A STUDY OF SOME EFFECTS OF SEVEN SYSTEMS OF FARMING UPON CROP YIELDS AND SOIL STRUCTURE

By

Lynn S. Robertson, Jr.

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Soil Science

Year 1955

Approved R. L. Cook

A STUDY OF SOME EFFECTS OF SEVEN SYSTEMS OF FARMING

UPON CROP YIELDS AND SOIL STRUCTURE

By

Lynn S. Robertson, Jr.

ABSTRACT

Crop yields and soil structure analysis were determined on established crop rotation experimental field plots.

Rotation caused no consistant difference in sugar beet yields from one year to the next. The yields from some rotations were not as high as they might have been because low nitrogen levels frequently limited growth. Also, black root, a sugar beet disease, was prevalent during several seasons. This disease seemed to manifest itself equally in the seven systems of farming. However, where beets followed alfalfa brome hay, recovery from the disease did not appear to occur as rapidly or to the same degree as in the other systems of farming.

Sugar beets after beans resulted in the highest yields for the 10 year period. The lowest yields occurred in a cash crop rotation which did not include a nitrogen supplying legume crop.

Physical analysis of the sugar beet seed beds showed little or no difference in soil conditions. However, differences in the root bed developed later in the season. The cash crop rotation, which did not include a nitrogen-adding legume crop, was in the poorest physical state as was indicated by aggregate analyses, total and non-capillary pore-space analyses, penetrometer records, and percolation studies.

The highest corn yields occurred where corn was preceded by a leguminous hay crop. One year of alfalfa-brome in a crop rotation had the same effect on corn yields as did two years of this hay in the rotation. Clover-timothy in a rotation instead of alfalfa-brome resulted in 10 per cent smaller yields. The placing of a sugar beet crop between an alfalfa-brome hay crop and the corn crop also caused a 10 per cent reduction in corn yield.

The lowest corn yields were obtained in a cash crop rotation which did not include a nitrogen adding legume.

Dry screen analyses of seed beds indicated there was little difference in the physical status of the soil at planting time.

The results of the aggregate analyses of the corn soil showed that the sod crop in the rotation was responsible for the differences in total as well as water stable aggregates.

The systems of farming did not affect the structure of the soil below plow depth sufficiently to cause measurable differences.

Porosity determinations, both total and non-capillary, indicated that systems of farming did affect the structure of the soil. The highest percentages were obtained on the plots where sod crops were included in the rotations. The lowest porosities were obtained from the cash crop rotations.

Penetrometer records indicated that various systems of farming caused great differences in the structure of the soil and that it was possible to measure these differences with a penetrometer. A new type of recording penetrometer was developed as a tool for rapid measurements and proved to be successful.

A simple rapid soil test which is based on the stability of soil aggregates to water was devised.

A STUDY OF SOME EFFECTS OF SEVEN SYSTEMS OF FARMING UPON CROP YIELDS AND SOIL STRUCTURE

By

Lynn S. Robertson, Jr.

A THESIS

Submitted to the School of Graduate Studies of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Soil Science

1955

BIOGRAPHICAL SKETCH

The author was born September 19, 1916 in Lafayette, Indiana, the son of Adella C. and Lynn S. Robertson.

He attended elementary and high schools in West Lafayette and was graduated from Purdue University in 1940, receiving a bachelor of science degree in agriculture. In 1941, he received a master of science degree in agriculture, having majored in soils and minored in crops and farm management.

In 1941, he married Elizabeth Ainsworth. The same year he was granted an Assistantship in the Soil Science Department, Michigan State College which he held until being made a full time employee of the department in 1943. Since that time his principal interests have centered around soil fertility investigations particularly in regard to the heavier soils.

Currently he is a member of the International Soil Science Society, Soil Science Society of America, American Society of Agronomy, American Society of Sugar Beet Technologists and the Society of Sigma Xi.

ACKNOWLEDGEMENT

The writer expresses gratitude to Mr. Lee Ferden for the laboratory facilities which he so generously made available on his farm. This study would not have been possible without the laboratory into which he gratuitously installed electricity and running water.

Gratitude is also expressed to Dr. N. S. Hall who helped outline the plan of study; to Dr. C. E. Millar and Dr. R. L. Cook for their suggestions during the course of investigation; to Prof. C. M. Hansen who supervised the construction of the penetrometer; to Prof. E. C. Sackrider and Mr. B. A. Meyers of the Soil Conservation Service for the help they provided during some of the soil collection periods; and to Dr. A. E. Erickson, Dr. R. L. Cook, and Dr. L. M. Turk for their suggestions during the preparation of this manuscript.

Acknowledgement is gratefully given to the Farmers and Manufacturers Beet Sugar Association for their assistance in the establishment and maintenance of the plots upon which this work was done.

TABLE OF CONTENTS

CHAPTER		PAGE

I. INTRODUCTION

At a 1939 meeting of agronomists and others interested in the production of sugar beets in Michigan, attention was focused on the lack of experimental results pertaining to crop rotation and sequence under Michigan's climatic and soil conditions. It was not possible to cite experimental evidence in regard to such questions as, "What crop should immediately precede sugar beets in a rotation? Are legumes essential in a sugar beet rotation, and if so which legume has the greatest effect on beets? What portion of the rotation time should be allotted to the legumes?"

In order to obtain satisfactory answers to these and other questions, the Ferden sugar beet rotation experiment was started in the spring of 1940. Since that time crops have been harvested each year. By 1950 the rotations had completed two cycles in which observations and yield determinations had been made. Definite answers to some of the questions had been determined, and as usually occurs, new questions had arisen.

Since the experiment was started and particularly after the second cycle of the rotation started, many observations were made in regard to soil structure. Mr. Ferden had noted that the soil in the no legume rotation plowed harder than in other rotations. Water seemed to drain more rapidly through the soil on the plots where alfalfa had grown. The workers when blocking and thinning beets, regulated the speed of their work so they would be assigned the task of blocking the beets which were grown after alfalfa-brome hay because "the ground, she soft in little field--

big field have hard ground". The workers remembered this difference when they returned to work the beets for the second year.

The purposes of this study were:

1. To summarize the sugar beet and corn yields during the second cycle of the rotation.
2. To report observations which were made during the ten year period in regard to both soils and crops.
3. To make measurements on the soil in order to determine to what extent rotations had affected its physical properties.
4. To develop a rapid soil test of an empirical nature which would give an indication of the structure of a soil.

II. REVIEW OF LITERATURE

A. Crop Rotations--General

A great many studies have been made in regard to crop rotations and their effects upon yields. However, most of these studies have not included sugar beets, but primarily corn, oats, wheat, potatoes, and cotton. Many have compared a continuous system of cropping with a rotation system.

Wier (57) made a study of the results of rotation experiments in various parts of the United States and Rothamsted, England. He found that the effects of fertilizers and of crop rotations, when both were used, added to the effectiveness of each other and that maximum yields were possible only when both were used together. Liming acid soils increased the relative effectiveness of crop rotations in that it regulated the crops which could be grown effectively in the rotations. Similar conclusions may be drawn from a large number of experiments dealing with grain crops (6, 15, 19, 51, 54, 57, 58, 59).

B. Sugar Beet Rotations

The sequence of alfalfa-corn is generally considered to be very good but this is not the case for alfalfa-sugar beets. Leighty (29) reports that "ordinarily the yields of sugar beets immediately following alfalfa are low". Lill and Rather (31) state that the number of organisms causing black root of beets is intensified in quantity by the growing of alfalfa on infected soil; "Hence under conditions favorable to black root organisms, the stand of sugar beets may be affected adversely if alfalfa is the immediate forerunner".

Afanasiev, Morris and Carlson (1) showed that seedling diseases of beets occurred in increasing amounts where they were planted after corn, potatoes, oats, alfalfa, beans, and beets.

Harris' (22) report shows that sugar beet yields were higher in a rotation which included alfalfa than in one which included sweet clover. It was better, however, to grow sweet clover than to depend entirely on non-legumes. Beets were not grown immediately after alfalfa in any of the rotations in this study.

The effect of cash crops upon sugar beet yields according to Lill (30) with an oats-sugar beets sequence taken as a base are as follows: barley (+ 0.26 tons); beans (+ 1.44 tons); and corn (+ 1.62 tons). In another publication (32) Lill indicated that the sequence of soybeans-sugar beets was better than corn-sugar beets. If the soybeans were cut for hay, the yields were higher than if the soybeans were used for seed.

C. Management of Sugar Beet Rotations

Plowing Time and Tillage. Soil management practices in a particular crop sequence can affect beet yields considerably. One year's data by Lill and Rather (31) showed that mid-August plowing of alfalfa sod resulted in higher beet yields than did spring plowing. Robertson's (43) data, however, showed that early spring plowing was better than November plowing. There is need for more investigation in regard to time of plowing. This problem is being investigated in a field experiment started in Michigan in 1950 (48).

It is thought that implements other than the plow affect the structure of the soil. Numerous field experiments are now in progress to determine the importance of tillage methods upon crop growth. In regard to sugar beets, Cook and Peikert (12, 13), in what was considered to be a typical rotation for the area in which the experiments were conducted, rather than a desirable rotation, found great differences in weed population resulting from various tillage methods. They suggested that weeds influenced growth more than did the resulting physical condition of the soil caused by different implements. The results of these experiments and others (47) indicate that a minimum amount of tillage leaves the seed and root bed in a more porous state.

Manures. The value of livestock manure is apparently related to the natural fertility conditions of the soil rather than to rotations. Nuchols' (37) summary states that greater returns were obtained by the use of manure on low yielding fields than on fields of higher production. The results of Cook, Millar and Robertson (11) indicate that green manure, sweet clover, alfalfa, or grass are better than stable manure in furnishing nitrogen for young sugar beet plants. These conclusions were drawn from field and greenhouse experiments on what would be classed as good fertile sugar beet soils. The use of manure for beets apparently is advocated much more widely in the West than in Michigan.

Fertilization. There are very few data in regard to fertilization in different crop rotations. Lill (33) in a progress report, concluded that "the growth of the alfalfa crop upon the soil apparently had a tendency to upset the balance of plant food elements in the soil by increasing the amount of nitrogen and reducing the amount of phosphorus". This is in agreement with Robertson's (43) explanation of why some years beets after alfalfa respond more to high fertilizer rates than do beets after corn or wheat. Furthermore, Lill (33) concluded that the "unbalancing effect of the alfalfa crop upon the mineral plant food elements may be corrected to such an extent by the application of phosphoric acid to the soil that the sugar beet seedling can resist the attacks of the black root organisms and make normal growth". As far as is known, very little regard is given to the type of rotation being practiced when planting time fertilizer recommendations are made. No reference is made in regard to different methods of fertilization or fertilizer analysis in the Fertilizer Recommendation Bulletin (18) for Michigan. However, for certain crop sequences, particularly where beets follow small grains, those who make fertilizer recommendations usually suggest that until the time of the last cultivation the nitrogen status of the beets be closely observed. Where deficiencies occur, nitrogen side dressings should be made. Their recommendations are partially based upon side dressing results obtained on the Ferden Farm (44, 46).

Soil Structure. There has been very little published in regard to sugar beet rotations and soil structure. Farnsworth (16) and Farnsworth and Baver (17) have made important contributions in the field of soil structure and sugar beet rotations. Their work showed a definite relationship between cropping systems, non-capillary porosity, and sugar beet stands and yields. Yoder (64) states that "the only position in the rotation that insures a structural stability of the root bed sufficient to insure adequate aeration and drainage for beets is to place them immediately after a sod crop. High organic matter input and grass roots both contribute to water resistant soil granulation".

III. PLAN OF STUDY

This investigation was undertaken in order to determine the effect of systems of farming upon crop yields and upon soil structure. If differences in soil structure could be measured, it was hoped that the data could be used as a basis for the development of a quick test of an empirical nature which could measure soil structure.

The plan of study included the following:

I Crop yields and observation on growth characteristics.

- A. Sugar beets
- B. Corn

II Plowing time observations.

III Physical determinations.

- A. Dry screen analyses of soil from corn and sugar beet seed beds.
- B. Aggregate analyses of soil from corn and sugar beet root beeds.
- C. Total and non-capillary porosity analyses of soil from corn and sugar beet root beds.
- D. Physical determinations on soil before plow depth.
- E. Quick tests for determining soil structure.
    1. Penetrometer studies.
        - a. Plumb-type penetrometer.
        - b. M.S.C. penetrometer.
    2. Percolation studies.

IV. EXPERIMENTAL FIELD SET UP

A. Description of Soil on the Ferden Farm

The Lee Ferden Farm is located in the sugar beet growing area of Saginaw County, Michigan, three miles south of Chesaning in the NW$\frac{1}{4}$ of section 33, T9N, R3E. The soil has been mapped by the farm planners of the Soil Conservation Service, Saginaw, Michigan, and is described as having a surface soil similar to Brookston or Clyde soil and a "brownish-yellow, heavy, plastic silty clay sub-soil similar to Toledo". Veatch (56) has indicated the soil on which the plots are located as being a member of the Brookston series.

Soil analyses showed that the surface soil contained 25 to 28 per cent clay and 50 to 58 per cent sand. It, therefore, was classed as a Brookston sandy clay loam. According to Lynd (34) the soil contained 7.8 per cent organic matter; had a pH of 6.8, and a base exchange capacity of 13.45 m. e. per 100 gms. of soil, of which 8.95 m. e. are calcium, 0.165 m. e. are magnesium, and 2.45 m. e. are hydrogen. An open ditch lies along the west side of the plots and the field is tiled at every four rods. However, the subsoil structure is such that the soil drains rather slowly. There is a very gentle slope, 14 feet per mile, which allows some surface drainage.

B. Description of the Plots and Systems of Farming

Seven 5 year rotations were studied. They were as follows:

1. Barley, alfalfa-brome, alfalfa-brome, corn, sugar beets
2. Barley, alfalfa-brome, alfalfa-brome, sugar beets, corn
3. Barley, alfalfa-brome, alfalfa-brome, beans, sugar beets
4. Barley, oats, alfalfa, corn, sugar beets
5. Barley, oats, clover-timothy, corn, sugar beets
6. Barley, beans, wheat, corn, sugar beets
7. Barley, green manure*, beans, wheat, green manure*, corn, sugar beets

The green manure crop was seeded with barley and was plowed under for beans, and was seeded in the spring on wheat to be plowed under for corn.

The plots were arranged in a split plot randomized block design. Two fertilizer rates account for the split plot design. Since the "high" fertility plots (1,000 pounds of 2-16-8 per acre per rotation) have outyielded the low fertility plots during the first cycle of the rotation, this study was made only on the high fertility plots. Therefore, for the purpose of this study, the plots were treated as a randomized plot experiment. The rotations were replicated four times and all crops appeared each year. Barley and sugar beets occurred in all rotations. Corn appeared in all but one of the rotations.

So far the plots have been described as a crop rotation experiment. Actually, the plots represented systems of soil management within given crop rotations. Therefore, in this treatise the terms "crop rotations" and "systems of farming" are used interchangeably. The systems of farming have been numbered—called rotation number—for the sake of convenience.

---

* Mixture of alsike, June, Mammoth, and sweet clover.

The use of livestock manure, and the disposition of crop residues were regulated according to the systems of farming which might be practiced with the different rotations. In rotations 1, 2, and 3 manure at the rate of 10 tons per acre was applied for corn and beans. In rotations 4 and 5 with only 20 per cent of the land in hay, a farmer would not feed as many cattle so the manure applications were 7 tons per acre. No manure was applied in rotations 6 and 7 because under such farming systems livestock are not generally raised.

Corn stover was left on all the plots. Straw and sugar beet tops were returned to the plots in rotations 6 and 7.

A complete description of the plots and how they have been handled has been published (10).

According to the original plans for the experiment sweet clover was to be seeded in barley and wheat in rotation 7. When this was attempted, poor stands of sweet clover resulted because an insect (Sweet clover curculio) devoured the small plants. Starting in 1945, a mixture of alsike, June, mammoth, and sweet clover was substituted for the sweet clover. Since that time, good stands of the leguminous mixture were obtained.

V. GENERAL OBSERVATIONS

During the course of this experiment, several changes occurred in the physical setup of the experiment which should be mentioned. At a few locations, short strings of tile were placed below certain series of plots which seemed to drain slowly. These tile have aided considerably in draining local areas which were naturally wetter than the rest of the field. Also, the open ditches were cleaned out in 1947 and this materially decreased the flow of surface water across the plots in the spring. On this soil, adequate drainage is of prime importance for satisfactory crop yields. Since installation of this additional drainage the soil has been much more uniform and has worked up easier in the spring.

The crops grown in this experiment were probably adequately fertilized in regard to phosphorus and potash because there was little evidence of a deficiency of these nutrients.

This was not the case for nitrogen. Sometimes, the crop yields were lower than they would have been if adequate nitrogen had been available. The cash crop rotations supplied much less nitrogen than did those rotations which might fit into a livestock system of farming. Periodically, the corn yields were increased by side-dressed nitrogen even where corn followed immediately after an alfalfa-brome hay crop.

The sugar beets, despite the fact that they received planting time applications of manganese and boron, during some seasons showed deficiency symptoms for these nutrients.

VI. EFFECTS OF SYSTEMS OF FARMING ON CROP YIELDS

Only the yields of sugar beets and corn are reported in this study because the other crops had some variable other than rotation which might influence the yields. For example, the barley was fertilized with 500 pounds of 2-16-8 in Rotations 1, 2, and 3; and with 250 pounds in 4, 5, 6, and 7. Therefore, it would not be justifiable to compare the yields where there were these two fertilizer rates and suggest that differences might be due to crop rotations.

The crop yields of the first cycle of these rotations have been published (11).

A. Sugar Beet Yields

Sugar beet root yields were used to indicate the yield rather than pounds of sugar per acre because sugar determinations have shown little differences as caused by rotations. This procedure should reduce the experimental error which might be obtained if sugar analyses were included in the interpretation of the data.

The sugar beet yields are shown in Table 1. No yields were obtained in 1947 because the beets had to be dragged up after replantings failed. Black root disease decreased the stand of both plantings to such an extent that the plots had to be abandoned for that year. In 1948, 1949, and 1950 all of the beets had black root, but seemed to out-grow the disease as the season progressed. Almost average yields for the area were obtained.

Table 1.

The Effect of Systems of Farming on Sugar Beet Yields

Tons of beets per acre

Rotation Number	Crop Sequence[1]	1946	1947	1948	1949	1950	Mean 1941-1945	Mean 1946-1950	Mean 1941-1950
1	Ba-A-A-C-SB	12.87	0.00	12.33	9.00	11.08	10.34	9.06	9.70
2	C-Ba-A-A-SB	16.76	0.00	8.86	8.32	8.04	10.88	8.40	9.64
3	Ba-A-A-Be-SB	15.36	0.00	12.33	10.09	10.57	10.24	9.67	9.96
4	Ba-O-A-C-SB	14.31	0.00	11.67	8.69	9.75	10.45	8.88	9.67
5	Ba-O-Cl-C-SB	13.22	0.00	11.46	10.05	9.10	10.04	8.77	9.41
6	Ba-Be-W-C-SB	11.26	0.00	10.66	8.77	8.81	9.64	7.90	8.79
7	Ba(gm)-Be-W-(gm)-C-SB	13.01	0.00	11.64	8.79	10.49	10.08	8.79	9.44
	Significance	**	--	*	--	--	--	*	**
	L.S.D. at 5%	2.52	N.S.	2.35	N.S.	N.S.	N.S.	1.24	0.67

[1] Ba-barley
Be-navy bean
A-alfalfa brome hay
C-corn
SB-sugar beet
O-oats
Cl-clover-timothy hay
W-wheat
gm-green manure mixture-alsike, June, sweet clover

During the first cycle of the rotations, the highest yields occurred where sugar beets followed two years of alfalfa-brome hay (Rot. 2). The yields were somewhat higher than where sugar beets followed beans (Rot. 3). However, by the end of the second cycle this difference disappeared and the yields after beans were higher than those after alfalfa-brome hay. Greenhouse experiments suggested that the beans-sugar beets sequence resulted in higher beet yields than did alfalfa-sugar beets (11). This is because the yield of beets after alfalfa has not been consistently good. In fact, in 1948, 1949, and 1950 the yields from Rotation 2 (alfalfa-brome, beets) were lower than from the cash crop rotation (Rot. 6).

The data in Table 2 show that the low yields where beets followed alfalfa (Rot. 2) indirectly were related to the number of marketable sugar beets. In seven out of nine years this rotation produced less marketable beets than did any of the other rotations. The data in this table are slightly misleading in that a uniform spacing of beets in the row is assumed. This, however, was not the case and it partially accounts for the relatively high stand counts which some years were associated with relatively low yields.

Rotation 6 (all cash crop) has consistently produced low beet yields. The low yields are partially a result of insufficient nitrogen being supplied by the soil in this rotation. This was more evident in this rotation than in any of the others (Table 3).

The beets in all of the rotations except Rotation 2 (beets after alfalfa-brome hay) required more nitrogen than was naturally supplied by the soil. The plant tissue tests reported in Table 3 and the nitrogen side dressing results showed this to be true.

Table 2

The Effect of Systems of Farming Upon Number of

Marketable Sugar Beets

Rotation Number	Crop Sequence[1]	Marketable Beets per 100 Feet of Row 1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	Mean
1	Ba-A-A-C-SB	85	75	95	94	71	82	0	91	54	101	83
2	C-Ba-A-A-SB	76	64	70	89	65	82	0	71	54	80	72
3	Ba-A-A-Be-SB	96	75	92	99	65	85	0	89	57	83	82
4	Ba-O-A-C-SB	94	79	92	97	80	81	0	100	57	93	86
5	Ba-O-Cl-C-SB	91	67	93	93	72	81	0	93	57	83	80
6	Ba-Be-W-C-SB	96	72	90	90	83	86	0	98	56	86	84
7	Ba(gm)-Be-W-(gm)-C-SB	89	72	91	87	73	90	0	89	63	92	83
	Significance	**	*	*	--	--	--	--	--	--	--	--
	L.S.D. at 5%	8	8	11	--	--	--	--	--	--	--	--

[1] Ba-barley
Be-bean
A-alfalfa brome hay
C-corn
SB-sugar beet
O-oats
Cl-clover timothy hay
W-wheat
Gm-green manure

Table 3

The Effect of Systems of Farming Upon Nitrate Tissue Test of

Sugar Beets During 1946[3]

Rotation Number	Crop Sequence[1]	Nitrate Tissue Test and Sampling Date[2] 5-3	5-21	6-7	6-21	7-15	7-29	8-29	10-7	Yield T/A.
1	Ba-A-A-C-SB	H	H	H	H	L	L	L	B	12.87
2	C-Ba-A-A-SB	H	H	H	H	H	H	H	H	16.76
3	Ba-A-A-Be-SB	H	H	H	H	M	M	M	L	15.36
4	Ba-O-A-C-SB	H	H	H	H	M	L	L	L	14.31
5	Ba-O-Cl-C-SB	M	M	H	H	L	L	B	B	13.22
6	Ba-Be-W-C-SB	H	M	H	M	L	B	B	B	11.26
7	Ba(gm)-Be-W-(gm)-C-SB	H	H	H	M	M	L	B	B	13.01

1 Ba-barley
Be-bean
A-alfalfa brome hay
C-corn
SB-sugar beets
O-oats
Cl-clover timothy hay
W-wheat
Gm-green manure

2 Composite samples from all replication

3 H-- high
M-- medium
L-- low
B-- blank

The side dressing results in 1948 showed an increase in yield ranging from 0.90 tons in Rotation 7 to 2.28 tons in Rotation 5. Two-hundred pounds of ammonium sulfate was applied at the last cultivation. In 1949, inspite of the fact that the side dressed rows did not contain as many beets as did the check rows, side dressing in Rotations 6 and 7 increased the yields 0.85 and 1.81 tons, respectively. The beets were not side dressed in 1950.

In this experiment, the effect of rotations upon beet yields was not as great as upon corn yields. This is undoubtedly due to the fact that sugar beets followed corn in all except two rotations. Corn followed six different crops.

B. Corn Yields

In this experiment corn occurred in only six of the rotations. The yields of corn, as affected by rotations, have been very consistent (Table 4).

The corn yields arranged themselves into three groups. Where corn followed wheat (Rot. 6) the yields were the lowest in the experiment every year during the 10 year period. This was partially caused by the extreme nitrogen deficiency which occurred each year. When the corn was side dressed with nitrogen, the yields were increased to such an extent that there was little difference in yields in this rotation and the rotations which included alfalfa. In 1948, 1949, and 1950 the yields in this rotation were increased 15.0, 22.1, and 20.0 bushels, respectively, where the corn was side dressed with 200 pounds of ammonium sulfate at the time of the last cultivation. No side dressing was made previous to 1948, but

Table 4

The Effect of Systems of Farming on Corn Yields

Bushels of shelled corn per acre

Rotation Number	Crop Sequence[1]	1946	1947	1948	1949	1950	Mean 1941–1945	Mean 1946–1950	Mean 1941–1950
1	SB-Ba-A-A-C	58.2	52.7	48.8	99.0	64.2	44.8	64.58	54.69
2	Ba-A-A-SB-C	53.7	32.6	60.0	87.3	58.5	39.7	58.44	49.07
4	SB-Ba-O-A-C	62.9	48.1	50.0	98.8	63.1	45.8	64.58	55.19
5	SB-Ba-O-Cl-C	59.1	44.4	33.3	94.7	63.1	40.7	58.92	49.81
6	SB-Ba-Be-W-C	40.8	30.8	26.0	62.9	50.1	33.8	42.12	37.96
7	SB-Ba(gm)-Be-W(gm)-C	54.1	37.3	42.7	86.2	55.9	40.5	55.24	47.87
	Significance	**	**	**	**	**	**	**	**
	L.S.D. at 5%	9.7	5.4	10.5	15.2	12.1	4.2	4.8	3.0

[1] SB-sugar beets
Ba-barley
Be-bean
A-alfalfa brome hay
C-corn
Cl-clover timothy hay
W-wheat
gm-green manure-alsike, june, sweet clover
O-oats

deficiency symptoms and plant tissue tests indicated that severe nitrogen starvation occurred (Table 5).

The second group includes three rotations, where corn followed sugar beets (Rot. 2), where it followed clover-timothy hay (Rot. 5), and where it followed wheat which was seeded with a leguminous green manure mixture. The corn yields in these three rotations were consistently higher than in the cash crop rotation (Rot. 6), but were lower than where corn followed alfalfa. The one inconsistent figure, in Rotation 2 in 1948, was the result of the sugar beet failure in 1947. Thus in 1948 corn actually followed summer fallow, which in turn had followed alfalfa, instead of following sugar beets.

This second group could be subdivided into two smaller groups on the basis of growth characteristics. The corn which followed the wheat--green manure, and that which followed the clover timothy, consistently responded to nitrogen side dressing. The increases in yield due to nitrogen were smaller, though, than they were in the cash crop rotation. There was no difference in maturity of the crop as indicated by moisture determinations.

The corn which followed sugar beets frequently grew much slower than in any of the other rotations and stalks remained green longer in the fall. No data are available in regard to maturity of the grain because the corn was always harvested some time after a killing frost. Evidently this fact accounts for the lack of data showing a difference in maturity of the grain.

Another observation was made on this rotation in regard to the color of the corn before it reached knee height. Frequently many of the corn plants had a purple tinge identical to the phosphorus deficiency symptoms

Table 5

The Effect of System of Farming Upon Corn Plant

Tissue Tests for Nitrate in 1946[3]

Rotation Number	Crop Sequence[2]	Nitrate Tissue Test[1] Date of Test 6-3	6-25	7-5	7-10	7-15	8-1	8-9	8-20	9-5	Bu/A.
1	SB-Ba-A-A-C	H	H	H	VH	M	L	B	L	B	58.2
2	Ba-A-A-SB-C	H	M	M	H	H	M	L	B	B	53.7
4	SB-Ba-C-A-C	H	H	H	VH	M	M	B	B	B	62.9
5	SB-Ba-O-Cl-C	H	H	M	M	M	L	B	B	B	59.1
6	SB-Ba-Be-W-C	H	M	H	M	B	B	B	B	B	40.8
7	SB-Ba(gm)-Be -W(gm)-C	H	H	H	M	B	L	B	B	B	54.1

[1] VH-very high, H-high, M-medium, L-low, B-blank

[2] SB-sugar beets
Be-beans
Ba-barley
A-alfalfa brome hay
C-corn
Cl-clover timothy hay
W-wheat
gm-green manure mixture of alsike, June, and sweet clover
O-oats

[3] Composite samples from all replications

described by Cook and Millar (9). Plant tissue tests indicated a low phosphorus level. This deficiency seemed to be more intense during those springs having more than normal rainfall and lower than normal temperatures.

The highest corn yields occurred where corn followed immediately after alfalfa-brome. Whether the alfalfa-brome hay was left one or two years made no difference in the yields. The yields from these two rotations (Rot. 1 and 4) have been significantly higher than where corn followed clover-timothy, sugar beets, or wheat. The plants in these two rotations have tested higher in nitrogen and nitrogen side-dressings have not materially increased yields.

Plant tissue tests made during the growing season have always given positive tests for P and K in the plants from all of the rotations. This indicates that regardless of the fact that the corn did not receive fertilizer at planting time, the plants obtained adequate amounts of these two nutrients.

VII. PLOWING TIME OBSERVATIONS

The effect of systems of farming on the physical status of the soil was very noticeable when the plots were being plowed. This was more evident when the plowing was for corn than for beets because corn followed more different crops (Plate 1).

Corn followed two years of alfalfa-brome hay in Rotation 1. When the sod was plowed, it turned over in long ribbons and had a glossy appearance. The soil appeared to be very tight or dense, but when dry broke into fragments with most of the fragments varying between one-half and three inches in diameter. This has occurred within 15 minutes after plowing. The soil seemed to dry much more rapidly than where some other crop was plowed under.

In Rotation 2, corn followed sugar beets. When the soil was plowed for corn, it turned over in large clods, many of them over a foot in diameter (Plate 1). Under the feet, the plowed soil felt tough and hard. Drying caused very little fragmentation of the clods. When the beets had been harvested during wet weather, as they were in 1948, it was possible to observe the effects of tractor wheels in the plowed soil. The trucks which hauled the beets to the factory had more effect on the soil than did the wheels of the harvesting tractor. In either case, the compacted soil was evident even where the furrow had been turned to a depth of 8 or 9 inches. The soil in the wheel tracks dried slowly and did not break up readily with a disc during seed bed preparation. Since these observations were made, trucks have not been allowed on the plots, even though the soil seemed relatively dry. Rotation 4 had one year of alfalfa preceding corn. More alfalfa roots were visible after plowing than in Rotation 1. The soil turned over in indistinct ribbons composed of very angular fragments varying between one and three inches in diameter. Upon drying, the fragments broke into smaller pieces and the soil had a similar appearance to the soil in Rotation 1 except that the furrow slice was less distinct.

Corn followed clover-timothy hay in Rotation 5. When these plots were plowed, the soil turned over in an indistinct ribbon composed of small fragments less than two inches in diameter (Plate 3). Upon drying, the fragments broke down into particles no larger than three-quarters inch. In 1947 and 1948, after plowing manure spreader tracks were plainly visible on the plots in this rotation (Plate 4). They were not seen on any of the other rotations.

In Rotation 6, corn followed wheat. When the land was plowed for corn in this rotation, the individual furrow slices were not distinguishable in that they were composed of small (less than one inch) angular fragments. The plowed plots were level and showed little indication of individual furrow slices. The fragments did not break down upon drying. The soil in this rotation always seemed wetter than in any of the other rotations at plowing time. Also the plow did not cut as wide a furrow and was harder to keep in the soil when the moisture content was low (Plate 2).

In Rotation 7, corn followed wheat in which had been seeded a green manure mixture. At plowing time the furrow slices were not distinct and contained a large number of angular fragments varying between one and three inches in diameter. The soil was similar to that in Rotation 4, but upon drying, these fragments did not break up into smaller fragments. In this respect, the soil was similar to that in Rotation 6.

In Rotation 2, sugar beets followed alfalfa-brome hay. At plowing time the soil had the same appearance as did the soil on the plots in Rotation 1, where corn was to be planted.

Beets followed beans in Rotation 3, but the beans did not affect the characteristics of the plowed soil differently than did corn which preceded the beets in all of the other rotations. When the corn stover was plowed under, the soil turned over as indistinct ribbons composed of varying sized clods.

These observations alone are not of much value. However, after a rain it was not difficult to see the relationship of soil appearance to water stable soil particles. Generally speaking, the smaller the soil particles, the less distinct ribbons during plowing, the less stable were the soil particles. This undoubtedly was due to the influence of the grass roots. Under the conditions of this experiment, there were always more brome grass roots than timothy roots which probably accounted for the more stable soil particles on these plots.

VIII. METHODS USED IN PHYSICAL DETERMINATIONS

A. Dry Screen Analysis of Seed Beds

Dry screen analyses were made on screens measuring approximately 2 x 4 feet. Soil was sampled with a small square nosed spade to a depth of 3 inches at 20 random locations in each plot the day after the crop was planted. The total amount of soil removed from a plot for screen analysis varied between 30 and 50 pounds. Care was taken to keep all aggregate breakage at a minimum. The soil that was caught on the screen was removed and weighed and that which passed through the screen dropped onto the next screen having a smaller size opening.

B. Aggregate Analysis of Root Beds

Soil samples were collected in the spring after planting time, but previous to the first cultivation, with a spade to a depth of 7 inches. This was approximately plow depth. Samples were from four random locations per plot. The four samples from each plot were composited. After the soil was partially air dried, it was passed through a 10 mm screen and then completely air dried. The material finer than 5 mm was then removed by screening. The 5 to 10 mm material was then used for aggregate analysis. This was done so that aggregates of uniform size might be compared. Preliminary investigations showed that this procedure, using uniform size soil particles, reduced the experimental errors. Actually the screened sample represented between 49 and 86 per cent of the original soil sample depending on its moisture content at sampling and screening time.

There was no relationship between the per cent of the original soil sample used for the aggregate analysis and the systems of crop rotations.

Water stable aggregates were determined by the principle outlined by Yoder (62). The laboratory-made wet-sieving apparatus operated four nests of sieves simultaneously at 30 strokes per minute through a distance of 50 mm. The sieving time was 30 minutes. Standard wire sieves having a 6 inch diameter and openings of 4.00, 2.00, 1.00, 0.50, 0.25, and 0.10 mm were used.

Twenty-five grams of the soil was used for each determination. The air dry soil was placed on the top sieve and the nests of sieves were set in motion. After sieving, the soil material which had collected on each sieve was dried and weighed.

Review of Literature on Aggregate Analysis. Bouyoucos (4), Rhoades (41), Cole and Edlefsen (7), and Yoder (62) have proposed methods for measuring the aggregation of soils, but Yoder's procedure has probably been used as much or more than any of the other procedures because of its simplicity. Retzer and Russell (40) have stated that all of the procedures are empirical in nature in that care in operation is needed to obtain reproducible results. Laws and Evans (26) have shown a decrease in aggregation of a rendzina soil resulting from years of cropping. VanBavel (55) has shown a decrease in aggregation from virgin sod to rotational corn to continuous corn. Klute and Jacob (25) have shown that the stability of aggregates in the 2 - 5 mm fraction separated from the air dry soil was significantly increased by the addition of organic matter to soils. These have been the general conclusions of other investigations (20, 24, 38, 60, 61).

C. Porosity Studies of Root Beds

Porosity determinations were made on a pF table similar to the one described by Leamer and Shaw (28). Soil sample cores were collected from random locations on the sugar beet and corn plots, except that attention was paid to row location. Core samples were always taken 10 inches from the corn rows and 7 inches from the beet rows. This was done to minimize the effect of the soil which is thrown towards the rows during cultivation. These distances from the rows represented areas where soil accumulation or soil removal was at a minimum. Cores were taken of the surface soil and no attempt was made to remove the crusts which always formed.

Review of Literature on Porosity. Slipher (50) has enumerated several important requirements of an ideal soil structure. Others could perhaps be added. Most of the requirements are directly related to soil porosity even though some of them are not of an agronomic nature. It would seem that an ideal soil structure should (1) offer minimum resistance to root penetration, (2) permit free intake and moderate retention of rainfall, (3) provide an optimum soil-air supply with moderate gaseous exchange between soil and atmosphere, (4) hold to a minimum the competition between air and water for occupancy of pore space volume, (5) provide a maximum resistance to erosion, (6) facilitate the placement and coverage of green manures and other organic residues, (7) promote microbial activity, and (8) provide stable traction for farm implements. Thus according to Yoder (63), the requirements of a desirable structure are not of a singular nature, but must meet "biologic, agronomic, and engineering objectives".

If soil porosity is related either directly or indirectly to these eight characteristics of an ideal soil structure, it is easily understood why soil porosity determinations are of great value. However, experience has shown that total pore space determinations fail to adequately characterize the physical status of soils in regard to plant growth responses. At the present time, probably the best known method and most widely used method characterizes the soil as to both total pore space and air space. Several techniques have been devised for such determinations (5, 21, 27, 36), but the one of Leamer and Shaw (28) has been used most widely because it utilizes a simple apparatus which allows for rapid determination of a large number of samples.

Bradfield and Jamison (5) have suggested the term "non-capillary" pores, the pores between the aggregates which regulate drainage, percolation, and aeration. Nelson and Baver (36) have suggested that where only one tension is to be used to express non-capillary porosity, the logical tension would be 40 centimeters of water. Baver and Farnsworth (2) showed a direct relation between pores drained at this tension and the yield of sugar beets. These results would seem to indicate that for general work, one point on the pore size distribution curve is sufficient to give a good indication of the soil's physical status if the proper point is chosen.

Leamer and Shaw (28) have stated that "in those regions where tiling is necessary, tension (in centimeters of water) equal to the depth of the tile would seem to be very satisfactory". Therefore in this investigation a tension of 90 centimeters was used, which is the approximate depth of the shallowest tile.

D. Penetrometer Studies of Root Beds

A soil penetrometer is an instrument which measures the resistance offered by a soil to penetration by a probe. It would seem that penetrometers should have been widely used, but there are several reasons why this has not been true. The instruments are for the most part complicated in design, expensive to build, and bulky and laborious to use. Also, soils are so heterogeneous that a few records from a given plot do not give a true picture.

Review of Literature on Penetrometer Studies. Several designs have been published (14, 23, 39, 45, 49, 53). Probably the most novel idea in regard to penetration studies is that recorded by Cuplin (14) when he used a 0.45 caliber revolver and measured the depth of penetration of the bullet as an index of soil hardness.

Many soil conditions influence penetrometer records. Stone and Williams (52) and Reed (39) considered that penetrometer readings could be used as indices of porosity. McKibben and Hull (35) have shown very high correlation coefficients between soil stability (resistance to compaction) and penetrometer records. Shaw, Haise, and Farnsworth (49) concluded that soil moisture is the dominant factor influencing these records. They also feel that it is not practical to attempt to correlate penetrometer records in terms of specific soil properties. Richards (52) has shown how difficult it is to separate the effect of roots and soil. Many references cite instances of difficulty encountered in interpreting penetrometer records, the same references conclude that the penetrometer furnishes just one of the many measurements that are necessary to evaluate a given soil condition correctly.

E. Percolation Studies

The equipment used for the studies included glass tubes measuring 1 3/4 inches in diameter by 8 inches long and screens containing 64 one-sixteenth inch round holes per square inch. These screens were suspended under one end of the glass tubes.

Soil was air dried and passed through a 4 mm screen. It was then passed over a 1 mm screen. The soil material which was retained on the 1 mm screen was used. One hundred cc of soil was placed in the glass tube on a disc of filter paper which had been placed over the screen. The soil was soaked for 40 hours in water and then the percolation rate was determined by measuring the time required to percolate 100 cc of water through the soil. A water head of two inches was maintained during the percolation time. A paper disc was placed on top of the soil to decrease aggregate destruction while water was being poured onto the soil.

A series of experiments leading up to the described procedure were performed. The soil samples were screened to a uniform size to accentuate the differences in percolation rate which occurred before screening.

IX. RESULTS OF PHYSICAL DETERMINATIONS

A. Dry Screen Analysis of Sugar Beet and Corn Seed Beds

In preparing a seed bed for corn or beets, care was taken to have as nearly as possible the same type of seed bed for all of the rotations. The amount of work required to fit a seed bed has been the same for all rotations. Seed bed preparation has usually included two workings with a double disc and one with a spring harrow followed by a spike harrow. Occasionally some extra work was necessary on small areas but the locations were not confined to certain rotations.

Sugar Beet Seed Bed. The results of the dry screen analyses of the sugar beet seed beds are shown in Table 6. Crop rotations caused no differences in these analyses.

Corn Seed Beds. The results of the dry screen analyses of the corn seed beds are shown in Table 7. The data show that the seed bed in the cash crop rotation (Rot. 6) was significantly more cloddy than in the other rotations. The plots where corn followed two years of alfalfa-brome hay (Rot. 1) contained 21.4 per cent more fine soil material than did the plots where corn followed wheat (Rot. 6). This would indicate that it requires more work to fit a similar seed bed in a cash crop rotation than in one which included two years of alfalfa-brome hay.

The current idea of reducing the number of tillage operations to a minimum could be practiced more easily where a rotation included a good alfalfa-brome crop. This type of rotation makes it possible to fit a

Table 6

The Effect of Systems of Farming upon Dry Screen Analysis

of Sugar Beet Seed Beds in 1949

Rotation Number	Crop Sequence[2]	Per Cent Aggregates (by wt.) Within Size Limits Indicated[1] 2"	2-1	1-½	½-¼	¼-1/8	1/8"
1	Ba-A-A-C-SB	4.2	14.3	13.0	16.5	15.7	36.3
2	C-Ba-A-A-SB	2.1	8.4	11.0	18.7	21.5	38.0
3	Ba-A-A-Be-SB	4.8	10.2	12.4	16.7	16.3	39.6
4	Ba-O-A-C-SB	2.8	9.2	12.3	18.1	17.6	40.0
5	Ba-O-Cl-C-SB	3.7	10.8	13.1	18.5	19.5	34.4
6	Ba-Be-W-C-SB	2.6	8.7	13.2	18.4	17.5	39.6
7	Ba(gm)-Be-W-(gm)-C-SB	3.7	11.2	12.8	17.4	15.8	39.1

1 Average of 4 determination - one from each replication

2 SB-sugar beets
Ba-barley
A-alfalfa brome hay
C-corn
O-oats
Cl-clover timothy hay
Be-bean
W-wheat
gm-green manure

Table 7

The Effect of Systems of Farming Upon Dry Screen

Analysis of Corn Seed Beds in 1949

Rotation Number	Crop Sequence[2]	Percent (by wt.) of Clods within Size Limits indicated[1] 2"	2-1	1-½	½-¼	¼-1/8	1/8"
1	SB-Ba-A-A-C	0.3	7.3	10.0	18.0	20.1	44.3
2	Ba-A-A-SB-C	0.0	15.2	15.0	16.8	15.3	37.7
4	SB-Ba-O-A-C	0.7	7.8	13.9	23.7	17.9	36.0
5	SB-Ba-O-Cl-C	0.0	4.0	11.8	22.4	19.6	42.2
6	SB-Ba-Be-W-C	3.1	13.0	19.4	21.5	14.6	28.4
7	SB-Ba(gm)-Be-W-(gm)-C	1.3	7.3	14.9	23.0	17.5	36.0

1 Average of 4 determination - one from each replication

2 SB-sugar beets
Ba-barley
A-alfalfa brome hay
C-corn
O-oats
Cl-clover timothy hay
Be-bean
W-wheat
gm-green manure

comparable seed bed in fewer operations.

In Rotation 4, corn followed one year of alfalfa-brome hay. The soil in this rotation did not crumble as finely as it did in Rotation 1. The hay in this rotation has never contained as much brome grass as has Rotation 1. This is because the brome grass is slow to become established and it is not until the second year that it represents a very significant part of the hay mixture. It is thought that the brome grass was responsible for the difference in the condition of the soil in these two rotations.

Differences in stand of corn plants on these plots have not been noticed, so possibly the differences in the seed beds were minor in regard to seed germination and growth. Counts were made only in 1947. The numbers of plants were 958, 865, 941, 989, 958, and 841 per 1,080 feet of row in Rotations 1, 2, 4, 5, 6, and 7, respectively. These figures indicate no relationship to the differences in seed beds as measured in 1949.

B. Aggregate Analysis of Corn and Sugar Beet Root Beds

Corn Root Beds. In 1946, soil samples were taken from the corn plots in Rotations 1 and 6. Preliminary investigations indicated a great and a meaningful difference in the results of the aggregate analyses of samples taken from the two rotations. The soil from the livestock system of farming contained greater percentages of the large aggregates and the aggregates were more stable, as is shown in Table 8.

Table 8

The Effect of Systems of Farming Upon Aggregate

Analysis of Corn Root Beds in 1946

Rotation Number	Crop Sequence[1]	Particles retained on each screen (%) Particle size distribution (mm) 10-4	2-1	1-.5	.5-.25	.25-.10	less .1
1	SB-Ba-A-A-C	11.4	9.4	14.0	21.2	19.2	13.0
6	SB-Ba-Be-W-C	9.3	7.0	13.7	25.1	23.5	16.7

[1] SB-sugar beets
Ba-barley
A-alfalfa brome hay
C-corn
Be-bean
W-wheat

Table 9

The Effect of Systems of Farming upon Aggregate

Analysis of Corn Root Beds in 1947

Rotation Number	Crop Sequence[1]	Particles retained on each screen (%) Particle size distribution (mm) 10-4	4-2	2-1	1-.5	.5-.25	.25-.10	less .1
1	SB-Ba-A-A-C	8.0	6.6	6.7	14.6	22.5	22.6	19.0
2	Ba-A-A-SB-C	8.1	6.6	6.6	13.2	26.1	20.8	18.6
4	SB-Ba-O-A-C	15.1	7.7	55.7	15.4	20.0	14.8	21.3
5	SB-Ba-O-Cl-C	10.5	8.9	6.2	11.2	22.4	22.0	18.8
6	SB-Ba-Be-W-C	2.6	4.6	4.8	9.5	24.2	31.9	22.4
7	SB-Ba(gm)-Be -W-(gm)-C	8.6	5.3	5.4	11.8	26.0	24.0	18.9
	Blue grass	36.6	10.4	8.4	8.9	11.7	8.1	15.9

[1] Ba-barley
Be-bean
A-alfalfa brome hay
C-corn
SB-sugar beet
O-oats
Cl-clover timothy hay
W-wheat
gm-green manure

Table 10

The Effect of Systems of Farming Upon Aggregate

Analysis of Corn Root Beds in 1949

Rotation Number	Crop Sequence	Particles retained on each screen (%) Particle Size Distribution (mm) 10-4	4-2	2-1	1-.5	.5-.25	.25-.10	less .10
1	SB-Ba-A-A-C	5.4	3.8	5.5	13.4	27.0	27.7	17.2
2	Ba-A-A-SB-C	3.9	4.4	4.9	12.1	26.1	30.4	18.2
4	SB-Ba-O-A-C	5.4	2.9	5.8	13.2	27.5	25.8	19.4
5	SB-Ba-O-Cl-C	7.3	3.0	5.3	12.3	26.5	28.4	17.2
6	SB-Ba-Be-W-C	2.1	2.3	4.1	11.6	28.4	30.4	21.1
7	SB-Ba-(gm)-Be-W-(gm)-C	1.6	2.8	5.4	12.9	28.4	30.2	18.7

Table 11

The Effect of Systems of Farming upon Aggregate

Analysis of Sugar Beet Root Beds in 1947

Rotation Number	Crop Sequence[1]	Particles retained on each screen (%) Particle Size Distribution (mm) 10-4	4-2	2-1	1-.5	.5-.25	.25-.10	less .10
1	Ba-A-A-C-SB	5.4	8.1	5.8	10.4	22.9	24.2	23.2
2	C-Ba-A-A-SB	10.6	7.9	5.7	9.9	21.1	22.5	22.3
3	Ba-A-A-Be-SB	5.0	7.6	5.5	9.6	22.5	25.4	24.4
4	Ba-O-A-C-SB	8.1	7.0	5.7	9.8	19.2	21.9	28.3
5	Ba-O-Cl-C-SB	6.9	7.1	5.2	10.6	21.1	24.3	24.5
6	Ba-Be-W-C-SB	6.3	6.8	5.7	9.9	22.8	25.5	23.0
7	Ba-(gm)-Be-W-(gm)-C-SB	7.4	10.5	6.0	10.2	21.1	21.7	23.1
	Grass	36.6	10.4	8.4	8.9	11.7	8.1	15.9

[1] Ba-barley
Be-bean
A-alfalfa brome hay
C-corn
O-oats
Cl-clover timothy hay
SB-sugar beets
gm-green manure

The 1947 aggregate analyses of the soil from the corn plots (Table 9) indicate that one year of hay (Rot. 4 and 5) in a rotation resulted in more water stable aggregates than did two years of hay, but such was not the case in 1949 (Table 10). The data from all three years show that the soil from the cash crop rotation was the least stable and was aggregated to a lesser degree than was the soil from any of the other rotations.

Sugar Beet Root Beds. The aggregate analyses of the soil from the sugar beet plots (Table 11) show little difference in aggregation between Rotations 1, 3, 4, 5, 6, and 7. In Rotation 2 (beets after alfalfa), the soil was more stable and better aggregated than the soil in any of the other rotations. This is in agreement with observations that have been made by the beet workers at blocking and thinning time and by Mr. Ferden at cultivation time.

If the aggregate analyses of the corn and beet soils are compared with the aggregate analyses of soil under sod located in a little used alley way adjacent to the plots, the potential value of grass as an aggregating agent is fully realized. Inspection of the screens during the time the analyses were made showed clearly the mechanical effect of the grass roots in binding some of the smaller aggregates together to form larger ones.

It is thought that the aggregate analysis of soil samples taken at the time these were obtained reflect the influence of the preceding crop. If this is the case, the great difference in aggregation of the soil obtained from the corn and sugar beet plots in Rotation 6 might suggest that corn has an aggregating effect upon the soil. The validity of this idea is doubtful, but the difference is so striking that further investigation along this line should be made.

C. Total and Non-Capillary Porosity of
Corn and Sugar Beet Root Beds

<u>Corn Root Beds</u>. Total porosity determinations made on soil samples collected in the early part of the growing season suggested that there was no difference caused by crop rotations (Table 12). The samples from the plots where corn followed wheat (Rotation 6) contained particles of straw and therefore, it was thought that the straw might significantly raise the total per cent porosity. This, however, was not the case but it is believed that the presence of the straw did materially influence the results of the determinations. The fragments of straw were still visible in the samples which were collected at corn harvest time, but much of their structure had been lost so that they probably did not affect these determinations nearly so much as they did earlier in the season. Despite this, at harvest time the soil in the cash crop plots contained the lowest per cent pore space. The 1948 data are in agreement with those obtained in 1947.

The results of the non-capillary pore space determinations showed no difference in the soil under the different systems of farming in 1947. In 1948, at harvest time, the soil in the Rotation 6 plots had the lowest non-capillary pore space. The greatest non-capillary pore space occurred where corn was preceded by two years of alfalfa-brome hay. The effect of alfalfa-brome sod in a rotation was evident. The leguminous green manure crop in Rotation 7, which preceded the corn, significantly increased

Table 12

The Effect of Systems of Farming upon Total and Non-Capillary

Pore Space of the Soil in the Corn Plots

Rotation Number	Crop Sequence[4]	Per cent total pore space July 15[1] 1947	Oct. 15[2] 1947	Oct.[3] 1948	Per cent Non-Capillary pore space June 15[1] 1947	Oct. 15[2] 1947	Oct.[3] 1948
1	SB-Ba-A-A-C	45.8	48.2	50.3	11.3	10.8	10.4
2	Ba-A-A-SB-C	45.2	45.8	49.3	9.4	8.9	9.7
4	SB-Ba-O-A-C	45.0	49.0	48.8	12.2	9.9	9.8
5	SB-Ba-O-Cl-C	46.0	49.3	48.4	12.3	9.4	9.0
6	SB-Ba-Be-W-C	44.5	43.9	45.4	10.4	5.7	7.7
7	SB-Ba-(gm)-Be-W-(gm)-C	45.1	46.8	47.4	11.9	9.4	8.7
	Significance	--	**	**	--	--	**
	L.S.D.	N.S.	2.5	1.4	N.S.	N.S.	0.9

(Sampling date and per cent pore space)

1 Average of 12 determinations
2 Average of 8 determinations
3 Average of 44 determinations
4 SB-sugar beets, Ba-barley, A-alfalfa brome hay, C-corn, O-oats, Cl-clover timothy hay, Be-beans, W-wheat, gm-green manure

the non-capillary pore space but was not as effective as was the alfalfa-brome in Rotations 1, 2, and 4.

<u>Sugar Beet Root Beds</u>. Porosity determinations were made on the sugar beet plots in 1947 despite the fact that the beets were not harvested. The results of the June 12 sampling (Table 13) from replication number one showed a difference in total porosity. However, the differences were not consistent with previous crops so it is believed that the differences represent natural soil variations rather than the effects of crop rotation. Porosity determinations were made a short time after the beets were replanted and the results of these determinations indicate no differences caused by rotations. The results of the September determinations show a significant difference in total porosity. The porosity was highest on the plot where sugar beets followed alfalfa-brome hay (Rot. 2). The differences in total porosity between the June 17 and September 23 sampling dates indicate that the total porosity on these plots decreased as the growing season progressed. Such a decrease did not occur on the plots where sugar beets followed alfalfa-brome hay.

The 1948 results are in agreement with the 1947 results. More confidence is placed in these results than in the results for 1947 because a much larger number of determinations were made. This resulted in a better picture of the conditions which actually existed. The total porosity was highest on the plots where alfalfa-brome hay preceded the beets, and significantly the lowest where beets were grown in a cash crop rotation which did not include a nitrogen-adding legume.

The results of the non-capillary pore space determinations are shown in Table 13. Previous to the first cultivation no difference in non-capillary

Table 13

The Effect of Systems of Farming upon Total and Non-Capillary

Pore Space of the Soil in the Sugar Beet Plots

		Sampling Date							
		Per cent total pore space				Per cent non-capillary pore space			
Rotation Number	Crop Sequence[5]	June 17[1] 1947	June 17[2] 1947	Sept. 25[3] 1947	Oct.[4] 1948	June 12[1] 1947	July 17[2] 1947	Sept. 23[3] 1947	Oct.[4] 1948
1	Ba-A-A-C-SB	48.5	52.6	46.3	46.4	17.1	23.5	14.2	9.7
2	C-Ba-A-A-SB	53.8	50.6	50.7	50.0	23.1	19.8	21.3	13.5
3	Ba-A-A-Be-SB	51.1	53.0	46.6	45.7	16.6	24.2	14.2	11.2
4	Ba-O-A-C-SB	52.3	53.1	44.6	45.5	21.7	22.9	12.3	10.0
5	Ba-O-Cl-C-SB	52.0	54.5	47.3	47.3	19.4	24.2	14.1	9.0
6	Ba-Be-W-C-SB	53.9	53.8	45.2	41.4	20.0	23.4	9.5	7.5
7	Ba-(gm)-Be-W-(gm) -C-SB	49.2	52.8	44.2	44.9	17.7	23.1	10.9	9.8
	Significance	*	--	**	**	--	--	**	**
	L.S.D.	2.7	N.S.	3.2	2.6	N.S.	N.S.	4.5	2.1

1 Replication 1.--average of 4 determinations
2 All replications--average of 8 determinations
3 Replication 1.--average of 3 determinations
4 All replications--average of 60 determinations
5 Ba-barley — Be-beans
A-alfalfa brome hay — Cl-clover timothy hay
C-corn — gm-green manure
SB-sugar beets — O-oats

pore space existed in the beet soils. The same phenomenom occurred between July and September as occurred for the total porosity determinations, in that a significant decrease in non-capillary porosity occurred in the soil on every rotation except where alfalfa preceded the beets.

The 1948 data, generally speaking, are in agreement with the 1947 data. The soil on the Rotation 6 (cash crop) plots had the smallest amount of non-capillary pore space and the soil on the plots where beets followed alfalfa-brome contained the most. No significant differences occurred in the results obtained on the soils from Rotations 1, 4, 5, and 7. The soil where beets followed beans contained more non-capillary pore space than did the soil where beets followed corn.

D. Physical Determination on Soil Below Plow Depth

Several investigators have indicated that in order to maintain a desirable subsoil structure deep rooted legumes must be grown in a rotation. They theorize that the deep rooted crops produce roots which are capable of penetrating the naturally more dense subsoil. The action of the roots is manifested in three ways: 1. After the roots die, vertical channels are left in the soil, thus improving drainage and aeration; 2. The roots and root hairs, physically and chemically, act as aggregating agents thus causing better structure; 3. The deep penetrating roots add much needed organic matter to the subsoil, thus potentially improving its physical status.

Aggregate analysis (Table 14) and porosity determinations (Table 15) of subsoil samples do not substantiate these theories. However, it may not be correct to attempt to evaluate the validity of these theories on the basis of the evidence presented because these rotations are only

Table 14

The Effect of Systems of Farming upon Aggregate Analyses

of Soil Below Plow Depth - 7 to 10 inches in 1947

Rotation Number	Crop Sequence[1]	Per Cent Composition Particle Size Distribution (mm)						
		4	4-2	2-1	1-.5	.5-.25	.25-.1	less .1
	Corn Plots							
1	SB-Ba-A-A-C	5.7	8.3	10.8	16.9	22.1	13.0	23.2
6	SB-Ba-Be-W-C	5.2	8.0	10.0	16.4	22.9	15.4	22.1
	Beet Plots							
2	C-Ba-A-A-SB	3.4	7.5	7.8	14.6	18.6	21.2	26.9
6	Ba-Be-W-C-SB	2.1	11.3	8.5	15.5	15.2	19.1	28.3

[1] SB-sugar beets
Ba-barley
A-alfalfa brome hay
C-corn
W-wheat
Be-beans

Table 15

The Effect of Systems of Farming Upon Non-Capillary and

Total Porosity of Soil Below Plow Depth 7 to 10 Inches

Rotation Number	Crop Sequences[5]	Non-Capillary Porosity		Total Porosity	
	Sugar Beet Plots	8-4-47[1]	6-15-48[2]	8-4-47[1]	6-15-48[2]
1	Ba-A-A-C-SB	7.0	9.6	45.3	42.2
2	C-Ba-A-A-SB	6.9	10.3	43.8	41.5
3	Ba-A-A-Be-SB	7.0	8.7	44.5	42.6
4	Ba-O-A-C-SB	7.0	8.8	44.5	43.4
5	Ba-O-C-C-SB	6.5	9.3	44.1	44.1
6	Ba-Be-W-C-SB	5.8	10.0	44.1	43.8
7	Ba-(gm)-Be-W-(gm)-C-SB	6.2	8.1	44.9	39.2
	Significance	N.S.	N.S.	N.S.	N.S.
	Corn Plots	7-31-47[3]	6-21-48[4]	7-31-47[3]	6-21-48[4]
1	SB-Ba-A-A-C	6.6	6.4	42.4	46.4
2	Ba-A-A-SB-C	6.6	6.9	44.5	45.3
4	SB-Ba-O-A-C	8.7	7.3	44.2	44.0
5	SB-Ba-O-Cl-C	6.8	6.6	45.8	43.1
6	SB-Ba-Be-W-C	5.0	7.6	43.7	43.6
7	SB-Ba-(gm)-Be-W-(gm)-C	6.6	6.4	42.9	44.2
	Significance	N.S.	N.S.	N.S.	N.S.

[1] Average of 4 determinations from each replication
[2] Average of 10 determinations from replication 1 and 2
[3] Average of 25 determinations from replication 1 and 2
[4] Average of 10 determinations from each replication
[5] Ba-barley Be-beans
A-alfalfa brome hay Cl-clover timothy hay
C-corn gm-green manure
SB-sugar beets O-oats

in their second cycle. The data do indicate that if the theories are valid, it is not possible to improve subsoil structure in a few years. The process must be included in a long range plan.

E. Penetrometer Studies

Plumb Type Penetrometer. In view of the observations that had been made in regard to soil structure, preliminary investigations with a soil penetrometer were started in 1946 with an instrument designed by Stone and Williams (Plate 10). This instrument has an iron plumb weighing 1500 gms. which is dropped through a hollow tube from a height of approximately four feet. The inches of soil penetrated by the plumb is used as an index of the physical status of the soil. The instrument has one serious handicap in that only the surface soil is considered. This penetrometer has one advantage in that a large number of records can be made from a given soil area very rapidly. The data in Table 16 indicate that this is absolutely necessary. The data shown in this table were taken from four replications of the same treatments and indicate an average penetration into the soil of 5.0 inches by the plumb. The data show a significant difference between replications in the experiment as well as between halves of the same plot. This table is included to illustrate some of the problems encountered in making physical measurements of the soil particularly where it is not possible to take composite soil samples such as the soil chemist does. The variations are undoubtedly due to differences that naturally occur in the soil and differences caused by various tillage implements.

The data from the corn plots (Table 17) show that crop rotations did

Table 16

A Sample of Penetrometer Records Showing

Variation Within Plots

(Rotation 1--Sugar Beet Plots — 5-3-46)

Record Number	Inches of Penetration by Penetrometer Plumb								
	R1		R2		R3		R4		
	E	W	E	W	E	W	E	W	
1	4.5	4.5	4.8	5.5	5.0	4.2	5.0	3.8	
2	5.0	4.5	3.8	5.2	5.5	5.2	4.5	5.8	
3	4.8	4.5	3.5	6.0	5.5	4.8	5.5	6.5	
4	5.2	4.5	4.5	6.2	5.2	6.0	5.0	7.8	
5	4.8	4.2	4.8	6.2	5.5	5.5	5.0	6.8	
6	4.5	4.0	5.0	4.2	4.2	5.2	5.0	4.2	
7	3.8	6.0	4.5	6.0	4.5	5.0	4.2	5.0	
8	5.2	5.0	5.2	5.2	5.2	4.2	6.8	5.5	
9	4.5	7.0	4.2	5.5	5.2	5.0	5.0	6.2	
10	5.0	5.5	4.8	4.8	4.5	6.8	7.0	5.0	
Mean	4.73	4.85	4.51	5.00	5.03	5.11	5.30	5.48	5.00
Range	1.4	3.0	1.7	2.0	1.3	2.6	2.8	4.0	4.3

R--replication; E-east one-half of plot; W--west one-half of plot.

Table 17

Penetrometer Records on Corn, Sugar Beet and Barley

Plots in 1946, 1947, and 1948

Inches of Penetration by Penetrometer Plumb

Rotation Number	Corn[1]				Sugar Beets[1]			Barley[2]		
	5-3-46	5-21-46	7-16-47	7-16-48:	5-3-46	5-21-47	7-16-48:	5-3-46	5-21-47	7-22-48
1	4.5	7.1	5.3	3.4	5.3	5.4	5.2	4.8	5.8	4.3
2	4.7	6.2	4.0	3.2	5.7	5.1	5.3	4.9	5.5	4.5
3					5.3	5.4	5.3	4.9	5.5	4.6
4	4.7	6.7	5.2	3.5	5.3	5.3	5.4	4.9	5.5	4.8
5	4.7	7.0	5.3	3.3	5.3	5.3	5.3	5.0	5.6	4.8
6	6.1	6.9	5.3	3.6	5.3	5.4	5.5	4.9	5.6	4.3
7	5.9	6.6	5.1	3.4	5.3	5.3	5.3	4.5	5.4	4.6
Significance	*	*	*	*	*	--	--	--	--	--
L.S.D. at 5%	0.3	0.4	0.4	0.3	0.2	N.S.	N.S.	N.S.	N.S.	N.S.

[1] Average of 40 determinations

[2] Average of 40 determinations except for the 7-22-48 samplings which are an average of 20 determinations

Spring Type Penetrometer. By 1948, it was evident that the type of penetrometer being used was not supplying data which indicated anything except that there were differences in the soil in the corn plots. Differences in soil structure could be seen that were greater than the records indicated. In an effort to record such differences, a new type of penetrometer was designed (44). This instrument, shown in Plate 9, makes possible an examination of soil compaction to a depth of 12 inches.

The instrument was designed to meet the following requirements: (1) compact--so that it might be transported in an automobile; (2) light-weight--for one man operation; (3) rapid performance--a large number of readings in a short time; (4) versatile--useful under many soil conditions; (5) inexpensive to construct and maintain; (6) functional--indicate soil conditions to a depth of 12 inches.

The curves shown in Figure 1 prove that the instrument is sensitive and capable of measuring differences in the physical status of soil. The data from which these curves were constructed were from the tillage plots on the college farm at corn planting time. The curves show clearly that differences in soil compaction occurred as a result of the different tillage methods, both as to compaction at the surface and at greater depths.

With such extreme variations in the physical status of a soil one wonders if various tillage methods might mask the effects of systems of farming to such an extent that crop rotations could be considered only of minor importance.

Corn Plots. The 1949 penetrometer records from three of the rotations are shown in Figure 2. The soil conditions on all of the rotations produced the same type of penetrometer curve. The soil, to a depth of three

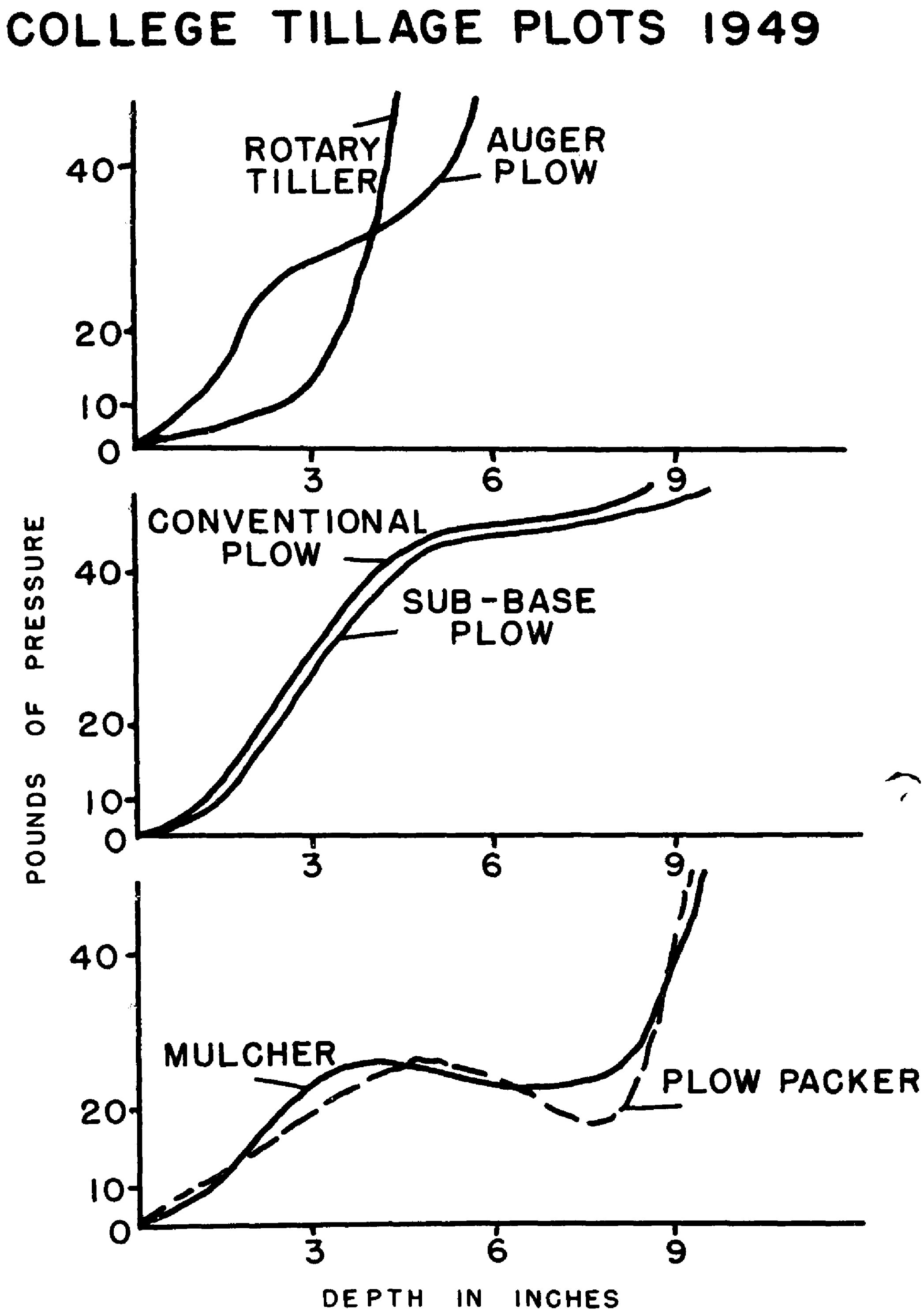

Figure 1

Penetrometer Records from College Tillage Plots at

Corn Planting Time

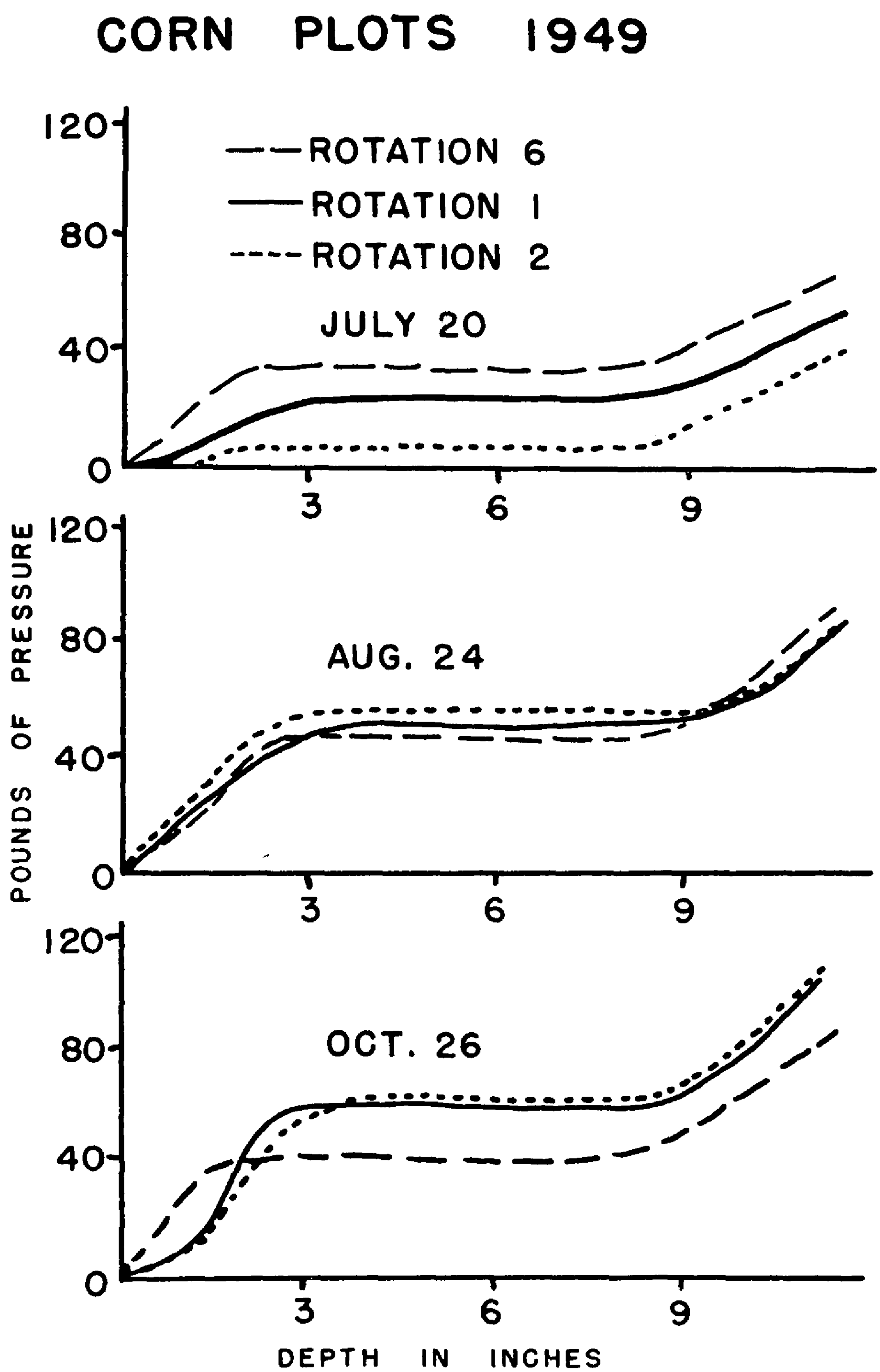

Figure 2

Penetrometer Records from 1949 Corn Plots Comparing the Soil in Rotations 1, 2, and 6 During the Growing Season inches, was more compact than the soil below that depth. The only curve which indicated a significant difference between rotations was made on July 20. At that time, the soil where cash cropping had been practiced, offered more resistance to the probe than did the soil on the Rotation 2 plots. In 1950 (Figure 3) the surface soil in Rotation 6 to a depth of approximately two inches offered more resistance to a probe than did the surface soil in any of the other rotations. This difference did not manifest itself until late in the growing season as is shown in (Figure 4).

Sugar Beet Plots. The soil on the beet plots was similar to that on the corn plots in that early in the growing season, rotations did not influence the type of curve drawn by the penetrometer. However, the records which were made in October showed that the soil where alfalfa had preceded beets (Rot. 2) offered much less resistance than where corn had preceded the beets (Rot. 1, 4, 5, 6, 7). This occurred both in 1949 and 1950 (Figures 5, 6, 7).

Barley Plots. The data from the barley plots (Figures 8, 9) show that extreme caution should be used in interpreting penetrometer records. The barley in Rotation 6 had no seedings and in Rotation 1 alfalfa-brome was seeded in the barley. The rapidly growing seedlings in Rotation 1 apparently reduced the surface soil moisture in this rotation to such an extent that the difference between rotations was reflected in the type of penetrometer curves obtained. It required more pressure to force the probe into the soil on the plots which contained alfalfa. It may also have been true that the alfalfa seedling roots increased the pressure which was required to force the probe into the soil.

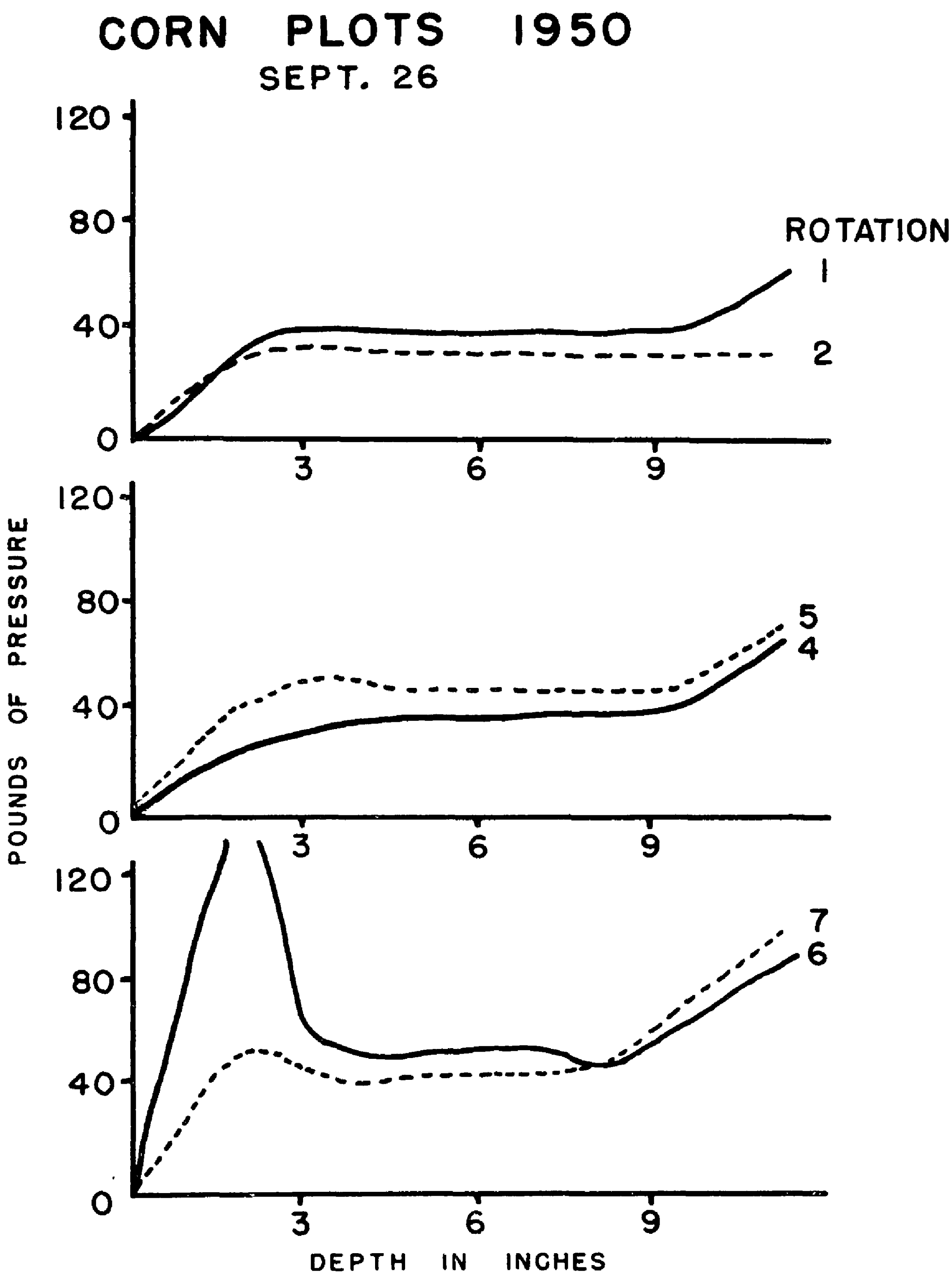

Figure 3

Penetrometer Records from 1950 Corn Plots Comparing the Soil in Rotations 1, 2, 4, 5, 6, and 7

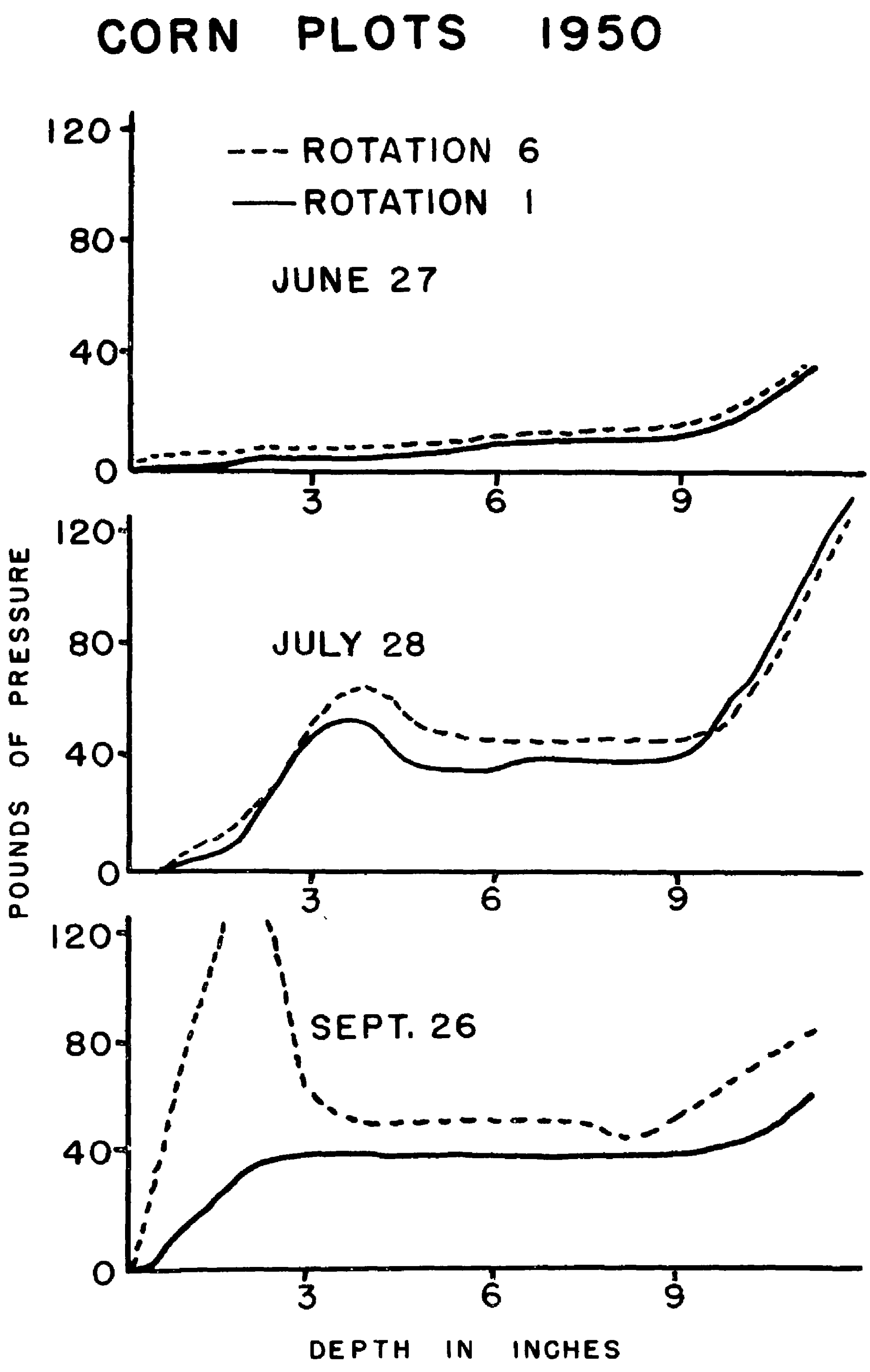

Figure 4

Penetrometer Records from 1950 Corn Plots Comparing the Soil in Rotations 1 and 6 During the Growing Season

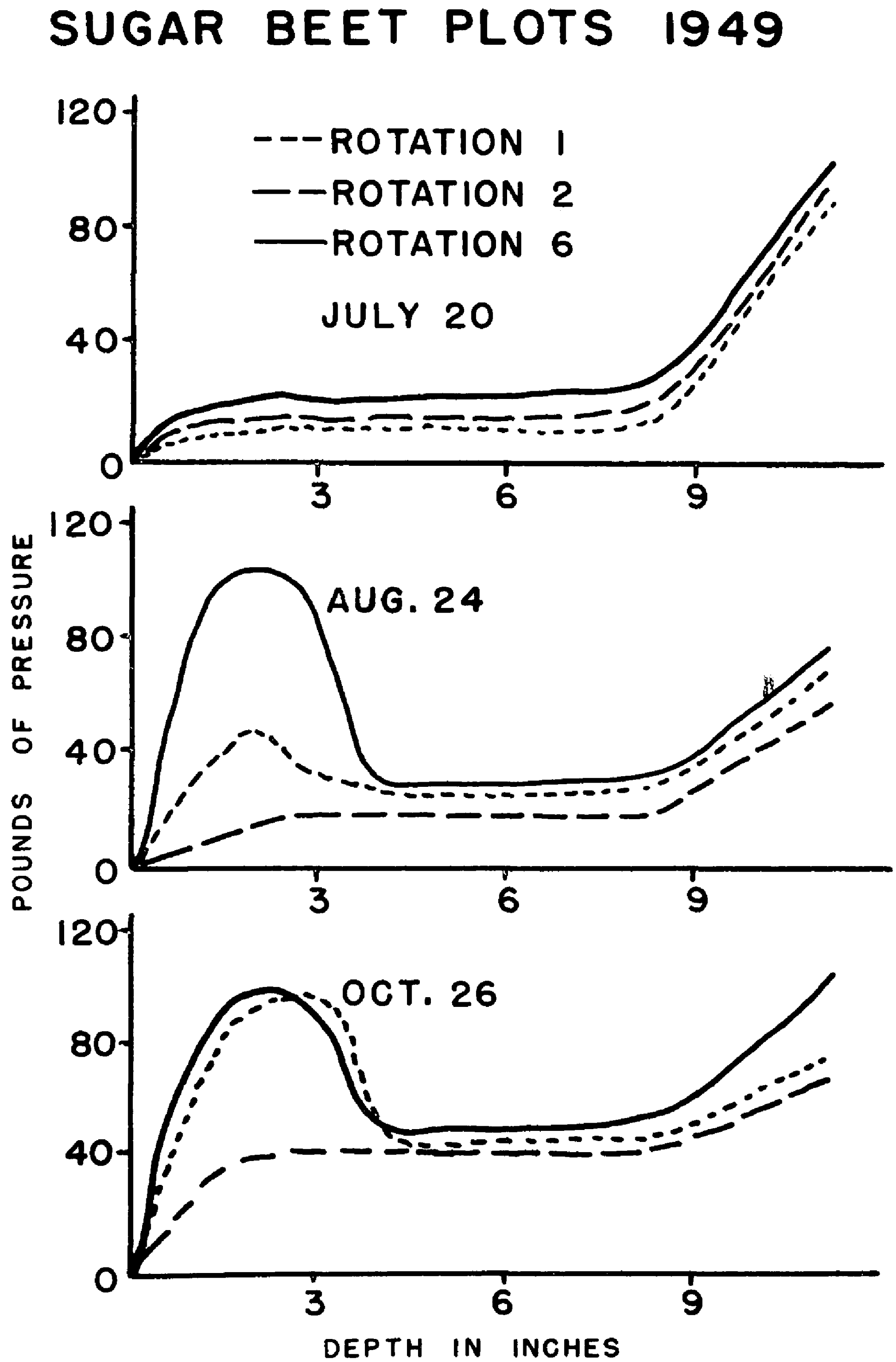

Figure 5

Penetrometer Records from 1949 Sugar Beet Plots

Comparing the Soil in Rotations 1, 2, and 6

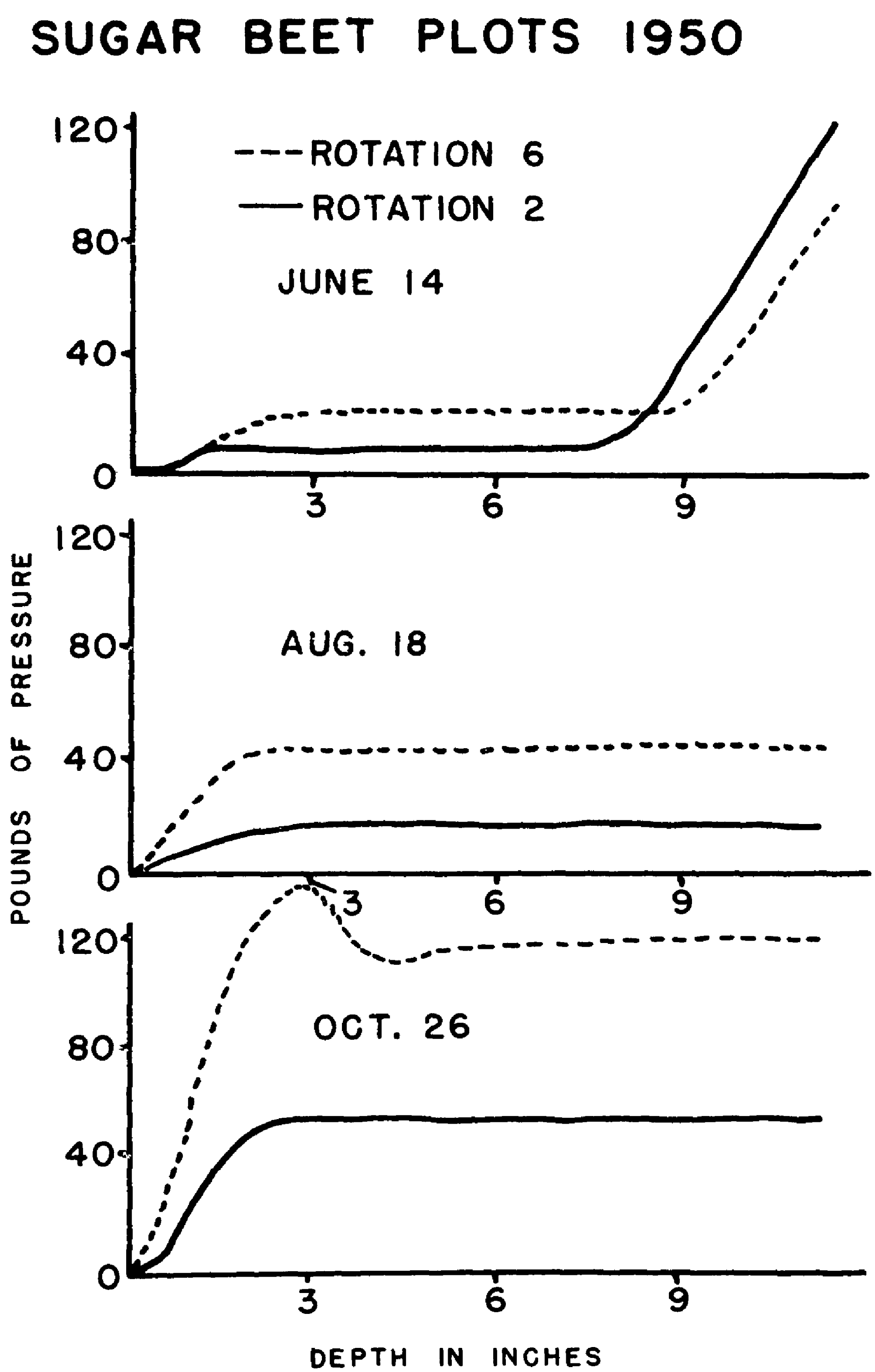

Figure 6

Penetrometer Records from 1950 Sugar Beet Plots

Comparing the Soil in Rotations 2 and 6

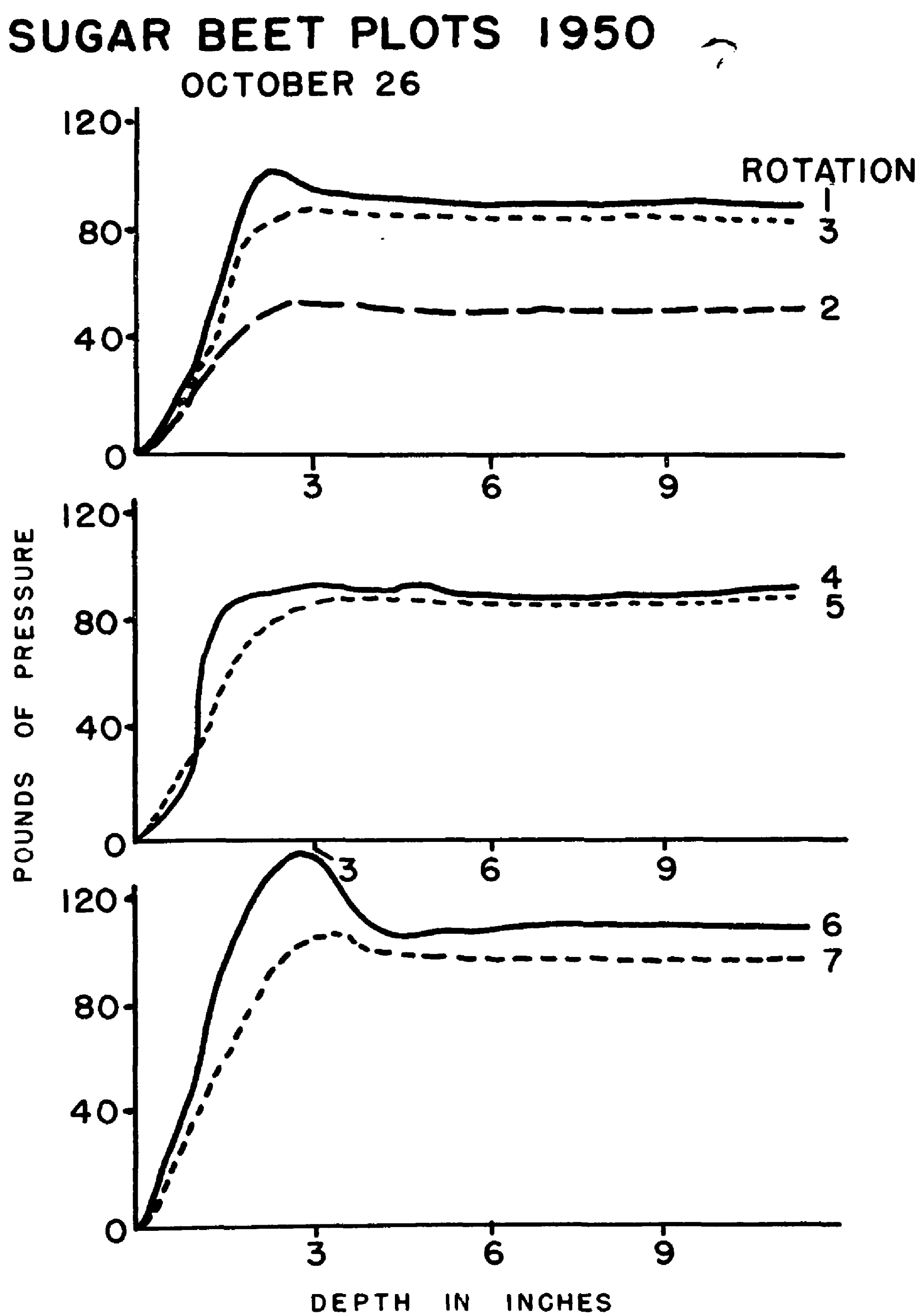

Figure 7.

Penetrometer Records from 1950 Sugar Beet Plots

Comparing the Soil in Rotations 1, 2, 3, 4, 5, 6, and 7

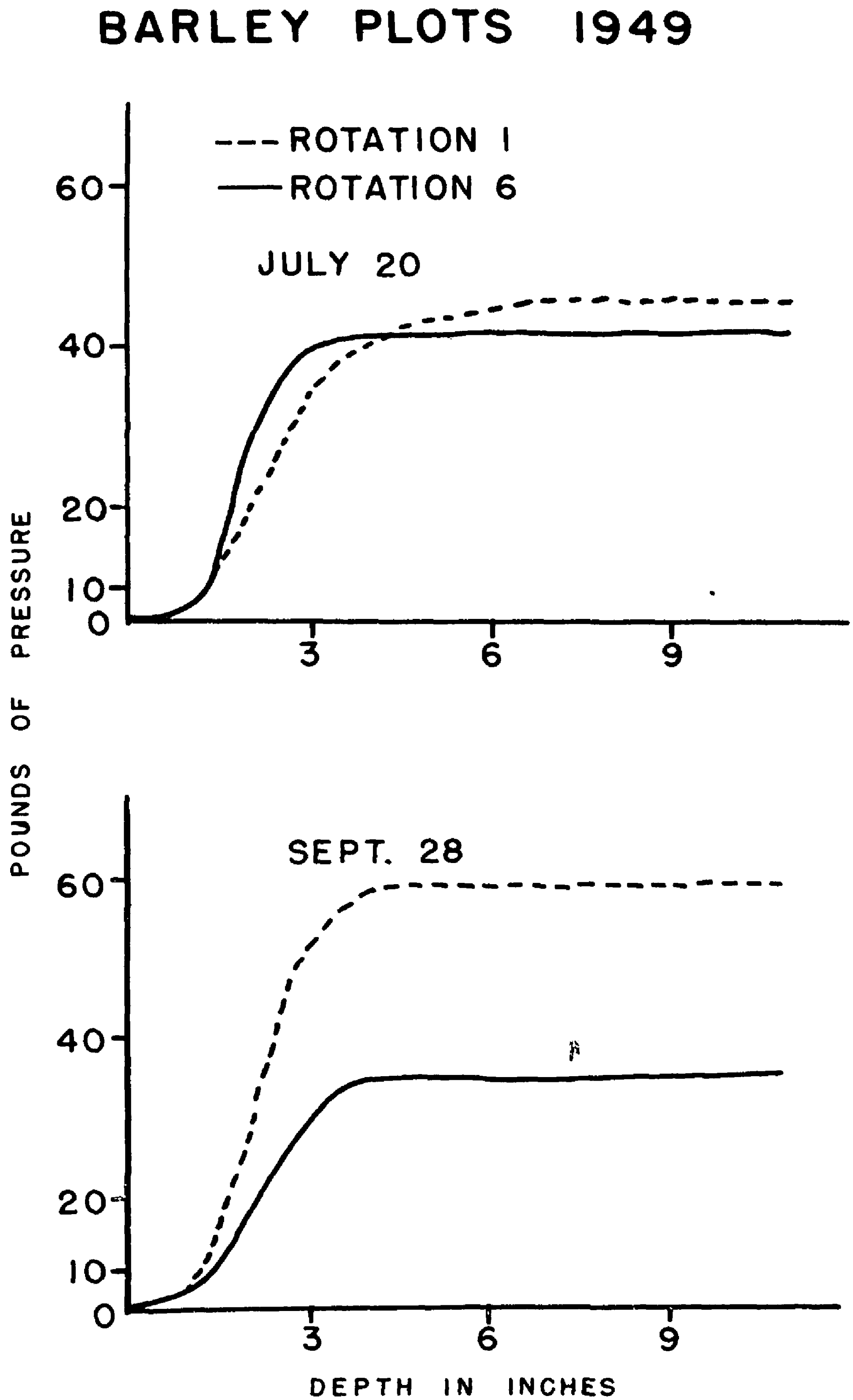

Figure 8

Penetrometer Records from 1949 Barley Plots Comparing the Soil in Rotations 1 and 6

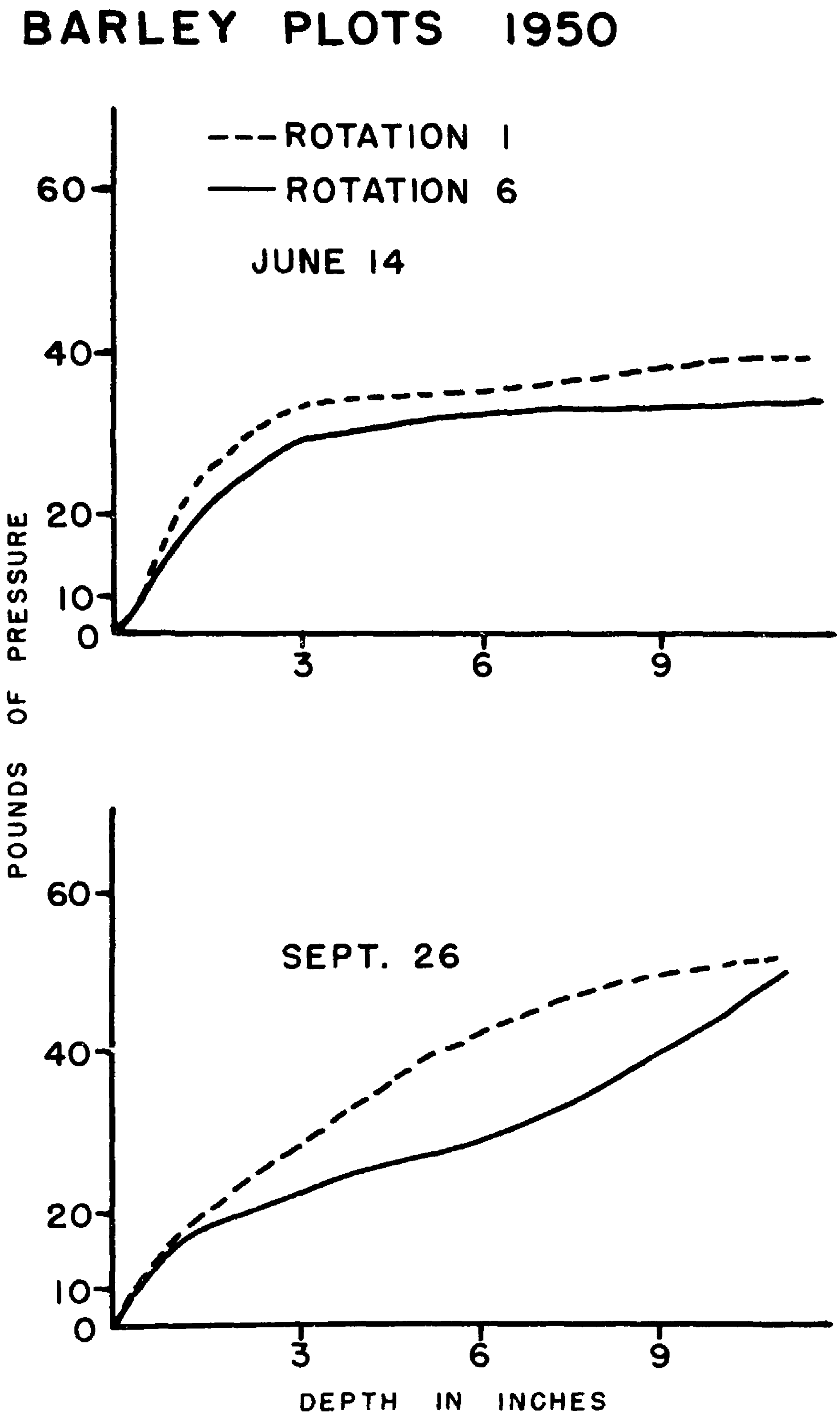

Figure 9

Penetrometer Records from 1950 Barley Plots Comparing the Soil in Rotations 1 and 6

F. Percolation Studies

Percolation studies were made during the winter of 1948-1949 on soil which was to be planted to corn and to sugar beets in 1949.

The data (Table 18) reveal that a great difference existed in the percolation rate of soils on the rotation plots. The results obtained on the soils taken from the sugar beet plots showed that where alfalfa-brome had been grown the least time was required for the water to percolate through the soil. The soil from the clover-timothy and the green manure rotation plots came next in time requirement and the soil from the non-legume plots retained the water the longest. The same relationship was expressed by the beet yields in those years that the highest yields were obtained.

The data for corn show the same general relationship in that the highest yields and fastest percolation rates were obtained on the same soil. The lowest yield and percolation rate occurred on the soil from the cash crop plots.

The data reveal a strong relationship between percolation rate and crop yields. Further investigations in this direction seem desirable from the standpoint of a single, simple and rapid test which measures soil structure. It is felt that this procedure indirectly measures soil aggregate stability to water. This point is most important in regard to the structure of surface soils because it is possible to fit a reasonably good seed and root bed with conventional implements. The surface soil structure problem (crusting) invariably arises after the crop has been planted and after several rains have occurred.

Table 18

The Effect of Systems of Farming Upon Percolation

Rates of Soils to be Planted to Sugar Beets and

Corn in 1949

Rotation Number	Crop Sequence[2]	Time in seconds required to collect 100cc of water	
		Sugar Beet Plots[1]	Corn Plots[1]
1	Ba-A-A-C-SB	335	285
2	Ba-A-A-SB-C	360	290
3	Ba-A-A-Be-SB	295	
4	Ba-O-A-C-SB	320	325
5	Ba-O-Cl-C-SB	430	335
6	Ba-Be-W-C-SB	660	540
7	Ba-(gm)-Be-W-(gm)-C-SB	510	380

1 Averages of determinations made from samples taken from replication 1 and 2.

2 Ba-barley
A-alfalfa brome hay
C-corn
SB-sugar beets
Be-beans
O-oats
Cl-clover timothy hay
W-wheat
gm-leguminious green manure mixture

This hypothesis is illustrated in Plates 7 and 8. A virgin soil has no crust on the surface of the soil. A cultivated soil usually crusts during the growing season. It is thought that the thickness of the crust is closely related to the water stability of the soil aggregates.

X. DISCUSSION

The ability of the soil to produce crops is dependent not only on the proper supply and balance of nutrients, but also upon such air and water relations as will make possible the most efficient use of available nutrients by the plants. In this study, it was found that corn and sugar beet yields were somewhat dependent upon the proportion of time during the rotation in which the land was devoted to the growth of nitrogen adding legumes. Subsequently it was found that different rotations caused different soil conditions to exist and that it was possible to measure differences in soil conditions by several procedures. The relationship of soil conditions to available nitrogen supply and its ultimate effect on crop yields is vague until one reviews the work of Doiarenko (3). He found that nitrate formation in the soil varied directly with the per cent non-capillary porosity. More specifically, 2.7, 24.5, 35.1 and 38.7 per cent non-capillary porosity resulted in the formation of 9.0, 19.1, 34.0, and 45.8 milligrams respectively of nitrogen as nitrate nitrogen.

Observations, made after plowed plots had dried and had been rewetted showed that the various systems of farming influenced the stability of the soil aggregates. The all-cash-crop rotation caused the soil aggregates to be relatively unstable whereas the inclusion of a leguminous green manure in a rotation materially increased aggregate stability. It is thought that at plowing time the stability of the aggregates at the surface of the soil is related to the natural size of the aggregates. In other words, small aggregates have a greater surface

two soil layers.

No consistent differences were observed in the effects of one versus two years of alfalfa-brome hay upon crop yields and soil structure. The ten year averages in corn yields were within a bushel of each other. The 1947 aggregate analyses of the soil on the corn plots showed the most stable aggregates to exist on the plots where corn followed one year of alfalfa-brome hay. This, however, did not occur again in 1948. During that year the physical determinations failed to reveal a difference in the results obtained where alfalfa-brome had been grown one as compared to two years. The data obtained where clover timothy hay was grown were not unlike those obtained on the soil which had produced alfalfa-brome hay.

The ten year averages of the corn yields where corn was preceded by one year of alfalfa-brome hay and by one year of clover-timothy hay clearly indicate the more desirable effect of alfalfa-brome upon corn yields.

The cash crop rotation (Rot . 6), which had no nitrogen supplying legume crop, consistently produced the lowest corn yields. It was on these plots that the soil was in the least desirable physical condition.

The inclusion of green manure crops in a cash crop rotation (Rot. 7) resulted in greater yields of all the crops in the rotation. Aggregate analyses, penetrometer studies, porosity determinations, and percolation studies have all indicated that the soils where the leguminous green manure crops were grown were in a better physical condition than were those where they were omitted.

The results of the studies on the sugar beet plots are in agreement with the results obtained from the corn plots. In Rotation 2, sugar beets followed two years of alfalfa-brome hay. All of the analyses indicated that the soil in this rotation had a more desirable physical condition, in regard to porosity and aggregation than did any of the others. The yields from this rotation however have not always been the highest. Undoubtedly, black root disease partially accounts for this because the number of marketable beets produced in this system of farming was lowest in six out of the nine years record. Stand counts made during the growing season suggest a direct relationship to number of marketable beets. No difference has ever been observed on the effect of systems of farming upon number of diseased beets. However, it has been observed that where beets followed alfalfa, recovery from this disease was much slower and not as complete as where beets followed some other crop.

Apparently there is some factor other than black root which retards the growth of beets when they are grown after alfalfa-brome hay. Since the yields were so variable from one year to the next it would seem that weather conditions influence the rapidity and extent of the decomposition of the alfalfa-brome grass plants. Further investigation on this subject is necessary.

At the end of the growing season the soil in this rotation was in a better physical condition than the soil in any of the other rotations. Regardless of the better soil conditions farmers do not like to grow sugar beets after alfalfa because they have experienced the same variable yield results and usually blame it on black root.

The results from the physical determinations on the sugar beet soils in the other rotations where legumes were included, failed to indicate rotation differences. They were, however, different from the results obtained on the soils in the non-legume rotation (Rot. 6). The results obtained from physical measurements on Rotation 6 soils were markedly different from those obtained on soils where legumes had been grown. Also plot yields were always low in Rotation 6. This indicates a correlation between yields and the soils physical conditions. The results of the determination made on the barley plots show that the sod crops were responsible for the differences in the physical characteristic of the soil. Barley was the third crop after the sod. By that time it was impossible to detect soil differences by any of the physical measurements.

It was found that it is extremely difficult to measure the structure of the soil on epxerimental plots. The area where these plots were located was selected because the soil was believed to be uniform. It was found, however, that the soil varied greatly, even within very short distances. Variables in the natural physical composition of the soil, differences caused by the placement of tile under the plots, and the resulting variations in moisture conditions at the time the soil was worked, soil compaction caused by tractors, trucks, manure spreaders, etc., and by various tillage implements, are all factors which contribute to the heterogeneous structure existing within the soil body. In addition, the soil is a very dynamic body in that changes in its physical status are occurring at all times. If the changes always occurred at the same rate and in the same direction, it would be much easier to develop methods which reliably indicate the soils physical status.

Because variations in soil do exist in most fields, one sometimes wonders about the validity of sampling techniques where less than one per cent of the total area is used for the physical determinations, especially for those procedures which involve the soil in the undisturbed state. A one per cent sampling on these plots would require 907 penetrometer records or 100 core samples. These are unreasonable numbers to work with. It was found that the data could be duplicated much easier in the procedures which made use of composited soil samples than in those procedures which utilized core samples.

Since it was believed that composited samples were easier to obtain and would more nearly reflect the average conditions within a plot, the first prerequisite for a suitable "quick test" which would indicate the physical status of a field would utilize composited soil samples. The second requirement for this test would be that it measured the stability of the soil under water. The reason for this is based on observations which indicate that both driving rain and standing water destroy the naturally occurring aggregates. Several ideas which involved screening or slump tests were tried before attempting the percolation test which is an adaptation of the old procedure used to demonstrate percolation rates. A different interpretation however was placed on the results in that it was felt that the test actually measured the stability of the aggregates to water and that percolation rate is regulated by the "ultimate" state of the soil particles after they have been subjected to standing water for a definite length of time. The results of this test on soil samples taken from the experimental plots were in agreement with the results of accepted methods of determining soil structure. However, further investigation should be made before using it on soils from other locations.

The highest crop yields were produced where a sod crop had been plowed under immediately previous to the row crop.

XI. SUMMARY

Some effects of seven systems of farming upon sugar beet and corn yields and on the physical status of soils were studied.

The systems of farming caused no consistent difference in sugar beet yields from one year to the next. The yields from some systems were frequently not as high as they might have been because often a low nitrogen level limited growth. Also, black root--a sugar beet disease--was prevalent during several seasons. This disease seemed to manifest itself equally in the seven systems of farming. However, where beets followed alfalfa-brome hay, recovery from the disease did not appear to occur as rapidly or to the same degree as in the other systems of farming.

Sugar beets after beans resulted in the highest yields for the ten year period. The lowest yields occurred in a cash crop rotation which did not include a nitrogen supplying legume crop.

Physical analysis of the sugar beet seed beds showed little or no difference in soil conditions. However, differences in the root bed developed later in the season. The cash crop rotation, which did not include a nitrogen-adding legume crop, was in the poorest physical state as was indicated by aggregate analyses, total and non-capillary pore-space analyses, penetrometer records, and percolation studies.

The highest corn yields occurred where corn was preceded by a leguminous hay crop. One year of alfalfa-brome in a crop rotation had the same effect on corn yields as did two years of this hay in the rotation.

Clover-timothy in a rotation instead of alfalfa-brome resulted in 10 per cent smaller yields. The placing of a sugar beet crop between an alfalfa-brome hay crop and the corn crop also caused a 10 per cent reduction in corn yields.

The lowest corn yields were obtained in a cash crop rotation which did not include a nitrogen adding legume.

Dry screen analyses of seed beds indicated there was little difference in the physical status of the soil at planting time.

The results of the aggregate analyses of the corn soil showed that the sod crop in the rotation was responsible for the differences in total as well as water stable aggregates.

The systems of farming did not affect the structure of the soil below plow depth sufficiently to cause measurable differences.

Porosity determinations, both total and non-capillary, indicated that systems of farming did affect the structure of the soil. The highest percentages were obtained on the plots where sod crops were included in the rotations. The lowest porosities were obtained from the cash crop rotations.

Penetrometer records indicated that various systems of farming caused great differences in the structure of the soil and that it was possible to measure these differences with a penetrometer. A new type of recording penetrometer was developed as a tool for rapid measurements and proved to be successful.

A simple rapid soil test which is based on the stability of soil aggregates to water was devised.

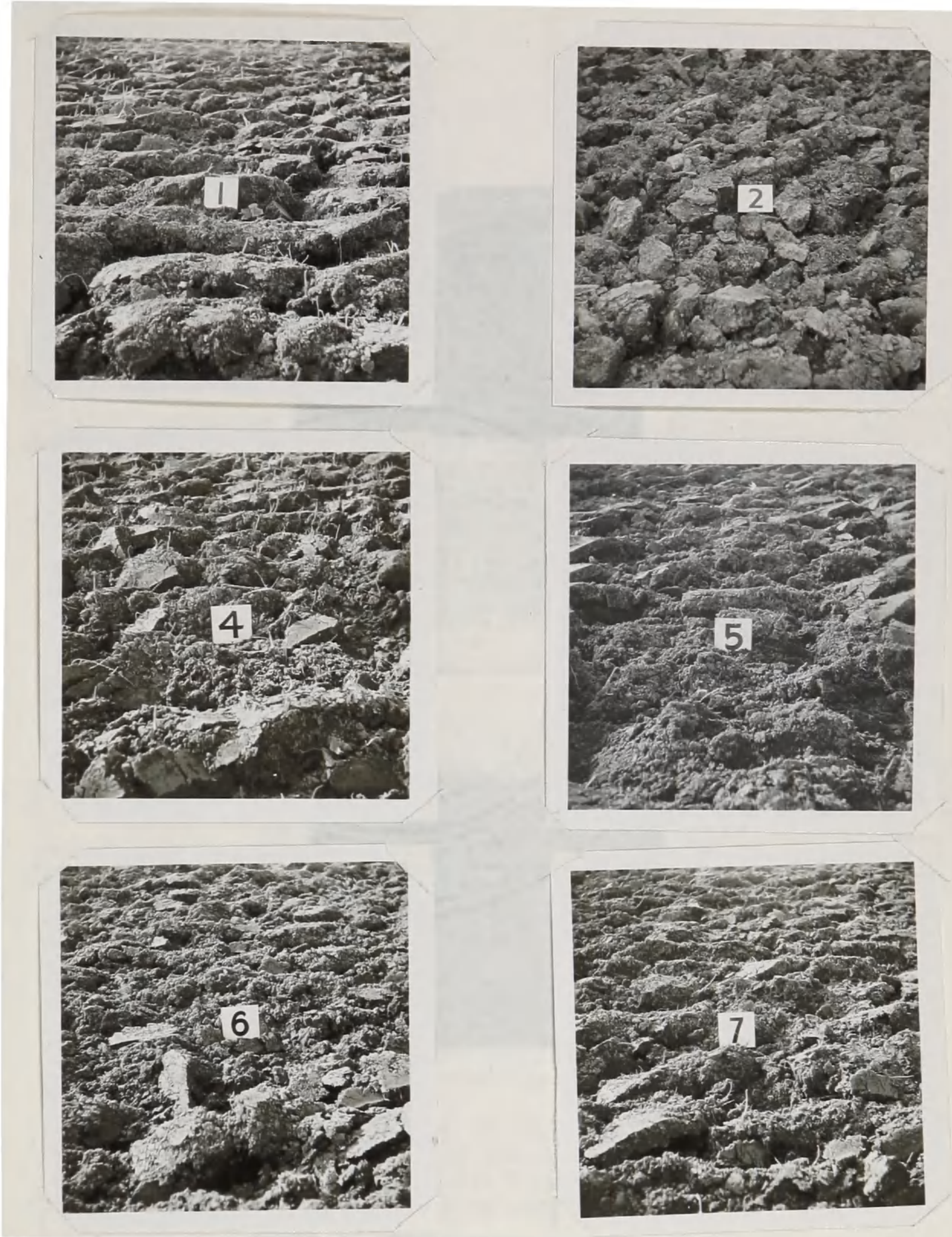

Plate 1. The effect of crop rotations on soil conditions immediately after plowing for corn. 1. Three year old alfalfa-brome sod 2. Sugar beet ground 4. Two year old alfalfa-brome sod 5. Two year old clover-timothy sod 6. Wheat ground 7. Wheat and green manure ground.

Plate 2. Crop sequence affects plow behavior. A narrower and shallower furrow is cut at plowing time on the plots in the cash crop rotation. Wheat stubble is plowed under for corn in this rotation.

Plate 3. An illustration of the "distinct ribbons" which are formed when an alfalfa-brome sod is plowed, and the "indistinct ribbons" of the clover-timothy and the cash crop rotations. Front to Rear -

Rot. 2 -- 2 year alfalfa-brome hay
Rot. 5 -- 1 year clover-timothy hay
Rot. 4 -- 1 year alfalfa-brome hay
Rot. 6 -- Wheat stubble
Rot. 3 -- 2 year alfalfa-brome hay
Rot. 7 -- Wheat stubble and green manure
Rot. 1 -- 2 year alfalfa-brome hay

Plate 4. Manure spreader tracks where clover timothy sod had been plowed under for corn. Tracks have never been noticed where alfalfa-brome sod has been plowed under for corn.

Plate 5. The effect of soil conditions upon the standing ability of corn grown in a livestock system of farming (Rot. 5) and in a cash crop system of farming (Rot. 6). Many roots of the corn plants grown in this rotations were rotting in 1947. The roots of the corn plants grown on either side of this plot and in a livestock system of farming showed little evidence of root decomposition.

Plate 6. The effect of two crop rotations upon soil conditions at the end of the growing season. The surface soil in rotation 5 (clover-timothy rotation) showed clear evidence of the clods which had formed at the time of the last cultivation. The soil in the cash crop rotation gave little evidence that the soil had ever been cultivated. In 1947, the surface of the soil in this rotation had an appearance similar to a recently rolled clay tennis court.

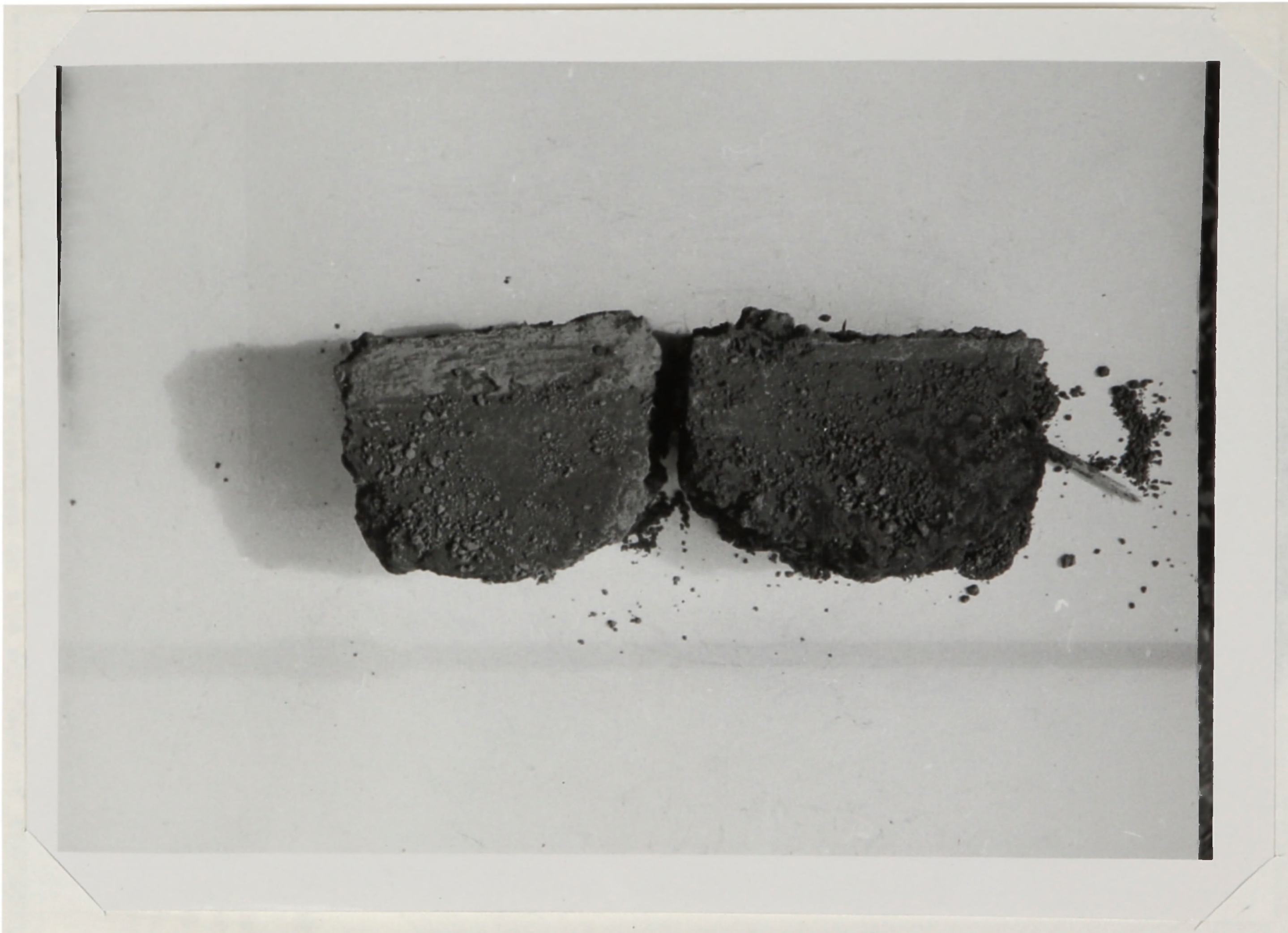

Plate 7. The effect of two crop rotations upon crust formation of soils subject to a (left) cash crop rotation (Rot. 6) and to a legume rotation (Rot. 1). Samples for this picture were taken from the corn plots in August. (compare with Plate 8)

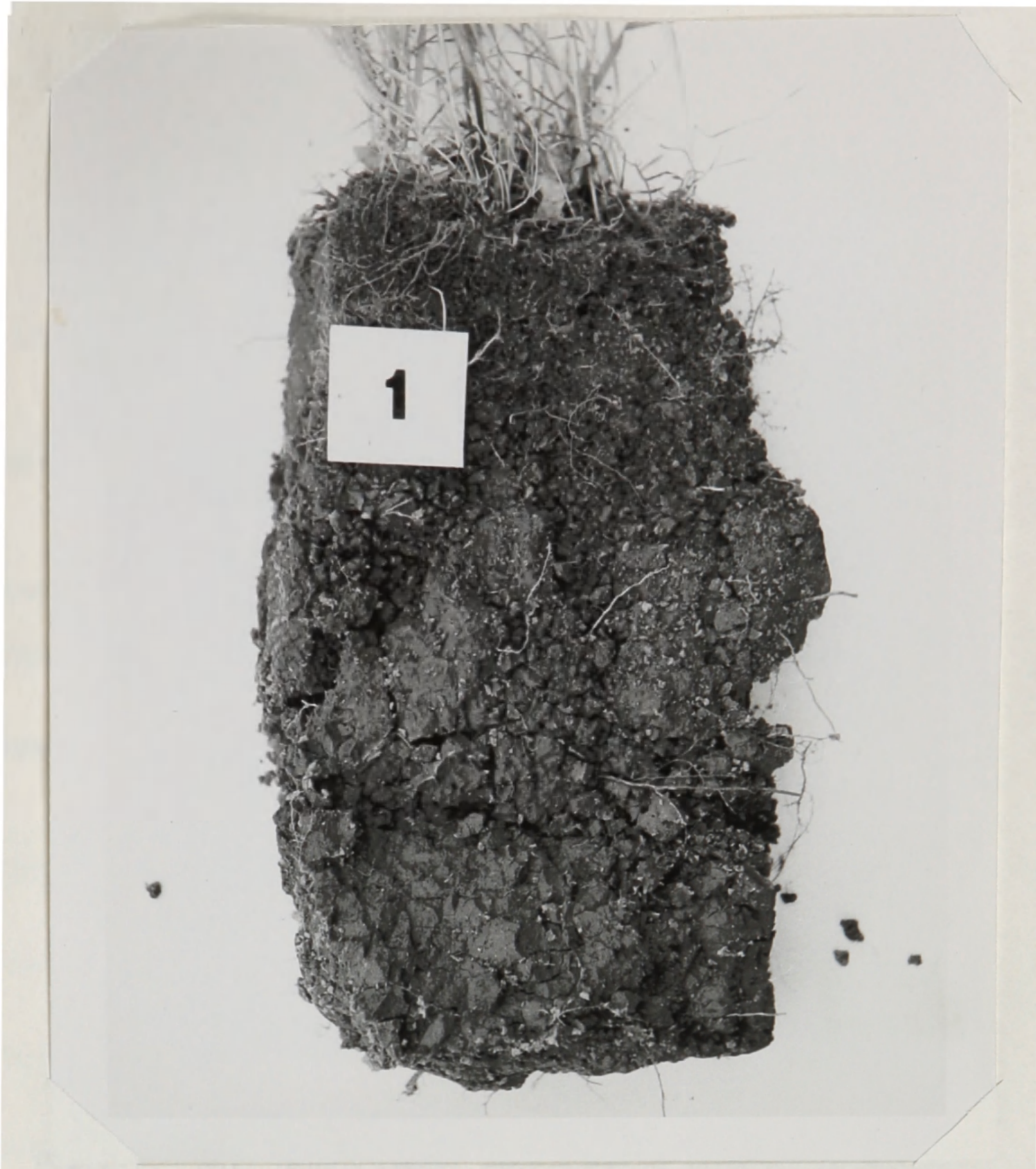

Plate 8. A portion of a soil profile (7 by 16 inches) showing the structure of a virgin soil.

0 to 2 inches - granules less than 1/8 inch diameter.
2 to 3 inches - granules less than 1/4 inch diameter.
3 to 3.5 inches - dense granules which have a tendency to show a platy type of structure.
3.5 to 5 inches - graduation from the above to a blocky structure.
5 to 16 inches - blocky structure.

Note - no crust formation on the surface of the soil (compare with Plate 7)

Plate 9. Soil penetrometer developed to measure relative soil conditions. A probe is slowly forced into the soil and a curve is drawn which indicates the pounds of pressure required to force the probe to a given soil depth.

LITERATURE CITED

1. Afanasiev, M. M., Morris, H. E., and Carlson, W. E. 1942 The effect of preceding crops on the amount of seedling diseases of sugar beets. Proc. Amer. Soc. of Sugar Beet Tech. 435-436.

2. Baver, L. D., and Farnsworth, R. B. 1940 Structural effects in the growth of corn and sugar beets. Soil Sci. Soc. Amer. Proc. 5: 45-48.

3. Baver, L. D. 1940 Soil Physics, pp. 162. John Wiley and Sons.

4. Bouyoucos, G. J. 1935 A method for making mechanical analysis of the ultimate natural structure of soils. Soil Sci. 40: 481-485.

5. Bradfield, R., and Jamison, V. C. 1938 Soil Structure--attempts at its quantitative characterization. Soil Sci. Soc. Amer. Proc. 3: 70-76.

6. Christie, G. I. 1925-26 Comparative Value of Crop Rotations. Ind. Agr. Expt. Ann. Rpt. 39: 42.

7. Cole, R. C., and Edlefsen, N. E. 1935 A sedimentation tube for analyzing water stable soil aggregates. Soil Sci. 40: 473-479.

8. Cook, R. L., Unpublished data. Michigan State University, East Lansing, Michigan.

9. Cook, R. L., and Millar, C. E. 1949 Plant Nutrient Deficiencies. Mich. Agr. Expt. Sta. Spec. Bul. 353.

10. Cook, R. L., Millar, C. E., and Robertson, L. S. 1945 A crop rotation field layout with an illustration of the statistics involved in combining several years data. Soil Sci. Soc. Amer. Proc. 10: 213-218.

11. Cook, R. L., Millar, C. E., and Robertson, L. S. 1946 Sugar Beets in seven Michigan systems of crop rotations. Proc. Amer. Soc. Sugar Beet Tech. 73-87.

12. Cook, R. L., and Peikert, F. W. 1949 A comparison of tillage implements and their effect on crop yields. Mich. Agr. Expt. Sta. Quart. Bul. 32: 104-118.

13. Cook, R. L., and Peikert, F. W. 1950 A comparison of tillage implements. Ag. Eng. 31: 211-214.

14. Cuplin, Claude 1936 Studies on the relation between cultivation implements, soil structure and the crop. Jour. Agr. Sci. 26: 122-135.

15. De Turk, E. E., Bauer, F. C., and Smith, L. H. 1927 Lessons from the Morrow Plots. Ill. Agr. Expt. Sta. Bul. 300.

16. Farnsworth, R. B. 1939 Soil Physics studies on sugar beets. Proc. Amer. Soc. Sugar Beet Tech., Eastern Div., 52.

17. Farnsworth, R. B., and Baver, L. D. 1941 The effect of soil structure on sugar beet growth. Proc. Amer. Soc. Sugar Beet Tech., Eastern Div., 74-84.

18. Fertilizer Recommendations. 1952 Michigan Extension Bulletin 159, East Lansing, Michigan.

19. Funchess, M. J. 1925 The utilization of legumes in the rotation. Jour. Amer. Soc. Agron. Vol. 17: 398-403.

20. Gish, R. E., and Browning, G. M. 1948 Factors affecting the stability of soil aggregates. Soil Sci. Soc. Amer. Proc. 13: 51-55.

21. Haines, W. B. 1927 Studies in the physical properties of soils IV: a further contribution to the theory of capillary phenomenon in soils. Jour. Agr. Sci. 17: 264-290.

22. Harris, L. 1943 Studies of Beet Top silage production in the irrigated rotation experiments at the Scottsbluff, Nebraska, Field Station. Proc. Amer. Soc. Sugar Beet Tech., 770-777.

23. Henin, S. 1936 Some results obtained in soil investigations by means of the dynamometer bores of Demolon-Henin. Soils Res. 5: 1-20.

24. Johnston, J. R., Browning, G. M., and Russell, M. B. 1943 The effect of cropping systems on aggregation, organic matter content and loss of soil and water in a Marshall silt loam. Soil Sci. Soc. Amer. Proc. 7: 105-108.

25. Klute, A., and Jacob, W. C. 1949 Physical properties of Sassafras silt loam as affected by long time organic matter additions. Soil Sci. Soc. Amer. Proc. 14: 24-28.

26. Laws, W. D., and Evans, D. D. 1949 The effects of long time cultivation on some physical and chemical properties of two Rendzina soils. Soil Sci. Soc. Amer. Proc. 14: 15-19.

27. Leamer, R. W., and Lutz, J. F. 1940 Determination of pore-size distribution in soils. Soil Sci. 49: 347-360.

28. Leamer, R. W., and Shaw, Byron 1941 A simple apparatus for measuring non-capillary porosity on an extensive scale. Jour. Amer. Soc. Agron. 33: 1003-1008.

29. Leighty, E. C. 1938 "Crop Rotations" U.S.D.A. Yearbook of Agriculture, p. 430.

30. Lill, J. G. 1940 Crop sequence effects and the results with the sugar beet crop on the Merrill Farm of the Lake Shore Sugar Company, Merrill, Michigan. Mich. Agr. Expt. Sta. Quart. Bul. 23: 29-32.

31. Lill, J. G., and Rather, H. C. 1943 Sugar Beets after alfalfa. Mich. Agr. Expt. Sta. Quart. Bul. 26: 129-133.

32. Lill, J. G. 1946 A study of the crop sequence and fertilization factors in crop production. Jour. Amer. Soc. Agron. 38: 795-803.

33. Lill, J. G. 1947 The effect of fertilizer on sugar beets grown after alfalfa. Proc. Amer. Soc. Sugar Beet Tech. Eastern Div., 52-64.

34. Lynd, J. Q. 1948 Diagnosis of plant nutrient deficiencies by means of soil tests, plant tissue tests, and foliar analysis. PhD. Thesis, Soil Science Department, Michigan State College, East Lansing, Michigan.

35. McKibben, E. G., and Hull, D. O. 1940 Soil penetrometer tests as a means of predicting rolling resistance. Ag. Eng. 21: 231-234.

36. Nelson, W. L., and Baver, L. D. 1940 Movement of water through soils in relation to the nature of the pores. Soil Sci. Soc. Amer. Proc. 5: 69-76.

37. Nuckols, S. B. 1942 Use of manures for sugar beets. Proc. Amer. Soc. of Sugar Beet Tech., 121-137.

38. Olmstead, L. B. 1946 The effect of long-time cropping systems and tillage practices upon soil aggregation at Hays, Kansas. Soil Sci. Soc. Amer. Proc. 11: 89-92.

39. Reed, I. F. 1940 Use of power driven soil resistance records for study of compaction of soils by tractors. Agr. Eng. 21: 281-283.

40. Retzer, J. L., and Russell, M. B. 1941 Differences in the aggregation of a Prairie and Gray Brown Podzolic soil. Soil Sci. 52: 47-58.

41. Rhoades, H. F. 1932 Aggregate analysis as an aid in soil structure studies. Amer. Soil Survey Assoc. Rpt. 13: 165-169.

42. Richards, S. J. 1941 A soil penetrometer. Soil Sci. Soc. Amer. Proc. 6: 104-107.

43. Robertson, L. S. 1947 1946 Results on the Ferden rotation experiment. Proc. Amer. Soc. Sugar Beet Tech., Eastern Div., 33-37.

44. Robertson, L. S. 1949 Results of side dressing experiments on the Ferden Farm in 1948. Proc. Amer. Soc. of Sugar Beet Tech., 63-65.

45. Robertson, L. S., and Hansen, C. M. 1950 A recording soil penetrometer. Mich. Agr. Expt. Sta. Quart. Bul. 33: 1-4.

46. Robertson, L. S. 1950 Plant tissue testing as a guide to side dressing sugar beets. Proc. Amer. Soc. Sugar Beet Tech., 348-352.

47. Robertson, L. S. 1950 New rotations on the Ferden Farm. Unpublished data.

48. Robertson, L. S. 1951 Ferden Farm Rotations. Proc. Amer. Soc. Sugar Beet Tech., Eastern Div., 113-116.

49. Shaw, B. T., Haise, H. R., and Farnsworth, R. B. 1942 Four years experience with a soil penetrometer. Soil Sci. Soc. Amer. Proc. 7: 48-55.

50. Slipher, J. A. 1932 The mechanical manipulation of the soil as it affects structure. Trans. Amer. Soc. Agr. Engr. 26: 58-60.

51. Smith, G. E. 1942 "Sanborn Field" Mo. Agr. Expt. Sta. Bul. 458.

52. Stone, A. A., and Williams, I. L. 1939 Measurement of Soil Hardness. Ag. Eng. 20: 25-26.

53. Swanson, C. L. W. 1950 A portable soil core sampler and penetrometer. Agron. Jour. 42: 447-451.

54. Throwbridge, P. F. 1926 Experiment Station Progress. N. Da. Agri. Expt. Bul. 194. p. 11.

55. Van Bavel, C. H. M. 1949 Mean Weight-diameter of soil aggregates as a statistical index of aggregation. Soil Sci. Soc. Amer. Proc. 14: 20-23.

56. Veatch, J. O. 1940 Private communication.

57. Weir, W. W. 1926 A study of the value of crop rotation in relation to soil productivity. U.S.D.A. Bul. 1377, p. 67.

58. Welton, F. A., and Norris, V. H. 1924 Yields of wheat following potatoes and relation of nitrates in soil to these. Jour. Amer. Soc. Agron., 16: 519-534.

59. Williams, C. G. 1927 Forty-fifth annual report of the Ohio Agr. Exp. Sta. Ohio Agr. Expt. Sta. Bul. 402, p. 28.

60. Wilson, H. A., and Browning, G. M. 1946 Soil aggregation, yields, runoff and erosion as affected by cropping systems. Soil Sci. Soc. Amer. Proc. 10: 51-57.

61. Wilson, H. A., Gish, R., and Browning, G. M. 1947 Cropping systems and seasons as factors affecting aggregate stability. Soil Sci. Soc. Amer. Proc. 12: 36-38.

62. Yoder, R. E. 1936 A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Jour. Amer. Soc. Agron. 28: 337-351.

63. Yoder, R. E. 1937 The significance of soil structure in relation to the tilth problem. Soil Sci. Soc. Amer. Proc. 2: 21-33.

64. Yoder, R. E. 1947 The Holgate Rotation Experiments with sugar beets --a progress report. Proc. Amer. Soc. Sugar Beet Tech., Eastern Div., 39-42.