THE EFFECT OF CROPPING SYSTEMS AND CULTURAL PRACTICES ON SOIL COMPACTION ON A NORGE LOAM

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Soil compaction is recognized as a major limitation on crop yields in practically all of the medium textured soils of Oklahoma in cultivation, particularly in soils on nearly level slopes where more intensive cropping is now being practiced.

In common agricultural practice, normal tillage operations prevent the occurrence of permanently compacted zones in the surface soil; however, a zone of compaction often is formed immediately below the tilled layer.

Mechanized farming is believed to be having an important effect on soil structure. Machines are continually being made larger and heavier. The weight of the machinery and the speed of travel, together with the vibration caused by the power unit, would seem to tend toward general compaction of the soil, particularly where the kind of farming practice causes soil structure to deteriorate. If the soil is too wet or too dry when worked, its structure may be permanently damaged. In actual farming practice, the optimum moisture content for plowing is difficult to determine as a field may contain different soil types and topography. The moisture content will change during the time required for the operation.

Field observations show that the detrimental effects of dense sub-surface layers are numerous. Other than the effect of drainage and non-capillary porosity, these compacted layers also may reduce soil oxygen supply and prevent the escape of carbon dioxide, thus inhibiting root growth, bacterial activity, and the conversion of certain plant nutrients into available forms.

Many times these hidden compacted layers are not noticed until severe symptoms are brought to the attention of the farmer. Yellow spots may appear in a field of wheat although soil tests show the fertility of the soil to be adequate. By digging into the soil, one may find dense layers below plow depth, so dense that in many instances root development will completely stop or turn at right angles and follow along the top of the restrictive layer.

Soil compaction causes a considerable reduction in water infiltration rates and in turn results in less available moisture for plant growth. Erosion problems also are increased by soil compaction. In Oklahoma, where drought conditions occur almost every year during some part of the growing season, this factor alone could account for a marked reduction in yields.

The objectives of this experiment were to study the effects of various cultural and management practices on the ability of the soil to form a compact zone and to determine the major causes of these compacted layers in a Norge loam.

REVIEW OF LITERATURE

Previous work on soil compaction has been confined primarily to the engineering field; however, much more attention is being given now by those concerned with crop production.

It has been found by Bradfield (2)[1] that many fine-grained soils under continued cultivation tend to become more dense, especially where cropped for long periods to crops without a grass or legume rotation; and as they become increasingly dense more of the rain is lost as run-off. The destruction of the original organic residues has resulted in reduced biological activities, the natural structural aggregates have been destroyed, and the soil particles tend gradually to assume a position of closer packing. Bradfield says in a paper on soil conservation:

> In many cases from 25 to 30 percent more soil is crammed into a cubic foot than was present in the virgin soil. This has reduced porosity, especially the volume of the larger pores through which water penetrated readily and through which the soil received the necessary ventilation. As a result of these changes in structure, root development is hampered, the storage capacity of the soil for water is reduced, flood hazard is increased, and the damage from frequent periodic droughts is magnified.

Compaction resulting from tractors and disks in orchards in California have been discussed by Parker and Jenny (20). They found the effects of the tractor were very detrimental

[1]Figure in parentheses refers to Literature Cited.

to water infiltration in both dry and wet soil. In the wet soil pronounced soil compaction was produced. Disking of dry and wet soil greatly reduced water infiltration and increased resistance to core weight values, but the effect on wet soil did not occur until the second irrigation after treatment.

Jamison and his co-workers (11) reported the depth to which compaction was observed, by passing a rear wheel pneumatic farm tractor tire on Cecil clay, was nearly as great in the "moist" as in the "wet" condition. Compaction immediately beneath the tires was evident at depths varying from 17 inches below the surface in the loose soil to 12 inches in the soil that was heavily compacted at the beginning of the experiment. The tire did little more than loosen about an inch of topsoil by slippage of the lugs where the soil was dry and compacted.

Weaver (26) found that Davidson loam was compacted to its maximum density from tractor usage somewhere in the range of 11 to 15 percent moisture content. Bin tests showed that annual tractor use is capable of compacting that soil to a depth of nine inches, or below the normal loosening operations, when the moisture content is near the optimum for plowing.

McGeorge and Breazeale (16) suspected much subsoil puddling or compaction arises from the concussion of power driven farm implements. When a soil is vibrated, as with power driven machinery, one of the principal conditions developed is an almost complete elimination of air from the soil with the soil mass being converted into a continuum approaching a gel. Plants in the puddled soil gave the appearance of having died from want of water, yet the soils were saturated. They gave two conditions which might contribute to the behavior of the plants in the puddled soil. One of these was a restricted root system which was unable to supply the moisture requirement of the plant, and the other was the inability of the roots to extract the water from the puddled soil.

Lawton (15) has shown that packing of soils causes a marked reduction in growth of corn by decreased aeration. Lack of aeration reduced the total absorption of certain elements by the corn plants. He found that by forcing air through mechanically packed soils at a high moisture content the top and the root growth of the corn was greatly stimulated. Increase in the growth of corn was greatest when phosphorous and potassium were not limited factors.

Smith and Cook (22) worked with sugar beets and found that the effect of compaction in lowering growth and yield was more serious than the addition of excess water. They also found that compaction of the soil alone and in combination with excess water resulted in marked disturbance of the normal oxidation and nitrification processes which occur in the soil.

Hoffer (10) attributes the failure of corn, on certain Indiana soils, to respond to fertilizer treatments to the lack of sufficient soil aeration brought about by soil compaction.

There is a close connection between the air conditions around the roots and their uptake of water and nutrients. Chang and Loomis (4) grew wheat, maize, and rice plants in water solutions in quartz sand, and showed that by increasing the carbon dioxide content of the solution the uptake of water and some plant nutrients was reduced. The uptake of potassium and nitrogen was reduced considerably, while reducing the oxygen content of the solution and keeping the carbon dioxide content low, by bubbling through nitrogen gas, had little effect on the plants' uptake of either water or nutrients.

The association of organic matter with soil structure and state or degree of compaction is generally recognized. Free and his co-workers (7) adapted the Proctor method to study the relationship of soil organic matter to compactibility. They concluded that probably the most important finding in their study was the degree of compactibility and permeability of soils under mechanically applied forces is associated with the amount of organic matter. The high organic matter groups tested could be worked with 10 percent more moisture before compacting to the same degree. Apparently, the organic matter not only determines the moisture content at which maximum compaction occurs for a given soil, but also has a marked influence on the amount of compaction.

Many topsoils that were originally granular or crumb in structure have been changed as a result of cultivation and poor management practices to a fine fragmental or massive structure. With these changes in structure the percolation rate has decreased, percent of pore space has been reduced, and the volume weight has increased. Klingebiel and O'Neal (14) stated that the degree of difference between the structure in the plow layer, the plow sole, and the soil beneath the plow sole depends upon the kind of soil and the intensity to which it has been cropped. Level, light-colored silt loam soils that were originally low in organic matter do not have a very stable type of structure, and when the soil is cultivated the structure breaks down rapidly. In general, prairie soils have a more stable type of structure and will stand more severe cropping, but eventually they too break down under strenuous cropping.

Van Doren and Klingebiel (24) found that soil treatments and cropping systems have a pronounced effect on permeability to water and that volume weight also was affected.

Olmstead, Page, and Willard (18,19) showed that cropping systems and tillage practices had a very marked effect on the physical condition of the soil. They found that a combination of fibrous rooted grasses and deep rooted legumes gave the most favorable physical condition for maximum yields.

Klingebiel and O'Neal (14) reported that raindrop action, past soil management, and type of soil were probably the most important factors influencing the formation of soil crusts. Crusts play a very important role in the rate at which water and air will enter the soil. They found the surface crust to be approximately one-third as permeable as the soil beneath it.

Mechanical compaction by raindrops plays an important role in the formation of the thin surface crust on some soils which Duley (6) has shown to have a very marked effect on infiltration. In discussing the formation of this sealing layer, he speaks of it having a high volume weight but believes it is due to the action of the raindrops fitting some of the finer particles around the larger ones rather than to an increase in fine material. He shows that this smooth layer was formed even on sand when it was sprinkled. He proposed that, as far as his studies have gone, the thin compact layer which forms on the surface of bare soils by rains has had a greater effect on intake of water than have soil type, slope, moisture content, or profile characteristics.

Hilgard (9) stated that granular (coarse) sediments themselves, in the absence of clay, may, because of their angular shape, form a very closely packed mass far from suitable for vegetative growth. He described what "would be called a very sandy loam" which at depths varying from 18 to 36 inches had a hardpan impervious to water and roots.

It contained no cementing material and when taken out was easily crushed between the fingers. Its imperviousness was due almost solely to the close packing.

Bull (3) has found the "plow-sole" to exist on all soils, tight, hard, or sandy, irrespective of the slope in the wheat belt of Western Oklahoma. He has made many comparative infiltration studies of soil having "plow-soles." Soil analysis shows these soils to be low in organic matter, usually less than 1.5 percent.

Jensen (12) has found "plow-soles" to occur in all soil types investigated in the Riverside, Redlands, and Corona areas of California. Coarse granitic soils, as well as the heavier clay loam soils, are subject to the "plow-sole" formation. He observed that "plow-soles" did not form under citrus trees where the soil had not been cultivated, especially where an organic mulch was maintained. In many groves the fibrous citrus roots did not penetrate the "plow-sole," though roots were found in the hard layer. It appeared that such penetration of roots was formed during rainy seasons when the "plow-sole" was soft and maintained in a moist condition. He also found that the percentage of iron and aluminum in the colloid suspension from a soil to be directly correlated with the readiness with which the soil formed a "plow-sole."

Beeson and Murphy (1) found that alfalfa taproots penetrated into and below a hardpan subsoil where lime and manure were added to the soil. Veihmeyer and Hendrickson

(25) showed that the soil density above which roots do not penetrate is not necessarily the same for all soils. Doneen and Henderson (5) did not think that apparent density of the soil was a sensitive criteria for compaction. Laboratory experiments designed to correlate soil density with infiltration rate show that at low apparent densities a small increase in the density results in a marked decrease in the infiltration rate, while at high densities a relatively large increase in density causes only a slight further reduction in infiltration rate. Soil density is a measure of total porosity but does not give the size distribution of the pores. The large pores are most important in the rapid conduction of water.

The level of organic matter and nitrogen in the soil, nitrogen fixation, production of available nitrogen, decomposition of residues, and the degree of aggregation depend on a suitable temperature for microbial activity (21).

Richards, Hagan, and McCalla (21) state that a microbial population active at a low temperature may produce a greater quantity of a better aggregating substance than it would produce at a high temperature. It is possible that at higher temperatures effective organic-aggregating substances are produced that are rapidly destroyed through the activities of the organisms since high temperatures favor more rapid decomposition of organic matter. This view is supported by the shorter incubation period for maximum aggregation at higher temperatures, followed by a rapid decline in aggregation.

METHODS AND MATERIALS

The data included in this thesis are material gathered from a field study on the Oklahoma Agricultural and Mechanical College Agronomy Farm, located near Perkins, Payne County, Oklahoma. The samples studied were on plot series 1000 and 1100 located in S1/2, NW1/4, N1/2 Sec. 36, T.18 N, R.2 E.

Description of the Soil Studied

The soil in this study has been classified as Norge Loam.[1] Norge Loam is of the Reddish Prairie great soil group developed under prairie grasses. It is developed entirely in mantle of transported materials originating in the flood plain of the Cimarron River, probably during the middle and late Pleistocene time.

The profile is described as follows:

A_{1p}	0-6"	Brown (7.5 YR 5/3; 4/2 when moist)[2] loam; weak medium granular; friable; permeable; pH 6.0; grades to the layer below.
A_1	6-14"	Brown (7.5 YR 5/3; 4/2 when moist) loam containing visible very fine

[1]Personal communication or unpublished data supplied by H. M. Galloway.

[2]Munsell color chart.

sand; breaks first into angular fragments; moderate medium granular; friable; porous and permeable; pH 6.0; contains many worm holes, worm casts, and pin holes; crushes slightly more reddish than the above colors (7.5 YR 5/4) and grades to the layer below.

B_1 14-22" Brown (7.5 YR 5/3; 4/3 when moist) clay loam thinly and faintly streaked with light-brown; moderate medium subangular blocky; firm; hard when dry; permeable; pH 6.0; contains many pores and pin holes and occasional black concretions; becomes more streaked in the lower part, and grades to the layer below.

B_{2-1} 22-32" Reddish-brown (5 YR 5/5; 4/5 when moist) light sandy clay with a few, medium distinct yellowish-red (5 YR 4/6) mottles and a few, fine light-brown (7.5 YR 6/3) streaks; compound weak coarse prismatic and moderate medium subangular blocky; firm; hard when dry; slowly permeable; pH 6.5;

occasional medium black concretions; grades to the layer below.

B_{2-2} 32-44" Light-brown (7.5 YR y/4; 5.4 when moist) light sandy clay with common coarse distinct brownish-yellow and yellowish-red mottles; weak coarse prismatic and weak medium subangular blocky; firm; slowly permeable; pH 6.5; occasional medium and coarse black concretions and ferruginous films; grades through a 4 to 6 inch transition to the layer below.

B_3-C_1 44-54" Reddish-yellow (7.5 YR 6/6; 5/6 when moist) heavy sandy clay loam containing much coarse sand; fragmental breakage; weak medium subangular blocky; firm; permeable; pH 7.0; occasional fine black concretions and streaks of brownish-yellow and brown; grades to the layer below.

C_1 54-66" Light-brown (7.5 YR 6/5; 5/5 when moist) light sandy clay loam streaked with strong-brown and yellowish-brown; weak medium granular; friable; slightly hard when dry; permeable; pH 7.0; occasional

		black concretions; grades to the layer below.
C_2	66-84"	Streaks of light-reddish-brown, strong-brown, and reddish-yellow fine sandy loam with lenses of light sandy clay loam; friable and permeable; pH 7.0.

This is a very uniform soil from which there has been little loss of surface soil due to erosion. This land is smooth enough to cultivate without the use of terraces, and the few present are almost straight. The soil absorbs water well which prevents the formation of wet places behind the terrace ridges. It is a responsive soil and has few hazards to management.

History of the Cropping Systems

Continuous Cotton Fertility Study--Series 1000.

This experiment was started in 1931 and has been in continuous cotton since then, a total of 24 years.

Lespedeza Fertility Study--Series 1100.

This series is closely associated with a soil in virgin condition as the soil has never been worked with the exception of straight disking to work the fertilizer into the surface. This soil will be referred to in this study as a virgin soil. Lespedeza has been established for several years; however, fertility treatments were not started until the fall of 1954.

Alfalfa Rotation Study--Series 1000-1100.

This rotation study was started in 1931. Alfalfa is grown for four years on half of the area, and the other half of the area is in rotation with spring oats, winter barley, Darso, and cotton. The cotton and barley in rotation with alfalfa soils were studied in this thesis.

Collection of the Soil Samples

Undisturbed core samples were taken from continuous cotton and virgin soil plots with a steel cylindrical sampler equipped with a driving assembly and cutting edge similar to the one shown by Van Doren and Klingebiel (24).

The core samples were collected at three inch intervals from 2 to 14 inches. They were placed in paraffin coated one pint ince cream cartons for transporting to the laboratory for analyses.

Laboratory Analyses of Soil Samples

The undisturbed core samples were weighed immediately upon reaching the laboratory, placed in an oven at 105° C. for 24 hours, and reweighed. Bulk density, moisture content, void ratio, and specific gravity were determined by the methods described by Means (17). The following formulas were used:

$$\text{Bulk Density} = \frac{\text{weight of soil (dry)}}{\text{volume of soil}} \text{ (calculated from the dimensions of the core sampler)}$$

$$\text{Water Content} = \frac{\text{weight of soil, wet} - \text{weight of soil, dry}}{\text{weight of the soil, dry}}$$

$$\text{Volume of Voids} = \text{total volume of soil} - \text{volume of solids}$$

$$\text{Void Ratio} = \frac{\text{volume of voids}}{\text{volume of solids}} \text{ or } \frac{\text{specific gravity}}{\text{dry density}} - 1$$

The specific gravity, Gs, of soil solids was determined with a pycnometer bottle from the weight of the bottle filled with deaired[3] distilled water, Wbw; the dry weight of a sample of soil solids, Ws; and the weight of the bottle filled with deaired distilled water, Wbws.

$$Gs = \frac{Ws}{Wbw + Ws - Wbws}$$

Compaction tests for determining optimum moisture content for maximum compaction under a given compactive effort were determined according to the method described by Means (17). The standard Proctor test was used.

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[3]Air was removed from the distilled water by applying a vacuum to the pycnometer bottle for about 15 minutes.

A mechanical analysis (pipette method) was made as described by Kilmer and Alexander (13). The sample was treated with hydrogen peroxide for the removal of the organic matter, washed, filtered, and dispersed using sodium hexametaphosphate as the dispersing agent. The sand was separated from the silt and clay by washing the dispersed sample through a 300-mesh sieve. The various sand fractions were obtained by sieving; 20 and 2 micron fractions were obtained by pipetting.

Organic matter content of the soil sample was measured indirectly by the "wet combustion process" (8) of organic carbon oxidation.

Infiltration rates were studied on continuous cotton, virgin soil, barley in alfalfa rotation, and cotton in alfalfa rotation plots. The studies were conducted in the field. Metal cylinders were driven into the soil to a depth of about six inches. A container with the same dimaeter as the cylinder with a small rubber hose for regulating the flow of water from the container to the cylinder was placed above the cylinder. Depth measurements of the water in the container and the cylinder were subtracted from the initial measurements to give the infiltration rate in inches per unit of time. The third hour measurements have been suggested as being the most accurate.[4]

[4]Personal suggestions on infiltration rates and equipment supplied by Mr. Edd Roberts, Extension Soil Conservationist, Extension Division, Oklahoma Agricultural and Mechanical College.

Temperatures were recorded on continuous cotton, virgin soil, barley in rotation, and cotton in rotation plots by means of a Dickson Minicorder. This is an automatic clock-like apparatus that records the temperature on a chart which is marked off in degrees, hours, and days and is attached to an eight-day clock that cuases the chart to make one complete circle each week, Figure 1. Temperature readings were taken at two and six inch depths. The minicorders were all placed in a constant temperature room and calibrated to coincide with a thermometer before being transferred to the field.

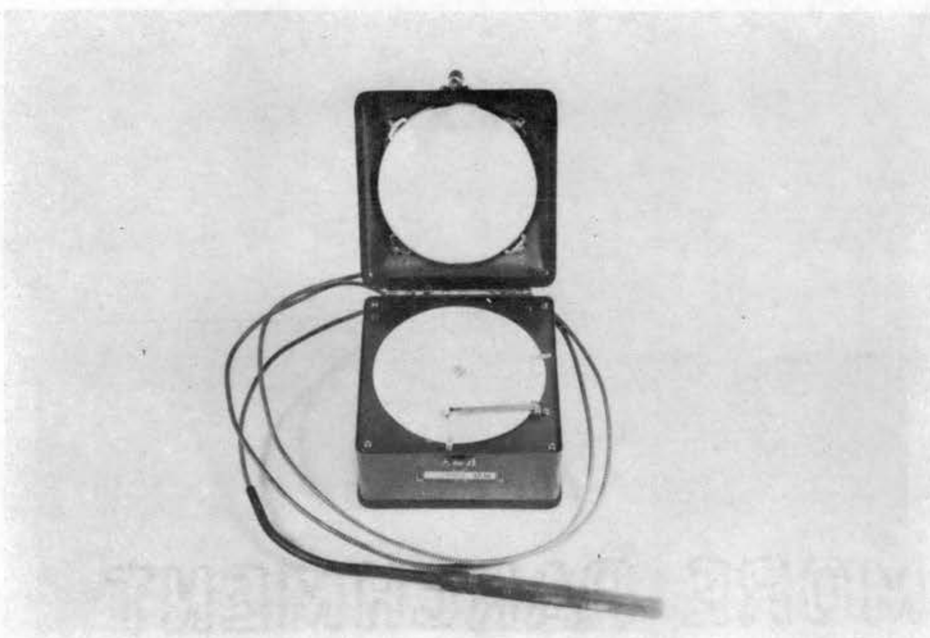

Figure 1--The Dickson Minicorder

RESULTS AND DISCUSSION

Soil compaction is not as easily recognized as some of the other properties of soil since it is generally located below the surface of the soil. It can usually be detected with the help of a spade or soil tube. Moisture content varies greatly from time to time, and soils that are extremely wet or dry make identification difficult. Certain symptoms can help in detecting compaction pans. Cloddy, lumpy soil with extremely fine, almost invisible pores within the lump are good signs. Layers can sometimes be observed.

These symptoms are good indicators of soil compaction; however, bulk density is probably the most reliable method of detecting them. Bulk density is the weight of a known volume of soil (including pore space) compared to the weight of an equal volume of water. Bulk density will range from approximately 1.0 for a loose, cultivated surface soil to as high as 2.1 for a tight subsoil or compaction pan. A normal soil properly worked will be loose and mellow at the surface with a progressive increase in bulk density with depth. Virgin soil profiles also show this trend as illustrated in Table I.

Data in Appendix Table 1 give the results of laboratory analyses on the soil studied.

TABLE I

BULK DENSITY FOR A CONTINUOUSLY CROPPED AND A VIRGIN NORGE LOAM

Sample Depth (inches)	Bulk Density* Virgin Soil	Bulk Density* Continuously Cropped
2-5	1.47	1.56
5-8	1.51	1.63
8-11	1.54	1.58
11-14	1.56	1.58

*Average of 16 samples in continuously cropped plots and five samples in the virgin soil.

Bulk Density Measurements

Bulk density measurements for a virgin soil and a continuously cropped soil are given in Table I and graphically in Figure 3.

Analyses of variance of bulk densities between cropping systems are given in Table II. This shows only the 5 to 8 inch soil depth to be significantly different between cropping systems, although the 2 to 5 inch depth was close to the 5 percent level for significance. In the continuously cropped soils, the 5 to 8 inch layer had higher bulk densities than either the layer above or below. Since the 5 to 8 inch layer was higher in bulk density than the layer below, this seems to point out a compaction zone or layer at this depth. This compact layer could also be detected with a spade or probe, and upon digging into the soil a layer could be observed at the depth where the soil had been turned by the plow, Figure 2.

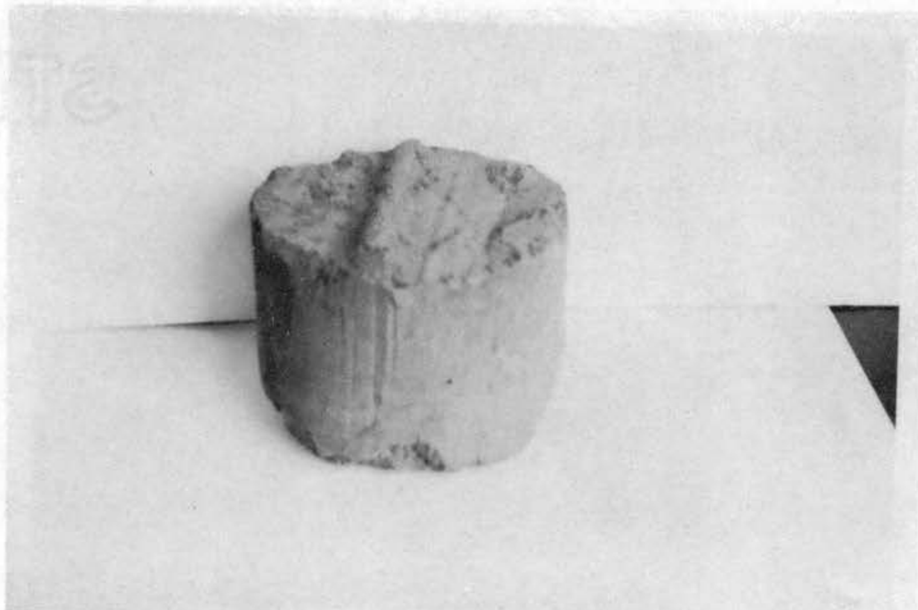

Figure 2--Compact zone at plow depth

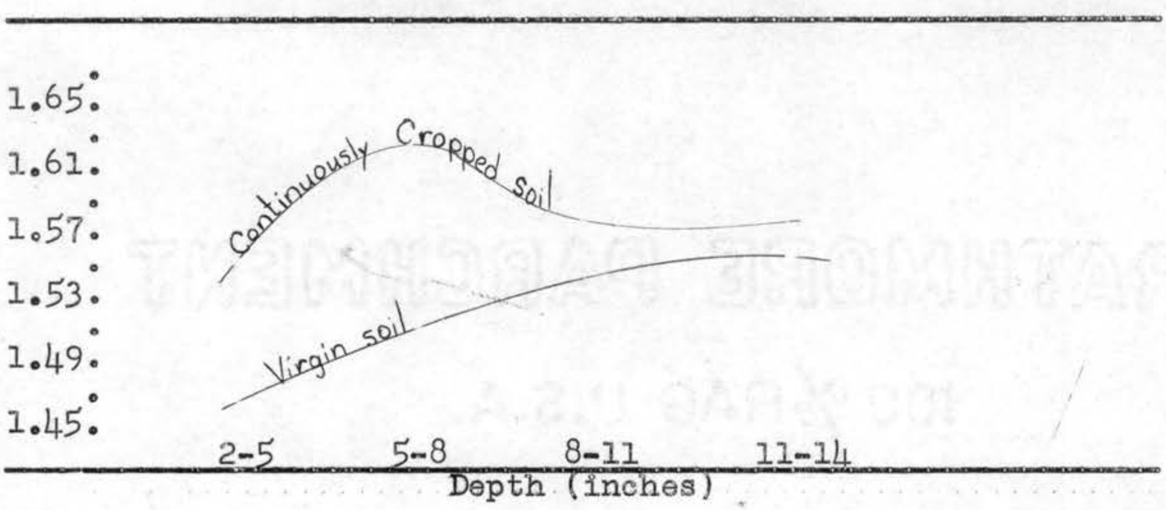

Figure 3--Bulk density comparisons for continuously cropped and virgin Norge Loam

TABLE II

ANALYSES OF VARIANCE OF BULK DENSITIES BETWEEN CROPPING SYSTEMS

Analysis of variance for 2 to 5 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.0440	.0055
Cropping systems	1	.0144	.0144
Error	7	.0296	.0042

Analysis of variance for 5 to 8 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.0334	.0041
Cropping systems	1	.0264	.0264**
Error	7	.0070	.0010

**significant at the 1 percent level

Analysis of variance for 8 to 11 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.0105	.0013
Cropping systems	1	.0030	.0030
Error	7	.0075	.0010

Analysis of variance for 11 to 14 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.0063	.0007
Cropping systems	1	.0001	.0001
Error	7	.0062	.0008

Effect of Cropping Systems on Organic Matter

Along with water, timber, and minerals, organic matter is a natural resource that has been exploited by careless farming practices.

The prevalent cropping systems have reduced the organic matter level of Oklahoma soils considerably. Since Oklahoma was opened to cultivation, approximately (average of 20,000 analyses) 36 percent of the organic matter has been lost at the rate of one percent per year. The organic matter percentages determined from various depths of the two soils are shown in Table III.

TABLE III

EFFECT OF CONTINUOUS COTTON CROPPING OF A NORGE LOAM ON ORGANIC MATTER CONTENT

Depth (inches)	Virgin soil O.M.%*	Continuous cropping O.M.%*
2-5	1.81	1.01
5-8	1.62	1.15
8-11	1.51	1.35
11-14	1.51	1.34

*Average of 16 samples taken from continuously cropped soils and five samples taken from the virgin soil

Continuous cropping with cotton has reduced the organic matter level 44.2 percent in the topsoil as compared to the virgin soil; however, the organic matter seems to approach an equilibrium with the virgin soil at about 12 inches.

The virgin soil shows a gradual decrease in organic matter with depth. This is illustrated by Figure 4.

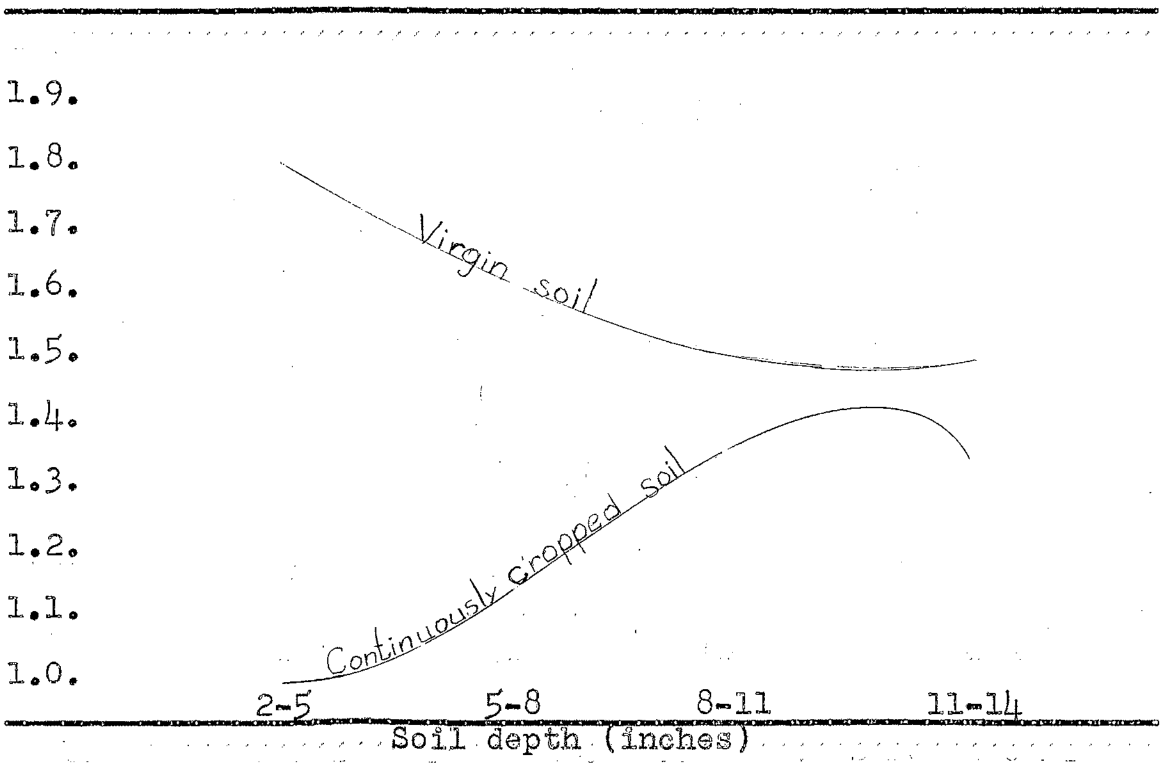

Figure 4---Comparison of organic matter levels for a continuously cropped and a virgin Norge Loam

The analysis of variance of organic matter levels between treatments, Table IV, shows the 2 to 5 inch and the 5 to 8 inch soil depths to be significantly different between the two cropping systems.

TABLE IV

ANALYSES OF VARIANCE OF ORGANIC MATTER LEVELS BETWEEN CROPPING SYSTEMS

Analysis of variance for 2 to 5 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.8156	.1019
Cropping systems	1	.6442	.6442**
Error	7	.1734	.0247

**significant at the 1 percent level

Analysis of variance for 5 to 8 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.3890	.0486
Cropping systems	1	.2941	.2941**
Error	7	.0949	.0135

**significant at the 1 percent level

Analysis of variance for 8 to 11 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.2489	.0311
Cropping systems	1	.0938	.0938
Error	7	.1551	.0221

Analysis of variance for 11 to 14 inch depth			
Source of variation	d.f.	S.S.	M.S.
Total	8	.1200	.0150
Cropping systems	1	.0450	.0450
Error	7	.0750	.0107

Effects of Soil Particle Size Distribution on Soil Compaction

Compacted layers are generally thought to be most likely to develop on medium textured soils; however, they have been found to exist, also, on fine and coarse textured soils. Bull (8) states that they have been found to exist on all soils, tight, hard, or sandy, irrespective of the slope in the wheat belt of Western Oklahoma. An attempt was made in this study to determine if there was any accumulation of a given size particle in the zone of compaction. Averages of the percent of sand, silt, and clay determinations from continuously cropped and virgin soils are given in Table V.

TABLE V

PARTICLE SIZE DISTRIBUTION OF A CONTINUOUSLY CROPPED AND A VIRGIN NORGE LOAM

Depth (inches)	% sand	% silt	% clay
Virgin Soil*			
2-5	52.44	34.31	13.25
5-8	50.53	32.65	16.82
8-11	47.67	32.88	19.44
11-14	46.18	33.02	20.80
Continuously Cropped Soil*			
2-5	55.71	30.63	13.66
5-8	50.02	35.56	14.44
8-11	45.91	35.51	18.57
11-14	44.48	35.81	19.71

*Average of 16 samples in continuously cropped and five samples in virgin soils

In general, there was a small increase in percentage of clay with depth and a decrease in percentage of sand as shown by the analysis of variance, Table VI. The variability in particle size distribution between cropping systems was not significant for any of the soil separates. The silt particles were not significantly different either with cropping systems or depth.

Formation of Crusts

Some work by Duley (6) has shown that the compact layer formed at the surface of the soil by the action of raindrops may not only be of a greater volume weight than the underlying soil, but in many cases will contain a higher percentage of coarse material and less organic matter. He accounts this to the fact that some of the finer inorganic material and lighter organic matter are brought into suspension in the runoff water moving over the surface and are carried down the slope leaving more of the coarse and heavier material behind.

Results from mechanical analyses of a crust formed on the surface of the soil studied are given in Table VII. The particle size distribution shows a larger percentage of silt and clay in the surface crust than in an area immediately below this crust. Bulk densities were higher in the surface crust than below, and the pores were noticeably smaller. Since this soil is fairly level, and the rains previous to the formation of the crust were of such a nature that very little water was lost by run-off, the lighter organic matter and the finer materials in suspension were left on the surface. The beating and splashing effect of the raindrops has fitted the smaller particles around the larger ones, thus reducing the large pores.

Infiltration Studies

Infiltration rates are sometimes used as a measure of soil compaction; however, the data from Table VIII show a great variation in the intake rate of water by the soil. The third hour rate was selected as being the most accurate because it was assumed that all cracks, worm holes, and root channels were filled by this time. By using the third hour readings, the soil in the alfalfa-cotton rotation had the lowest infiltration rate with 0.29 inches per hour. The continuously cotton cropped soil followed closely with 0.37 inches per hour. The virgin soil had a rate of 0.70 inches per hour, and the soil in the alfalfa-barley rotation had the highest rate of 3.25 inches per hour, an increase of over 78 percent over that of the virgin soil.

Evidence that machinery does reduce the infiltration rate by being rolled over the soil was noted when the infiltration apparatus was set up over a track left by the binder when the plots were harvested. Two trials gave an average of 4.00 inches per hour infiltration as compared to 1.75 inches per hour in the track, a reduction of about 56 percent.

TABLE VI

ANALYSES OF VARIANCE OF THE PARTICLE SIZE DISTRIBUTION FOR THE CROPPED AND VIRGIN NORGE LOAM

Analysis of variance for the sand fraction			
Source of variation	d.f.	S.S.	M.S.
Total	35	1032.7744	29.5078
Cropping systems	1	.3555	.3555
Depths	3	502.6886	167.5628**
Error	31	529.7303	17.0880

**significant at the 1 percent level

Analysis of variance for the silt fraction			
Source of variation	d.f.	S.S.	M.S.
Total	35	426.2987	12.1700
Cropping systems	1	12.0128	12.0128
Depths	3	55.3964	18.4654
Error	31	358.8895	11.5770

Analysis of variance for the clay fraction			
Source of variation	d.f.	S.S.	M.S.
Total	35	406.5365	11.6153
Cropping systems	1	8.7014	8.7014
Depths	3	270.2216	90.0738**
Error	31	127.6135	4.1165

**significant at the 1 percent level

TABLE VII

SOME PHYSICAL AND CHEMICAL SOIL PROPERTIES IN AND BELOW THE CRUST FORMATION ON A NORGE LOAM

	% Sand	% Silt	% Clay	% O.M.	Bulk Density
Crust	44.04	43.51	12.45	1.1	1.59*
Below crust	46.95	41.91	11.08	.96	1.39*

*Bulk density measurements were obtained by the hot paraffin method.

From the appearance of the tracks left by the binder, the soil was too wet; therefore, a greater reduction in water intake took place than would normally have occurred.

In setting up and removing the cylinders used in the infiltration studies, a dense, compact layer was observed at the depth of cultivation. This layer was difficult to penetrate with a spade while the immediate area occupied by the row was much more penetrable. The pressing action due to the sweeps used in cultivation had not occurred directly in the row; therefore, they resulted in less compaction. It has been suggested that the moisture content of the soil can determine the degree of maximum compaction; therefore, proper timing of cultivation may be essential in maintaining desirable tilth in soils.

TABLE VIII

INFILTRATION STUDIES ON CROPPING SYSTEMS

Continuous cropping	Infiltration rate (inches/hour)		
	1st hr.	2nd hr.	3rd hr.
Location 1	1.00	0.25	0.25
2	1.00	0.37	0.62
3	0.75	0.37	0.25
Average	0.92	0.33	0.37

Virgin soil	1st hr.	2nd hr.	3rd hr.
Location 1	2.00	0.87	0.75
2	3.00	0.75	0.75
3	2.25	0.87	0.62
Average	2.42	0.83	0.70

Barley in rotation with alfalfa plots	1st hr.	2nd hr.	3rd hr.
Location 1	4.50	4.12	4.75
2	2.62	1.50	1.75**
3	3.50	2.75	3.25
Average	3.54	2.79	3.25

Cotton in rotation with alfalfa	1st hr.	2nd hr.	3rd hr.
Location 1	1.12	0.25	0.25
2	1.12	0.25	0.37
3	0.87	0.62	0.25
Average	1.04	0.37	0.29

**Low infiltration of location 2 may be because of the track of the binder.

Optimum Moisture Content for Maximum Compaction

The optimum moisture content for maximum compaction for the rotation practices are shown in Figure (V).

Maximum compaction occurred when the moisture content was between 12 and 15 percent for the soil studied with the exception of continuous cropping which had about 9 percent moisture at maximum compaction. Maximum bulk densities obtained with the same compactive effort were as follows: 1.81 for the virgin soil; 1.87 for barley plots; 1.88 for cotton in rotation plots; and 1.97 for continuously cropped plots. Since continuously cropped soils showed the highest bulk density with the same compactive effort, and it occurred at a lower moisture content, it tends to point out that this soil may require more careful timing of the tillage practices.

Temperature Studies

The daily fluctuations of soil temperature for two and six inch depths are given in Figure 6. Temperatures in the surface two inches were much higher than at six inches, and the variation between maximum and minimum temperatures was much greater in the two inch depth; however, the difference between cropping systems was much greater in the six inch depth.

The virgin soil gave the lowest maximum temperature readings and showed less variation between maximum and minimum temperatures than any of the cropping systems. The minimum temperatures were similar for all cropping systems in the two inch depth. The virgin soil gave the lowest minimum and maximum temperatures in the six inch depth throughout the experiment.

The lower maximum temperature readings in the virgin soil were believed to be because of an organic mulch which was present on the surface.

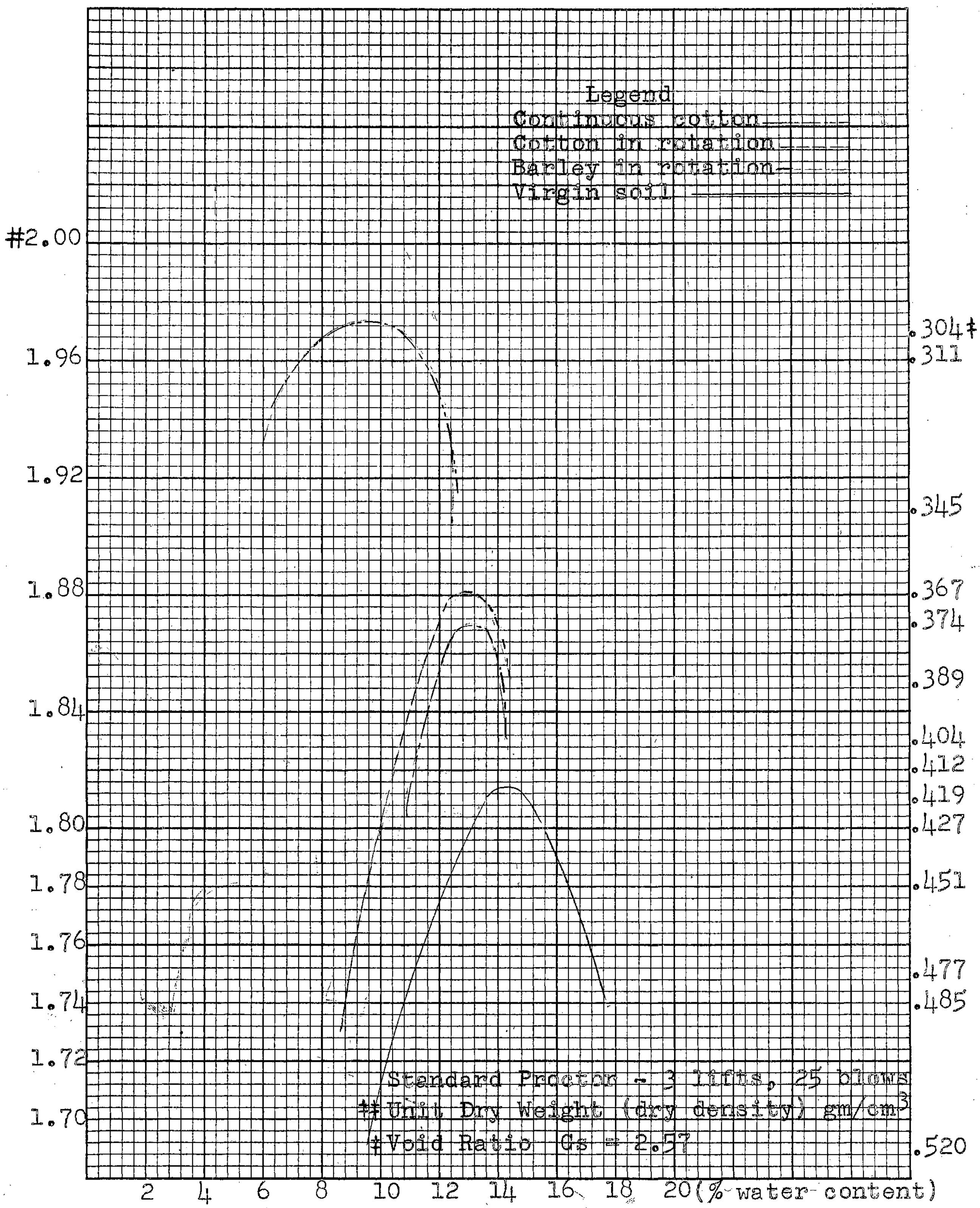

Figure 5--Optimum moisture content for maximum compaction

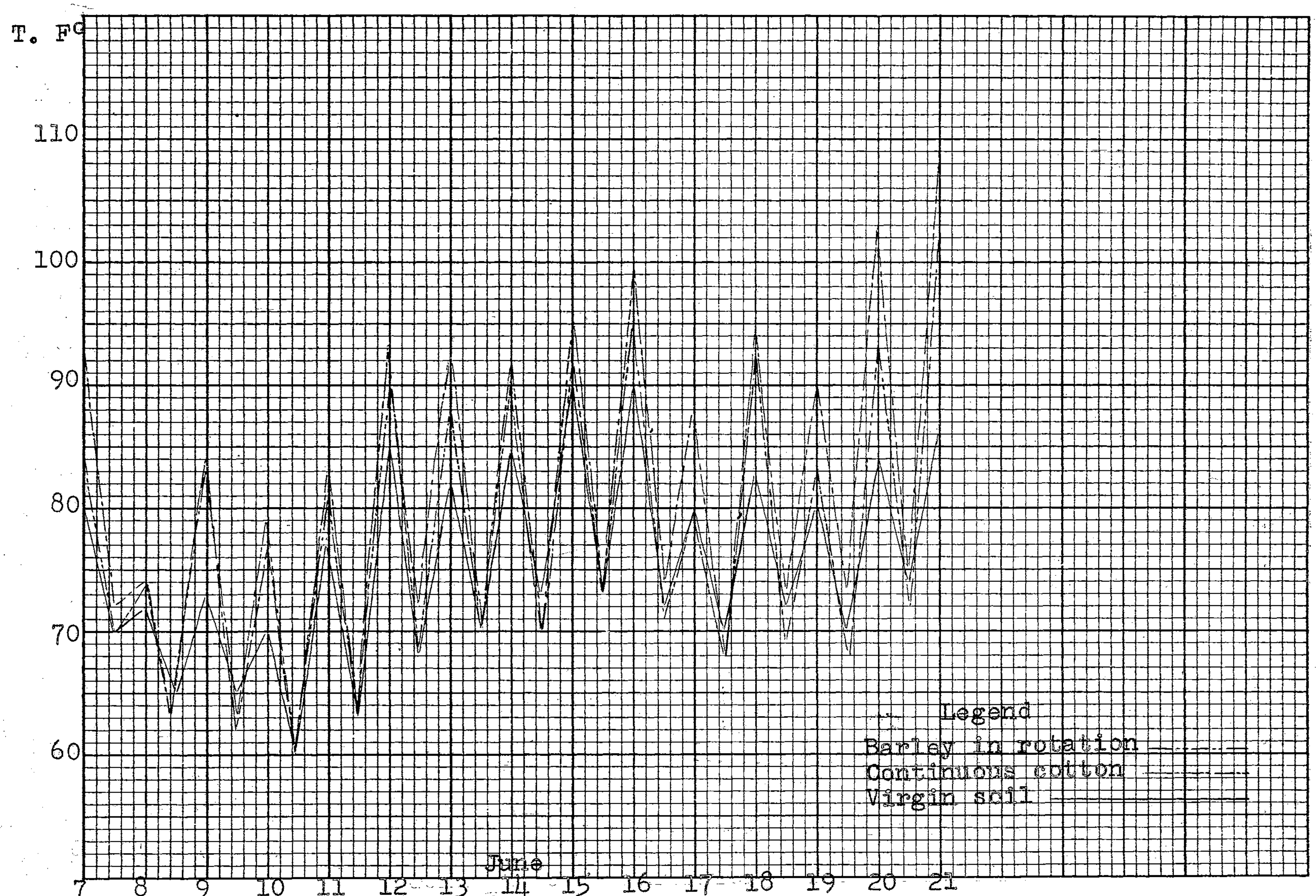

Figure 6--Soil Temperature (two inches deep)

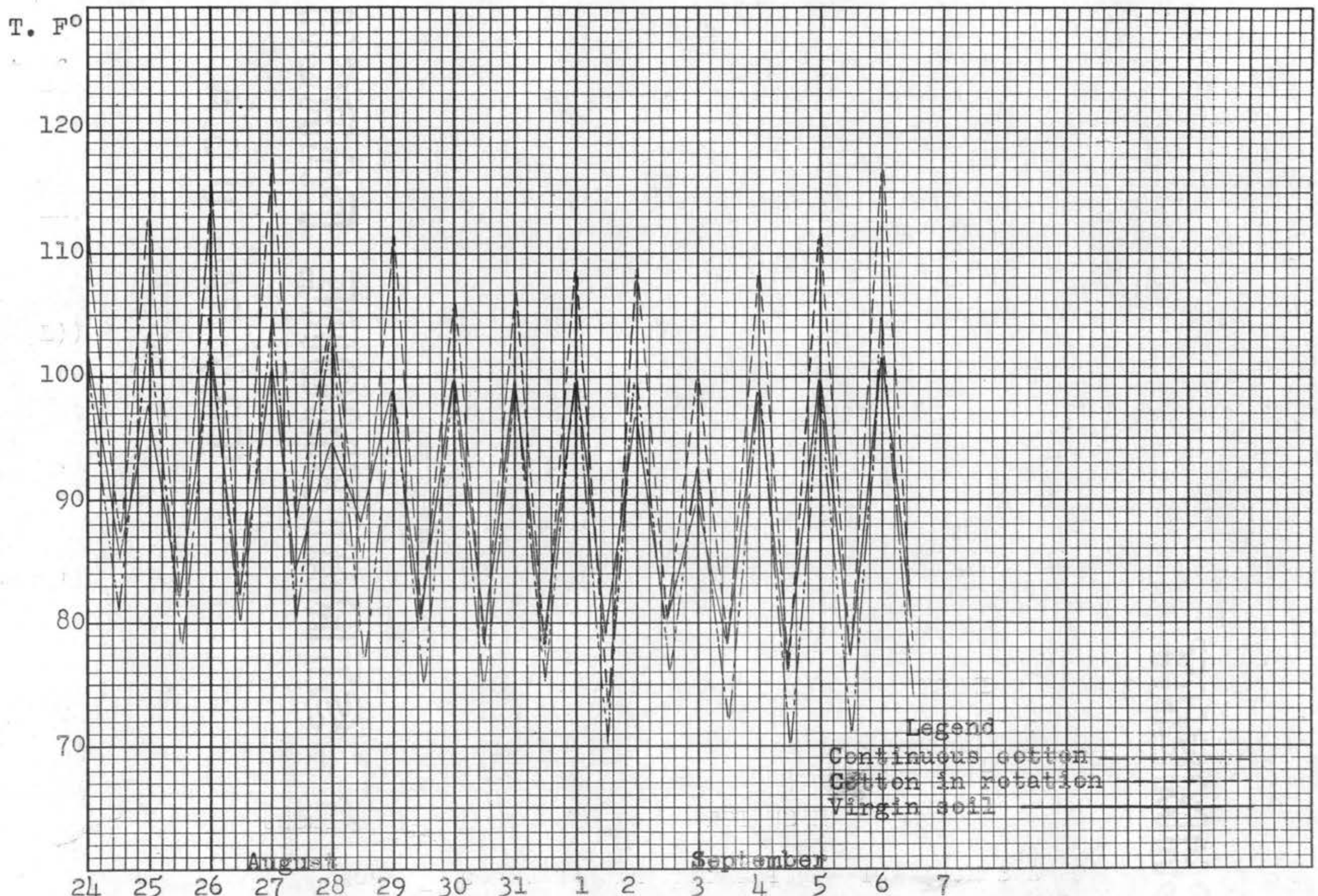

Figure 6 (cont.)--Soil Temperature (two inches deep)

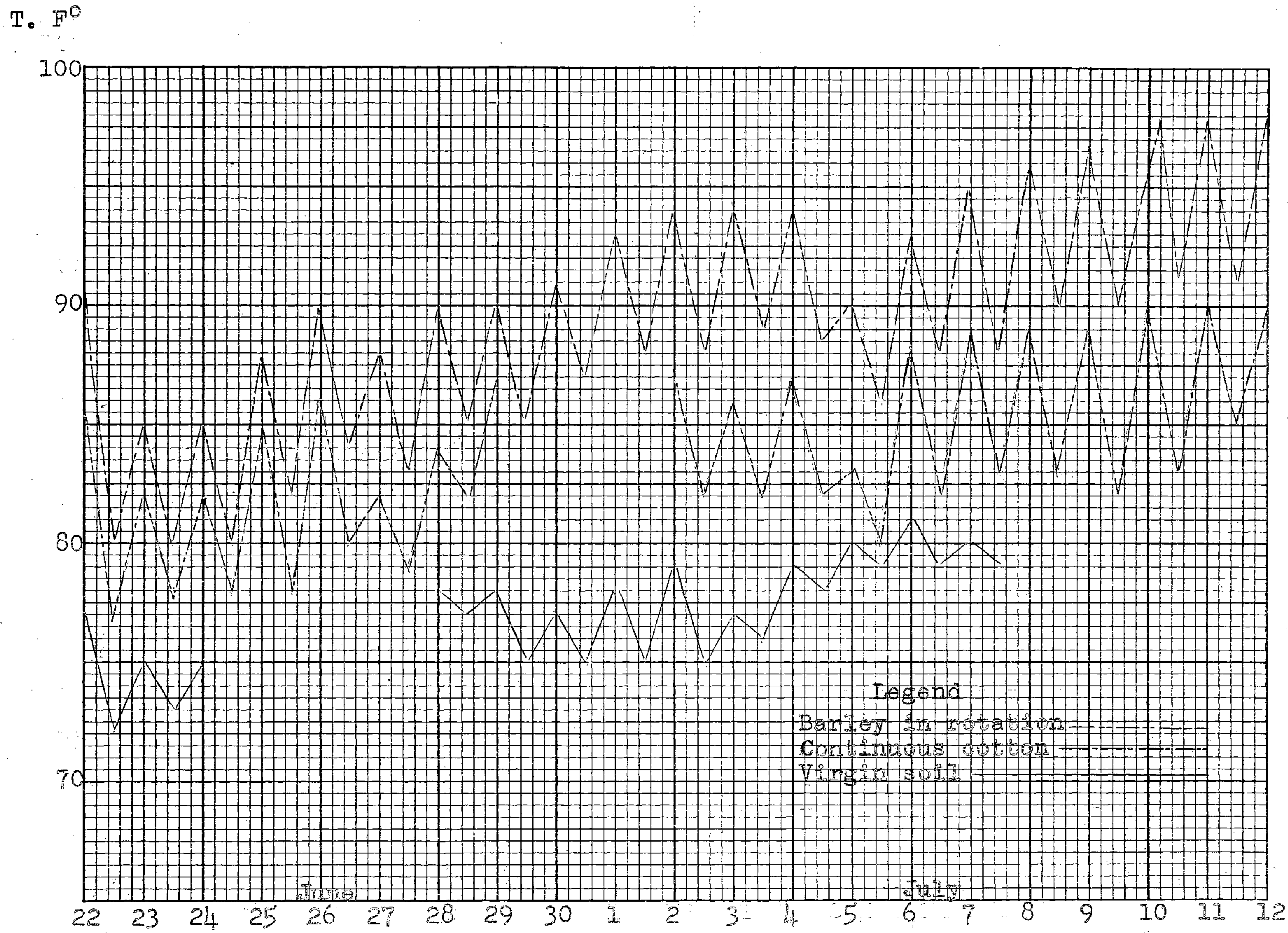

Figure 6 (cont.)--Soil Temperature (six inches deep)

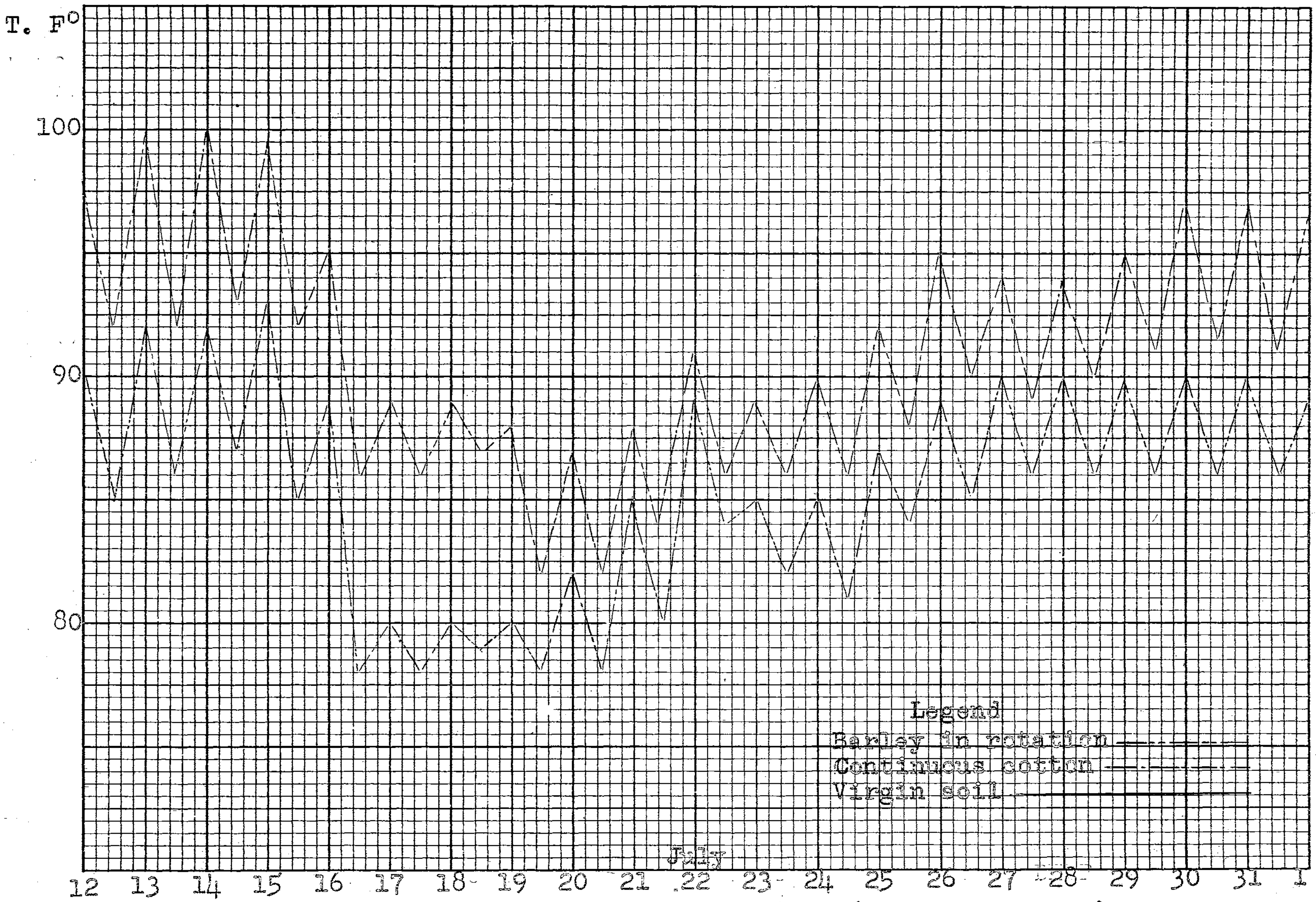

Figure 6 (cont.)--Soil Temperature (six inches deep)

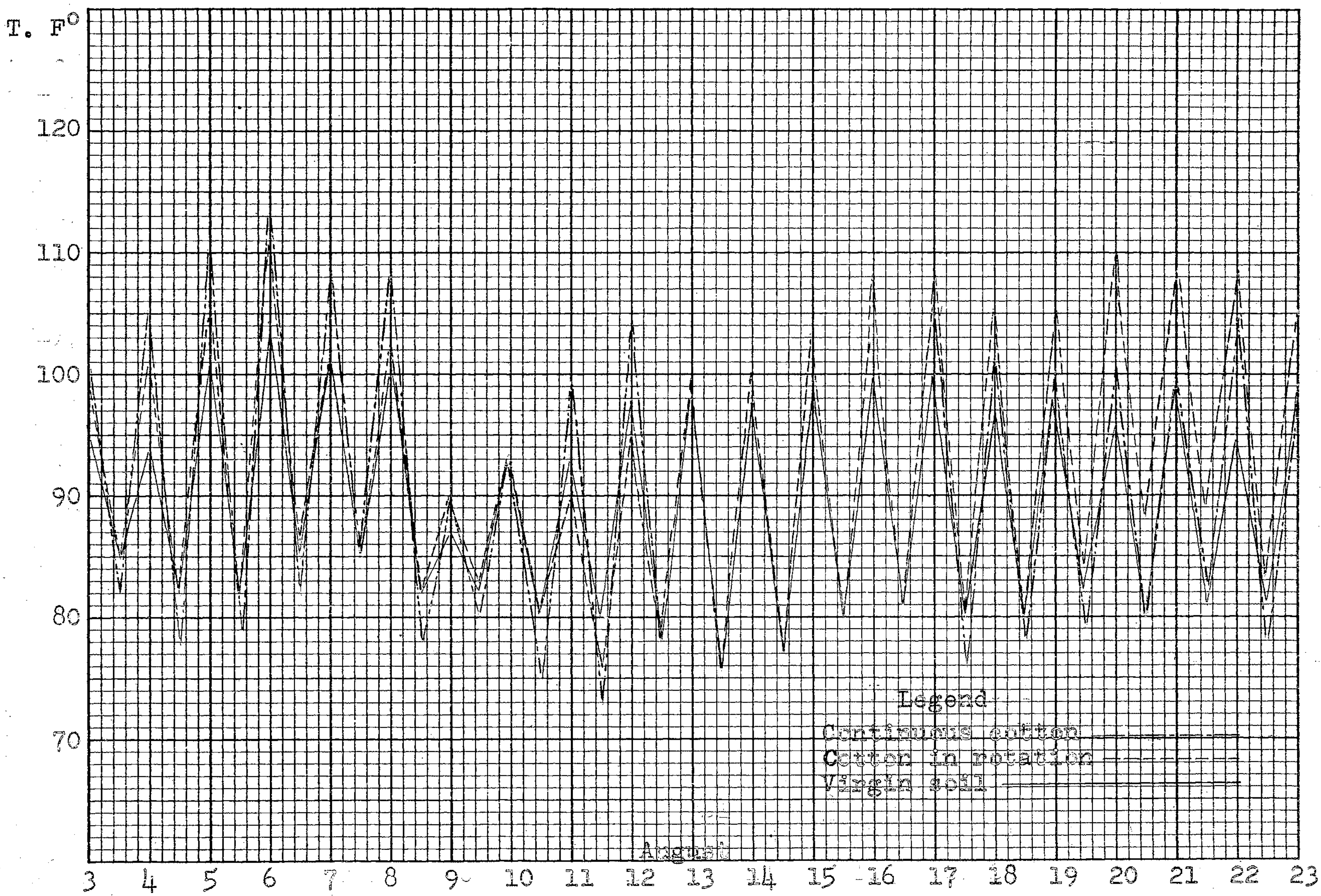

Figure 6 (cont.)--Soil Temperature (two inches deep)

SUMMARY AND CONCLUSIONS

An experiment was conducted on the Oklahoma Agricultural and Mechanical College Agronomy Farm near Perkins. The study was on the effect of different cropping systems and tillage practices on the ability of the soil to form a compacted layer. The effect of these cropping systems and cultural practices on several physical conditions of the soil were studied.

1. Bulk density measurements showed higher figures for the 5 to 8 inch layer, indicating the existence of a compacted layer at this depth.
2. A gradual increase in bulk density with depth in both the virgin and continuously cropped Norge Loam was determined.
3. Organic matter determinations showed a reduction of about 44 percent in the surface of the continuously cropped soil. Analysis of variance showed the 2 to 5 and the 5 to 8 inch depths to be significantly different in organic matter content between cropping systems.
4. There was no significant difference in particle size distribution due to the cropping systems. Silt was not significantly changed either with depth or cropping systems, while the percentage of

sand decreased slightly and clay increased slightly with depth.

5. The particle size distribution of a soil crust showed a higher percentage of clay and silt in the surface of the crust than directly below it. The intensity of the rains previous to the formation of the crusts and to the level condition of the field has resulted in little if any water lost as run-off, and the smaller silt and clay particles were deposited on the surface instead of being carried away by the run-off water.

6. A mixture of sand, silt, and clay seems to be present in about the right proportion for the smaller particles to occupy the pores between the larger ones when the particles are worked about and packed by the action of the raindrops to produce compacted layers in a Norge Loam when cultivated.

7. Infiltration studies seem to point out the effect of intensive cultural practices on the ability of the soil to take in water. Infiltration rates were much lower in every instance where the soil had been intensively cultivated.

8. Barley in rotation with alfalfa plots gave the highest infiltration rate. The fact that this was above the rate for a virgin soil was attributed to the loose and mellow condition of the surface soil. Although the barley plots were plowed and seeded

before either the continuous cropping or cotton in rotation plots, it was in a much better physical condition. This was believed to be because of fewer passes over the soil with heavy machinery and to the effect of the fibrous root system of the barley plants.

9. Compaction tests revealed that the continuously cropped Norge loam soil could not only be compacted to a greater degree, but also could be compacted at a much lower moisture content. This seems to point out the danger of working this soil when the moisture content is near the optimum for plowing.

10. The value of an organic mulch in reducing the surface temperature of the soil was shown in the virgin soil; however, the shading effect of the cotton at later growth stages has about balanced out this effect.

11. Periods of desiccation, along with the optimum proportion of sand, silt, and clay when cultivated, tend to produce compacted layers in the Norge loam.

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APPENDIX

APPENDIX TABLE 1

LABORATORY ANALYSIS OF NORGE LOAM

Virgin Soil:

Sample No.	Depth	Bulk Density	Organic Carbon	Size Class and Diameter of Particles (in mm.)						Other Classes (in mm.)	
				Coarse Sand 1-0.5	Medium Sand 0.5-0.25	Fine Sand 0.25-0.1	Very Fine Sand 0.1-0.05	Silt 0.05-0.002	Clay <0.002	0.02-0.002	Total Sand
	Inches		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
S1/2 1110A											
48	2-5	1.42	1.8	2.73	10.00	21.00	19.61	32.41	13.85	8.83	53.74
31	5-8	1.51	1.6	2.17	10.02	20.60	19.70	35.10	12.42	9.77	52.48
18	8-11	1.53	1.4	2.01	8.91	22.04	13.45	35.75	17.84	11.35	46.41
32	11-14	1.57	1.4	2.43	8.86	16.86	16.05	34.50	21.31	10.77	44.19
N1/2 1110A											
9	2-5	1.53	1.8	2.19	9.78	20.99	17.99	34.87	14.14	10.85	50.96
24	5-8	1.54	1.5	2.24	9.26	18.62	17.35	35.73	16.80	9.78	47.47
28	8-11	1.56	1.5	2.20	9.11	18.09	16.48	35.28	18.84	11.12	45.88
43	11-14	1.56	1.5	2.11	8.58	17.60	16.74	35.17	19.78	11.05	45.05
S1/2 1108B											
28	2-5	1.51	1.4	2.00	9.41	19.93	18.32	38.51	11.83	6.53	49.66
9	5-8	1.52	1.6	2.36	9.96	20.58	17.90	29.36	19.86	7.36	50.78
48	8-11	1.55	1.6	2.46	9.74	19.67	17.33	31.34	19.43	7.24	49.23
39	11-14	1.58	1.4	2.13	9.45	19.60	16.65	31.08	21.09	10.05	47.83

APPENDIX TABLE 1 (cont.)

Virgin Soil:

Sample No.	Depth	Bulk Density	Organic Carbon	Size Class and Diameter of Particles (in mm.)						Other Classes (in mm.)	
				Coarse Sand, 1-0.5	Medium Sand 0.5-0.25	Fine Sand 0.25-0.1	Very Fine Sand, 0.1-0.05	Silt 0.05-0.002	Clay <0.002	0.02-0.002	Total Sand
	Inches		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
N1/2 1108B											
37	2-5	1.40	1.8	2.45	10.85	20.68	19.43	31.88	13.67	7.28	54.45
35	5-8	1.49	1.8	2.22	9.88	15.60	22.95	30.33	19.01	7.09	50.66
39	8-11	1.55	1.6	2.41	9.84	20.03	17.37	30.74	19.59	7.53	49.67
43	11-14	1.56	1.6	2.34	9.28	19.17	17.26	30.95	20.99	16.69	48.06
N1/2 1110B											
24	2-5	1.50	1.4	2.31	10.18	21.15	19.76	33.90	12.70	9.24	53.40
32	5-8	1.52	1.4	2.33	10.05	20.27	18.62	32.72	16.01	10.70	51.27
18	8-11	1.52	1.5	2.06	9.01	18.74	17.37	31.30	21.52	8.96	47.18
14	11-14	1.57	1.5	2.01	8.82	18.71	17.05	33.37	20.85	9.93	45.78

APPENDIX TABLE 1 (cont.)

Continuous Cotton:

Sample No.	Depth	Bulk Density	Organic Carbon	Size Class and Diameter of Particles (in mm.)						Other Classes (in mm.)	
				Coarse Sand, 1-0.5	Medium Sand 0.5-0.25	Fine Sand 0.25-0.1	Very Fine Sand, 0.1-0.05	Silt 0.05-0.002	Clay <0.002	0.02-0.002	Total Sand
	Inches		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
S1/2 1007B											
45	2-5	1.49	0.8	2.85	9.08	33.25	21.43	18.16	15.22		66.62
44	5-8	1.64	1.1	2.58	12.07	26.36	20.12	29.43	9.44	6.02	61.13
35	8-11	1.51	1.4	2.53	11.02	22.04	17.63	33.97	12.80	10.03	53.23
48	11-14	1.59	1.4	2.49	9.78	21.27	17.46	32.04	16.97	10.03	50.99
N1/2 1007B											
38	2-5	1.40	0.8	2.13	10.82	24.53	20.94	30.87	10.71	5.68	58.42
42	5-8	1.65	1.3	2.58	10.99	22.35	17.00	32.82	14.26	8.72	52.92
47	8-11	1.56	1.2	2.30	9.98	20.37	16.70	31.70	18.94	10.09	49.36
24	11-14	1.57	1.2	2.16	9.93	20.43	16.26	31.98	19.12	10.10	48.90
S1/2 1007A											
33	2-5	1.62	1.0	2.27	11.62	24.36	20.88	28.78	12.09	6.78	59.13
46	5-8	1.65	1.2	2.69	10.99	21.43	16.72	32.81	15.66	10.12	51.83
34	8-11	1.63	1.2	2.07	9.46	19.38	18.72	33.41	16.94	8.41	49.65
37	11-14	1.61	1.4	2.39	9.63	19.63	16.87	30.95	20.52	7.81	48.53

APPENDIX TABLE 1 (cont.)

Continuous Cotton:

Sample No.	Depth	Bulk Density	Organic Carbon	Size Class and Diameter of Particles (in mm.)						Other Classes (in mm.)	
				Coarse Sand, 1-0.5	Medium Sand 0.5-0.25	Fine Sand 0.25-0.1	Very Fine Sand 0.1-0.05	Silt 0.05-0.002	Clay <0.002	0.02-0.002	Total Sand
	Inches		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
N1/2 1007A											
24	2-5	1.62	1.0	2.10	8.90	18.33	18.40	33.21	19.05	6.54	47.70
48	5-8	1.67	1.1	2.26	9.54	20.23	18.06	34.66	15.24	9.95	50.10
38	8-11	1.63	1.2	2.27	8.87	18.60	17.33	34.60	18.77	10.92	46.63
24	11-14	1.67	1.2	2.18	9.03	18.65	15.73	31.88	22.53	11.88	45.59
Crust	0-.25	1.59	1.1	2.17	8.76	15.27	16.31	43.51	12.45	12.53	44.04
Below Crust	1-3	1.39	0.96	2.85	10.55	16.80	16.70	41.96	11.08	10.31	46.95
S1/2 1009A											
42	2-5	1.63	1.0	2.26	10.79	22.42	19.06	31.73	13.72	6.04	54.55
48	5-8	1.64	1.2	2.22	9.44	20.12	18.06	32.28	17.88	9.21	49.84
34	8-11	1.61	1.4	1.96	8.24	18.70	16.86	33.50	19.55	9.03	46.95
33	11-14	1.56	1.5	1.71	8.29	17.78	16.97	33.06	22.18	10.51	44.76
N1/2 1009A											
44	2-5	1.54	1.2	2.04	9.46	20.42	19.95	33.53	14.61	9.00	51.86
45	5-8	1.62	1.2	1.89	9.15	19.70	18.45	36.89	13.92	8.38	49.19
38	8-11	1.59	1.2	2.05	8.83	17.38	15.03	35.66	21.05	13.26	43.29
45	11-14	1.60	1.2	1.85	7.91	18.25	16.15	34.06	22.96	12.28	42.98

APPENDIX TABLE 1 (cont.)

Continuous Cotton:

Sample No.	Depth	Bulk Density	Organic Carbon	Size Class and Diameter of Particles (in mm.)						Other Classes (in mm.)	
				Coarse Sand, 1-0.5	Medium Sand 0.5-0.25	Fine Sand 0.25-0.1	Very Fine Sand, 0.1-0.05	Silt 0.05-0.002	Clay <0.002	0.02-0.002	Total Sand
	Inches		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
S1/2 1009B											
36	2-5	1.64	1.0	2.59	12.63	26.86	20.49	26.52	10.89	7.28	62.59
47	5-8	1.68	1.0	2.06	9.49	19.85	18.62	37.31	12.66	8.93	50.03
41	8-11	1.53	1.3	1.70	9.20	20.04	17.84	35.23	15.80	10.81	48.97
26	11-14	1.63	1.4	2.17	8.95	18.64	16.71	36.19	17.34	11.35	46.47
N1/2 1009B											
46	2-5	1.65	0.9	2.86	12.13	24.46	20.83	29.17	10.53	5.49	60.30
35	5-8	1.66	1.0	2.43	10.82	22.10	19.54	34.47	10.64	8.16	54.89
43	8-11	1.57	1.0	2.16	9.74	20.72	18.73	32.45	16.20	8.51	51.35
37	11-14	1.46	1.2	2.05	9.49	20.18	19.13	34.43	14.72	7.69	50.85
S1/2 1012A											
32	2-5	1.48	1.0	1.77	8.82	19.78	20.03	36.03	13.58	8.21	50.39
14	5-8	1.59	1.3	1.78	7.89	16.77	17.66	37.81	18.09	12.38	44.10
11	8-11	1.54	1.8	2.02	7.60	16.16	16.73	35.12	22.36	12.65	42.52
39	11-14	1.54	1.6	1.45	6.59	13.74	15.35	38.81	24.05	13.89	37.14

APPENDIX TABLE 1 (cont.)

Continuous Cotton:

Sample No.	Depth	Bulk Density	Organic Carbon	Size Class and Diameter of Particles (in mm.)						Other Classes (in mm.)	
				Coarse Sand, 1-0.5	Medium Sand 0.5-0.25	Fine Sand 0.25-0.1	Very Fine Sand 0.1-0.05	Silt 0.05-0.002	Clay <0.002	0.02-0.002	Total Sand
	Inches		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
N1/2 1012A											
28	2-5	1.59	1.2	2.33	9.85	21.74	17.49	34.21	14.38	9.11	51.41
5	5-8	1.55	1.4	1.82	6.60	15.25	17.32	42.70	16.31	12.48	40.99
12	8-11	1.55	1.4	1.36	6.24	13.79	16.06	42.93	19.62	13.77	37.95
50	11-14	1.55	1.5	1.59	6.02	13.33	14.88	43.09	21.10	0.46	35.81
S1/2 1012B											
31	2-5	1.57	1.3	4.49	8.65	21.22	19.21	31.56	14.84	12.74	53.60
9	5-8	1.60	1.3	1.70	8.72	18.95	18.43	40.34	11.86	11.82	47.80
2	8-11	1.56	1.3	2.08	8.24	16.67	16.43	38.41	18.17	11.70	43.42
49	11-14	1.55	1.4	2.58	7.68	16.10	16.61	44.47	12.54	17.16	42.99
S1/2 1012B											
22	2-5	1.50	1.1	1.70	9.55	20.52	20.15	33.73	14.23	7.49	51.94
18	5-8	1.63	1.0	2.09	8.81	18.05	18.47	35.19	17.38	11.00	47.43
40	8-11	1.54	1.6	1.60	6.73	14.42	15.40	39.19	22.65	9.33	38.16
15	11-14	1.59	1.6	1.66	7.09	14.52	15.47	38.70	22.56	12.52	38.74

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