THE EFFECT OF THE MOLDBOARD PLOWSHARE CONDITION ON THE FORMATION OF "PLOW-SOLE"

By

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THESIS AND ABSTRACT APPROVED:

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PREFACE

These investigations were conducted during the summer and fall of 1950. The laboratory studies were conducted on the campus of Oklahoma A. and M. College, Stillwater, Oklahoma and the field studies were conducted near Blackwell Lake, located seven miles west of Stillwater, Oklahoma.

An effort has been made to acquaint the reader with some of the possible causes of the formation of "plow-sole".

The author corresponded with several agricultural libraries and some of the leading soil technicians in search for information which had any relation to the formation of plow-sole. The extent of existing information on this subject is surprisingly scarce. A brief review of literature which may have a direct relation to the formation of the "plow-sole" has been included.

The author wishes to express his appreciation to Professor E. W. Schroeder, Head of the Department of Agricultural Engineering, for the valuable cooperation in directing his graduate studies and for aid in the analysis of results and the preparation of the thesis.

The author acknowledges the contributions of Mr. Louis E. Derr, State Soil Scientist, Soil Conservation Service, for guidance in dealing with problems related to infiltration, permeability and the formation of the "plow-sole".

Mr. W. O. Ree, Project Supervisor, Soil Conservation Service (Research), Outdoor Hydraulics Laboratory, was very cooperative by allowing the use of a plot of soil on which to conduct the field studies.

Mr. James E. Garton, Department of Agricultural Engineering, gave valuable assistance by giving numerous helpful suggestions.

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Edd D. Rhoades

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I. INTRODUCTION

During the past 15 years tremendous strides have been made in the adoption of soil conserving practices in the farming industry throughout the United States. This trend, to conservation farming, has been accelerated by the efforts of the many agricultural agencies, both public and private, the many agricultural colleges and individual farmers. The program of conservation farming began to receive increased publicity during the drouth years of early 1930-1935, because people began to realize that the soil was not an everlasting source of food, without proper management. The war years from 1940 to 1946 called for an all out effort to produce more food. This was accomplished at the partial expense of proper land management.

The "plow-soles" or plow-pans, and other dense subsurface layers found in some agricultural soils are recognized for their detrimental effect on plant development. These relatively impervious layers interfere with proper soil drainage and reduce the availability of moisture by checking its capillary rise.

The term "Plow-Sole", refers to the hard compacted strata of soil, characterized by a high apparent density and a low permeability rate, which occurs immediately below normal plow depth. Its upper limit is the lower limit of the soil mulch established by cultivation and it has been found to vary in thickness from a very thin, almost microscopic layer to 3 inches. The hardness or resistance to penetration of the plow-sole varies from a thin brittle crust to a layer difficult to penetrate with a spade. When the "plow-sole" is moist it is usually soft and easily broken. When the soil profile is moist the "plow-sole" may be felt with a small probe.

The problem of "plow-sole" exists in practically all of the area of Oklahoma in cultivation, with particular emphasis being made in the rolling red plains, reddish prairie, cross timbers, cherokee prairies and high plains.

Compaction of soil may be defined as a process whereby the individual particles of a soil are forced more closely together by some outside force being applied. Compactive forces are dynamic and originate from a wide variety of man-made and natural sources. Common sources are rolling vehicle wheels, trampling by livestock and the impact of rainfall. The end results are always a reduction of soil porosity and an increase in soil density, the latter being a common measure of compaction. The compactibility of a soil is dependent on its moisture content, colloid content, grain size distribution, initial density and the magnitude of the compactive forces.

In common agricultural practice, normal tillage operations prevent the occurrance of permanently compacted zones in the surface soil. It is of importance however, that those agents which contribute to compaction below the tilled layer be recognized.

Field observations show that the detrimental effects of this "plow-sole" condition are numerous. Other than the effect on drainage and non-capillary porosity, this compacted layer or zone may also 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.

Though these detrimental conditions have been in a large measure attributed to chemical cementation of soil particles, there is evidence to show that physical compaction is an important factor. Nikiforoff et al.[12]

found that certain hardpans in Coastal Plain Soils were caused by physical compaction.

The elimination or a reduced effect of "plow-sole" conditions will have the following desirable effects; (a) increased rate of infiltration and permeability, resulting in decreased rates and amounts of run-off. A relatively small increase in infiltration and permeability may eliminate run-off from a large number of rainfall storms, therefore reducing soil erosion. (b) Increased crop yields resulting from a more readily available supply of soil moisture.

Considerable confusion exists over the meaning and use of the term "infiltration" and "permeability". Infiltration refers to the entrance of a fluid <u>into</u> a medium and permeability refers to the movement of a fluid <u>through</u> a medium. Many definitions of these terms are to be found in textbooks and current literature. Infiltration may be said to refer to the absorption of liquid water by a zone of aeration. In rainfall and irrigation studies it usually refers to the passage of water into the soil surface. Permeability of soils refers to a specific dynamic property of each macroscopic volume element of soil, namely the readiness with which each volume element transmits water. In a quantitative sense it is the amount of water that will cross a unit area in the soil in unit time under the action of unit driving force.[1]

Therefore, from the above definitions, the infiltration interface may be visualized as the "gateway" into which water must pass to enter the soil. This interface is infinitesimally thin.

Infiltration may be controlled by the permeability of a lower strata, and hence by the degree of saturation of the soil just below the infiltration interface.

In analyzing this problem of "plow-sole" formation it appears that there may be several reasons for the existance of this restrictive zone or layer: (1) compaction by heavy equipment, (2) plowing and tillage operations when soil is at or near its optimum moisture content for compaction, (3) using dull or improperly set tillage equipment, (4) plowing or stirring at approximately the same soil depth year after year, (5) the settling out of the finer soil separates of silt and clay upon the plowed zone or at the contact point between the tilled and non-tilled soil, and (6) leaching of soluble elements from the upper soil horizon which may settle out at some defined zone.

Tillage operations are among the greatest consumers of power on the farm. More than 50 years ago King[8] showed that plowing with the moldboard plow involved the shearing, lifting, inversion and pulverization of soil, all of which occur in opposition to the cohesive, adhesive, frictional, and mass properties of the soil.

However, his study did not show any information regarding the effect of plowing on the zone immediately below the plowed depth.

Trullinger[17] says:

> For purposes of engineering studies of tillage, the soil at any particular instant, is considered to be a dynamic body in equilibrium. When subjected to external forces, such as plowing or tillage, which tends to rupture or distort its form or structure, it is momentarily thrown out of equilibrium and unbalanced forces cause it to react in certain definite ways until it again reaches a state of equilibrium.

Nichols[11] showed by extensive research with the moldboard plow that its design was very important in the manner in which it accomplished its purpose. He explained that as the point of the plow advances in the soil its bluntness, compared with soil particles, catches a part of the soil which it drives ahead in the form of a wedge. This soil wedge is compressed until its resistance to compression equals the resistance encounted in driving it into the soil. As this wedge advances through the soil there is a constant rolling motion of the soil along its sides due to the interlocking of small particles. Then the force required to roll or slide soil over soil, may be termed internal frictional resistance or "shear". "Shear" of the soil in tillage practice is usually preceded by a compression of the soil when the moisture is within what is ordinarily considered the plowing range. The lower plastic limit of the soil is usually considered near the point at which good tillage conditions occur. His study did not include any effect of plowing upon infiltration or permeability of the soil immediately beneath the plowed depth.

In highway construction, where compaction of earth fills is of significant importance, it has been determined that with proper moisture control light equipment may give superior results to those obtained from very heavy equipment without proper moisture control.

By analyzing the previous paragraphs it may be reasonable to assume that when plowing with a moldboard plow the compressed soil wedge which forms in front of the plowshare is either fractured by "shear" or "tension". If the failure or rupture of the wedge is by tension, a condition of "gouging" may exist in the plow furrow. The wedge, then is usually carried with the plow slice over the curvature of the moldboard and is pulverized by its inverting action. However, if this wedge is fractured by shearing action, the initial point of breakage must be some slight unknown distance in front of the leading edge of the plowshare. Assuming that the fracture is directly in line with the greatest forward thrust, that is, directly in front of the leading or cutting edge of the plowshare, a portion of the compressed soil wedge will be left in the bottom of the plow furrow. It may also be assumed that the amount by which the soil wedge is compressed by the given force is primarily dependent on the moisture content. Likewise, if there is a rolling motion of soil on soil, there is possibility of creating a puddled condition.

With the above assumptions and possibilities, the condition of the layer or zone of soil immediately beneath the plow depth is a factor in the formation of "plow-soles". Observation of plowing with a moldboard plow show combination of "gouged" areas below the cutting edge of the plow, intermingled with a shiny, glazed surface at exactly the depth of the cutting edge of the plow.

An important need exists for conducting investigations which will determine the effect of tillage machinery on the intake rate of moisture through this zone immediately below the tilled depth.

II. OBJECT

The purpose of this study was, therefore, to determine the effect of moldboard plowshare condition on the formation of "plow-sole". Specific objectives were:

1. To investigate the relation of soil moisture content to the compactibility of the test soil.

2. To determine the liquid and plastic limits of the test soil.

3. To determine whether or not the use of a moldboard plow was capable of affecting the permeability of a soil.

4. To determine by comparison the difference in permeability caused by plowing with sharp and dull plowshares.

5. To investigate the effect of the tractor furrow wheel on permeability.

Objectives 1 and 2 are discussed in the section of this paper entitled "Laboratory Studies". Objective 3, 4, and 5 are discussed in a subsequent section entitled "Field Studies".

III. PREVIOUS WORK

A review of available literature indicates that a relatively small amount of research or investigation on this subject has been done in the past, therefore there is a scarcity of reliable information on the subject.

Numerous investigations have been made which are indirectly related to the formation of "plow-soles". Most of these investigators studied the effect of some dynamic force on the compactability of certain soils under specific conditions.

Data obtained by Woods[20] on numerous soils show the general relationship existing between certain soil constants and the maximum dry density attainable under a given compactive effort. He demonstrated that the maximum dry density varies inversely with moisture content for the soils studied at each of the following soil constants:

1. Upper Plastic or Liquid Limit
2. Lower Plastic Limit
3. Plasticity Index
4. The Optimum Moisture Content for Maximum Compaction at a Given Compactive Effort.

In brief, the greatest compacted dry densities were attained at relatively low moisture when associated with soils of low plasticity indicies.

Nikiforoff et al.[12], op. cit.

> Splitting of the hard-pans along the cleavages shows a moist glistening surface heavily coated with gray clay over which are distributed imprints of living roots. In general, roots, except for the finer ones common in the streaks to the very base of the pan, do not penetrate the hard-pan. Direct examination of hard-pan in the field suggests that its hardness is not due to cementation. This was further demonstrated by several simple experiments. Lumps of hard-pan submerged in water or in contact with water disintegrated completely and almost instantly. Such rapid slacking would not be expected if the pan were cemented.

Parker and Jenny[13] at the California Citrus Experiment Station studied soil compaction by track type tractor and by repeated disking. Their investigations revealed: Citrus growers usually witnessed good water penetration in young orchards but within a few years after the orchard was planted, the infiltration capacity often declined. The presence of a zone of soil compaction in the orchards as suggested by probe resistance values was confirmed by a study of volume weights.

They also reported that on dry Ramona loam soil, near the wilting point, the effect of compaction and cultivation on water infiltration in the first irrigation after treatment was very striking. Treatment consisted of traversing a plot of ground so that every part of the plot was traversed 33 times with a 2-ton Caterpillar tractor and an adjacent plot was disked 50 times with a wide double disk, having 22 inch diameter, which penetrated the soil about 6 inches. Furrows were made having the same slope on the tractor treated plot, disked plot, and on two adjacent check plots. Indicies of rates of water infiltration were determined by means of a "constant flow method". Four liters per minute entered the upper end of each furrow. The position of the front of the stream running down the furrow was then recorded at various time intervals. The tractor and the disk treatment were both very detrimental to water infiltration. In five hours water traveled nearly 3 times as far in the furrows of the treated plots as in those of the check plot, a condition which reflected poor water penetration in the former.

Reed[15] at the U.S.D.A. Tillage Machinery Laboratory measured tractor tire compaction of soil in terms of soil resistance to an electrically operated penetrometer probe. He found that the mean value of resistance to penetration was greatest beneath the centerline of the tire track and receded to a normal uncompacted value at approximately 15" from the centerline. He also observed that the resistance was greater beneath a preumatic rear tire than beneath that of a crawler track or a steel lug-equipped wheel. This condition indicates poor water penetration. His work did not include a study on the effect this had on infiltration or permeability.

Weaver[19] in a study of tractor use effects on volume weights found that maximum normal annual use of a preumatic tired tractor was capable of compacting soil to a depth of nine inches when the soil is near optimum for plowing. Hiw work did not include a study of infiltration or permeability on these test plots.

Jensen[7] in California apparently has conducted more research on the subject of "plow-sole" formation than any other individual. He found that if soil from citrus groves was put in pots and irrigated and the surface layer stirred to form a soil mulch, a hard crust would form under the mulch by the time all of the soil was dry. Soil immediately below the crust usually retained a crumbly structure and did not harden. He observed that "plow-soles" did not form under citrus trees where the soil had not been cultivated, especially where 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 were formed during rainy seasons when the "plow-sole" was soft and maintained in a moist condition.

McGeorge and Breazeale[9] reports:

> Structural breakdown is most often attributed to careless tillage. Soil structure will be seriously disturbed when a soil that is within a certain range of moisture content which reaches its

> maximum at the moisture equivalent is subjected to some type of mechanical disturbance. Within this range of moisture content the soil particles tend to arrange themselves into a compact mass of impermeable material.
>
> The degree of puddling is a function of the moisture content of the soil at the time it is plowed, cultivated, or otherwise disturbed. While maximum puddling or compaction occurs at the moisture equivalent, lesser compaction will take place within a certain range both above and below this point.

Several years ago the Soil Conservation Service developed field techniques and equipment for measuring infiltration rates of soils. The use of this equipment began to show some very striking information in regard to the rate in which soil would take water. In analyzing the results of these infiltration tests, it was observed that sometimes fine textured, slowly permeable soils would take water more readily than coarse textured freely permeable soils. Upon field examination it was determined that some soils had restrictive layers at depths where tillage implements had been used. This zone, up to three inches in thickness, appeared to be the "bottleneck" on infiltration rates. Numerous comparisons were made on a given soil by first making infiltration tests on the original undisturbed soil and then removing the surface plus the observable compacted zone and making additional infiltration tests. In most all observed tests the infiltration rates were many times faster on the zone below the apparent restrictive layer.

This investigation led to further studies on the effects of "plow-sole" on the ability of crops to develop adequate root systems. Many short growing crops such as wheat, soybeans, vetch, etc., would not extend their root systems below the plowed mulch. The roots of the plant upon reaching the compacted zone or "plow-sole" in many instances would completely stop development or turn at right angles and follow along the top of the restrictive layer. See Figs. (1) and (2).

Professor G. B. Bodman and Professor C. F. Shaw[3] in 1927 made density determinations under and between citrus trees, respectively, on two or three soil types in Southern California, and found, many times, a striking difference in porosity between the two positions. Immediately beneath the overhanging branches of the citrus trees, beyond the reach of the cultivating implement, the soil frequently had a higher porosity and lower bulk density. These results were mimeographed but the supply has long been exhausted.

Bull[5] 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 soils having "plow-soles". Analysis show these soils to be low in organic matter, usually less than 1.5 percent.

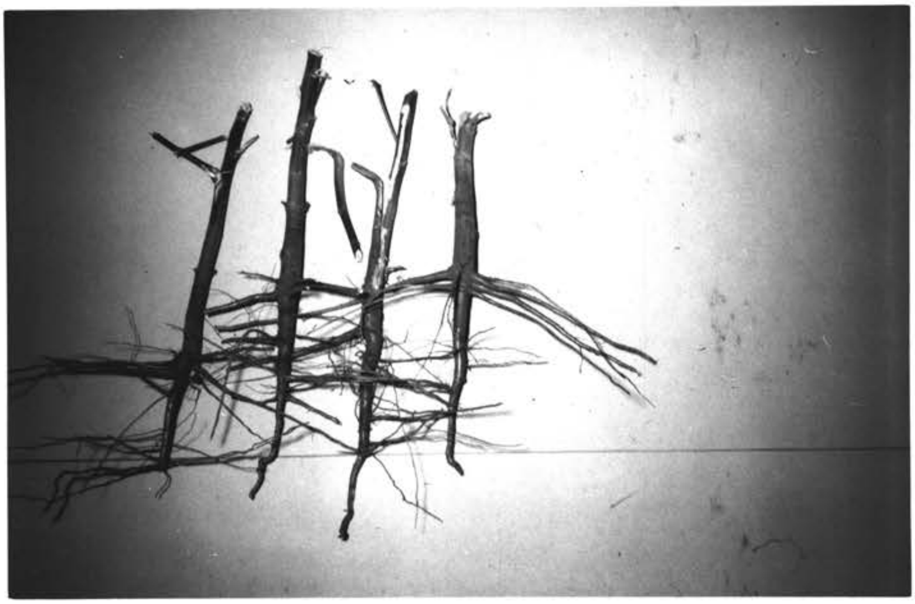

Fig. 1 - This picture shows a group of 4 cotton plants removed from the Agronomy Farm of Oklahoma A. & M. College, during the Fall of 1950. "Plow-sole" conditions were found to exist on this plot at a depth of 6.0 inches from the surface. The plant roots indicate they encountered some form of difficulty in penetrating the soil at that depth as shown at the black line in the picture.

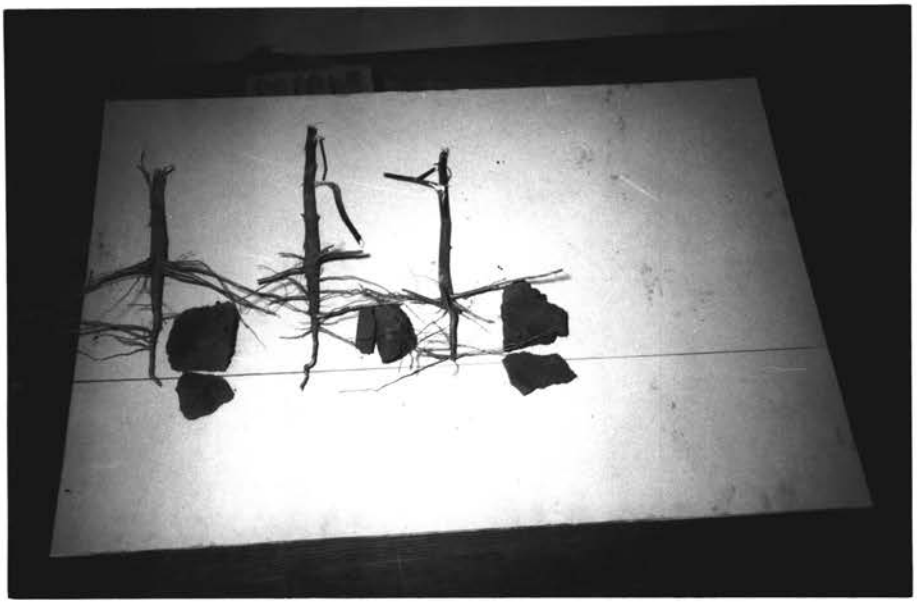

Fig. 2 - This picture shows a group of cotton plants removed from the Agronomy Farm at Oklahoma A. & M. College during the Fall of 1950. Also is shown the formation of a "Plow-sole" condition that was found to exist at a depth of 6.0 inches. Note the smoothness of the fractured soil samples at the 6.0 inch depth. The plant roots encountered difficulty in penetrating this zone. Presence of this condition was observed throughout the summer of 1950 by use of an Oliver Core sampler and also by the use of a spade.

IV. DESCRIPTION OF TEST SOIL

The soil plot selected for test was on an old abandoned cultivated field, approximately one-eighth mile downstream from Lake Carl Blackwell, Stillwater, Oklahoma. This site was selected because of its proximity to a ready source of water supply which was anticipated to be needed to control the moisture content of the soil during the investigations. The area had been retired from cultivation sometime prior to the construction of the dam. The site was on a deep, medium-textured, very slowly permeable soil in the reddish prairie area. It was a brown silt loam which when dry was relatively massive. Although the soil was on a slope of approximately one percent, there was evidence of erosion. The surface crust is very plaity, which indicates a very slow intake of water. The surface crusts to approximately 1/4 inch thickness, following application of rain or irrigation water; that is, the surface soil breaks down readily. This condition indicates that the percentage of water-stable aggregates in the surface soil is very low.

There was considerable indication of insect activity, which would tend to granulate and open the soil. Vegetation consisted almost entirely of threeawn (Aristida) grass. The only recent cultural practices consisted of a double disking to a depth of approximately 3 inches with a tandum disk in the Spring of 1950. The area was then seeded with African Weeping Lovegrass (Eragrostis Curvula), however a dry spring season prevented a large growth of vegetative cover.

Preliminary investigation of the plot revealed that a so called "Plow-sole" condition existed at approximately 6 inches depth. It was determined that the area had not been plowed at that depth in more than twelve years. A distinct horizontal fracture at that depth was easily produced by jarring a 12 inch profile secured by a spade. There appeared to be a very thin compacted crust at this depth. This fact was proved by the use of an Oliver Core sampler and a probe.

In order to obtain a study of the soil grain size distribution in the vicinity of this plow-sole formation, duplicate soil samples of soil were taken as follows:

(1) Two samples of soil 2.5 to 3 inches above the fracture

(2) Two samples of soil 0 to 1/3 inch above the fracture

(3) Two samples of soil 0 to 1/3 inch below the fracture

(4) Two samples of soil 4.0 to 4.5 inches below the fracture.

The Bouyoucos[4] hydrometer method of mechanical analysis of grain size distribution was used. The results of this determination is shown in Table 1. This study reveals no particular excess accumulation of clay or silt in either zone adjacent to the fracture plane.

It was necessary to completely destroy the presence of this plow-sole prior to the proposed test, therefore the plot of ground was cultivated to a depth of 10 inches July 5, 1950 with a Graham-Hoeme plow, equipped with chisel and knife assembly. This cultivation was repeated four times with direction of travel changed 45 degrees each cultivation. This treatment left the soil in a loose pulverized condition.

Table 2 shows the date and amount of natural rainfall that fell on the plot after the above cultivation and prior to any test plowing.

From the previous discussion as outlined in the introduction of this paper, it was decided that the effect of plowing on permeability below the plowed layer using sharp and dull plowshares should be investigated at different moisture percents.

TABLE 1

	2.5-3.0" Above Horizontal Fracture	0-1/3" Above Horizontal Fracture	0-1/3" Below Horizontal Fracture	4.0-4.5" Below Horizontal Fracture
Sand	24.8	22.4	22.0	16.6
Silt	52.7	51.0	50.5	49.8
Clay	22.5	26.6	27.5	33.6

Average of duplicate determinations of grain size distribution by Bouyoucos Hydrometer method of mechanical analysis

TABLE 2

Date	Amount Of Rainfall In Inches	Date	Amount Of Rainfall In Inches	Date	Amount Of Rainfall In Inches
7-7-50	1.59	8-1-50	1.51	9-5-50	0.44
7-10-50	0.96	8-2-50	0.69	9-13-50	0.39
7-13-50	0.26	8-4-50	0.02	9-14-50	1.33
7-17-50	0.67	8-15-50	0.16	9-15-50	0.42
7-18-50	0.54	8-17-50	0.07		
7-19-50	0.34	8-21-50	0.19		
7-20-50	1.81	8-23-50	0.56	10-3-50	0.20
7-21-50	1.30	8-26-50	0.05		
7-22-50	0.46	8-29-50	0.47		
7-23-50	0.17				
7-29-50	0.64				

Rainfall record as recorded at the Outdoor Hydraulics Laboratory, Lake Carl Blackwell, between the period of July 5, 1950 to October 21, 1950.

V. LABORATORY STUDIES

A. Compactibility of Test Soil

1. Equipment

The equipment used in the laboratory studies was the same as that normally used by dam and highway construction engineers to determine soil moisture-density relations and met the specifications required for performance of the Standard Proctor Compaction Procedure[14]. The apparatus is shown disassembled and partially assembled in Figs. (3) and (4) respectively.

Fig. (3) shows a base plate (A) recessed slightly to accomodate a 10.31 cm. diameter brass compaction cylinder (B) which has a capacity of 972 cubic centimeters. Thumb screws on the base plate and flanges on the cylinder furnished a means of securely attaching the two parts. A collar extension (C) was placed on the cylinder to provide room for excess soil. A compacting drop hammer (E) was inclosed by the tubular sleeve (D) which controlled the height from which the hammer was dropped.

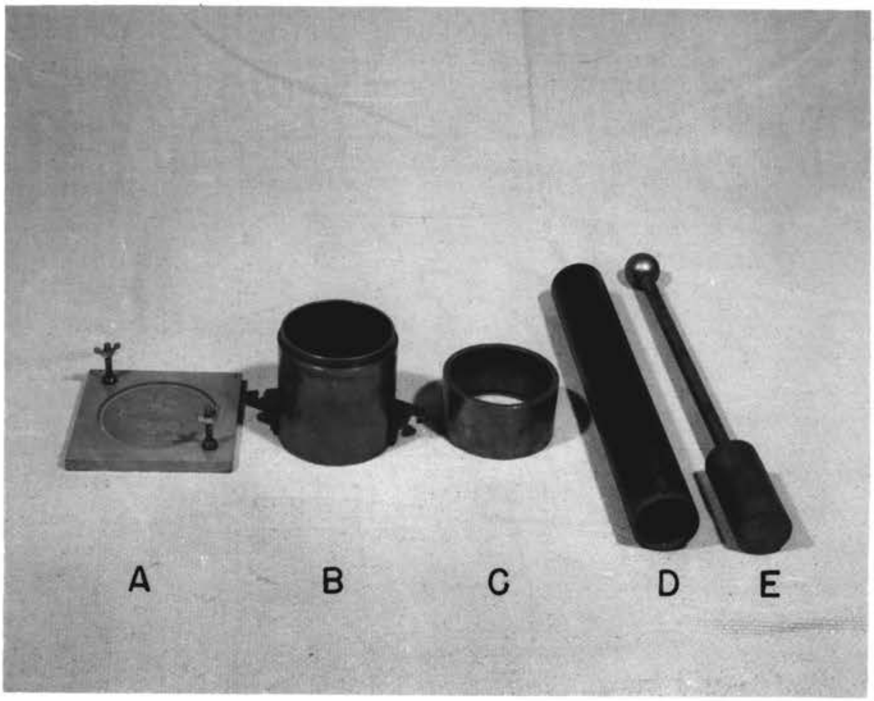

Fig. 3 - Standard Proctor Apparatus for Determination of Optimum Moisture Condition for Maximum Soil Compaction (Unassembled).

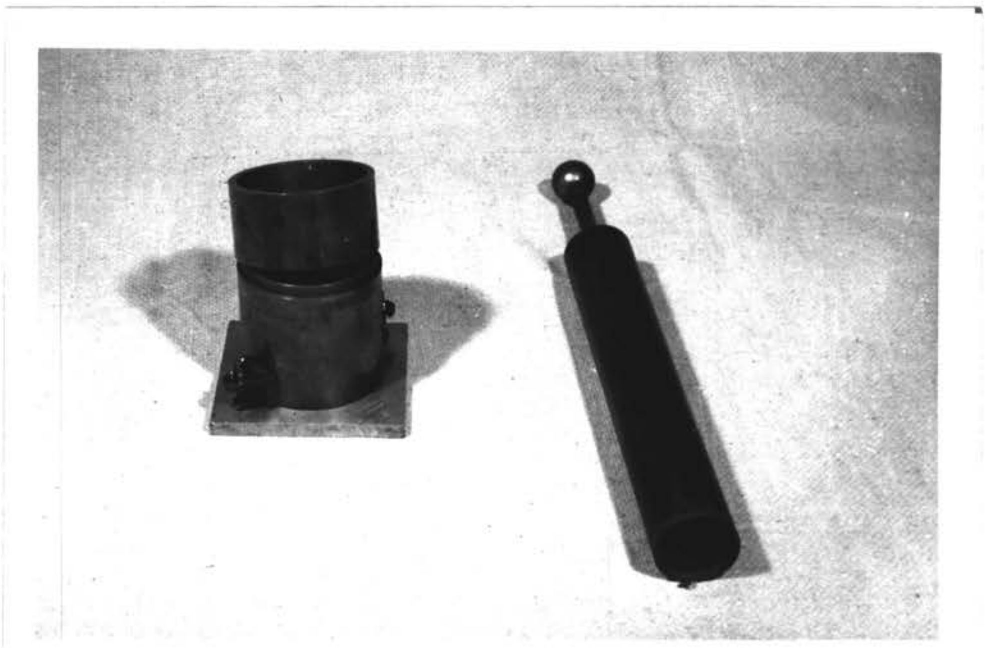

Fig. 4 - Standard Proctor Apparatus (Partially Assembled).

2. Procedure For Proctor Test

The Standard Proctor Procedure was slightly modified in two tests to show that maximum compaction is obtained at different moisture percentages when varying the compactive effort. Therefore, the extent of compaction of the soil wedge in front of the plowshare when plowing primarily depends on the moisture content and the compactive effort. However, the compactive effort is dependant on the shearing strength or the tensile strength. The shearing strength and tensile strength probably decreases with an increase in moisture percent.

The equivalent of approximately 6 pounds of dry soil was used throughout each test. In the Standard Proctor test the soil is compacted by tamping the soil in three layers of about equal thickness, each layer in turn being subjected to 25 blows by the $5\frac{1}{2}$ lb. drop hammer, each blow having a free full of 12 inches. The two modified tests were similar to the Standard, except one was subjected to 20 blows on each of the three layers and the other was subjected to 30 blows on each of the three layers. This operation was repeated at various soil moisture contents ranging approximately between 3.5 and 19.0 percent of the dry weight.

After each operation the collar was removed and the excess soil was struck off flush with the upper edge of the cylinder. The soil remaining in the cylinder was then weighed and a small sample of approx. 100 grams was taken from the center of the cylinder for moisture determinations. Dry density determinations were made by correcting the weight of the compacted soil for moisture content and dividing the result by the cylinder volume.

Before each packing operation the soil was screened through a square mesh sieve having 1/4 inch openings.

3. Results of Compactibility Tests

The data obtained from the laboratory test are shown in Table 3. The table is divided into three sections, each representing a given compactive effort. The left-hand column in each section contains the moisture content at which the soil was compacted and the right-hand column contains the corresponding values of dry density.

The data in Table 3 are also illustrated graphically in Fig. (5). Each curve represents the moisture density relations for a given compactive effort.

TABLE 3

MOISTURE-DENSITY RELATIONS OF THE TEST PLOT AT THREE COMPACTIVE EFFORTS

Compactive Effort 20-Impacts Per Layer With 5½ Lb. Hammer Having 12 Inch Free Fall (Modified Proctor)		Compactive Effort 25-Impacts Per Layer Of Soil With 5½ Lb. Hammer Having 12 Inch Free Fall (Standard Proctor)		Compactive Effort 30-Impacts Per Layer Of Soil With 5½ Lb. Hammer Having 12 Inch Free Fall (Standard Proctor)	
Water Content (% dry weight)	Dry Density (gm/cc)	Water Content (% dry weight)	Dry Density (gm/cc)	Water Content (% dry weight)	Dry Density (gm/cc)
5.07	1.59	3.48	1.63	3.28	1.65
6.09	1.61	4.21	1.64	5.32	1.66
7.24	1.64	5.17	1.61	6.38	1.67
8.40	1.65	6.42	1.64	8.08	1.75
9.58	1.71	10.57	1.76	10.08	1.81
10.71	1.74	12.05	1.84	11.98	1.88
11.72	1.77	14.30	1.83	14.11	1.85
13.10	1.79	15.66	1.79	15.25	1.80
13.98	1.82	17.83	1.73	18.28	1.71
15.00	1.79				
16.47	1.75				

4. Discussion of Compactibility Tests

As the moisture content increased in each test, cohesion was gradually offset by increased lubrication between the soil particles and each curve of Fig. (5) reached a peak density. Beyond this peak, increases in moisture percent proportionately increased void ratios, resulting in a lowering of the dry densities.

The greatest compactive effort produced the greatest dry densities. The moisture content at which peak densities occurred was greatest when the compactive effort was lowest and decreased progressively with increases in compactive effort.

The moisture content at which peak compaction occurred lies between 12.0 and 14.0 percent, the exact value depending on the magnitude of the compactive effort.

The laboratory procedure is not comparable with plot compaction by reason that it dealt with a confined soil of known magnitude. Field soils are relatively unconfined and the weight of soil affected by a given compactive effort cannot be said to remain constant throughout a given moisture range. The compactive force exerted by the plowshare on the soil wedge is difficult to determine, for no two profiles of a given soil are likely to have the same moisture contents, the same mechanical and chemical composition and the same initial densities. This compactive force is affected by the design, the adjustment, the sharpness, and the extent to which the plowshare is worn.

The results of the Proctor tests give a picture of the basic behavior of the test plot when compacted.

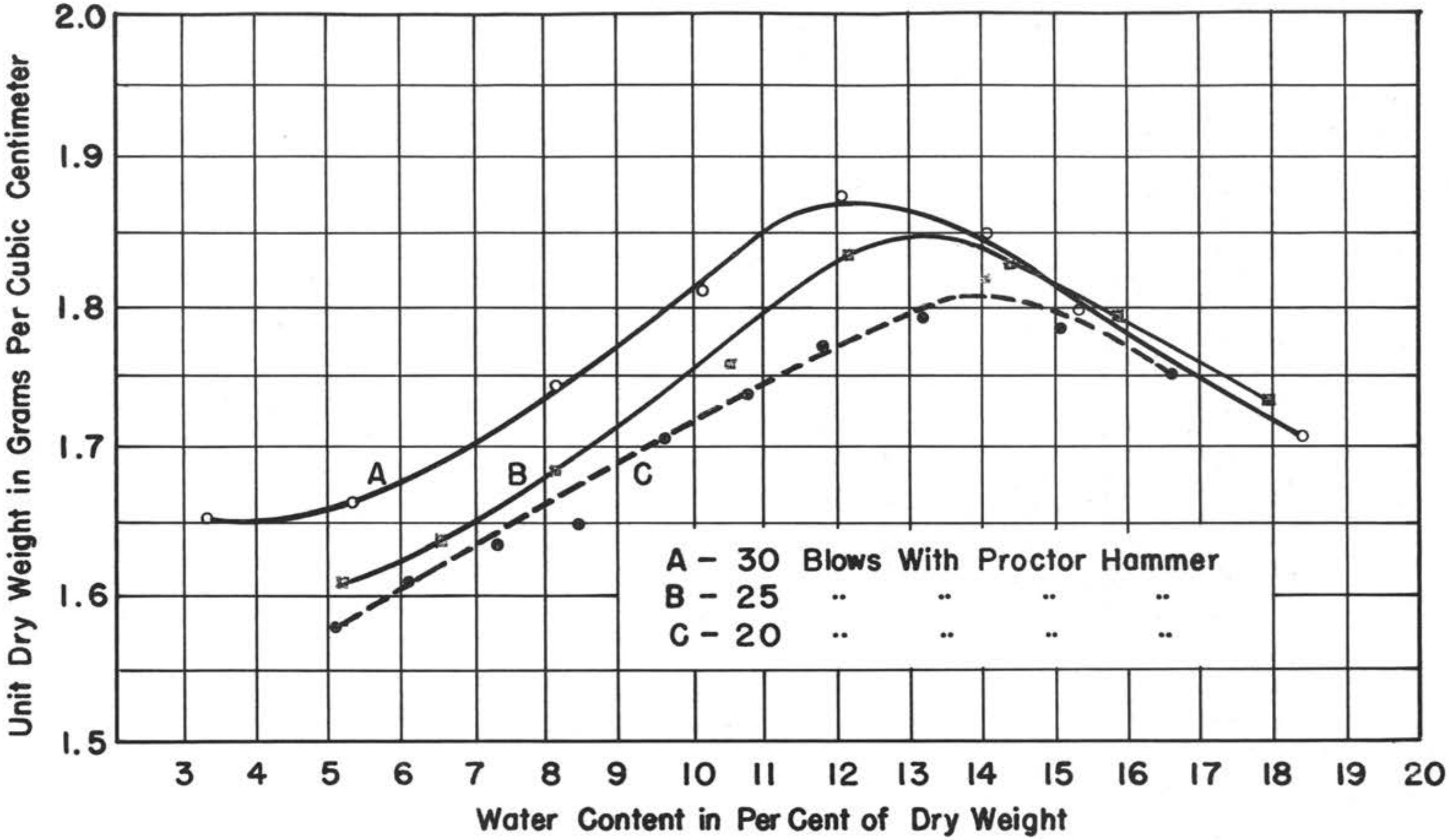

Fig. 5 MOISTURE-DENSITY RELATIONS FOR THREE DIFFERENT COMPACTIVE FORCES.

B. Plasticity

Plasticity may be defined as the ability of a material to be deformed rapidly without rupture, without elastic rebound, and without volume change. In the study of soils in relation to agricultural engineering the Upper Plastic Limit, Lower Plastic Limit and the Plasticity Index are of importance.

The Upper Plastic Limit is essentially that moisture percent at which the soil will begin to flow when lightly jarred. The Lower Plastic Limit is the moisture percent at which the soil will start to crumble when rolled into a thread 1/8 inch in diameter under the palm of the hand. The Plasticity Index is the numerical difference in percent of soil moisture between the Upper and Lower Plastic Limits.

These limits were determined in the laboratory as follows:

Upper Plastic Limit	29.8%
Lower Plastic Limit	19.0%
Plasticity Index	10.8%

The method of making these determinations was outlined by Means[10].

VI. FIELD STUDIES

1. Equipment

Probably the most common type moldboard plow used by the average farmer in Oklahoma is the tractor-drawn 2-bottom 14 inch moldboard plow. The plow used in this investigation was a new McCormick-Deering hydraulic control, No. 8, High Speed, tractor plow with 2 - 14 inch plowshares, as shown in Fig. (6). Two additional plowshares were secured which had been used extensively and were old, dull and excessively worn. Comparison of the new plowshares and the old dull and excessively worn plowshares may be made by referring to Fig. (7).

The tractor used throughout the test was a new International Harvester, Farmall "M", rear wheels equipped with B. F. Goodrich Silvertown, Super Hi Cleat, 6 ply, 12x38 tractor tire.

Soil samples for moisture, and permeability determinations were obtained with a Pomona Soil Sampling Device[2]. This apparatus was equipped to take undisturbed core samples 2.0 inches long and 1.9 inches in diameter in brass tubes. This device is shown in Figs. (8) and (9).

The permeability of the soil samples which was determined in the laboratory will be discussed under the heading of Field Studies. The apparatus for this determination is shown in Fig. (10).

Fig. 6 - McCormick-Deering, Hydraulic Control, Plow Used in the Tests.

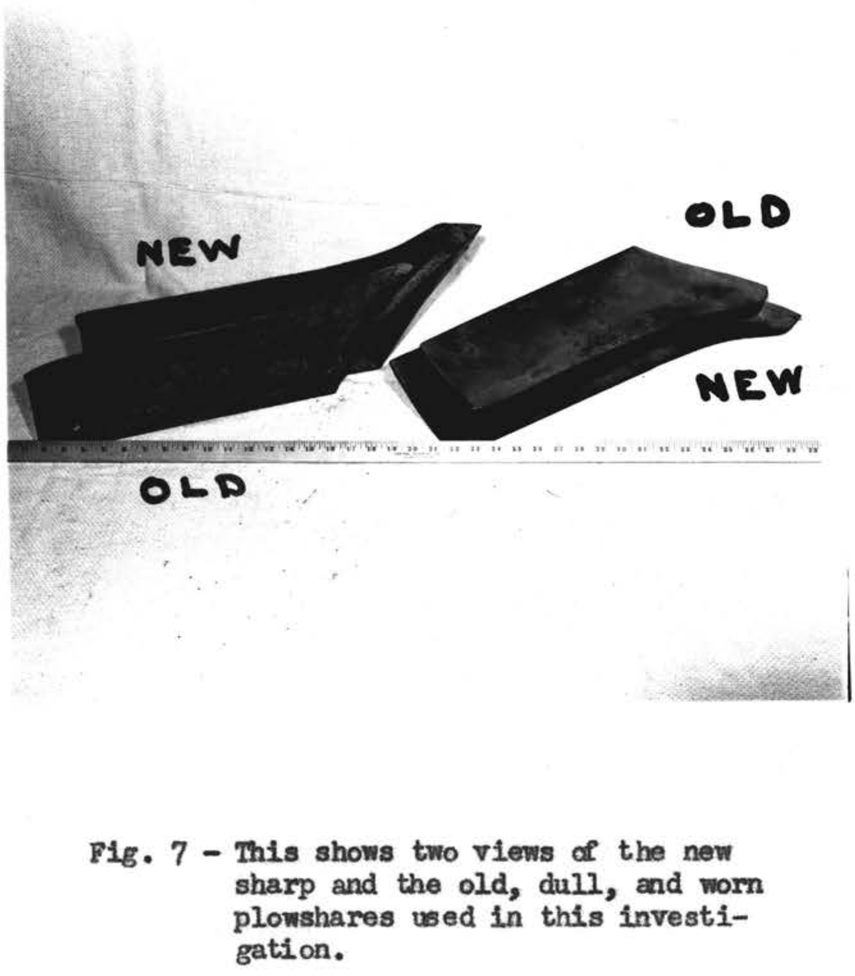

Fig. 7 - This shows two views of the new sharp and the old, dull, and worn plowshares used in this investigation.

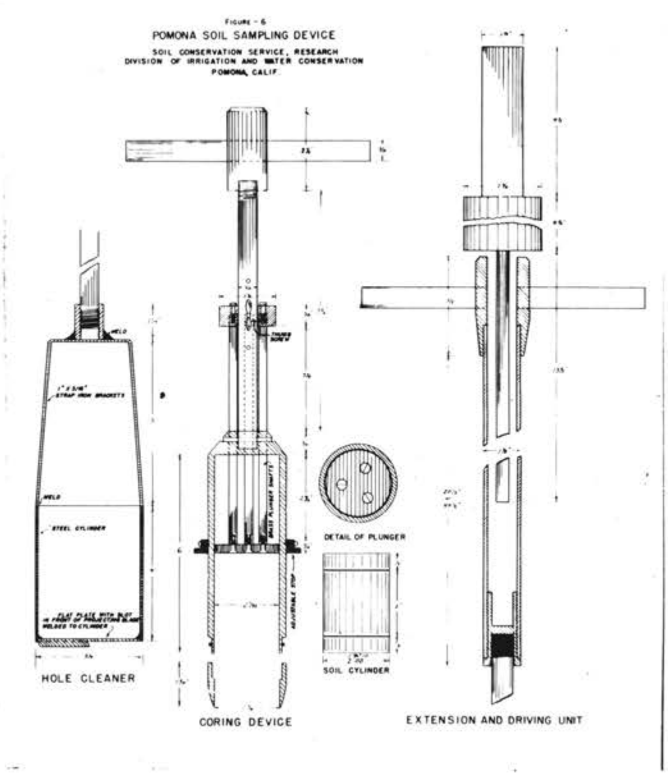

Fig. 8 - A diagramatic view of the Pomona Soil Sampling Device. The Hole Cleaner was not used in this investigation.

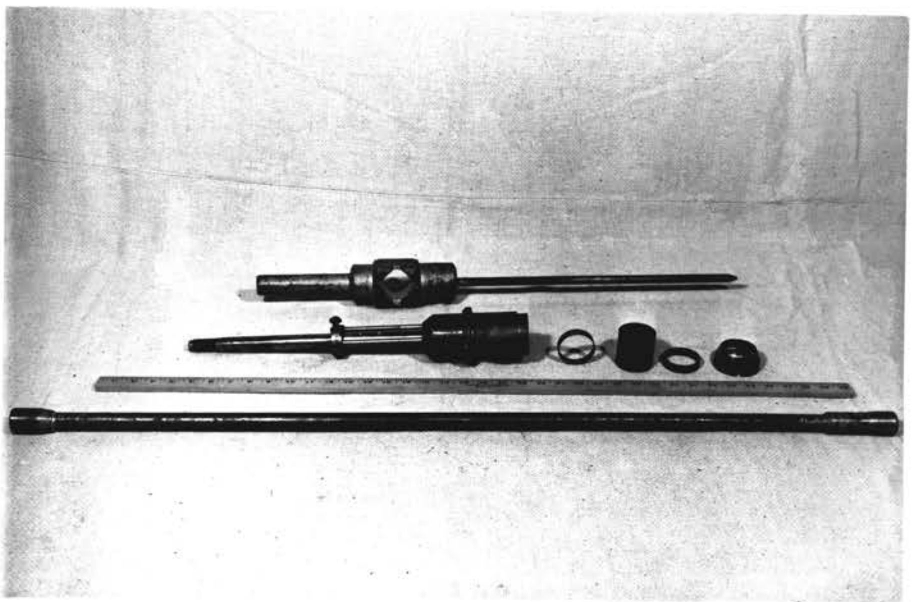

Fig. 9 - Unassembled view of the Pomona Soil Sampling Device.

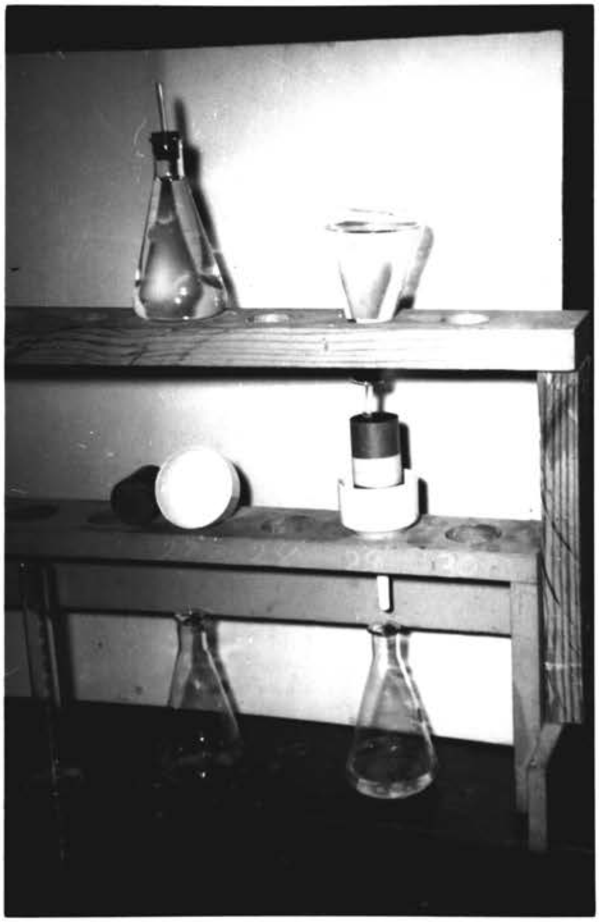

Fig. 10 - Constant head permeameter for determining the coefficient of permeability.

2. Methods Of Treatment

Since a large majority of farmers usually start plowing their ground as quickly after rains as possible, it was decided to make the initial plowing trial at a moisture content that was slightly too wet. This moisture content was arrived at by molding a sample of the soil by hand and noting the appearance of the soil when crumbling the molded sample.

On August 18, 1950 it was decided that the test plot was slightly too wet for ideal plowing conditions. An average of 40 moisture samples at a depth from 6.5 to 8.5 inches revealed a moisture content of 21.6 percent. All plowing operations were conducted as nearly as possible to a depth of 6.5 inches. The length of the plot was approximately 175 feet and all furrows plowed were in the same direction, approximately parallel to the contour of the land. Average speed on all tests was approximately 3.0 miles per hour. Check plots were provided for the purpose of securing comparative samples.

Undisturbed core samples from 5 different treatments at this moisture percentage were collected and the coefficient of permeability determined. These different treatments are described below:

Treatment I - Undisturbed core samples of soil were secured in the furrow behind the plow when new-sharp plowshares were attached. These samples were obtained on the areas in the furrow which exhibited a glazed-shiny appearance. The core sampling device was driven into the ground so that this surface was within approximately 1/4 inch of the top of the brass tube. Samples 2 inches in length were taken at a depth from 6.5 to 8.5 inches.

Treatment II - Undisturbed core samples were obtained similar to those secured in Treatment I, except the new-sharp plowshares were replaced by the old, dull and excessively worn plowshares. These samples were also obtained on the areas in the furrow which exhibited a glazed-shiny appearance.

Treatment III - Undisturbed core samples were obtained similar to those secured in Treatment II, except the core sampling device was driven into the ground so that the glazed-shiny surface extended beyond the top of the brass tube approximately 1/4 inch. This treatment was conducted to observe any difference in the coefficient of permeability that might have been caused by the glazed-shiny surface condition in the bottom of the plowed furrow.

Treatment IV - Undisturbed core samples were secured from an adjacent check plot area at a depth from 6.5 to 8.5 inches. This area was not plowed in any manner other than the original treatment on July 5, 1950.

Treatment V - Undisturbed core samples were obtained while plowing under the same conditions as outlined in Treatment II. These samples were obtained in the plowed furrow after being compacted by the cleats on the rear wheel tire which normally runs in the plowed furrow and before being covered with soil from the plow which followed.

The bottom and top of the samples were made flush with the edge of the brass tubes by the use of a hacksaw blade which aided in preventing any sealing effect on the ends of samples. This operation was not applied to those samples where a glazed surface was desired for the test. In Treatment V the area compacted by the cleats was increased by an average wheel slippage of approximately 14.6 percent. See Fig. (11) for a view of the tractor tire used.

When plowing with a two bottom moldboard plow, it is necessary for one tractor wheel to travel in the furrow. Treatment V was made in order to observe the permeability of the area beneath the tire. Considerable research has been conducted on tractor compaction as previously discussed.

All samples at the time of sampling were carefully retained in the brass tube and placed in a tight soil can and transported to the laboratory for determination of the coefficient of permeability by the constant head method, similar to that outlined by Aronovici[2], op. cit. except the samples were not placed on a tension plate.

3. Subsequent Treatment

Many writers have mentioned that the optimum moisture condition for plowing was in a range somewhere just below the plastic limit of the soil. Since the plastic limit was determined at 19.0 percent moisture, Treatments I through V were duplicated at a moisture content between 16.0 and 17.0 percent. Before the moisture dried to that range, additional rainfall delayed the test a considerable time. See Table 2 for the additional rainfall.

On October 21, 1950 an average of 40 samples of soil from 6.5 to 8.5 inches depth showed the moisture content at 16.1 percent. The method of plowing and securing soil samples were identical with those previously described, therefore description of the procedure will not be duplicated. The subsequent treatments are numbered I-A, II-A, and etc. to correspond to treatments I, II, and etc. respectively.

The samples from Treatments I through V had sufficient moisture so that the bond or friction between the soil sample and the brass sample tube was sufficient to prevent dislodging of the sample with ordinary care. However, Treatments I-A, II-A and etc. were carried out at a much lower moisture percent and the bond between the drier soil and the brass tube was such that it required extra special care in securing the sample and then preventing it from becoming dislodged from the tube. A small unmeasured amount of water was added to the bottom of each soil can, so that by capillary action the samples would swell sufficiently to prevent excessive rapid flow or turbulent flow thus preventing a channeling effect along the walls of the soil sample.

Fig. 11 - Soil Samples in Treatment V and V-A were obtained in the imprints of the tractor tire cleats, as indicated above.

4. Theory Of Permeability

As previously defined, permeability is the facility with which water is able to travel through a column of soil. This travel is considered to be a velocity which is usually expressed as inches per hour. The ability of water to travel through soil is one of the most important of soil properties. In the study of flow of water through soil, Darcy's Law is of considerable importance. Darcy demonstrated that the rate of flow of water through soil is proportional to the hydraulic gradient.

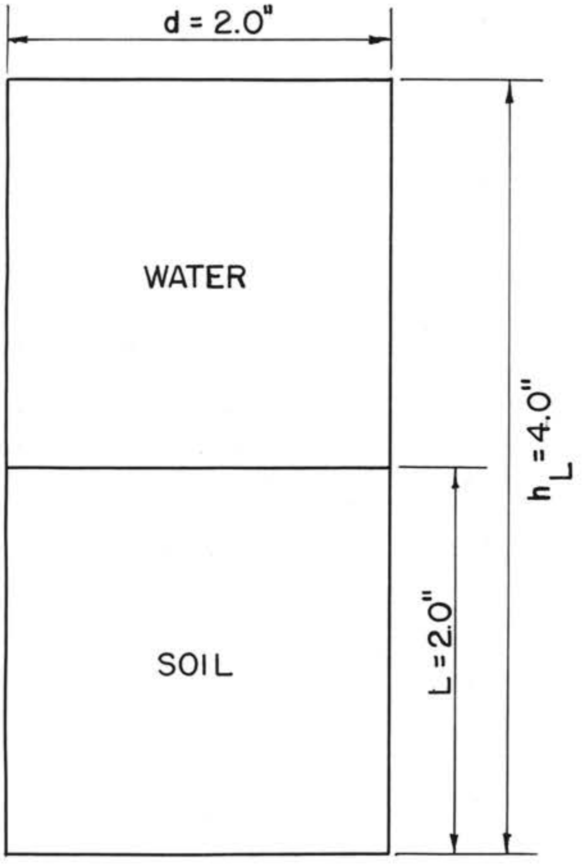

Fig. 12 - A sketch showing the dimensions of the permeameter.

Darcy's Law is written:

$$Q = kAi$$

If $Q = A\,V$

Then $V = k\,i$

Where $i = \frac{h_L}{L}$

Then $Q = k\,A\,\frac{h_L}{L}$

$$k = \frac{Q\,L}{A\,h_L}$$

Where:

Q = The rate of flow of water in cu. in./hr.

A = The total cross-sectional area of the soil in sq.in.

V = The velocity of flow in in./hr.

k = Darcy's coefficient of permeability in in./hr.

i = The hydraulic gradient $(\frac{h_L}{L})$

L = The length of the soil column in inches.

h_L = The difference in hydraulic head between the two ends of the soil column in inches.

From Fig. 12, $L = 2.0''$

$h_L = 4.0''$

$$A = \frac{\pi d^2}{4} = \frac{\pi (1.9)^2}{4} = 2.835 \text{ sq. in.}$$

Substituting in $k = \frac{QL}{A\, h_L}$

$$\frac{Q \times 2.0}{2.835 \times 4.0} = (0.1764 \times Q) \text{ in./hr.}$$

here k has the dimension of velocity.

5. Procedure For Determining Permeability

The apparatus used for determining the coefficient of permeability "k" is called a permeameter. The permeameter used in this investigation was of the constant head type. See Fig. (10) and Fig. (12) for a picture and sketch of the apparatus used. This type consisted of a constant head water supply system (which was an inverted bottle arrangement), some fast filter paper, copper wire screen for supporting the soil, a Buchner funnel, time piece, and a graduated flask for measuring the volume of flow. The filter and screen were more permeable than the soil tested.

The soil samples were brought to the laboratory for determining the coefficient of permeability. The procedure followed for setting up the permeameter and making the test was as follows:

1. A 2.0 inch metal collar of the same inside diameter as the cylinder holding the soil sample was placed on top of the sample for the purpose of making a water reservoir. Collars and cylinders were joined by the use of drafting tape, making a water tight connection.

2. A rack was made by drilling 10 holes in each of the two boards and placing one above the other so that the holes were in alignment. The distance between the boards was fixed so that the water level on top of the soil column could be maintained at a constant elevation, at the top of the reservoir.

3. The Buchner funnel for holding the sample was placed in the bottom hole. A wire screen was placed in the bottom of the funnel and a piece of fast filter paper was placed on top of the screen.

4. The soil sample was placed in the funnel on the screen and filter

paper. A piece of filter paper was cut and placed over the top of the soil to prevent disturbance when water was applied to the reservoir.

5. The reservoir was filled with water very carefully and then the inverted flask filled with water maintained a constant head of water.

6. The quantity of water which had flowed through the column of soil was measured at the end of each 60 minute period. The first period of time began after the flow had started.

Containers of sufficient size were placed under the funnel to catch the total amount of water passing through each sample in one hour. At the end of one hour the amount of water that had passed through the sample was determined in cubic centimeters and converted into cubic inches by dividing by 2.54.

The value of the hydraulic gradient was arbitrarily set at 2. The U. S. Regional Salinity Laboratory[18], states "the hydraulic gradient is usually set somewhere in the range of 2 to 4. Values as high as 10 do not seem to affect the results significantly."

6. Analysis Of Permeability Tests

Tables 4 through 11 outline the values obtained in the permeability tests from Treatments I through IV and I-A through IV-A. These tables show the rate of flow of water through each sample. The measurements of the rates of flow of water started after water had percolated through all of the samples and was dropping from the Buchner funnel. The period of time between the application of water and the start of the test was always less than one hour. These tables also show the average coefficient of permeability in inches per hour when a hydraulic gradient of 2 was used.

The results of the permeability tests of individual samples in each treatment reveal a considerable variation in the rate of flow of water between samples. Many possible causes for this variation may exist. Values of the coefficient of permeability which are high may indicate a high degree of aggregation with a resulting increase in porosity. Holes caused by macro-organisms or decayed plant roots may have been present in the sample. High values may also be the result of shattering of the sample during collection in the field. Values which appear to be too low may have been the result of previous compaction. Variations in soil moisture within a treatment result in different compactive forces caused by plowing. The different forces in turn affect the degree of compaction of the sample and the coefficient of permeability.

Table 14 and Fig. (13) summarize the results of the different treatments so that the values obtained in one test may be readily compared with the values of another.

Results of treatment I compared with results of Treatment II indicate that the use of dull plowshares decreased the coefficient of permeability. When comparing results of Treatments I and II with results of Treatment III, the permeability of samples from Treatment III, was less than that from Treatment I but greater than that from Treatment II, indicating that the glazed-shiny surface decreased the permeability. However, the compactive force probably was transmitted downward through the soil a distance greater than the approximately 1/4 inch removed from the samples from Treatment III. The value of the coefficient of permeability from Treatment IV compared with the other treatments indicates that all treatments in the original test where machinery was involved caused a reduced coefficient of permeability.

The values of the coefficient of permeability of Treatments I-A and II-A indicate that the compactive forces were greater than in Treatment I and II. This may be explained by the results of the Proctor Compactibility Test on page 24. The moisture content at which maximum compaction occurs is greatest when the compactive effort is lowest and decreases progressively with incrases in compactive effort.

The values of the coefficient of permeability of Treatment III-A compared with Treatment III indicate that the magnitude of the compactive forces may have been greater in III, but because of the lower moisture content in III-A, the soil was affected to a shallower depth. Therefore, it is probable that the volume of soil removed from the top of the samples in Treatment III-A represented a larger percent of the compacted soil than the similar volume removed from the samples of Treatment III.

The results of Treatment IV-A indicate that Treatments I-A, II-A, and V-A caused a very serious decrease in the permeability of the soil. Treatment III-A was affected to a smaller degree.

Because of the low rate of water movement through the samples of Treatment V the values in Table 12 represent the coefficient of permeability for a 12 hour period rather than a one hour period. An average value of coefficient of permeability of 0.08 inches per hour was obtained for the nine samples in the test period of 12 to 24 hours after applying water. The quantity of flow through samples 4 and 6 probably reflect factors other than the influence of the tire cleats.

The results of Treatment V-A as shown in Table 13 indicate that the tractor tire caused a severe reduction of the coefficient of permeability.

TABLE 4

Date of Plowing: August 18, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour		
	1st. Hour	2nd. Hour	3rd. Hour
1	120.0	123.0	123.0
2	222.0	224.0	228.0
3	95.0	89.0	95.0
4	112.0	119.0	129.0
5	121.0	112.0	110.0
6	32.0	23.0	16.0
7	-	10.0	12.0
8	4.0	3.0	3.0
9	11.0	8.0	6.0
10	6.0	4.0	3.0
Ave. cc/hr.	80.3	71.5	72.4
Ave. Q in cu. in./hr.	31.65	28.15	28.52
Ave. Coefficient of permeability (k) in./hr.	5.58	4.97	5.03

Treatment I - Samples were obtained from the plowed furrow having a glazed-shiny appearance which was produced by plowing with a 2-bottom moldboard plow when the new-sharp plowshares were attached. The Table shows the rate of flow of water through the soil samples. The average moisture content was 21.6 percent.

TABLE 5

Date of Plowing: August 19, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour		
	1st. Hour	2nd. Hour	3rd. Hour
1	-	6.0	5.0
2	44.0	32.5	26.0
3	30.0	30.0	29.5
4	10.5	9.5	9.0
5	11.0	6.5	5.0
6	37.0	29.5	25.5
7	5.0	3.5	2.5
8	17.0	13.0	12.0
9	8.0	1.0	0.5
10	56.0	17.0	9.0
Ave. cc/hr.	24.2	14.8	12.4
Ave. Q in cu. in./hr.	9.52	5.83	4.88
Ave. Coefficient of permeability (k) in/hr.	1.68	1.03	0.86

Treatment II - These samples were obtained from the plowed furrow having a glazed-shiny appearance which was produced by plowing with a 2-bottom moldboard plow when the old, dull, and excessively worn plowshares were attached. The table shows the rate of flow of water through the soil samples. The average moisture content was 21.6 percent.

TABLE 6

Date of Plowing: August 22, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour		
	1st. Hour	2nd. Hour	3rd. Hour
1	7.0	6.0	5.0
2	7.0	7.0	6.0
3	-	1.0	1.0
4	81.0	77.0	71.0
5	36.0	32.0	28.0
6	24.0	21.0	18.0
7	13.0	10.0	9.0
8	58.0	51.5	47.0
9	138.0	126.0	125.0
10	15.5	12.0	12.0
Ave. cc/hr.	42.2	34.4	32.2
Ave. Q in cu. in./hr.	16.59	13.54	12.68
Ave. Coefficient of Permeability (k) in./hr.	2.93	2.39	2.23

Treatment III - These samples were obtained from the plowed furrow with the glazed-shiny surface extended through the sample tube approximately 1/4 inch and removed with a hacksaw blade. This plot was plowed when the old, dull, and excessively worn plowshares were attached. The table shows the rate of flow of water through the soil samples. The average moisture content was 21.6 percent.

TABLE 7

Date of Plowing: August 22, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour		
	1st. Hour	2nd. Hour	3rd. Hour
1	41.0	31.0	28.0
2	170.0	120.0	127.0
3	307.0	275.0	268.0
4	46.0	33.5	30.0
5	124.0	107.0	99.0
6	32.0	24.0	21.5
7	315.0	310.0	308.0
8	104.0	87.5	84.5
9	86.0	62.5	53.0
Ave. cc/hr.	136.1	116.7	113.2
Ave. Q in cu. in./hr.	53.6	45.9	44.6
Ave. Coefficient of Permeability (k) in./hr.	9.45	8.10	7.86

Treatment IV - These samples were obtained from an adjacent check plot, where no plowing operation had been performed. The table shows the rate of flow of water through the soil samples. The average moisture content was 21.6 percent.

TABLE 8

Date of Plowing: October 21, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour	
	1st. Hour	2nd. Hour
1	28.0	28.0
2	2.0	1.0
3	11.0	12.0
4	18.0	17.0
5	118.0	111.0
6	54.0	43.0
7	7.0	6.0
8	10.0	9.0
Ave. cc/hr.	31.0	28.38
Ave. Q in cu. in./hr.	12.20	11.18
Ave. Coefficient of Permeability (k) in./hr.	2.15	1.97

Treatment I-A - These samples were obtained in a manner similar to those from Treatment I using the new-sharp plowshares, except the plowing was at a later date and the average moisture content was 16.1 percent. This table shows the rate of flow of water through the soil samples.

TABLE 9

Date of Plowing: October 21, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour	
	1st. Hour	2nd. Hour
1	15.0	13.0
2	1.0	1.0
3	5.0	3.0
4	3.0	2.0
5	1.0	1.0
6	8.0	7.0
7	1.0	1.0
8	1.0	2.0
9	22.0	20.0
10	1.0	3.0
Ave. cc/hr.	5.8	5.3
Ave. Q in cu. in./hr.	2.28	2.09
Ave. Coefficient of Permeability (k) in./hr.	0.40	0.37

Treatment II-A - These samples were obtained in a manner similar to Treatment II using the old, dull, and excessively worn plowshares, except the plowing was at a later date and the average moisture content was 16.1 percent. This table shows the rate of flow of water through the soil samples.

TABLE 10

Date of Plowing: October 22, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour	
	1st. Hour	2nd. Hour
1	244.0	232.0
2	62.0	60.0
3	156.0	140.0
4	44.0	42.0
5	78.0	77.0
Ave. cc/hr.	116.8	110.5
Ave. Q in cu. in./hr.	45.95	43.50
Ave. Coefficient of Permeability (k) in./hr.	8.10	7.67

Treatment III-A - These samples were obtained in a manner similar to Treatment III using the old, dull, and excessively worn plowshares, except at a later date and at an average moisture content of 16.1 percent. The glazed-shiny surface was extended through the sample tube approximately 1/4 inch and removed with a hacksaw blade. This table shows the rate of flow of water through the soil samples.

TABLE 11

Date of Plowing: October 22, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour	
	1st. Hour	2nd. Hour
1	94.0	138.0
2	70.0	50.0
3	248.0	253.0
4	305.0	208.0
5	232.0	234.0
6	262.0	304.0
7	114.0	87.0
8	127.0	108.0
9	181.0	176.0
Ave. cc/hr.	181.44	173.11
Ave. Q in cu. in./hr.	71.4	68.2
Ave. Coefficient of Permeability (k) in./hr.	12.60	12.01

Treatment IV-A - These samples were obtained from an adjacent check plot under similar conditions of Treatment IV, except the plowing was at a later date and the average moisture content was 16.1 percent. This table shows the rate of flow of water through the soil samples.

TABLE 12

Date of Plowing: August 18, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per 12 Hour Period
1	0.0
2	2.5
3	2.5
4	27.0
5	0.0
6	87.0
7	0.0
8	1.0
9	5.0
Ave. cc/12 hrs.	13.9
Ave. cc/hr.	1.16
Ave. Q cu. in./hr.	0.46
Ave. Coefficient of Permeability (k) in./hr.	0.08

Treatment V - These samples were obtained in the impression made by the tire cleats of the rear wheel which traveled in the plowed furrow. This table shows the rate of flow of water through the soil samples. Measurement of the rate of flow through all samples was begun after each had been subjected to the head of water for a period of 12 hours. Note that the rate of flow per hour is very small. Samples 1, 5, and 7 were impervious. There may have been some outside factor in samples 4 and 6 which offset the compactive forces produced by the tractor tire cleat.

TABLE 13

Date of Plowing: October 21, 1950

Sample No.	Quantity of Water Flowing Through Permeameter in Cubic Centimeters Per Hour	
	1st. Hour	2nd. Hour
1	0.0	0.0
2	5.0	8.0
3	0.0	1.0
4	8.0	5.0
5	17.0	6.0
6	12.0	11.0
7	0.0	0.0
8	11.0	8.0
9	9.0	8.0
10	2.0	1.0
Ave. cc/hr.	64.0	4.8
Ave. Q in cu. in./hr.	2.52	1.89
Ave. Coefficient of Permeability (k) in./hr.	0.44	0.33

Treatment V-A - These samples were obtained in the impression made by the tire cleats of the rear wheel which traveled in the plowed furrow. This table shows the rate of flow through the soil samples. Measurement of the flow through all samples was begun after each had been subjected to the head of water for 2.0 hours. Average moisture content was 16.1 percent when plowed.

TABLE 14

Treatment No.	Average Coefficient of Permeability	
	After 1st. Hour of Flow	After 2nd. Hour of Flow
I - New-sharp plowshare with glazed-shiny surface.	5.58	4.97
II - Old, dull, and worn plowshare with glazed-shiny surface.	1.68	1.03
III - Old, dull, and worn plowshare with glazed-shiny surface removed.	2.95	2.38
IV - No treatment - check plot.	9.45	8.10
V - Impression of tire in plowed furrow.	0.08	—
I-A - New-sharp plowshare with glazed-shiny surface.	2.15	1.97
II-A - Old, dull, and worn plowshare with glazed-shiny surface.	0.40	0.37
III-A - Old, dull, and worn plowshare with glazed-shiny surface removed.	8.10	7.67
IV-A - No treatment - check plot.	12.60	12.01
V-A - Impression of tire in plowed furrow.	0.44	0.33

Summary of the results of the different methods of treatment. Treatments I through V were conducted at an average moisture content of 21.6 percent. Treatments I-A through V-A were conducted on an adjacent plot at a later date with an average moisture content of 16.1 percent.

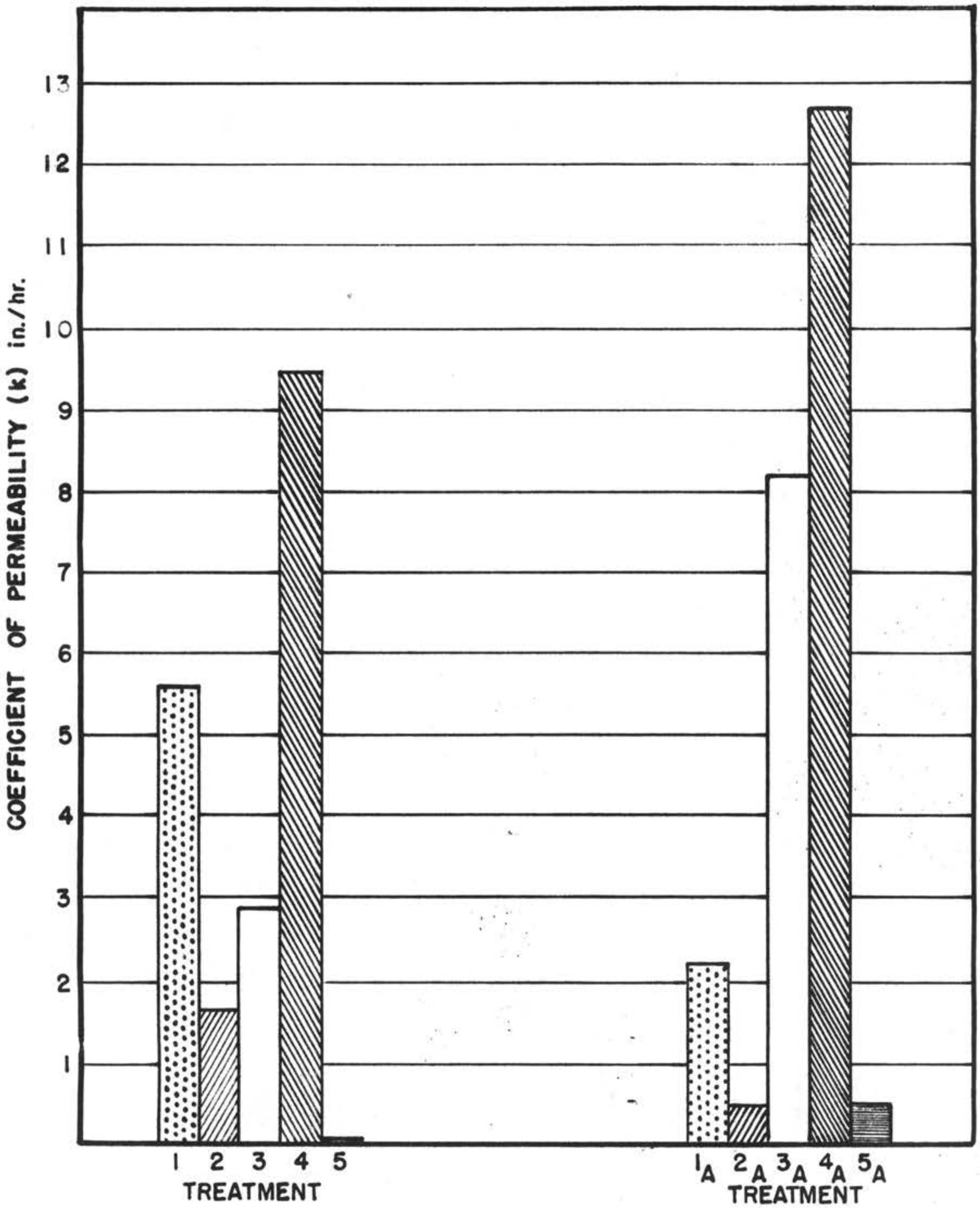

Fig 13 Values of the Coefficient of Permeability (k) in Inches Per Hour For the First Hour.

Treatments 1-5 Were Plowed at a Moisture Content of 21.6 %.
Treatments 1_A-5_A Were Plowed at a Moisture Content of 16.1 %.

SUMMARY AND CONCLUSIONS

This thesis discusses some of the physical properties and tests of soils and uses these properties and tests to measure the effect the moldboard plowshare condition may have in the development of a "plow-sole".

The compactibility tests conducted in the laboratory verified that the moisture content at which peak densities occurred was greatest when the compactive effort was lowest and decreased progressively with increased compactive effort.

The results of soil tests indicate plowing with either the sharp or dull plowshare reduces the coefficient of permeability below that of the check plot.

Machinery usage was found to cause a reduction in pereability. This reduction was probably caused by compaction and rearrangement of soil particles.

Samples from the glazed-shiny furrow areas which were produced by plowing with dull plowshares showed a permeability lower than similar samples obtained where the plowing was done with sharp plowshares.

The results of permeability tests indicate that the upper 1/4 inch of soil under the glazed-shiny surface is primarily responsible for the great reduction in permeability.

The cleats on the rear tractor tire which traveled in the furrow caused an extreme reduction in the coefficient of permeability.

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