Issued March 19, 1914.

PORTO RICO AGRICULTURAL EXPERIMENT STATION,

D. W. MAY, Special Agent in Charge,

Mayaguez, P. R.

Bulletin No. 14.

THE RED CLAY SOIL OF PORTO RICO.

BY

P. L. GILE,
Chemist.

AND

C. N. AGETON,
Assistant Chemist.

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS,
U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:
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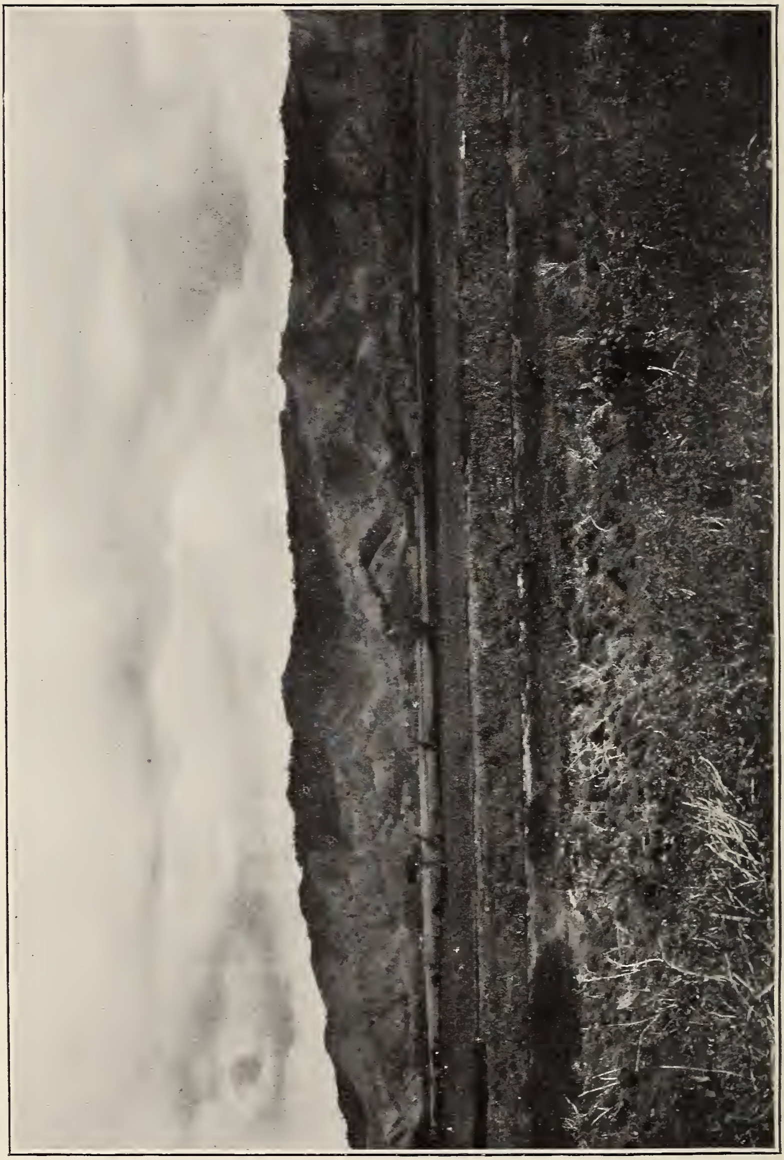

A VIEW OF ANASCO VALLEY, A TYPE OF RED CLAY LAND.

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PORTO RICO AGRICULTURAL EXPERIMENT STATION.

[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

Walter H. Evans, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

PORTO RICO AGRICULTURAL EXPERIMENT STATION,
Mayaguez, P. R., June 20, 1913.

SIR: I have the honor to transmit herewith a manuscript by P. L. Gile and C. N. Ageton on the Red Clay Soil of Porto Rico. This represents several years' work on soils, some of which have been devoted almost continuously to cane culture and are now in such condition that some radical treatment is necessary for their amelioration. The data contained herein will doubtless prove of value to planters and, it is hoped, will lead them to make further studies of means of improving these soils.

I respectfully recommend that the manuscript be issued as Bulletin 14 of this station.

Respectfully,

D. W. MAY,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

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INTRODUCTION.

In 1902 the Bureau of Soils made a soil survey of a strip of country 10 miles wide extending from Arecibo to Ponce.[1] Within this area 19 different types of soil were encountered, and this by no means embraces all the soil types that occur on the island. One of the chief types in respect to area, though not in fertility, is the red clay soil which is classified by the Bureau of Soils as Adjuntas clay. During the last six years considerable experimental and analytical work concerning the nature and treatment of this red clay soil has been carried on. The experiments are being continued, but inasmuch as such work is never really closed, it has seemed advisable to publish the results obtained thus far, with the idea that although they do not definitely answer all questions that may arise concerning this soil, they should aid in its more intelligent and profitable treatment.

DESCRIPTION OF PORTO RICAN RED CLAY.

COLOR, FORMATION, LOCATION, AND CROPS GROWN.

The Porto Rican red clay soil, or Adjuntas clay, as it has been classified, is a bright-red, dark-red, or brown clay. The color varies considerably, according to the content and state of oxidation of the iron, the amount of organic matter, and the moisture content. When dry the soil is brown or dark red, but when moist is bright or brownish red. In the lowlands there is generally little distinction between the surface soil and subsoil, the first foot or 8 inches being slightly darker in color than the subsoil. On the hill land the surface soil is generally a brighter red than that of the lowlands; the subsoil is also distinct in color from the surface soil, being a lighter red or yellow. On much of the hill land that is exposed to washing there is practically no surface soil.

Dorsey and his associates[2] describe the soil as residual, "being formed by the breaking down and decay of the igneous and volcanic rocks that form the backbone of the island. This disintegration has

[1] Porto Rico Sta. Bul. 3.

[2] Porto Rico Sta. Bul. 3, p. 30.

taken place to considerable depths, as shown by the soil mantle, in some places reaching a depth of 15 feet, the rock often showing decay beneath this." In the vegas or lowlands the surface soil has been formed partially by the decomposition of the rocks in situ and partially by washings from the surrounding hills.

This type of soil occupies the Anasco Valley (see frontispiece), the district around Mayaguez, the greater part of the San German Valley, certain areas on the east coast near Naguabo, and a large part of the interior around Adjuntas, Lares, Las Marias, and Caguas. It is one of the principal soil types in respect to area.

Coffee and sugar cane are the chief crops grown on the soil, coffee in the hill land and sugar cane in the valleys. In the hills bananas and native oranges are raised with the coffee. Some corn and small crops, as yams, yautias, and beans, are grown on the hill lands in the spring. Yams and yautias grow well on the soil. Tobacco is grown to some extent, but only successfully on lands where the drainage happens to be good.

PHYSICAL CHARACTERISTICS.

Physically the soil is a heavy clay. The five mechanical analyses made by the Bureau of Soils show that most of the particles are less than 0.05 mm. in size. The average composition of the five samples analyzed was as follows:

	Per cent.
Organic matter	0. 64– 3. 17
Gravel, 2 to 1 mm	. 00– . 74
Coarse sand, 1 to 0.5 mm	. 28– 1. 50
Medium sand, 0.5 to 0.25 mm	. 40– 1. 70
Fine sand, 0.25 to 0.1 mm	1. 94– 7. 46
Very fine sand, 0.1 to 0.05 mm	3. 48– 8. 90
Silt, 0.05 to 0.005 mm	32. 56–52. 30
Clay, 0.005 to 0.0001 mm	28. 94–57. 84

On account of its heavy nature the soil drains poorly in seasons of heavy rains and bakes badly during the dry months. After a prolonged dry period the soil cracks and fissures so that it dries out to a considerable depth. This fissuring is due to the shrinkage in volume of the soil on drying; it can be prevented by methods of conserving the soil moisture, such as surface cultivation and leaving trash between the rows of cane. The fissuring not only damages plant roots but increases the evaporation from the soil by exposing a greater surface to the air. The physical nature and difficulty of cultivation of the soil are its chief drawbacks, rendering it unsuitable for many crops.

The surface soil is often underlain by a layer of the parent rock which has been decomposed in situ so that it shows the original stratification but is quite impervious to water. In the alluvial lowlands this impervious layer may be at a considerable depth below the surface, but on the hills much exposed to erosion it is practically at the surface.

The lowland requires considerable ditching for successful cultivation. Tile drainage has also been found advantageous, but as water percolates through the soil very slowly the tile drains ought to be supplemented by some surface ditches for carrying off the excess of water from heavy rains. After continued heavy rains water often stands on the surface of the lowland soil for several days.

One of the prime requisites for the successful management of the soil is thorough and frequent cultivation. Unless the soil is maintained in good mechanical condition the full value of the plant food in the soil or of fertilizers applied can not be realized. Poor mechanical condition also enhances the damage done by root diseases of sugar cane. The benefits accruing from good cultivation in general are well known and they apply particularly to this soil. Without going into detail, some of the beneficial effects of plowing and cultivation are: Increasing the area and depth of the plant's root system; heightening bacterial activity that renders available certain compounds; affording a better circulation of air about the plant's roots; and conserving soil moisture in time of drought. Steam plowing of the soil to a depth of 20 to 30 inches has been found to improve the yield of sugar cane for several crops.

Care should be used in the cultivation of the soil. If cultivated when too moist the clay will puddle and it will be impossible to secure the "crumb" structure again for some time. When partially dried, or baked, cultivation is almost impossible. After a prolonged dry period, however, the soil cracks and fissures to such an extent that cultivation is again possible, the soil breaking up fairly well. The soil can be cultivated best after a few rains following a dry period.

CHEMICAL CHARACTERISTICS.

Analyses of 11 samples of surface soil and 6 samples of subsoil from different localities have been made by the method of the Association of Official Agricultural Chemists. The results of these analyses and a description of the samples are given in Table I. The loss on ignition represents the combined water and organic matter.

TABLE I.—*Acid analyses of red clay soil.*

Description of sample.	Laboratory No.	Insoluble matter.	Volatile matter.	Ferric oxid (Fe_2O_3).	Alumina (Al_2O_3).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Phosphorus pentoxid (P_2O_5).	Total.	Nitrogen (N).	Reaction to litmus.
		P. ct.	*P. ct.*	*Per cent.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
Mayaguez Experiment Station, valley soil.	18	60.38	11.55	23.91		0.85	3.58	0.30	0.20	100.77	0.19	Acid.
Mayaguez Experiment Station, valley subsoil.	19	59.44	10.69	25.95		.60	3.32	.47	.14	100.61	.12	Do.
Mayaguez Experiment Station, hill soil.	20	71.76	10.99	16.74		.16	.21	.14	.13	100.13	.26	Do.
Mayaguez Experiment Station, hill subsoil.	21	58.49	11.74	29.31		.13	.25	.28	.10	100.30	.09	Do.
Mayaguez Experiment Station, hill soil.	74	71.34	11.55	16.94		.14	.21	.11	.11	100.40	.20	Do.
Mayaguez Experiment Station, hill subsoil.	75	66.50	11.59	21.70		.04	.19	.13	.16	100.31	.11	Do.
Arecibo, Cambalache, soil.	15	62.16	12.28	24.91		.33	.44	.22	.17	100.51	.18	Do.
Anasco, Buenaventura, upper valley soil.	22	55.61	11.29	31.64		.49	.73	.40	.26	100.42	.12	Do.
Naguabo, San Cristobal, soil.	68	73.00	8.41	16.19		1.12	1.55	.15	.07	100.49	.15	Do.
Mayaguez, Aurelia, hill soil.	158	46.13	18.60	11.58	23.73	.32	.65	.06	.08	101.15	.32	Do.
Do.	159	52.01	13.76	13.07	20.71	.23	.07	.13	.09	100.07	.13	Do.
Hormigueros, San Francisco, valley soil.	448	60.43	12.43	10.97	13.76	.61	1.26	.18	.18	99.82	.14	Do.
Hormigueros, San Francisco, valley subsoil.	449	59.91	12.11	10.82	13.49	.56	1.70	.19	.20	98.98	.10	Do.
Hormigueros, San Francisco, valley soil.	450	62.11	10.90	11.76	11.84	.74	2.04	.13	.17	99.69	.11	Do.
Hormigueros, San Francisco, valley subsoil.	451	62.77	10.40	11.78	12.20	.81	2.35	.22	.13	100.66	.13	Do.
Anasco, Pagan, valley soil.	456	64.53	10.38	10.08	12.73	.65	1.18	.27	.18	100.00	.12	Do.
Anasco, Pagan, valley subsoil.	457	61.75	11.69	9.77	15.00	.71	1.43	.34	.19	100.88	.11	Do.

No carbonates were present in any of the samples and they were all more or less acid to litmus. The content of iron and aluminum is very high in all the samples, ranging from 16 to 35 per cent. The hill land of this type of soil seems to contain much less lime and magnesia than the low land. Some samples are low in phosphoric acid, potash, or nitrogen; the average of the samples, however, shows that the soil is not particularly lacking in any one element. The subsoil runs higher in potash than the surface soil. Chemically the chief characteristic of the soil is the high content of iron and aluminum. In those places where much of the iron is present in the soil as oxid or hydrate, instead of silicate, it may influence the fertility, since iron oxid promotes the oxidation of organic matter in the soil.[1] Some of the hill land seems to contain considerable oxid of iron.

[1] Storer. Agriculture in Some of its Relations with Chemistry. New York, 7. ed., vol. 1, p. 495.

The amount of organic matter in the red clay soil depends on the erosion to which the surface has been exposed and on the methods of cultivation. On the hill lands planted to coffee the content of organic matter is largely controlled by the erosion; in favored spots where the surface has not been washed there is a large amount of organic matter and the soil is of good texture; where it has been washed, however, the surface soil is very thin, low in organic matter, and of poor texture. The valleys, having received the surface washing from the hills, have a richer, deeper soil with considerable organic matter. The hill land, which is alternately in grass or corn and small crops, is generally very low in organic matter, as these hills are at times exposed to considerable erosion and no attempt is made to supply organic matter. A bad case of erosion of the hill land is shown in the frontispiece. In the lowlands, which are almost exclusively planted to sugar cane, the content of organic matter is low in the soils that have been cultivated most, as it has generally been the custom to burn the trash remaining after each crop of cane, and the only organic matter incorporated in these cases has come from weeds and grass turned under in the course of cultivation. The cultivation, by increasing bacterial action which oxidizes the humus, has tended to exhaust the humus and only very little organic matter has been returned.

The red clay soil is uniformly acid in its reaction to litmus. Containing no carbonates, the soil tends to become more acid with increase in organic matter and with the use of acid fertilizers or fertilizers that leave an acid residue, as ammonium sulphate. Besides the acidity due to organic acids, formed in the decomposition of the organic matter, there is possibly an acidity due to certain silicates in this soil.

Soil acidity is supposed to have an injurious effect on the general fertility of the soil by influencing the bacterial flora, the free living bacteria which assimilate atmospheric nitrogen and the nitrate-forming bacteria thriving best in a neutral or slightly alkaline medium. Many studies have shown that in acid soils the bacterial flora is depressed and the fungus flora increased. It has been well substantiated that many plants will not thrive in acid soils, that some plants seem indifferent to the acidity, while a few plants, such as the blueberry and sphagnum moss, require acid soils. Why different plants vary in this respect and how the plants sensitive to acidity are injuriously affected has not been discovered.

The acidity of the red clay is more or less injurious to sugar cane, as is shown by the increased yields obtained by liming. Whether coffee is much affected is not known, as thus far comparisons between the limed and unlimed soil with this crop have not given decisive results. Tobacco has been benefited by liming, and the growth of beans and corn on this soil should be consideraby increased by the same means. Malojillo, or Para grass, grows luxuriantly on the red clay of the lowlands, so is apparently well adapted to acid conditions.

EXPERIMENTS ON NORMAL RED CLAY SOIL.

Experiments have been carried out on the red clay soil of the lowlands to determine the lime and fertilizer requirements. As sugar cane is the chief commercial crop grown, all the following experiments have been with cane.

In 1911, 45 tenth-acre plats were established on this soil in the Anasco Valley at Central Pagan. The analysis of the soil and subsoil is given in Table I under Nos. 456 and 457. The field where the plats were established had been in continuous cane culture for six years, five crops of ratoon cane having been grown. Previous to this the land had probably been in pasture for several years, as it had been the custom on this plantation to plant only one-third of the land each year. The field where the three following experiments were carried on was plowed by a steam plow to a depth of 2 feet in May and replowed by bulls in August. Cristalina cane was planted in September, 1911, and cut in January, 1913. The fertilizers were applied in November in the furrow.

EXPERIMENT WITH LIME AT ANASCO.

This experiment comprised 16 plats. Liming at the rate of 1,500, 2.000, and 4,000 pounds per acre was tried, both with and without a complete fertilizer. Burnt lime partially slaked was applied in May and plowed under. The complete fertilizer used was made up of tankage, basic slag, and muriate of potash, and was applied so as to afford 50 pounds each of nitrogen, phosphoric acid, and potash per acre. The yields of cane from the various plats are given in Table II.

TABLE II.—*Effect of lime at Anasco.*

Treatment of plats.	Numbers of plats.	Yield of cane per acre.	Average yield of duplicate plats.
		Tons.	*Tons.*
Check, nothing	2 22	(1) 22.2	....
Lime, 1,500 pounds per acre	1 20	(1) 25.6	....
Lime, 2,000 pounds per acre	3 21	(1) 24.4	....
Lime, 4,000 pounds per acre	4 23	(1) 27.5	....
Complete fertilizer	6 18	29.1 23.1	26.1
Lime, 1,500 pounds per acre and complete fertilizer	5 16	31.6 21.7	26.7
Lime, 2,000 pounds per acre and complete fertilizer	8 17	33.8 26.1	30.0
Lime, 4,000 pounds per acre and complete fertilizer	7 19	33.4 30.0	31.7

[1] Weight lost.

The cane from plats 1 to 4 was mixed in the cutting, so the weight of the individual plats could not be secured, but the average weight for the four plats was 20.2 tons of cane per acre. Summarizing the results, the differences due to the lime can be seen in Table III.

TABLE III.—*Increased yield of sugar cane produced by different amounts of lime.*

Amount of lime applied per acre.	Numbers of plats.	Average yield of 3 plats, per acre.	Increase in yield due to lime, per acre.
		Tons.	*Tons.*
None	22, 6, 18	24.8	....
1,500 pounds	20, 5, 16	26.3	1.5
2,000 pounds	21, 8, 17	28.1	3.3
4,000 pounds	23, 7, 19	30.3	5.5

The eight plats in this table which received no fertilizer [1] averaged 22.6 tons of cane per acre, while the eight plats with the complete fertilizer averaged 28.6 tons, a gain of 6 tons of cane per acre for the complete fertilizer.

EXPERIMENT WITH FERTILIZERS AT ANASCO.

This experiment comprised 19 plats and was intended to show whether the soil is benefited by a complete fertilizer and whether any fertilizing element or elements are particularly effective.

All the plats in this experiment received lime at the rate of 1,500 pounds per acre. The different fertilizers were applied so as to afford 50 pounds of nitrogen, phosphoric acid, or potash per acre. The nitrogen was derived from nitrate of soda, the phosphoric acid from basic slag, and the potash from muriate of potash. The fertilizers and yields of the various plats are given in Table IV.

TABLE IV.—*Effect of different fertilizing elements at Anasco.*

Fertilizers applied per acre.	Numbers of plats.	Yield of cane per acre.	Average yield of plats of like treatment.
		Tons.	*Tons.*
Check, no fertilizer	1 20 30 34 42	(2) 25.6 28.0 30.8 30.7	28.8
Potash, 50 pounds	32 40	19.6 28.0	23.8
Phosphoric acid, 50 pounds	33 41	20.2 29.0	24.6
Nitrogen, 50 pounds	31 39	24.6 37.3	31.0
Potash and phosphoric acid, 50 pounds each	37 45	33.4 28.9	31.2
Potash and nitrogen, 50 pounds each	35 43	30.3 35.7	33.0
Phosphoric acid and nitrogen, 50 pounds each	36 44	34.0 37.5	35.8
Nitrogen, phosphoric acid, and potash, 50 pounds each	38 29	36.9 33.5	35.2

[1] These include plats 1 to 4, of which the average weight only was obtained. [2] Weight lost.

The above results show some variations due to irregularities in the experimental field. It is evident, for instance, that plats 31, 32, and 33 were situated in a poor part of the field, but the differences between these three plats are of the same order as the differences between the three duplicate plats, Nos. 39, 40, and 41, which were in the better part of the field. Because of this poor spot the averages of these plats are not to be compared with the other averages in the table, although the comparison of these three with each other is probably accurate.

The results show that the complete fertilizer has increased the yield by 6.4 tons of cane per acre. The preceding experiment also showed an increase of 6 tons of cane for the complete fertilizer. In regard to the relative value of the single fertilizing elements it seems evident that potash is not needed, since nitrogen plus phosphoric acid gave the same yield as these two elements plus potash. It appears that phosphoric acid is also unnecessary and that nitrogen alone increases the yield as much as a complete fertilizer. Because of the irregularities in the field it is not quite clear that phosphoric acid is entirely superfluous, but the results in general seem to point to that conclusion. The following experiment throws some light on this.

EXPERIMENT ON THE VALUE OF PHOSPHORIC ACID IN A BAT GUANO.

This experiment comprised 12 plats and was intended to show the value of the phosphoric acid in a bat guano, compared with the phosphoric acid of basic slag, on this soil. Since the soil included in this block of plats did not respond to phosphoric acid, no data were secured as to the relative value of the two sources of phosphoric acid, but the results are given here, as they tend to substantiate the conclusion of the preceding experiment that phosphoric acid was superfluous.

The plats were all limed at the rate of 1,500 pounds per acre. The nitrogen and potash applied were derived from the same sources as in the preceding experiment. The bat guano used contained 7.8 per cent total phosphoric acid, 3 per cent phosphoric acid soluble in ammonium citrate, and 0.4 per cent total nitrogen. The bat guano was applied in three different quantities, so as to afford 25, 40, and 60 pounds of total phosphoric acid per acre. The yields of the plats are given in Table V.

TABLE V.—*Test of bat guano compared with basic slag.*

Fertilizers applied per acre.	Numbers of plats.	Yield of cane per acre.	Average yield of duplicate plats of cane per acre.
		Tons.	*Tons.*
Nitrogen, 50 pounds; potash 75 pounds	25 13	29.5 38.9	34.2
Nitrogen, 50 pounds; potash, 75 pounds; phosphoric acid (from basic slag), 50 pounds	9 28	28.6 35.4	32.0
Nitrogen, 50 pounds; potash, 75 pounds; phosphoric acid (from basic slag), 25 pounds	12 24	35.1 29.7	32.4
Nitrogen, 50 pounds; potash, 75 pounds; phosphoric acid (from bat guano), 25 pounds	10 26	30.3 40.0	35.2
Nitrogen, 50 pounds; potash, 75 pounds; phosphoric acid (from bat guano), 40 pounds	14 27	37.8 34.2	36.0
Nitrogen, 50 pounds; potash, 75 pounds; phosphoric acid (from bat guano), 60 pounds	15 11	39.1 34.6	36.9

The plats with nitrogen, potash, and phosphoric acid averaged about the same as the plats with only nitrogen and potash, hence it appears that phosphoric acid was unessential.

EXPERIMENT WITH LIME AT MAYAGUEZ.

This was a small experiment comprising five twentieth-acre plats planted to sugar cane, variety B 1753. Burnt lime was applied at the rate of 500 and 3,000 pounds per acre, both with and without a complete fertilizer the first year. For the ratoon crop all the plats except the check received tankage. The complete fertilizer applied to plats 4 and 5 the first year contained 7.3 per cent nitrogen, 2.5 per cent phosphoric acid, and 4.5 per cent potash from dried blood, acid phosphate and sulphate, and muriate of potash. This was applied at the rate of 1,100 pounds per acre. The tankage, applied at the rate of 400 pounds per acre to plats 2, 3, 4, and 5 for the ratoon crop, contained 10 per cent nitrogen and 3 per cent phosphoric acid.

After planting it was noticed that the check plat did not drain as readily as the other plats, which were quite uniform in drainage. It is probable that the yield of the check plat is thus not comparable with the others. The results, given in Table VI, show, however, the differences in yield between the plats receiving 500 and 3,000 pounds of lime per acre.

TABLE VI.—*Effect of lime at Mayaguez.*

Treatment of plats.	Number of plat.	Yield per acre of first crop of cane.	Yield per acre of ratoon crop.
		Tons.	*Tons.*
Check, nothing	1	43.4	49.9
Lime, 500 pounds per acre	2	50.2	44.1
Lime, 3,000 pounds per acre	3	69.3	47.3
Lime, 500 pounds per acre, and fertilizer	4	57.3	44.7
Lime, 3,000 pounds per acre, and fertilizer	5	61.6	51.1

It will be seen that 3,000 pounds of lime per acre gave an increase over 500 pounds of lime both for the plant cane and the ratoons. If we leave out the results of plat 3 the first year, which seems abnormally high, the increase varies from 3.2 to 6.4 tons of cane per acre. This experiment alone is not conclusive but substantiates the other experiments.

SUMMARY OF RESULTS.

The preceding experiments show that this red clay soil was improved by liming and fertilization. The larger the applications of lime the greater were the increases obtained, so possibly the optimum amount is somewhat greater than 4,000 pounds of burnt lime per acre, which was the heaviest application tested. Nitrogen alone seemed to increase the yield of sugar cane on this soil as much as a complete fertilizer. In regard to the general applicability of these results it must be borne in mind that they are definite for the place where they were carried on, and, as the field was typical, they are instructive for considerable areas of the red clay but not for all of it. These results do not hold true for this type of soil which is in the "sick" condition.

EXPERIMENTS ON "SICK" RED CLAY SOIL.

In some places the red clay soil which has been in continuous cane cultivation for a long series of years has become very unproductive and does not respond to fertilizers or the usual soil amendments. Soil in this condition has been termed "sick" or "tired" rather than "worn out," although in what the sickness or tiredness consists has not been definitely determined.

Certain fields at Hormigueros in the San German Valley are at present in this tired condition. These fields have been in continuous cane cultivation for a long series of years, although for just how many years it is impossible to say as no records are available; report gives it as from 30 years to "always." Experiments have been carried on in this valley to see if the productivity could not be increased by some method of soil treatment other than resting. Under the economic conditions that cane is grown here, especially where the land is leased, it is desirable to plant all the land in cane every year.

In 1906–7 some fertilizer plats were tried at Hormigueros by the horticulturist.[1] Nitrate of soda, ammonium sulphate, potassium sulphate, and acid phosphate were used. In the heaviest application these materials were applied so as to yield 75 pounds of nitrogen, 85 pounds of phosphoric acid, and 125 pounds of potash per acre. The yield of cane on the plat receiving no fertilizer was 18.8 tons

[1] Porto Rico Sta. Bul. 9, p. 27.

per acre, that on the heavy complete fertilizer plat 21.4 tons—an increase of about 10 per cent for heavy fertilization.

In 1911–13 an experiment with a series of 42 tenth-acre plats was tried on the same soil, the analyses of which are given in Table I under Nos. 448 to 451. All the plats were plowed with a steam plow to a depth of about 2 feet in March, 1911, and again by bulls in September, 1911. Rayada cane was planted September 20, 1911, and cut January 7–8, 1913. All plats which received fertilizer were fertilized at the rate of 550 pounds per acre with a mixture containing 7.3 per cent nitrogen, 3.6 per cent phosphoric acid, and 7.3 per cent potash, derived from tankage, sodium nitrate, basic slag, and muriate of potash. The fertilizer was applied in the furrow six weeks after the cane had been planted. The following treatments were tried on separate blocks of plats: Thorough aeration of the soil before planting, applications of lime and stable manure, applications of fertilizer, carbon bisulphid, stable manure, and green manuring. The results of the different experiments are given separately.

EXPERIMENT ON THOROUGH AERATION OF THE SOIL BEFORE PLANTING.

As previous experience had indicated that this soil responded very little to fertilizers, it was thought that possibly the trouble was due to biological causes, in which case thorough aeration of the soil and exposure to sunlight previous to planting might be beneficial. The experiment comprised six plats, all of which were plowed by the steam plow in March and plowed again by bulls in September. Three of the six plats, however, were also plowed four times more at intervals of about five weeks, i. e., April 12, May 20, June 30, and August 5. All plats received the fertilizer described above. The results are given in Table VII.

TABLE VII.—*Effect of thorough aeration of "sick" soil before planting.*

Treatment of plats.	Numbers of plats.	Yield of cane per acre.	Average yield of plats of like treatment.
		Tons.	*Tons.*
Complete fertilizer, plowed twice	17	18.1	20.9
	19	20.1	
	21	24.5	
Complete fertilizer, plowed six times	16	19.5	21.5
	18	21.4	
	20	23.5	

The yield of the three plats in each lot receiving the same treatment vary considerably, but this is apparently due to the fact that the soil improves from plats 16 to 21, since No. 21 is better than No. 19, and No. 19 better than No. 17, also No. 20 is better than No. 18, which is better than No. 16. As the plats were alternated in the field, the average results are comparable and but little affected by this inequality in the soil. It will be seen that practically no improvement has resulted from frequently aerating the soil previous to planting. This of course does not mean that good preparation of the soil and cultivation during growth can be disregarded.

EXPERIMENT WITH LIME AND STABLE MANURE.

This experiment comprised 15 plats. The object of the experiment was to see if the soil would be benefited by heavy applications of lime, or lime plus stable manure. It was thought that in case the poor condition of the soil were due to bacterial causes, a heavy application of lime might improve the yield, since liming acid soils alters the bacterial flora and activities.

All 15 plats were plowed six times previous to planting, the same as plats 16, 18, and 20 of the previous experiment, and all received 550 pounds of fertilizer per acre. Burnt lime, only slightly slaked, was used in certain plats. This was applied after the land had been plowed by the steam plow, so it was well mixed with the soil by the subsequent shallow plowing. The stable manure was spread just previous to the two final plowings. The yields of the various plats are given in Table VIII.

TABLE VIII.—*Effect of lime and stable manure on "sick" soil.*

Treatment of plats.	Numbers of plats.	Yield of cane per acre.	Average yield of plats of like treatment.	Increase over check.
		Tons.	*Tons.*	*Tons.*
Check, nothing	3 9 14	21.2 26.7 24.7	24.2	....
Lime, 2 tons per acre	2 6 10	22.9 25.1 25.7	24.6	0.4
Lime, 4 tons per acre	5 12 15	25.9 25.0 25.5	25.5	1.3
Lime, 2 tons, and stable manure, 17 tons, per acre	1 7 11	25.6 24.8 24.0	24.8	.6
Lime, 4 tons, and stable manure, 17 tons, per acre	4 8 13	27.1 27.2 25.6	26.6	2.4

The increases produced by liming at the rate of 2 and 4 tons per acre, either alone or in conjunction with stable manure, were very small, ranging from 0.4 to 2.4 tons of cane per acre. It is thus evident that this treatment is of no benefit to the soil in its present condition.

EXPERIMENT WITH FERTILIZER, STABLE MANURE, CARBON BISULPHID, AND GREEN MANURE.

This experiment included 21 plats and was designed to show whether improvement could be produced by fertilizer alone, by fertilizer plus stable manure, by green manuring with cowpeas, or by application of a soil disinfectant. All the plats were plowed twice before planting as noted on page 15. Three plats received no fertilizer, three plats 275 pounds of fertilizer per acre, and all other plats fertilizer at the rate of 550 pounds per acre. Some plats in addition to the fertilizer received stable manure, carbon bisulphid. or cowpeas turned under.

The fertilizer, as in the other experiments, was applied in the furrow six weeks after the cane was planted. The stable manure was spread previous to the final plowing. The carbon bisulphid was applied two months before planting at the rate of 450 liters per acre; three plats receiving this quantity in one application, and three other plats receiving the same quantity in three applications made at intervals of two weeks. The carbon bisulphid was applied in small holes 8 to 9 inches deep and covered immediately with earth. The cowpeas were grown and plowed under previous to planting the cane. They made a rather poor growth and were not well supplied with nodules. The result with cowpeas therefore can not safely be taken as showing whether or not green manuring is beneficial. It has since been found that better results can be secured with sword beans on this soil. The yields of the plats are given in Table IX.

TABLE IX.—*Effect of fertilizer, stable manure, and carbon bisulphid on "sick" soil.*

Treatment of plats.	Numbers of plats.	Yield of cane per acre.	Average yield of plats of like treatment.	Remarks.
		Tons.	*Tons.*	
Check, nothing	24	21.0	18.7	
	27	20.0		
	32	15.0		
Fertilizer, 275 pounds per acre	35	19.0	18.5	No increase over check.
	38	19.0		
	41	17.5		
Fertilizer, 550 pounds per acre	23	21.0	21.7	3 tons more than check.
	28	23.5		
	31	20.7		
Cowpeas and fertilizer, 550 pounds per acre.	34	20.0	19.6	0.9 ton more than check.
	37	21.5		
	40	17.2		
Fertilizer, 550 pounds, and stable manure, 17 tons per acre.	36	24.8	23.0	1.3 tons more than fertilizer alone.
	39	24.1		
	42	20.2		
Fertilizer, 550 pounds, and carbon bisulphid (in 1 application), 450 liters per acre.	22	27.0	25.7	4 tons more than fertilizer alone.
	26	30.0		
	30	20.0		
Fertilizer, 550 pounds, and carbon bisulphid (in 3 applications), 450 liters per acre.	25	28.5	22.5	0.8 ton more than fertilizer alone.
	29	22.2		
	33	16.9		

The land in which this block of plats was situated was not quite so uniform as that in the experiment above, judged by the greater differences between the triplicate plats. Fertilizer alone gave very little if any increase of yield, 275 pounds of fertilizer yielding the same as no fertilizer, while 550 pounds gave an increase of 3 tons of cane. The plats with cowpeas plus 550 pounds of fertilizer gave only 1 ton more than the checks, which show that the stand of cowpeas secured was without effect and that probably the average increase produced by 550 pounds of fertilizer is somewhat less than 3 tons of cane. Stable manure plus fertilizer gave about 1½ tons more cane than fertilizer alone. This confirms the results in Table VIII, showing that stable manure was scarcely effective. The carbon bisulphid in one application seemed to give an appreciable increase while the carbon bisulphid in three applications gave practically no increase, hence it is probable that this treatment is not much more effective than any of the others.

EXPERIMENT WITH TRICRESOL,[1] FERTILIZER, AND STABLE MANURE.

In 1909 to 1911 a smaller experiment, carried out on the same plantation, gave results similar to those detailed above. In this case, however, the land had been rested two years previous to planting.

There were eight plats of one-twentieth acre each. Two check plats received nothing, two plats a complete fertilizer, two plats a complete fertilizer plus tricresol, and two plats stable manure. The fertilizer used contained 9 per cent nitrogen, 6 per cent phosphoric acid, and 6 per cent potash, derived from tankage, acid phosphate, and potassium sulphate. This was applied to the fertilizer plats at the rate of 500 pounds per acre. The stable manure was spread and plowed under previous to planting. The tricresol was applied in a 0.5 per cent solution a month before planting, by sprinkling the surface, plowing under, and sprinkling a second time. One plat received this solution at the rate of 3,840 liters per acre, the other plat at the rate of 7,680 liters per acre. Rayada cane was planted December 4, 1909, and harvested January 24, 1911. The yields of the different plats are given in Table X.

TABLE X.—*Effect of tricresol, fertilizer, and stable manure on the "sick" soil.*

Treatment of plats.	Yield of cane per acre.
	Tons.
Check, nothing	39.1
Do	37.0
Fertilizer	36.9
Do	36.1
Fertilizer and 3,840 liters 0.5 per cent tricresol per acre	35.0
Fertilizer and 7,680 liters 0.5 per cent tricresol per acre	33.6
Stable manure, 10 tons per acre	39.5
Stable manure, 20 tons per acre	40.1

[1] Tricresol is a nonvolatile disinfectant related to carbolic acid.

A comparison of the data shows that the fertilizer plats yielded practically the same as the checks; that the tricresol plus fertilizer plats yielded slightly less than the fertilizer alone, the depression being greater with the larger dose of tricresol; and that the stable manure plats yielded slightly more than the checks. All the plats were quite uniform in yield, so it is evident none of the treatments was beneficial and possibly the treatment with tricresol was slightly injurious.

EXPERIMENT WITH FERTILIZERS BY SUGAR PRODUCERS' STATION.

In 1911–12 a fertilizer experiment on this land was carried out by the Sugar Producers' Station.[1] The nitrogen used was derived from ammonium sulphate, the phosphoric acid from double superphosphate, and the potash from potassium sulphate. All plats except the check received either two or all three of the elements at the rate of 60 to 90 pounds per acre. The average yield of the 16 fertilizer plats was 21.7 tons of cane per acre, and the average yield of the four checks was 18.2 tons, showing a gain of 3.5 tons for the fertilizer. The results did not show that any one element was relatively more effective than the others.

SUMMARY OF RESULTS.

A general consideration of the previous experiments seems to show definitely that fertilizers on the "sick" red clay soil increase the yield of sugar cane but little. The moderate applications of fertilizers have not increased the yield at all, and heavy applications have increased the yield only slightly. This shows plainly that the growth of cane on soil in this condition is limited by some factor other than the supply of mineral nutrients.

Applications of stable manure have been as ineffective as commercial fertilizers, the experiment of 1909–1911 showing an increase of 2 tons of cane per acre from an application of 20 tons of stable manure, and the experiment of 1911–1913 showing an increase of 1.3 tons of cane from an application of 17 tons of stable manure.

Liming has also been without results, although the land is more or less acid in reaction to litmus. The managers of the plantation on which the experiments were made had in previous years tried moderate liming without results and the heavy applications of 2 and 4 tons of burnt lime per acre which were applied in the above experiments were also without effect.

Disinfectants, which in some cases have increased the yield of certain sick soils, were not beneficial on this soil. The applications of tricresol, a nonvolatile disinfectant, caused a slight depression rather than increase in yield. Applications of a volatile disinfectant, carbon bisulphid, which were much greater than could profitably be applied in practice, were also ineffective, although possibly a slight increase was produced.

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[1] J. T. Crawley, Porto Rico Sugar Producers' Sta. Bul. 3, p. 24.

ON THE DIFFERENCE BETWEEN THE NORMAL AND "SICK" RED CLAY SOIL.

The normal and sick red clay soils differ greatly in their productiveness and also in their response to fertilizers and lime, as the previous experiments have shown. The unproductive soil of Hormigueros in the San German Valley yields from 10 to 25 tons of cane per acre, the normal soil in the Anasco Valley yielding from 20 to 40 and 50 tons of cane per acre.[1] The rainfall in the two sections, which are about 10 miles apart, varies but little and the drainage of the land is the same. That the chemical composition of the two soils is identical, can be seen from Table I, analyses Nos. 448–457. Physically the two soils are very nearly the same; if there is any difference it is in favor of the Hormigueros soil.

The difference in the previous treatment of the two soils lies in the more continuous cultivation of the Hormigueros soil. At Anasco only one-third of the land on the plantation was in cane cultivation any one year, the rest of the land being in pasture, while at Hormigueros the land has been in continuous cane cultivation. With the more intensive cultivation of the Anasco soil it is probable that the productiveness of the two soils will become more nearly equal. That this difference in the intensity of the previous cultivation is the cause of the present difference in productivity seems probable, since it has been observed at Hormigueros that the land becomes much more productive after it has been left out of cultivation for two or three years.

Now that fields which have been planted more continuously than other fields should be less productive is not surprising, but it is surprising that the fields which have been cropped most heavily should respond least to fertilizers and other soil amendments. That these fields have been injured by the continuous cultivation of the same crop is apparent, but in just what the injury consists is not clear. The trouble is not due to a mere impoverishment of the soil, for fertilizers and stable manure are ineffective, nor to an increase in soil acidity, since liming is ineffective, nor to alterations in the biological processes which could be cured by superficial disinfection, since carbon bisulphid and tricresol are ineffective.

Recent work on the organic matter of the soil seems to show that in certain cases crop production may be affected by organic compounds resulting from the decomposition of crop residues left in the soil. To see whether the organic matter of the two soils showed any differences, 100-pound samples of the productive and unproductive soil were sent to the Bureau of Soils for examination. The report of Dr. Schreiner, who kindly had the examination made, is as follows:

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[1] These are the average yields obtained from records of the plantations and not from plats. Small plats give comparative but not absolute yields.

The work has been completed on the soil samples Nos. 1 and 2 which you sent to us for examination as to organic constituents, with the view that possibly some of the difficulties which you have noted in regard to the soils might be explained thereby. You will recall that sample No. 1 was from Hacienda San Francisco, Hormigueros, P. R., and that sample No. 2 was from Central Pagan, Anasco. The investigations have been made by Dr. E. C. Shorey and Mr. Lathrop.

From soil No. 1 no crystalline material whatever could be obtained from the ether extract at the place where we usually find dihydroxystearic acid. We must therefore conclude that some of the constituents which we have found in this extract in other cases, such as dihydroxystearic acid and trithiobenzaldehyde, as well as a number of other acids, are absent from this soil. The test for creatinin, which you remember is a nitrogenous soil constituent described in Bulletin 83,[1] was likewise found to be absent from this soil, as were also the purin bases such as xanthin or hypoxanthin. If any of these compounds are present in the soil they are in very minute quantities only, as no reactions whatever could be obtained therefor. The same is true of any of the pyrimidin bases such as cytosin. Histidin, one of the protein decomposition products, was present in this soil but the other closely associated products, arginin, lysin, and cholin, could not be found. At this point in our investigations the sample which you sent was exhausted and no further work could be done. You will see, therefore, that most of the compounds tested for in this sample were found to be absent, and in this respect the soil might be considered rather unusual from the point of view of the soils on the continent with which we have been working.

The soil No. 2 gave in the ether extract at the place where dihydroxystearic acid is usually found the compound trithiobenzaldehyde in good quantity. This was very definitely identified by its melting point. This is a sulphur compound which we have found in several soils and is more fully described in Bulletin 88.[2] Associated with it there was an aldehydelike compound and the indications were very strong that this aldehyde is salicylic aldehyde. The salicylic aldehyde which we have found in other soils is also described in Bulletin 88.[3] * * * I should here say that this aldehyde is toxic toward plants; even more so than dihydroxystearic acid. Mr. Skinner made a test of this aldehyde from your soil on wheat seedlings and found it to be toxic. Whether this material is also in soil No. 1, I can not say, as No. 1 was already exhausted when we found this compound in No. 2, so that we could not verify this point by making plant tests or chemical tests at the proper place. No pyrimidin bases could be found. Histidin, on the other hand, was present, but no arginin, lysin, or cholin. The purin bases were found in this soil sample and a strong xanthin reaction was obtained, indicating the presence of xanthin or guanin. No creatinin was found in this soil.

The chief points of interest between the two soils are the almost total absence of nitrogenous compounds in soil No. 1 while such compounds were found in No. 2, and the presence of trithiobenzaldehyde in soil No. 2, as well as the presence of what is probably salicylic aldehyde. Of course we can not draw the conclusion that the different properties of the two soils in the field is explained by these chemical differences, but it is indicated very strongly that the nature of the organic matter in the two soils is different, having arisen probably as the result of different biochemical activities. I am of the opinion that our investigations thus far do not disclose in what the real differences in the behavior of these two soils lie, as this would require further study.

From elimination of other causes rather than direct data it appears probable that the low productivity of the "sick" soil is due to the biological condition of the soil; either to an accumulation of organisms causing cane diseases or to some disturbance in the normal bacterial

[1] Schreiner et al., U. S. Dept. Agr., Bur. Soils Bul. 83.
[2] Shorey, U. S. Dept. Agr., Bur. Soils Bul. 88, p. 25.
[3] Shorey, U. S. Dept. Agr., Bur. Soils Bul. 88, p. 20.

life of the soil. The biological condition of the soil might affect the plant through the formation of organic compounds by the bacteria and fungi or through other means. There is some evidence of a different biological condition in the "sick" and normal soil in the report of Dr. Schreiner.

So long as this soil has to be planted continually to sugar cane it appears as though increased yield could only come by planting new varieties of cane which have been found to give heavier tonnage or more sucrose than the old Rayada or Cristalina varieties. Rotation with another crop would probably improve this soil as much as resting, but the nature of the soil and the climatic conditions are such that it is better suited for sugar cane than almost any other crop. Moreover, the principal commercial crops, as tobacco, pineapples, coffee, and citrus fruit, are either not adapted for rotation or not suited for this soil. The flooding caused by heavy rains, which sometimes occurs on this soil, renders it unsuited for many crops.

GENERAL REQUIREMENTS OF THE PORTO RICAN RED CLAY.

Certain general requirements of the Porto Rican red clay are apparent from the experiments and observations that have been made thus far. On account of its heavy nature and the flooding it is sometimes exposed to, the maintenance of good mechanical condition and provision for good drainage are of first importance. The reasons for this have already been pointed out in the first part of this report. To maintain this good mechanical condition much more cultivation is required on this type of soil than on more sandy soils.

Next in importance to cultivation and drainage are the needs for more humus and lime. It has been pointed out that this type of soil is uniformly acid and that much of it is low in organic matter. Addition of lime and organic matter is necessary for improving the bacterial and chemical condition of this soil as well as the mechanical condition. If well supplied with lime and humus, other factors being favorable, bacterial activity will be increased and certain plant foods be rendered more assimilable.

The importance of sufficient lime and humus in this soil, or any soil, can best be appreciated by a newer view of soil fertility—that soil fertility is not dependent so much on an absolute amount of inert material as on a certain rate of decomposition, which is largely governed by living and dynamic factors; that is, soil fertility is not so much the result of a quantity as of a rate.[1] The faster the rate, for instance, at which plant food is rendered available, the greater will be the fertility of a soil, other things being equal. The rate of soil decom-

[1] Of course quantity will in many cases influence rate.

position can be increased by "speeding up" the bacteria through liming and incorporation of organic matter.

The organic matter can be increased by plowing under the cane trash instead of burning it, by green manuring, i. e., growing leguminous cover crops and plowing them under, or by the direct application of organic materials, as stable manure, filter-press residue, coffee hulls, and tobacco stems. Canavali, or sword bean, has been found to be one of the best legumes for green manuring on this soil.[1] Burning the cane trash and so dissipating valuable organic matter and nitrogen into the air is particularly disadvantageous on this soil, which is in need of both substances. But where cane is badly infested with insects burning the trash may be advisable.

The fertilizer experiments carried on thus far show that fair increases on the normal soil can be secured by fertilization. For sugar cane on this soil nitrogen is the most essential element and probably gives as large increases as a complete fertilizer. Of course the fertilizer results secured with sugar cane as a test crop do not apply to conditions where other crops are grown. Tobacco, for instance, might need potash on this soil as much as nitrogen. Experiments to determine the best form in which to apply the nitrogen for sugar cane on this soil are in progress. From the chemical composition of this soil, i. e., the high content of iron and aluminum and the acid reaction, it is probable that when phosphoric acid is needed basic slag would be a good form in which to apply it. Basic slag has been found to give good results on heavy clays and its phosphoric acid is supposed not to be fixed by the iron and aluminum in the soil so quickly as that of more soluble phosphates. But if a quickly available form of phosphoric acid is desired for a short-time crop, basic slag would hardly give as good results as acid phosphate.

SUMMARY.

The Porto Rican red clay soil, one of the most extensive soil types on the island, is planted chiefly to coffee and sugar cane.

It is a fairly heavy clay, often underlain by an impervious subsoil and so requires good cultivation and drainage to be productive.

This type of soil is characterized chemically by a high percentage of iron and aluminum, moderate amounts of nitrogen, phosphoric acid, and potash, and no carbonates. It is almost uniformly acid and frequently low in organic matter.

The experiments thus far carried on with sugar cane on this soil show that the normal soil is benefited by liming and fertilizers. Nitrogen is the most essential element and probably increases the yield as much as a complete fertilizer.

[1] Porto Rico Sta. Rpt. 1911, p. 25.

Certain areas of this soil that have long been in continuous cane cultivation are in a "sick" or "tired" condition, not responding to fertilizers, lime, stable manure, nor superficial disinfection.

In what the "sickness" consists has not been determined, but it may be in the biological condition of the soil.

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