations on contour subsoiled plots than on plots subsoiled up and down slope. The significant differences between treatments that occurred in the moisture content of the subsoil were before and after the second irrigation only.

There was little difference in the moisture content of the soil during the last seven weeks of the growing season of corn irrespective of treatment. Results obtained by computation of available moisture using available climatological data were similar with direct soil moisture readings in estimating the amount of available moisture during the growing season of corn.

Corn roots penetrated the subsoil of Wolftever clay loam adequately on all treatments. Subsoiling did not affect root penetration or significantly increase corn yields.

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APPENDICES

APPENDIX A

APPENDIX A

SOIL PROFILE DESCRIPTIONS

Site No. 1: Wolftever Clay Loam

Site Location:

Knox County Tennessee, University of Tennessee Farm. Subsoiling runoff plots, 250 yards southeast of intersection of Highway 73 and Neyland Drive, 150 yards north of Fort Loudon Lake (Tennessee River).

Site Description:

Sloping (8-10%), moderate erosion; has been previously used in plot work and is presently in old sod of alfalfa, fescue, orchardgrass and Ladino clover. Moist when sampled.

Physiographic Position: Terrace

Profile Description:

A_p 0-5" Very dark gray (5YR 5/1) clay loam, moderate, medium granular structure; friable; clear smooth boundary; many pores, many roots and many worm holes.

B_{21} 5-13" Yellowish red (5YR 5/6) clay variegated with (10 YR 4/2) dark grayish brown; weak medium to coarse subangular blocky structure; clay skins continuous; natural fracture vertical; overlap small; friable to firm; clear smooth boundary; many roots, many pores, many worm holes and some mixing of material from above.

B_{22} 13-19" Yellowish red (5YR 4/8) clay with a few faint mottles of brownish yellow (10YR 6/8); moderate, medium to coarse subangular blocky structure; clay skins patchy; friable to firm; gradual smooth boundary; many roots, few large pores, few worm holes.

B_3 19-31" Yellowish red (5YR 5/6) clay loam with a few faint mottles of brownish yellow (10YR 6/6); moderate, medium angular blocky structure; clay skins thin, continuous; friable to firm; gradual smooth boundary; few large pores, a few fine roots.

C_1 31" + Yellowish red (5YR 5/6) clay loam with common, distinct mottles of brownish yellow (10YR 6/6); weak coarse blocky to massive structure; firm; no pores, few roots, few fine root channels.

Site No. 2: Wolftever Clay Loam

Site Location:

Knox County Tennessee, University of Tennessee Farm. Subsoiling runoff plots, 250 yards southeast of intersection of Highway 73 and Newland Drive, 150 yards north of Fort Loudon Lake (Tennessee River).

Site Description:

Sloping (8-10%), moderate erosion; has been previously used in plot work and is presently in old sod of alfalfa, fescue, orchardgrass and Ladino clover. Moist when sampled.

Physiographic Position: Terrace

Profile Description:

A_p 0-8" Dark brown (7.5YR 3/2) clay loam; moderate, medium coarse granular structure; friable; clear smooth boundary; many roots, many pores and many worm holes.

B_{21} 8-15" Yellowish red (5YR 5/6 to 4/6) clay; weak medium to coarse subangular blocky structure; clay skins continuous; natural fracture vertical; overlap small; friable to firm; clear smooth boundary; many worm holes and a large amount of mixing of material from above, also a few cobbles.

B_{22} 15-24" Yellowish red (5YR 5/6) clay loam with a few faint mottles of reddish yellow (7.5YR 6/6); moderate, medium to coarse subangular blocky structure; clay skins patchy; friable to firm; gradual smooth boundary; many roots, few large pores and few worm holes.

B_{31} 24-30" Yellowish red (5YR 5/8) clay loam with a few faint mottles of reddish yellow (7.5YR 6/8); moderate, medium to coarse subangular blocky structure; clay skins thin and continuous; friable to firm; gradual smooth boundary; a few large pores and a few fine roots.

C_1 30" + Yellowish red (5YR 5/8) clay loam with common mottles of reddish yellow (7.5YR 6/8); weak subangular blocky to massive structure; firm; no pores, a few roots and a few fine root channels.

Site No. 3: Wolftever Clay Loam

Site Location:

Knox County Tennessee, University of Tennessee Farm. Subsoiling runoff plots, 250 yards southeast of intersection of Highway 73 and Newland Drive, 150 yards north of Fort Loudon Lake (Tennessee River).

Site Description:

Sloping (8-10%), moderate erosion; has been previously used in plot work and is presently in old sod of alfalfa, fescue, orchardgrass and Ladino clover. Moist when sampled.

Physiographic Position: Terrace

Profile Description:

A_p 0-8" Dark brown (7.5YR 3/2) clay loam; moderate, medium to coarse granular structure; clear smooth boundary; many roots, many pores and many worm holes.

B_{21} 8-19" Yellowish red (5YR 5/8) clay; moderate to strong subangular blocky structure; clay skins continuous; natural fracture vertical; overlap small; clear smooth boundary; many roots in clusters; many pores; many worm holes and some mixing of material from above; a few small cobbles.

B_{22} 19-25" Yellowish red (5YR 4/6) clay loam with a few faint mottles of reddish yellow (7.5YR 6/8); moderate to strong, medium subangular blocky structure; clay skins continuous, but thin; natural fracture vertical; overlap small; gradual smooth boundary; a few medium pores, a few roots and a few worm holes.

B_{31} 25-30" Yellowish red (5YR 5/8) clay loam with a few faint mottles of reddish yellow (7.5YR 6/8); weak, medium to coarse subangular blocky to massive structure; friable to firm; gradual smooth boundary; very few pores and few roots.

C_1	30" +	Yellowish red (5YR 5/8) clay loam with common mottles of reddish yellow (7.5YR 6/8); weak, medium to coarse subangular blocky to massive structure, friable to firm; very few pores and a few very fine roots.

APPENDIX B

APPENDIX B

LABORATORY PROCEDURES

I. Soil pH

A. Place about 25 g. of air-dry soil (ground to a fineness to pass a 2 mm. sieve) in a 50 ml. beaker.

B. Add distilled water until thin, pasty mixture is obtained.

C. Allow to set until soil becomes well saturated.

D. Re-mix and place electrodes of pH meter into the soil misture and read pH directly.

II. Organic Matter

A. Reagents

1. Potassium dichromate, 1.0 N.

2. Ferrous sulfate, 0.5 N.

3. Concentrated H_2SO_4.

4. Ortho-phenanthroline ferrous complex indicator.

B. Procedure

Grind soil to pass an 80 mesh sieve, avoiding contact with iron or steel. Weigh a 1.00 g. sample and transfer to a 500 ml. Erlenmeyer flask. Add 10 ml. of $K_2Cr_2O_7$ followed by 20 ml. of concentrated H_2SO_4. Swirl gently to mix. Avoid throwing soil up onto the flask out of contact with the reagents. Stand on an asbestos pad for thirty minutes. Add 200 ml. of distilled water, 4 drops of indicator solution and titrate with $FeSO_4$. The color change is from green to red.

Percentage of organic matter is equal to:

$$\frac{(\text{ml. } K_2Cr_2O_7 \times N) - (\text{ml. } FeSO_4 \times N)\ (0.69)}{\text{weight of sample in grams}}$$

APPENDIX B (Continued)

III. Mechanical Analysis by the Pipette Method

A. Reagents

1. Hydrogen Peroxide (30%).

2. Hydrochloric Acid 0.1 N.

3. Ethyl Alcohol 95%.

4. Sodium Hydroxide 0.1 N.

B. Procedure

Weigh 10.00 g. of air-dry soil into a beaker. Weigh another 10.00 g. sample and determine moisture content to calculate exact amount of soil used. Add 10 ml. H_2O and stir. Place on a hot plate at low heat. Add 10 ml. H_2O_2, stir and continue low heat treatments. Repeat until there is no further oxidation of organic matter after the addition of the H_2O_2. Add water as necessary to keep soil in suspension. Add 50 ml. H_2O and mix. Transfer soil to a Buchner funnel fitted with a Whatman No. 42 filter paper. Use more water to complete transfer. Leach soil with 400 ml. 0.1 N HC_1. Wash out excess HC_1 with 50 ml. H_2O and then 150 ml. ethyl alcohol. Allow soil to dry and then transfer to a 500 ml. Erlenmeyer flask. Add 200 ml. H_2O, NaOH (6 ml. to sands and silts, 10 ml. to loams 14 ml. to clays, silty clays). Shake in a reciprocating shaker overnight. The pH should be between 8 and 9. Transfer soil suspension to a 300 mesh sieve, catching the filtrate in a 1000 ml. graduated cylinder. Wash the sieve until all the silt and clay has entered the graduate. The sand will remain on the screen and should be transferred to a tared beaker, dried at 105° C. for 24 hours, cooled and weighed.

$$\frac{(\text{wt. of beaker + sand}) - (\text{wt. of beaker} \times 100) = (\%\ \text{sand})}{\text{wt. of soil sample}}$$

Dilute the filtrate containing the silt and clay to 1 litter, mix well and allow to stand. At the end of 4 minutes and 40 seconds pipette a 25 ml. aliquot at 10 cm. depth using an aspirator bottle so as to take approximately 15 to 20 seconds in obtaining the sample. Transfer the aliquot to a tared weighing bottle, evaporate to dryness at 105° C., cool and weigh. Sedimentation time is based on a suspension temperature of 20° C.

APPENDIX B (Continued)

$$\frac{(\text{wt. of bottle + silt \& clay})-(\text{wt. of bottle})\ 4000}{\text{wt. of soil sample}} = (\text{\% silt \& clay})$$

At the end of 7 hours and 47 minutes pipette a 25 ml. aliquot at 10 cm. depth using an aspirator bottle so as to take approximately 40 seconds in obtaining the sample. Transfer the aliquot to a tared weighing bottle, evaporate to dryness at 105° C., cool and weigh. Sedimentation time is based on a suspension temperature of 20° C.

$$\frac{(\text{wt. of bottle + clay - wt. of bottle})\ 4000}{\text{wt. of soil sample}} = (\text{\% clay})$$

% silt and clay - % clay = % silt (.02 mm. - .002 mm.)
100 - (% sand + % silt + % clay) = % coarse silt (.05 mm. - .02 mm.)

IV. Low Moisture Tensions - Porous Plate Method

A. Materials

1. Source of Compressed Air.
2. Porous Plate.
3. Rubber Rings.
4. Pressure Cooker.
5. Pressure Regulator and Gauges.
6. Torsion Balances and Aluminum Dishes.
7. Oven.

B. Procedure

Wet the porous plate thoroughly, place the small rubber rings on the plate, and fill with air-dry soil. Pack soil slightly when dry. Add water to plate to wet soil from the bottom. Allow to stand overnight with free water to complete saturation. Place plate in cooker and properly seal all openings. Adjust air pressure to five pounds and allow 24 hours for the soil to reach equilibrium. Remove samples, weigh, dry in oven at 110° C., cool and weigh. To calculate moisture content on an oven dry basis:

APPENDIX B (Continued)

$$\frac{(\text{wt. wet soil}) - (\text{wt. dry soil})}{\text{wt. of dry soil}} = (\%\ \text{soil moisture})$$

Moisture content at 5 lbs. = 1/3 atmosphere or approximate field capacity.

V. <u>Higher Moisture Tensions - Pressure Membrane Method</u>

A. Materials

1. Tank of Compressed Nitrogen.

2. Pressure Membrane Apparatus.

3. Rubber Rings.

4. Pressure Regulator and Gauges.

5. Torsion Balance and Aluminum Dishes.

6. Oven.

B. Procedure

Soak the sausage casing membrane 12 hours before use. Place the membrane over a copper screen extractor plate. Place small rubber rings on the membrane and fill them with soil. Add water to wet from bottom, allowing 12 to 24 hours to complete hydration. Remove excess H_2O from plate with a pipette and fit top of apparatus correctly. Apply gas pressure slowly (nitrogen here) to 30 pounds (per square inch), and allow 24 hours for equilibrium. Remove apparatus top, transfer soil samples to aluminum dishes and weigh. Dry at 110°C. and weigh. To calculate moisture content on oven dry basis:

$$\frac{(\text{wt. wet soil}) - (\text{wt. dry soil})}{\text{wt. of dry soil}} = \%\ \text{soil moisture})$$

Repeat using 220 pounds pressure (15 atmospheres, approximate wilting point).

APPENDIX C

APPENDIX C

Table 10.--Physical and chemical properties for major horizons of three sites of Wolftever clay loam.

	Horizon	Depth	Site number I	II	III
Percent sand 2.0-0.05 mm.	A_p	0-7"	29.1	27.5	27.2
	B_{21}	7-16"	21.6	22.1	23.5
	B_{22}	16-23"	22.1	24.7	30.6
	B_3	23-30"	28.2	34.3	36.7
	C	30" +	38.6	37.3	41.5
Percent silt 0.05-0.002 mm.	A_p	0-7"	41.9	43.5	44.8
	B_{21}	7-16"	32.6	31.7	31.2
	B_{22}	16-23"	33.8	35.3	32.0
	B_3	23-30"	34.3	31.7	32.0
	C	30" +	30.9	27.9	33.2
Percent clay - 0.002 mm.	A_p	0-7"	29.0	29.0	28.0
	B_{21}	7-16"	45.8	46.2	45.4
	B_{22}	16-23"	44.1	40.0	37.5
	B_3	23-30"	37.5	34.9	31.3
	C	30" +	30.5	27.5	25.4
Percent organic matter	A_p	0-7"	2.7	1.9	2.6
	B_{21}	7-16"	0.6	0.2	0.7
	B_{22}	16-23"	0.7	0.2	0.4
	B_3	23-30"	0.4	0.2	0.2
	C	30" +	0.1	0.1	0.2
pH values	A_p	0-7"	5.1	5.1	5.0
	B_{21}	7-16"	5.5	5.3	5.1
	B_{22}	16-23"	5.5	5.2	5.0
	B_3	23-30"	4.7	4.5	4.2
	C	30" +	4.4	4.3	4.2
Bulk density g./cc.	A_p	0-7"	1.5	1.5	1.4
	B_{21}	7-16"	1.5	1.5	1.5
	B_{22}	16-23"	1.5	1.5	1.5
	B_3	23-30"	1.5	1.5	1.5
	C	30" +	1.5	1.5	1.5

APPENDIX C (Continued)

	Horizon	Depth	Site number I	II	III
Percent water 1/3 atmosphere	A_p	0-7"	20.6	21.3	23.9
	B_{21}	7-16"	27.9	26.0	29.3
	B_{22}	16-23"	27.4	24.7	28.1
	B_3	23-30"	29.7	24.3	28.4
	C	30" +	27.4	24.2	27.9
Percent water 15 atmosphere	A_p	0-7"	11.7	10.9	11.5
	B_{21}	7-16"	18.0	16.6	18.6
	B_{22}	16-23"	17.7	13.3	17.2
	B_3	23-30"	17.0	12.5	15.5
	C	30" +	15.3	12.0	14.1

APPENDIX C

Table 11.--Percolation, permeability, porosity and moisture at pF 1.7.*

Horizon	Number of cores	Depth of cores	Percolation rates Inch/hr.	Permeability index	Water drained pF 1.7 15 min. (ml/100 g.)	30 min. (ml/100 g.)	15 hrs. (ml/100 g.)	Moisture pF 1.7 Wt.%
				Site Number I				
A_p	3	1-4	4.0	5 (mod. rapid)	4.5	5.4	8.6	26.2
B_{21}	2	6-9	7.4	6 (rapid)	7.5	8.8	11.1	24.7
B_{22}	2	12-15	1.4	4 (mod.)	8.1	8.8	9.4	27.5
B_3	2	21-24	0.6	3 (mod. slow)	7.1	8.1	8.8	26.2
C	2	37-40	1.4	4 (mod.)	5.2	5.8	8.1	26.8
				Site Number II				
A_p	2	1-4	14.2	7 (very rapid)	7.6	8.4	10.8	22.7
B_{21}	2	10-13	4.9	5 (mod. rapid)	6.6	7.8	10.7	28.1
B_{22}	2	16-19	22.1	7 (very rapid)	8.5	9.5	12.0	27.2
B_3	2	26-29	6.1	6 (rapid)	6.9	8.5	11.7	26.5
C	2	32-35	12.2	7 (very rapid)	7.6	8.8	11.1	26.2
				Site Number III				
A_p	2	1-4	13.6	7 (very rapid)	8.5	9.1	13.0	25.0
B_{21}	2	9-12	5.5	6 (rapid)	6.2	6.6	8.9	27.4
B_{22}	2	21-24	3.8	5 (mod. rapid)	7.0	7.8	10.2	27.6
B_3	2	26-29	15.7	7 (very rapid)	7.9	8.5	10.1	26.0
C	2	32-35	4.0	5 (mod. rapid)	7.9	8.9	11.7	26.0

* Average of 3 sites.