A Study of the Effects of Seven Systems of Cropping Upon Yields and Soil Structure[1]

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A number of observations have been made in Michigan with regard to the effect of crop sequence upon yields and soil structure. During past years less progress has been made in increasing yields of sugar beets than of certain other farm crops. This is true despite the use of improved disease-resistant varieties, considerably more commercial fertilizer and more tile drainage. Sugar beets have commonly been grown on the better soils, those naturally high in organic matter. In many areas, little attempt has been made to improve or maintain the productive capacity of such soils by the growing of soil-building legumes. Consequently, organic matter has become depleted. Puddled soils and slow drainage have helped keep yields low.

As this deterioration of soil structure became evident, agronomists and others interested in the production of sugar beets in Michigan were asked for a solution to the problem. Would legumes and grasses improve the soils? How long should legumes be left in the rotation? Which legumes should be grown? What sequence of crops should be followed?

It was evident that these questions could not all be answered from existing experimental results, so it was decided that additional experiments should be started. Accordingly, the experiment involving seven systems of crop rotation was started in the spring of 1940. The effects of the different cropping systems on certain physical characteristics of the soil and the apparent relationship between those characteristics and crop yields are reported in this paper.

Description of Soil, Plots and Systems of Farming

The field experimental plots upon which these studies were made are located on the Lee Ferden farm near Chesaning, Michigan. The soil has been mapped as a Brookston sandy clay loam. Analyses showed that the surface soil contained 25 to 28 percent clay, 50 to 58 percent sand and 7.8 percent organic matter. The pH is 6.8, and the base exchange capacity is 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.

The seven systems of cropping are being conducted at two fertility levels. The plots are randomized with respect to systems of cropping and fertilizer levels and are replicated four times. Each crop is grown each year. For this study only the results from the high-fertility plots were considered, in order to be sure that fertility conditions did not limit crop growth.

The crop sequence in the seven systems of farming is as follows:

Rotation 1—Barley, alfalfa-brome, alfalfa-brome, corn, sugar beets.
Rotation 2—Barley, alfalfa-brome, alfalfa-brome, sugar beets, corn.
Rotation 3—Barley, alfalfa-brome, alfalfa-brome, beans, sugar beets.

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Rotation 4—Barley, oats, alfalfa-brome, corn, sugar beets.
Rotation 5—Barley, oats, clover-timothy, corn, sugar beets.
Rotation 6—Barley, beans, wheat, corn, sugar beets.
Rotation 7—Barley, green manure[3], beans, wheat, green manure[3], corn, sugar beets.

The green manure crops are seeded in the barley and wheat and are plowed under for beans and corn respectively the following spring. The sugar beets and grain in each rotation receive equal amounts of commercial fertilizer, 1,000 pounds per acre in five years. The beet crop receives 500 pounds and the balance is applied for grain. In the rotations which include two grain crops, each one received 250 pounds per acre. The fertilizer is 2-16-8. A complete description of the field layout was published in the 1946 Proceedings of the American Society of Sugar Beet Technologists.

Table 1.—The Effect of Systems of Farming on Sugar Beet Yields.

Crop Sequence[1]	Yield per acre-tons							
	1946	1947	1948	1949	1950	1941-1945 Means	1946-1950 Means	1941-1950 Means
Ba-A-A-C-SB	12-87	0.00	12.33	9.00	11.08	10.34	9.06	9.70
C-Ba-A-A-SB	16.76	0.00	8.86	8.32	8.04	10.88	8.40	9.64
Ba-A-A-Be-SB	15.36	0.00	12.33	10.09	10.57	10.24	9.67	9.96
Ba-O-A-C-SB	14.31	0.00	11.67	8.69	9.75	10.45	8.88	9.67
Ba-O-Cl-C SB	13.22	0.00	11.46	10.05	9.10	10.04	8.77	9.41
Ba-Be-W-C-SB	11.26	0.00	10.66	8.77	8.81	9.64	7.90	8.79
Ba(gm)-Be-W-(gm)-C-SB	13.01	0.00	11.64	8.79	10.49	10.08	8.79	9.44

[1] **Ba**—barley, Be—navy bean, A—alfalfa-brome hay, C—corn, O—oats, W—Wheat, **SB—sugar beet, CI—clover-timothy** hay, gm—green manure mixture—Alsike, **June,** Sweet clover.

Experimental Procedure

Dry screen analyses of the seed beds were made on screens having mesh sizes ranging from 2 inch to $^1/_8$ inch and measuring approximately 2 x 4 feet in size. The screens were made especially for this purpose. Soil was sampled with a small square-nosed spade to a depth of 3 inches at 20 random locations on each plot the day after the crop was planted. A weighed sample of soil was placed on the top (largest) sieve. That which remained on each sieve was removed and weighed. By calculation, the portion which passed through the finest sieve was determined.

Aggregate analyses were made in a laboratory-made wet sieving apparatus by the principle outlined by Yoder (5) .[4] Composited soil samples from each plot were collected after planting the crop but previous to the first cultivation. The soil was partially air dried and passed through a 10-mm. screen. The soil was then completely air dried and the material finer than 5 mm. was removed by screening. The 5 to 10 mm. soil material was then used for aggregate analysis.

Samples for porosity determinations were collected during the growing season. The determinations were made on a pF table similar to the ones described by Learner and Shaw (3) .

Penetrometer records were obtained with a self-recording penetrometer designed by Robertson and Hansen (4) .

[3] Mixture of alsike, June, mammoth and sweet clovers.
[4] Numbers in parentheses refer to literature cited.

Experimental Results

The yield data during the period 1946 through 1950 reported in this paper vary slightly from those reported elsewhere. This is because of a variation in the exact areas harvested on the plots used in this study. Attention is called also to the fact that this study involves only those plots which received the larger applications of fertilizer.

Sugar beet yields, as shown in Table 1, have varied considerably from year to year. No yields were obtained in 1947 because black root destroyed the stand. Severe infestations also occurred in 1948, 1949 and 1950, but the beets partially recovered and produced yields about average for the area. At the end of the first cycle of the rotations, the no-legume system of farming (rotation 6) had resulted in yields actually smaller than those recorded for the other systems but the difference was not statistically significant.

Table 2.—The Effect of Systems of Farming on Corn Yields.

Rotation number	Crop Sequence[1]	Yield per acre-bushels 1946	1947	1948	1949	1950	1941-1945 Means	1945-1950 Means	1941-1950 Means
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-SBC	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

Analysis of the results obtained during the second cycle of the rotations indicates that a significant difference did exist between yields in that rotation and those obtained in the livestock system of cropping where beans preceded sugar beets (rotation 3) . The analysis of the data from the two cycles of crop rotation shows that the four rotations which grew alfalfa-brome hay were all superior, as measured by sugar beet yields, to the one which did not include a legume. The effect of clover-timothy hay (rotation 5) on sugar beet yields was about equal to the effect of the two green manure crops in rotation 7. Each of these legumes proved to be slightly inferior to the alfalfa-brome hay.

The corn yield data are shown in Table 2. A significant difference in yield occurred each year and the differences in yield were consistent year after year. The corn yields seemed to arrange themselves into three groups. Where corn followed wheat with no legume in the rotation the yields were the lowest in the experiment every year during the 10-year period.

The second group included three rotations, where corn followed sugar beets (rotation 2) , where it followed clover-timothy hay (rotation 5) and where it followed wheat which was seeded with a leguminous green manure mixture (rotation 7) . The corn yields in these three rotations were consistently better than in the depleting rotation (rotation 6) , but were lower than where corn followed alfalfa. The one inconsistent figure, that for rotation 2 in 1948, was the result of the sugar beet failure in 1947. Thus, in 1948, corn on these plots actually followed summer fallow, which in turn had followed alfalfa, instead of following sugar beets.

The highest corn yields occurred where the crop followed immediately after alfalfa. There was no consistent difference between the effects of one and two years of alfalfa-brome hay. The yields from these two rotations (rotations 1 and 4) were significantly higher than where corn followed clover-timothy, sugar beets, or wheat.

The results of the dry screen analyses of the sugar beet and corn seed beds are shown in Table 3. Crop rotations caused no differences in these results for the sugar beet seed beds. Rotation did affect the size distribution of the aggregates in the corn seed beds in that the soil subject to the cash crop rotation contained more large clods than did that subject to any of the other systems of farming. The seed bed in this rotation contained even

Table 3.—The Effect of Systems of Farming upon Dry Screen Analyses of Sugar Beet and Corn Seed Beds in 1949.

		Sugar Beet Seed Beds Percent of Aggregates retained on the Screen Indicated[1]					
Rotatioin number	Crop Sequence	inches	2-1 inches	1-1/2 inches	VI-VA inches	1/2-V8 inches	1/8 inches
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	BaO 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
		Corn Seed Beds Percent of Aggregates retained on the Screen Indicated[1]					
Rotation number	Crop Sequence	2 inches	2-1 inches	I-1/2 inches	1i/2-1/4 inches	1/2-1/8 inches	1/8 . inches
	SB-Ba-A-A-C	0.3	7.3	10.0	18.0	20.0	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 determinations—one from each plot replication.

more of the larger aggregates than did the soil in the sugar beet seed beds. While these analyses were run only in 1949, observations have indicated that such conditions did exist during the other seasons. The large clods on the rotation 6 plots were probably not stable aggregates. This is indicated by the aggregate analysis data obtained later in the season.

The results of the aggregate analyses of the corn and sugar beet root beds during 1947 are shown in Table 4. The results of other years, in general, are in agreement with these data.

Considering the soil from the corn plots, that from the rotations which included the legume-grass hays contained greater percentages of the large aggregates and the aggregates were more stable. The data for 1947 suggest that one year of hay in a rotation results in more water stable aggregates than does two years of hay. This conclusion, however, was not justified by the results of other year's data not reported herein. Also, observations made at various times during the year do not justify this conclusion. In general, the soil from the cash crop rotation was less stable and was aggregated to a lesser degree than was the soil from any of the other rotations.

The aggregate analysis results obtained on the soil from the sugar beet plots show that little difference in aggregate existed among rotations 1, 3, 4, 5, 6 and 7. In rotation 2 (beets after alfalfa), the soil was more stable and better aggregated than was the soil in the other rotations. This is in agreement with the observations which have been made by the beet workers at blocking and thinning time and during cultivation.

If the aggregate analysis results on the corn and beet soils are compared with those on soil under sod located in a little used alleyway adjacent to the plots, the potential value of grass as an aggregating agent is fully

Table 4.—The Effect of Systems of Farming upon Aggregate Analysis of Corn and Sugar Beet Root Beds in 1947.

Rotation number	Crop Sequence	Corn Root Beds — Percent of aggregates retained on the screen indicated						
		10-4 mm.	4-2 mm.	2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.10 mm.	less. .1 mm.
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

Rotation number	Crop Sequence	Sugar Beet Root Beds — Percent of aggregates retained on the screen indicated						
		10-4 mm.	4-2 mm.	2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.10 mm.	less. .1 mm.
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	24.8
6	Ba-Be-W-C-SB	6.3	6.8	5.7	9.9	22.6	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

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.

The porosity data from the corn plot soils are shown in Table 5. These data suggest that there was no difference in the early part of the growing season in 1947, but that, as the season progressed, differences did occur. The soil in the plots where legumes are not grown (rotation 6) contained significantly less total pore space than did the soils in the green manure rotation plots.

No significant differences are evident in the non-capillary pore space data obtained in 1947. Perhaps too few determinations were made on each plot. In 1948, all of the soils subject to the livestock system of farming (rotations containing hay), except those where the hay was clover-timothy, had higher non-capillary porosity than did the soils where hay crops had not been grown (rotations *6* and 7). The soils of the clover-timothy rotation (rotation 5) contained greater percentages of non-capillary pore space than did the soils on the plots where no soil-building crops are grown.

Porosity determinations were made on the sugar beets soils in 1947 despite the fact that no crop was harvested. The June 12 sampling (Table 6) occurred before the beets were replanted. While there was a statistically significant difference in percent total pore space at that time, the differences are difficult to interpret because they do not agree with observation or yield determinations. After the beets were replanted, all of the plots had similar characteristics in regard to pore space.

Table 5.—The Effect of Systems of Farming upon the Total and Non-Capillary Pore Space of the Soil in the Corn Plots.

Rotation number	Crop Sequence	Percent pore space on the sampling dates indicated: Total July 15 1947	Total Oct. 15 1947	Total Oct. 1948	Non-Capillary June 15 1947	Non-Capillary Oct. 15 1948	Non-Capillary Oct. 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

Table 6.—The Effect of Systems of Farming upon the Total and Non-Capillary Pore Space of the Soil in the Sugar Beet Plots.

Rotation number	Crop Sequence	Percent pore space on the sampling dates indicated: Total June 12 1947	Total June 17 1947	Total Sept. 25 1947	Total Oct. 1948	Non-Capillary June 12 1947	Non-Capillary July 17 1947	Non-Capillary Sept. 28 1947	Non-Capillary Oct. 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

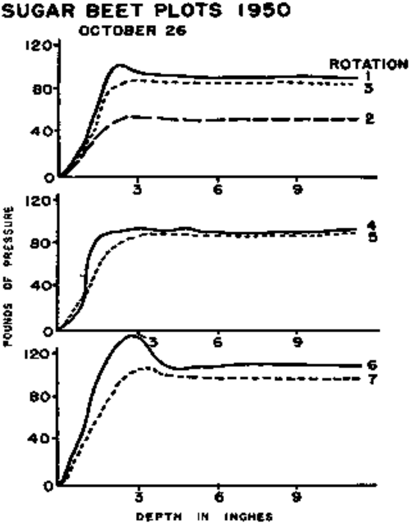

Figure 1. Penetrometer records from the 1950 Sugar Beet Plots comparing rotations 1, 2, 3, **4,** 5, **6 and 7.**

In the latter part of the 1947 and 1948 seasons, differences were found in both total and non-capillary pore space. This suggests that crop rotations caused differences in aggregate stability. The desirable effect of a hay crop (rotation 2) is evident in the total porosity data. Where a corn crop had been grown since the hay crop was plowed under, the pore space was significantly reduced. In 1948 the soil where legumes have not been grown during the experiment had the lowest percentage pore space, both total and non-capillary. That soil had the lowest percentage of non-capillary pore space also in 1947. Apparently, soil structure has reached an unstable state in that soil.

Perhaps one of the reasons why an increase in pore space, especially non-capillary, results in greater yields is that nitrification may take place more rapidly. The relationship between soil structure and nitrification was suggested by the data of Doiarenko (reported by Baver (1)) who found that non-capillary porosites of 2.7, 24.5, 35.1 and 38.7 percent resulted in the formation of 9.0, 19.1, 34.0 and 45.8 mgms. respectively of nitrogen as nitrate. Thus, the production of legumes not only supplies more nitrogen but soil porosity is increased and nitrification goes on at a more rapid rate.

A sample of the penetrometer records is shown in Figures 1, 2 and 3. The curves show that rotation and crop sequence have influenced the depth of the crust which formed on the soil surface after cultivation was completed.

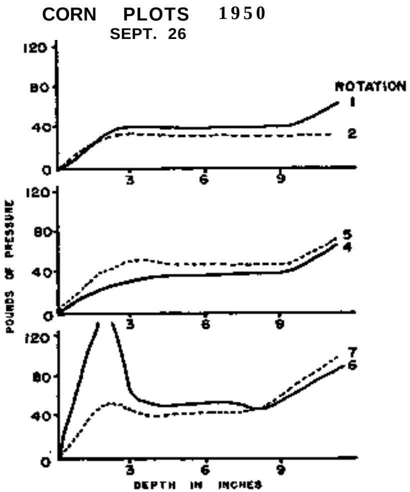

Figure 2. Penetrometer records from the 1950 Corn Plots comparing rotations 1, 2, 4, 5, 6 and 7.

The curves in Figure 3 show that the differences recorded by the penetrometer did not show up until late in the season. This was probably due largely to the cultivation. It may have been due partly to differences in water stability. As the season progressed, aggregates would more completely break down where structure was weak.

Summary

Seven Michigan systems of crop rotation and sequence were laid out in 1940 as an experiment on Brookston sandy clay loam. The primary purpose was to determine the value of legumes and legume grass mixtures in the production of sugar beets, corn, beans and the small grains. Major emphasis was placed on the beet crop. Plots were replicated four times and all crops occurred each year.

In. addition to yield measurements, certain physical studies have been made on the soils. These have included dry screen analyses of seed beds, aggregate analyses of root bed soils and porosity determinations made on core samples.

The production of alfalfa-brome hay in the rotation caused significant increases in yields of sugar beets. One year of hay was as beneficial as two. The highest yields of beets were obtained on plots where the crop followed beans which had followed alfalfa-brome. As a nine-year average, beets following corn, which in turn had followed alfalfa, produced yields equal to those produced by beets directly following alfalfa.

Two mixed clover green manure crops were about equal to one year of red clover-timothy hay as they affected sugar beet yields. The clovers were slightly inferior to alfalfa-brome.

Corn yields were markedly increased by the production of legumes and legume-grass mixtures in the rotation. Highest yields occurred where corn followed alfalfa-brome, either *one* or two years of hay. Somewhat lower yields resulted where corn followed the clovers or where sugar beets were grown between the alfalfa-brome and the corn. Very small crops have been harvested where corn was grown on plots which for eleven years have not grown a soil-building legume.

The soil-building crops have changed the structure of the soil. The dry screen analyses showed that soils prepared for corn contained more large clods where legumes had not been grown.

Aggregate analyses made on soil from corn plots showed that the soil on the plots where alfalfa-brome had been grown contained more of the

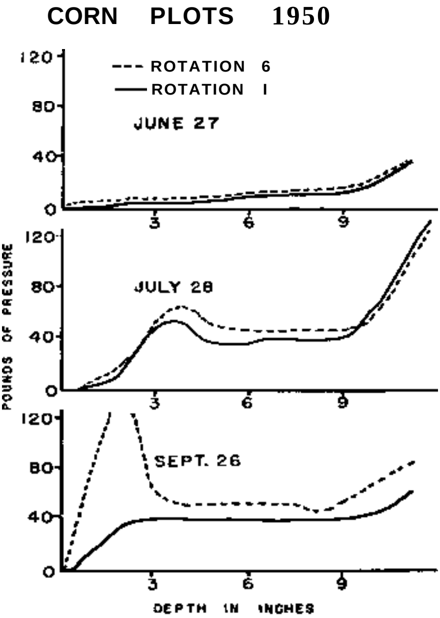

Figure 3. Penetrometer records from the 1950 corn plots comparing the soil in rotations 1 and 6 during the growing season.

large aggregates and more stable aggregates than did that from plots which had not produced a legume.

At the time of sugar beet planting, the soil on the plots which had grown alfalfa the previous year was in a more stable state of aggregation than that on any other plots.

Percentage pore space, both total and non-capillary, was increased by the production of legumes. Differences in pore space were greater during the later part of the growing season than at the beginning of the season.

Penetrometer studies showed that a hard crust formed at the surface of soils which had not raised a soil-building crop, but did not form to any appreciable extent where legumes had been grown.

Since greater yields and improved soil structure were the result of the cropping system, it may be true that some of the increase in yield was due to the improved structure.

Literature Cited

(1) BAVER, L. D.
1940. Soil Physics, pp 162. John Wiley & Sons, New York.

(2) COOK, R. L., MILLAR,, C. E., and ROBERTSON, L. S.
1946. Sugar Beets in seven Michigan systems of crop rotation. Proc. Amer. Soc. Sugar Beet Tech. 73-87.

(3) LEAMER, R. W., and SHAW, BRYON.
1941. A simple apparatus for measuring non-capillary porosity on an extensive scale. Jour. Amer. Soc. Agron. 33:1003-1008.

(4) ROBERTSON, L. S. and HANSEN, C. M.
1950. A recording soil penetrometer. Michigan Agr. Exp. Sta. Quarterly Bull. 33:1-4

(5) 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. 8:337-351.