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The Significance of Soil Variation in Raspberry Culture

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Some years ago the horticultural department of the Michigan Agricultural Experiment Station began a raspberry fertilization experiment in a field at South Haven. So far as was determined by a surface examination, this field presented conditions as uniform as is ordinarily available for plot experimentation. Accordingly, the field was planted to black and to red raspberries, plots were laid out, and fertilizers were applied. It is interesting to conjecture what conclusions might have been drawn from the experiments if the treatments had not been duplicated and if several check (unfertilized) plots had not been maintained. The first yield records showed very wide variations between plots fertilized alike and equally wide variations among the plots which had received no fertilizer at all. To determine the causes underlying these inconsistencies, the investigation here reported was undertaken.

Description of the Field

The topographical map (Fig. 1) shows that the field slopes very slightly to the north and east, there being a difference of nearly seven feet in elevation between the lowest and the highest points, about 240 feet apart. The surrounding fields present a similar topography. Certainly they are no more rolling. The topography of the field is such that surface water drains off well. Water was never known to stand on the surface of this field. Heavy rains disappear from the surface of the lowest portions within a reasonable length of time. The air drainage over the entire area would be considered uniform and good.

The surface soil varies in depth from four to nine inches. It is dark grey in color and ranges from fine sandy loam to loam. To all appearances it is uniform in composition. However, the surface soil alone reveals little information regarding the types of soil found in this field, using the term "type" to refer to the entire soil profile. At some locations in the field, clay is found immediately beneath the surface layer; at other points, it is found at depths varying from 12 to 75 inches from the surface. Where the clay does not come in immediate contact with the surface layer, this space is filled in with sand of various textures and colors. The undulating surface of the clay substratum connected with its imperviousness presents a logical condition for the formation of subsurface water-pockets which drain very slowly.

A detailed survey of the soil, to a depth of 75 inches, shows that five distinct soil types and two sub-types are represented in this field. They are designated as follows: Napanee loam; Brookston loam; Brookston

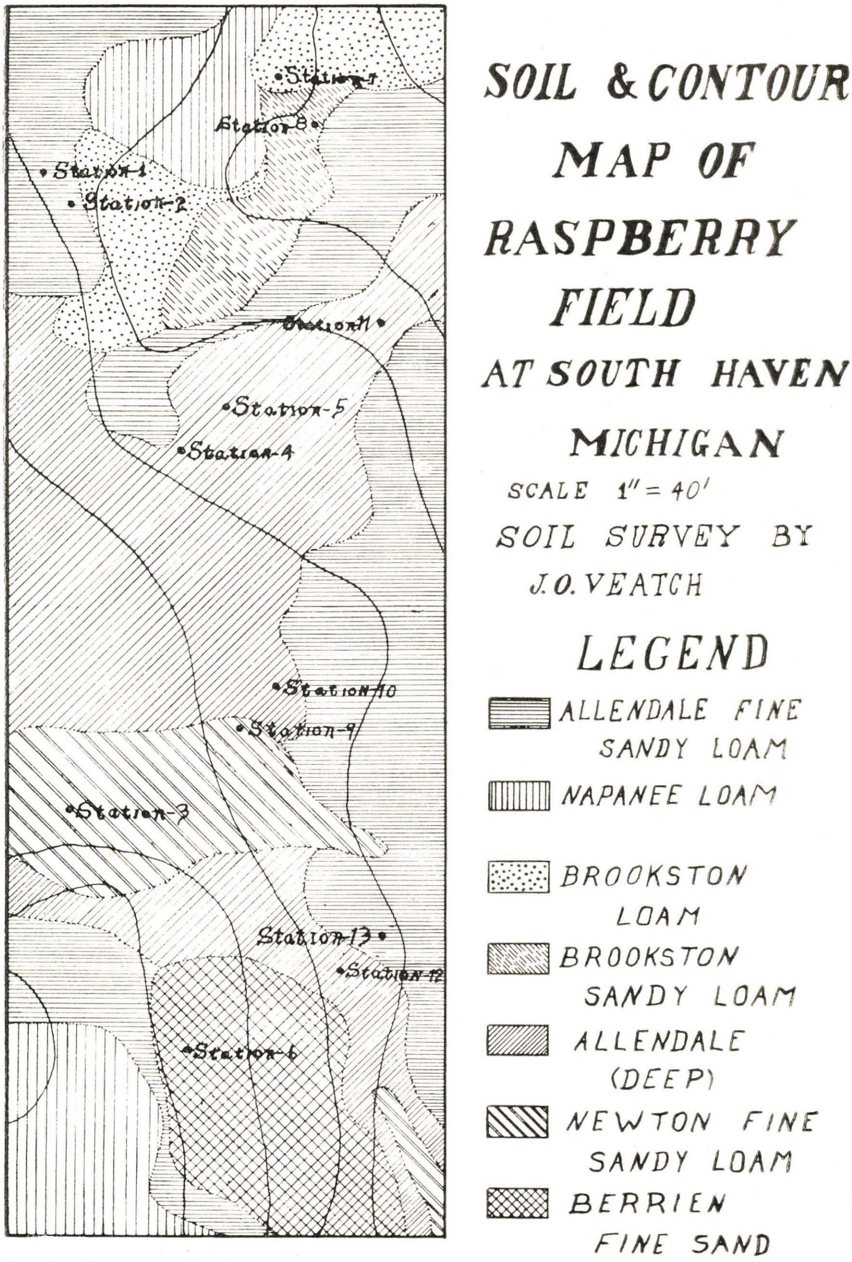


Fig. 1.—Topographical and soil map of the raspberry field, showing the location of the several stations.

sandy loam; Allendale fine sandy loam, a deep phase of Allendale sandy loam; Newton fine sandy loam; and Berrien fine sand. Detailed descriptions of these soil types are found in the appendix. This number of soil types, represented in two and one-half acres of ground, shows the great variation that is often found in the soil, even in areas where there is apparent surface uniformity.

Methods of Investigation

The investigation was started in September, 1924, when a soil survey was made of the entire field. In making this survey, about 75 profiles were obtained in the two and one-half acre area. The profiles were examined to a depth of 75 inches. The results of this survey led to the location of stations on the various types of soil, as indicated on the accompanying map (Fig. 1). Some stations were located rather close together, indicating a change of soil type or a more shallow or deeper phase of the same type. As stated, part of the field was planted to red raspberries and part to black raspberries. An effort was made to locate stations for study so that the behavior of both species of plants could be observed on each type of soil.

A well was established at each station to facilitate measuring the height at which free soil water was held throughout the season. This water level, as it is termed throughout the publication, is not the true water table but only the upper level of the free water held in the soil by the impervious clay substratum underlying the entire field.

These wells consisted of pieces of three-fourths inch gas pipe which were sunk into the ground to a depth below the water level. This depth was ascertained by the use of the soil auger. Each pipe was set on a few pieces of coarse gravel, that were previously dropped into the hole, in order to permit the rise and fall of water in the pipe. Other than the soil survey and the records of the heights of the water level, no data were taken until the spring of 1925.

Beginning in the spring of 1925, the depth to the water level at each station was taken at weekly intervals througout the growing season. Whenever this measurement was made, soil samples were taken for moisture determinations in each soil horizon down to and including the clay layer, provided the clay could be reached with the 70-inch auger. At intervals of two weeks, similar sets of samples were collected for laboratory determinations of nitrates, total soluble salts, colloidal material, and the degree of acidity or alkalinity.

Yield records were obtained in 1924 and 1925 for eight or ten individual plants immediately surrounding each station. These yields are reported in Table 1 in ounces of berries per plant.

In August, 1925, the root systems of two or more representative plants at each station were dug out, described, and photographed. The method used in making this study consisted of digging a trench, at the side of the plant to be examined, two to three feet wide, five to six feet long, and about four and one-half feet deep. This provided an open face into which one might dig with a hand pick equipped with a sharp point on one end. After sufficient practice and acquaintance with the soil texture, root systems were obtained almost in their entirety. Photographs were made while the root system was still attached to one side of the excavation. Such photographs show the relation of root distribution to soil horizons and height of water level.

After growth had ceased in the fall of 1925, cane measurements were made of representative plants at each of the stations. The same plants that furnished yield records earlier in the season were used for these growth measurements.

PRESENTATION OF DATA

Yields

Table 1 presents the yields, recorded in 1924 and 1925, of the plants immediately adjoining the various stations. On the basis of these figures, the locations are grouped as "good" or "poor"; the "good" locations are represented by stations 5, 6, 12, 4, 8, and 10, while stations 3, 2, 1, 7, 9, and 13 are classed as "poor" locations. Station 11 presents such wide differences in performance that it is not included in either group.

Table 1.—Yield records for 1924 and 1925.

Station	Yield per hill in onuces		Classification
	1924	1925	
1	.7	.5	poor
2	.9	.8	poor
3	4.2	4.8	poor
4	9.4	16.1	good
5	15.0	20.0	good
6	18.6	34.7	good
7	.3	Plants dead	poor
8	16.4	10.4	good
9	Plants dead	Plants dead	poor
10	17.6	10.9	good
11	27.1	8.5	....
12	12.9	21.2	good
13	Plants dead	Plants dead	poor

Soluble Salt Content

The amount of soluble material expressed in parts per 1,000,000 is sometimes used as a rough measure of "general fertility," that is, availability of various materials present in soil, including the essential elements. Thus a soil that contains less than 200 to 300 parts per 1,000,000 of soluble material, as determined by the freezing point depression, would generally be considered rather infertile. Determinations made at the various stations studied in this investigation, and reported in Table 2, show no consistent relationship between the total soluble materials in the soil and the yields of the raspberry plants. The group of "poor" locations contains, for every set of determinations made, both the highest and the lowest values. Lower soil strata, as reported in Table 3, exhibited the same lack of consistent relationship, both the highest and the lowest figures for the second horizon occurring in the group of locations classed as "poor" for raspberries.

Table 2.—Soluble material (in parts per million) in surface soils, in 1925, as determined by the freezing point depression.

"GOOD" SOILS

Station	April 28	May 26	June 23	July 21	August 20
6	500	625	725	500	475
5	450	525	675	450	425
12	475	600	725	475	450
10	425	600	725	675	400
8	425	625	725	475	500
4	475	425	525	475	450
11	575	650	800	800	550
"POOR" SOILS					
3	400	475	550	575	375
2	325	425	575	475	500
1	475	575	500	450	375
7	500	625	675	675	575
9	400	550	700	750	600
13	650	675	750	625	400

Note:—In this and the following tables, where figures are given for groups of "good" and "poor" stations, they are arranged in order, beginning with the one having the highest yield and growth records and ending with the one having the lowest yield and growth record.

Table 3.—Soluble material (in parts per million), of profile at each station, June 23, 1925.

Station	Horizon			
	Surface	Second	Third	Fourth
6	725	425	500	475
5	675	575	....	....
12	725	550	....	....
10	725	600	....	....
8	725	550	650	....
4	525	475	625	....
11	800	475	700	750
3	550	675	....	....
2	575	650	....	....
1	500	550	....	....
7	675	425	....	....
9	700	475	....	....
13	750	525	....	....

Nitrate Content

Acquaintance with the remarkable results secured in recent years by fertilization of orchards is likely to suggest nitrogen as the limiting factor to crop production in raspberries. The complete data on soil nitrates secured in this investigation are published in the appendix (Table 9). For ready comprehension, they are presented in simplified form in Table 4. Clearly, there is no close relation between the nitrate content recorded at any time and productivity. The group comprising the poorest locations generally has both the highest and the lowest quantities, both in surface soil and in subsoil. Even with allowance made for generally deeper penetration of roots in the more productive locations, a comparison of the subsoil of the better location with the surface soils of the poorer, shows no constant relationship. In general, the poorer locations appear to have been rather better supplied with nitrates than the more productive spots.

Table 4.—Nitrate in dry soil (parts per 1,000,000 of water extract), 1925.

"GOOD" SOILS

Station	Apr. 28 surface	9 inch depth	May 26 surface	9 inch depth	June 23 surface	9 inch depth	July 21 surface	9 inch depth	Aug. 20 surface	9 inch depth
6	2.1	T	2.1	1.5	5.0	1.6	8.6	2.4	3.5	0.9
5	1.9	1.9	1.5	T	6.0	1.3	5.4	2.3	1.8	1.1
12	2.8	4.5	1.5	T	5.5	1.0	1.4	T	1.1	1.5
10	1.3	2.2	1.5	T	4.5	3.8	1.0	1.0	1.1	1.2
8	2.3	2.8	3.3	2.1	5.4	1.5	11.0	1.5	3.2	0.9
4	2.3	1.8	1.8	1.5	T	1.1	3.8	1.4	T	1.0
11	2.0	1.3	1.5	1.3	7.3	1.5	5.5	5.1	3.0	1.5

"POOR" SOILS

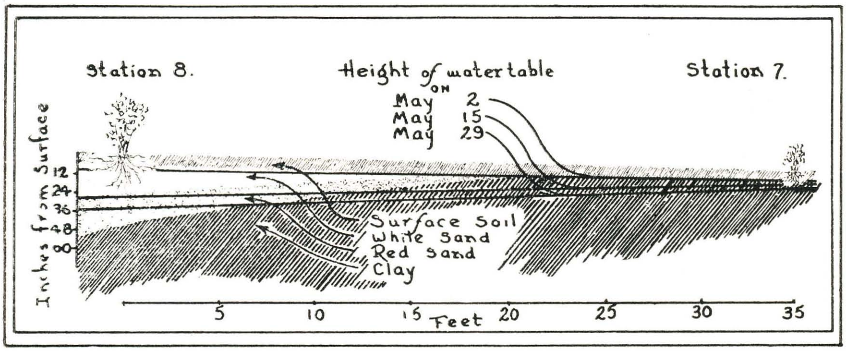
Station	Apr. 28 surface	9 inch depth	May 26 surface	9 inch depth	June 23 surface	9 inch depth	July 21 surface	9 inch depth	Aug. 20 surface	9 inch depth
3	1.9	1.8	2.0	T	T	T	T	T	2.5	1.2
2	1.9	2.1	3.1	3.3	7.3	3.0	7.5	6.5	1.9	3.3
1	5.0	2.3	3.2	2.0	1.0	1.9	6.0	3.1	6.4	5.4
7	4.0	5.4	3.4	6.8	6.0	5.0	....	6.7	7.4	4.3
9	T	2.9	1.4	1.2	7.6	T	12.1	3.0	5.5	2.5

*T signifies trace.

The fact that the soil at some of the stations where the raspberries made the best growth and yielded the heaviest showed a somewhat lower nitrate content than those where the plants were making unsatisfactory growth does not indicate that nitrates are unimportant in the culture of this fruit or that they were present in injurious amounts at any of the stations. It simply indicates that, in this field, nitrate supply was not the main limiting factor of growth, the smallest supplies of nitrate apparently being well above the minimal requirements. The somewhat lower amounts found in the soils where the growth was best may have been due to the removal of the nitrates by the more vigorous plants. It is probable, too, that the deeper root penetration in the better soils made available to the plants growing in them a total supply of nitrate considerably greater than that accessible to the shallow rooted plants growing in soils of a higher nitrate content. Incidentally, the data suggested that, at least in soils of medium fertility, nitrate applications will not compensate for the absence of a deep root system.

Soil Reaction

Soil acidity, as measured by hydrogen-ion concentration (Tables 5 and 6), appears not to have been closely related to raspberry performance. The soil at stations 1 and 2, where plants produced rather poorly, was slightly alkaline; and, at stations 5 and 6, where yields were best, the soil was uniformly highest in acidity. However, stations 7, 9, and 13, the poorest locations of all, occupied intermediate positions so far as acidity was concerned. The lower strata, as shown in Table 6, generally relationships, it may almost be said that height of water level was the limiting factor of growth and productivity in this field. Where the water level remained low throughout the season or where it approached the surface for only a few days in the spring, the roots penetrated deeply and branched profusely, shoot growth was vigorous, and yields moderate to heavy. Where it was high throughout the season or for a comparatively long period in the spring, the root system was shallow, cane and shoot growth was poor, yields were low, and the plants were short lived. This relationship is well brought out in Table 8. The roots seemed unable to penetrate a waterlogged layer in the spring and showed little tendency in mid-summer to grow down into soil which earlier in the season was saturated with water, even though moisture and aeration conditions were favorable during the summer. Roots have no lateral buds as stems do and do not have the same tendency to extend growth by branches when the tips are killed back. In most of the



Variations in Height of Water Table

"poor" locations, the roots had been killed back three or four inches from the tip. That it was the height of the water level rather than a high soil moisture content in the layers above the water level which usually limited root penetration and growth is evidenced both by soil moisture determinations through the season for the different layers and by the fact that in all cases but one (Station 6) the working level of the roots ranged to within a few inches of where the water level stood for a number of days. Presumably the sandy subsoils which the roots did not penetrate would have proved as good as those which they did penetrate had proper drainage been provided.

The ability of the roots thoroughly to penetrate the subsoil where its texture was sufficiently open and where the water level was low was as marked as their inability to penetrate where high water interfered seriously with aeration. They may not have been able to secure much of their nutrient supply from these subsoils, although the deep penetration placed within their range a greatly increased water supply in periods of drought and made possible vigorous growth and heavy production. The data do not warrant the statement that the raspberry plant is more or less independent of the character of the surface soil in which it is growing although they do warrant the statement that the

Figs. 2 and 3.—A general view at Station 1, one of the "poor" locations, and a view showing the root system of a typical raspberry plant at that point. Plants at this location produced on the average only half an ounce of berries apiece. The "working level" of the roots at this station was only seven inches, their maximum penetration only 10 inches. The water level was high—nine inches from the surface at two different times during the spring.

Figs. 4 and 5.—A general view at Station 7, one of the poorest locations in the entire field, and a view showing the root system of a typical raspberry plant at that point. Few of the plants in the vicinity of this station were alive at the close of the 1925 season. The nitrate supply at this station was relatively high, but the "working level" of the roots was only five inches deep and their maximum penetration 11 inches. The water level at this station was within nine inches of the surface for a period of nearly a month in the spring.

Figs. 6 and 7.—A general view at Station 6, one of the best locations in the entire field, and a view showing the root system of a typical raspberry plant at that point. The "working level" of the roots was 16 inches deep, their maximum penetration was 34 inches. At no time during the season did the water level rise to within two feet of the surface.

Table 8.—Root distribution and water levels at various stations.

"GOOD" SOILS

Station	Roots		Depth to free water		Difference between working level of roots and average of 3 lowest water level readings (inches)
	Working level (inches)	Maximum penetration (inches)	Av. 3 highest readings (inches)	Av. 3 lowest readings (inches)	
6	16	34	26	65	49
5	10	20	15	42	32
12	14	28	18	60	46
10	12	30	14	25	13
8	19	28	15	38	19
4	13	34	15	38	25
Average	14	29	17	45	31
"POOR" SOILS					
3	9	15	14	45	36
2	8	14	10	25	17
1	7	10	8	30	23
7	5	11	8	33	28
9	6	10	10	25	19
13	7	17	13	48	41
Average	7	13	11	34	27

plant thrives or fails to thrive depending on the character of the subsoil formations which tend to bring about varying conditions of drainage.

Discussion

If the total soluble salt content of a soil is indicative of the available fertility, the determinations then show that this was not a limiting factor in the growth of these raspberry plants because the differences found were insignificant.

Although the variations in soil acidity were wide, it is apparent that this was not a factor which limited growth in this field. The fact that some of the most vigorous and productive plants were found on the most acid soils shows that the raspberry is tolerant of a rather high degree of acidity.

The appearance and performance of this particular field bears a close resemblance to that of hundreds of other raspberry plantations in Michigan and, indeed, to that of many scores of fruit plantations of other kinds. It seems conclusive, therefore, that choice of a soil with a relatively low water level is a matter of first importance in establishing an orchard. There are, of course, other prerequisites of success, but without deep rooting, which is conditioned on a low water level, both growth and yield will be seriously limited and the plants are likely to be short lived. Determining the variations in the height of the water level before selecting the site for or planting the orchard may require considerable time and labor but it is a precaution that is well worth while, for it may result in preventing an almost endless amount of trouble and expense later on. A study of soil and subsoil conditions in orchards that are already planted, but where the trees are not thriving, may result in the abandoning of some orchard enterprises that otherwise would continue to be maintained and developed, only to end in failure eventually.

Finally, the lack of relationship prevalent in this case between plant performance and soil nitrates, soil moisture, and the like does not diminish their importance under other conditions. Were drainage made perfect in this field, yields would be likely to vary somewhat from spot to spot and perhaps a close relationship would be established between raspberry yields and soil nitrates or soil moisture or some other soil conditions. Without doubt there are many fields in which drainage is good and some of these other factors actually limit yields. There are many, however, in which poor drainage, sometimes plainly, sometimes less obviously, as in the case here recounted, is the chief limiting factor; in these fields, fertilization cannot be successful until drainage is improved.

SUMMARY

1. On a two and one-half acre field of raspberries, which had what appeared to be a reasonably uniform surface soil, five distinct soil types and two subtypes were found. These types are marked by differences in depth to clay substratum, in texture, amount of organic matter in the surface soil, reaction, and average moisture content.

2. Height of water level varied greatly from place to place in this field, marked variations often being found between points 25 to 50 feet apart. These variations were found to be correlated with the soil type.

3. Equally marked variations in the extent of the root development of the raspberry plants were found in different parts of this area.

4. The roots varied in depth of penetration from a minimum of 10 or 11 inches, with most of the roots at 5 to 7 inches from the surface, to a maximum penetration of from 30 to 35 inches, with the roots more or less completely filling the soil to a depth of from 16 to 19 inches.

5. Root development and depth of penetration were closely correlated with the height of the water level. Locations with a rather prolonged high water level had poor root development and shallow penetration; locations with a low water level had extensive root development.

7. Roots penetrated and branched freely in sandy, well aerated subsoil layers, where these subsoil layers were not waterlogged.

8. Top growth, yields of fruit, and longevity of the plants were directly proportional to the root development and consequently correlated with the height of the water level.

9. No correlation was found to exist between soil acidity, nitrate content of the soil or the concentration of its soluble salts and the plant growth in this field.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to Professors M. M. McCool, V. R. Gardner and F. C. Bradford for assistance in planning the work and organizing the data for publication, and to other members of the Soil and Horticultural Sections for their suggestions and criticisms during the progress of the work.

APPENDIX

Description of Soil Types

The following descriptions, which are supplied by J. O. Veatch of the Soils Section, Michigan State Agricultural Experiment Station, bring out the more important differences between the several soil types found in this field. (The figures refer to the numbers by which they are designated on the topographical and soil map (Fig. 1).

15. The Napanee Loam consists of a grayish, fine or heavy loam surface soil underlain by pale yellow or gray and yellow mottled, compact, highly retentive clay to depths of 4 feet or more. The humus content is medium; the soil is acid to neutral at surface, but contains free lime at shallow depths; the fertility is relatively medium to high; the average moisture is relatively high, but not excessive. The subsurface clay is dense and compact, but not sufficiently so to prevent entirely, penetration by plant roots.
27. The Allendale fine sandy loam consists of a thin covering of fine sand over relatively impervious clay; the sand in contact with the clay is more or less bleached, generally moist, and frequently saturated or water soaked, at 15 to 24 inches. The humus content is fair and the fertility medium. The sandy portion of profile commonly exhibits an acid reaction, while the underlying clay contains lime but may exhibit acid reaction. The excess of water in contact with the clay inhibits root development and successful plant growth. The growth of field crops is poor to good, depending upon season and artificial drainage, poorer during wet years, fair to good during dry years.
35. The deep phase of the Allendale sandy loam consists of 30 inches or more of sand over heavy clay. The sandy part of the soil is generally wet and saturated near the contact with the clay. Growth is variable, depending upon the season, the thickness of the sandy part and the efficiency of the artificial drainage.
29. The Newton fine sandy loam is characterized by a gray or nearly black (when wet) sandy surface or plow soil, underlain by dingy gray sand, which is wet or saturated at a depth of a foot or two. The fertility is low to medium and plant growth is likely to be poor due to high water level and excessive moisture. The soil is

generally acid. The Newton and the deep phase of the Allendale are closely allied and grade into each other. The first generally is higher in organic matter and has a higher average content of moisture.

20. and 32. The Brookston loam consists of a dark gray, high humus surface soil over a dingy gray subsurface loam or sandy loam, which in turn is underlain by a mottled gray and yellow clay. The fertility is medium to relatively high; the surface soil generally is not acid and an abundance of lime is present in the underlying clay at shallow depths. The clay is penetrable when artificially drained. Poor drainage is the chief limiting factor in growth. No. 32 appeared to be a little sandier than 20, but the division is perhaps of no considerable significance.

9. The Berrien loamy fine sand is a penetrable yellowish sand to depths of 3 feet or more. In places there is a fairly well marked rust colored or brownish horizon. The water level is 3 feet or more; the average moisture is relatively high, increasing with depth but generally is not high enough to inhibit plant growth. The soil is commonly acid to depths of 3 feet or more. The texture and structure is favorable for free root development to 3 feet or more. The organic matter is low to fair and the natural fertility low to fair.

Table 9.—Nitrates in dry soil, parts to the million of water extract, 1925.

Station	April 28	May 26	June 23	July 21	August 20
1 Surface 0-7	5.0	3.2	1.0	6.0	6.4
Sand 7-34	2.3	2.0	1.9	3.1	5.4
2 Surface 0-8	1.9	3.1	7.3	7.5	1.9
Clay 8-48	2.1	3.3	3.0	6.5	3.3
3 Surface 0-8	1.9	2.0	Trace	Trace	2.5
Sand 8-75	1.8	Trace	Trace	Trace	1.2
4 Surface 0-5	2.3	1.8	Trace	3.8	Trace
Sand 5-17	1.8	1.5	1.1	1.4	1.0
Clay 17-	4.8	3.3	2.0	3.3	1.6
5 Surface 0-5	1.9	1.5	6.0	5.4	1.8
Sand 5-56	1.9	Trace	1.3	2.3	1.1
6 Surface 0-4	2.1	2.1	5.0	8.6	3.5
Red Sand 4-20	Trace	1.5	1.6	2.4	.9
Hard Layer 20-30	Trace	Trace	1.4	2.9	.9
White Sand 30-75	Trace	1.5	Trace	2.6	1.5
7 Surface 0-5	4.0	3.4	6.0	*27.3	7.4
Clay 5-	5.4	6.8	5.0	6.7	4.3
8 Surface 0-7	2.3	3.3	5.4	11.0	3.2
White Sand 7-21	2.8	2.1	1.5	1.5	.9
Red Sand 21-30	3.5	3.0	3.1	3.2	2.6
9 Surface 0-9	Trace	1.4	7.6	12.1	5.5
Gray Sand 9-30	2.9	1.2	Trace	3.0	2.5
10 Surface 0-8	1.3	1.5	4.6	1.0	1.1
Gravelly Sand 8-16	2.2	Trace	3.8	1.0	1.2
11 Surface 0-5	2.0	1.5	7.3	5.5	3.0
White Sand 5-16	1.3	1.3	1.5	5.1	1.5
Yellow Sand 16-28	Trace	1.8	Trace	3.1	1.3
White Sand 28-56	5.2	1.8	1.5	1.4	2.5
12 Surface 0-8	2.8	1.5	5.5	1.4	1.1
Yellow Sand 8-72	4.5	Trace	1.0	Trace	1.5
13 Surface 0-8	6.0	1.4	13.0	13.6	3.6
Yellow Sand 8-60	5.3	2.4	4.1	2.7	3.5

*Foreign material present in sample.

Table 10.—Soil moisture determinations at weekly intervals during the growing season of 1925.

Station number	Sample number	4-22	4-28	5-8	5-15	5-22	5-29	6-6	6-11	6-19
1	1	22.2	22.2	20.9	20.5	23.7	20.2	19.3	18.8	20.8
	2	16.2	18.5	17.3	12.2	13.2	11.4	11.2	10.1	11.7
2	3	16.9	17.0	13.4	12.2	12.1	11.0	13.9	12.1	12.9
	4	21.3	21.7	20.8	20.0	20.6	20.0	19.1	19.3	19.8
3	5	18.1	18.4	17.7	15.2	14.1	15.8	14.5	12.3	14.9
	6	....	35.3	16.9	13.0	21.4	16.0	15.3	8.7	12.4
4	7	18.7	20.3	19.5	15.2	16.3	16.0	13.6	11.4	12.3
	8	14.8	16.8	16.0	13.9	11.8	10.9	8.4	5.9	5.8
	9	18.4	20.8	19.0	18.4	15.9	15.7	18.9	17.9	22.2
5	10	14.6	17.4	18.1	14.3	14.0	12.9	11.8	10.8	10.5
	11	18.3	18.0	18.6	12.3	13.7	11.4	8.6	13.8	8.3
6	12	17.7	17.8	17.9	16.3	16.1	16.0	15.6	14.0	13.8
	13	17.4	28.5	22.1	14.7	23.6	17.4	18.0	18.6	9.8
	14	14.1	17.3	15.2	9.4	9.0	7.4	8.3	7.4	6.2
	15	....	27.2	21.3	....	15.0	10.4	8.5	9.2	8.4
7	16	14.8	19.0	17.2	15.0	12.4	13.1	6.6	11.4	13.2
	17	18.7	16.5	23.6	21.3	20.4	19.8	17.5	19.2	16.8
8	18	23.6	22.5	20.6	22.6	22.6	22.3	15.4	19.3	19.4
	19	....	22.5	19.8	16.8	14.6	13.5	9.1	10.6	8.1
	20	....	22.8	20.1	18.1	17.8	18.0	15.0	16.4	14.8
9	21	21.5	20.2	17.6	19.1	18.7	18.0	17.1	18.4	17.2
	22	....	19.2	12.9	15.2	12.4	11.7	9.6	9.2	10.1
10	23	22.0	22.0	19.0	16.4	16.0	15.7	14.3	14.8	12.7
	24	17.8	20.6	14.6	12.8	10.3	10.1	7.9	6.2	10.5
11	25	13.3	15.9	18.2	17.8	12.5	18.4	14.8	16.1	20.0
	26	10.4	17.7	....	19.4	10.6	11.2	7.9	10.4	11.4
	27	20.0	25.0	....	19.7	17.9	14.9	12.8	10.5	14.9
	28	....	....	....	21.4	17.7	14.5	18.1	13.9	17.5
12	29	20.1	22.3	21.0	21.2	17.6	19.3	20.8	18.2	19.7
	30	22.0	17.4	17.1	14.4	12.2	11.0	11.6	13.0	14.7
13	31	16.0	13.9	17.9	18.9	15.2	16.4	15.4	14.9	14.3
	32	14.9	17.8	14.5	14.1	10.5	9.0	8.3	8.5	8.5

Table 10.—Continued.

Station number	Sample number	6-27	7-2	7-10	7-17	7-24	7-31	8-7	8-15	8-28	9-13	9-25
1	1	18.3	17.1	18.1	19.9	21.3	15.7	20.8	21.0	18.6	16.8	19.5
2	2	9.2	8.9	9.2	10.2	9.3	9.8	10.1	18.5	11.9	13.4	10.5
	3	13.5	16.0	9.3	10.7	9.5	12.7	10.5	15.9	12.9	12.1	16.5
	4	18.4	12.0	16.4	18.0	17.0	18.6	17.3	19.5	14.3	15.6	13.7
3	5	12.1	12.9	13.6	13.5	12.5	16.9	10.7	15.0	11.3	16.3	15.1
	6	3.4	7.7	7.9	7.0	4.4	10.2	7.7	12.3	7.0	9.2	10.0
4	7	12.1	8.8	12.7	10.7	7.6	13.6	13.0	14.3	12.9	13.8	14.0
	8	6.9	7.4	6.8	5.7	5.5	9.6	8.6	12.9	5.6	9.4	7.2
	9	16.0	16.1	15.5	12.3	13.5	13.2	16.8	16.9	15.3	14.5	17.3
5	10	10.2	11.3	10.0	10.9	9.9	10.7	9.6	14.2	17.7	11.0	9.8
	11	8.6	9.1	7.8	10.8	12.7	9.4	9.0	12.0	10.7	9.6	8.3
6	12	13.6	10.1	11.6	12.6	8.1	14.2	9.7	14.1	11.0	15.0	14.2
	13	10.2	12.2	39.8	15.5	9.0	14.2	8.7	14.2	14.6	17.5	12.0
	14	5.6	4.8	7.0	5.3	5.9	5.8	3.8	5.3	5.5	7 6	7.1
	15	8.2	4.6	5.2	4.7	5.5	4.9	3.1	4.3	3.9	4 2	4.0
7	16	15.3	8.5	12.2	14.7	13.6	16.8	14.0	18.4	9.9	14 3	15.2
	17	19.8	15.6	20.4	20.0	17.6	16.8	15.0	22.0	18.1	14.8	16.1
8	18	17.2	15.9	16.8	19.6	14.1	19.6	16.6	19.0	16.1	20.0	19.1
	19	9.4	7.3	5.6	4.6	9.8	6.4	6.3	11.0	8.5	11.4	10.0
	20	14.5	13.5	13.0	11.4	11.1	11.8	11.5	14.2	15.7	13.2	13.5
9	21	15.8	16.5	15.6	16.0	14.1	17.6	14.3	17.8	17.7	15.9	17.2
	22	7.3	8.8	6.5	7.5	6.7	9.1	7.1	14.0	10.3	8.6	10.2
10	23	14.4	13.8	12.2	13.8	10.1	13.4	12.7	15.1	14.3	16.1	14.7
	24	9.2	5.4	5.6	6.0	4.9	6.6	7.0	12.1	10.3	10.1	8.8
11	25	13.2	10.6	11.5	10.2	8.7	11.2	9.6	12.2	12.1	15.6	11.2
	26	6.0	7.4	7.8	6.9	7.4	9.7	10.0	6.9	5.3	9.9	9.3
	27	11.3	8.1	11.6	8.5	6.1	7.8	10.3	13.6	9.4	12.2	8.6
	28	15.4	12.2	11.9	5.5	4.4	9.0	8.8	17.5	13.3	11.3	9.8
12	29	16.7	15.7	17.1	16.9	16.1	16.4	16.8	18.6	18.0	17.6	15.1
	30	12.6	12.5	11.2	16.7	14.7	12.1	12.8	16.6	13.6	17.1	12.1
13	31	14.7	14.8	14.4	13.2	12.4	14.0	12.9	15.0	12.7	12.0	12.8
	32	8.2	7.3	7.8	5.1	8.3	10.2	6.1	11.5	7.3	10.5	7.5

Table 11.—Depth to free water at various locations (inches).

Station	April		May					June				July				August		
	22	28	2	8	15	22	29	6	11	19	27	2	10	17	24	2	7	15
5	17	17	15	15	16	16	17	19	20	20	24	24	25	24	25	25	32	29
6	30	29	24	24	31	30	41	46	49	55	53	53	54	56	56	57	70	58
12	21	27	15	18	28	32	35	55	55	51	50	50	50	49	50	47	47	38
4	18	23	12	15	25	30	33	34	38	37	36	37	37	34	37	38	38	36
8	15	20	10	19	27	30	32	36	36	37	37	38	38	38	38	38	38	25
10	14	18	9	19	26	28	29	30	30	30	32	32	33	33	33	33	30	21
11	27	28	28	24	21	24	21	26	28	28	30	32	36	40	45	47	45	40
3	18	15	12	15	21	26	30	34	36	37	37	39	41	43	45	45	45	37
2	11	11	10	10	11	12	13	14	18	17	17	18	20	20	24	23	29	16
1	9	16	9	13	21	22	25	28	30	29	27	29	31	23	25	18	24	7
7	10	9	7	8	9	11	12	12	14	16	22	24	25	25	25	25	25	24
9	11	14	6	16	16	20	21	23	23	23	23	23	25	24	26	22	23	19
13	16	21	13	21	29	35	40	41	42	42	44	44	46	45	48	48	47	31