STUDIES IN THE DRYING OF SOILS

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(Contribution from the Department of Soil Technology, Cornell University.)

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Introduction.

The drying of the soil by exposure to intense sunlight for some time has been made use of in certain arid regions of India to increase its productiveness. Since the drying of the soil in an arid region has a stimulating effect on crop growth, it is to be expected that the lowering of the moisture content in soils of the more humid regions, during seasonable changes, will influence their productiveness. The drying of the soil is a process that depends entirely on the climatic conditions, the degree and duration depending on the amount and distribution of the rainfall in the region concerned. In a study of the increased productiveness due to drying it will be necessary to consider the changes in the physical, chemical, and biological conditions of the soil.

The change in the physical condition of the soil due to drying may be easily observed in the field. A better tilth is obtained as shown by an increased granulation. This increased granulation is to a great extent due to the flocculation of the colloidal material.

The changes in the chemical composition due to drying have been studied by many investigators in relation to the amount of plant food recoverable when a sample has been previously dried, under various conditions and temperatures. Great differences in the amount of plant food recovered have been observed when a sample has been previously dried, which would show that the drying of the soil in the field may greatly influence the chemical composition. In the last decade much attention has been given to the biological changes which are taking place in the soil. In this connection drying has been considered as a partial sterilization, as the results have been similar to those obtained from a partial sterilization with steam or antiseptics.

The great importance of the biological factors cannot be ignored in the study of the drying of the soil, but at the present status of soil investigation they must be studied in connection with the biochemical changes produced.

It is the purpose of the investigation to study the effect of drying a soil on crop yield and its correlation with certain chemical and physiological changes taking place in the soil.

Review of Literature.

The successive drying and wetting of a soil greatly affects its physical condition. These processes cause an increased granulation, reducing the size of the granules and forming lines of weakness and cracks. In many ways this process is observed in the field but little data have been obtained experimentally showing the effect of successive drying and wetting upon the physical condition.

Wollny (1897)[2] studied the effect of drying and wetting a soil on the volume change. The results show that a decrease in volume is obtained by drying and wetting.

Cameron and Gallagher (1908) have shown that by repeated drying and wetting of a soil a point is reached where the volume on contraction due to drying is equal to the expansion on wetting. This condition they call a "natural packing" of the soil.

Fippin (1910) measured the effect of a repeated wetting and drying on clay soil by the force necessary to cause penetration. This force is reduced one half by five dryings and to one third by twenty dryings, granulation being increased 60 percent.

The effect of drying a soil has long been a problem to the soil chemist. Warington (1882) recognized the importance of drying a soil on the nitrate content. He found a reduction of nitrates in an oven-dried sample, a greater reduction when slowly oven-dried and an increase when air dried. He advises drying a sample in a room, at 55°–60° F., for twenty-four hours as he found very little nitrification taking place at this temperature.

Richter (1896) dried a garden soil in an oven at 100° C., and found an increase in the absorptive power for water and an increase in the nitrogen and soluble organic matter.

The investigations of King (1905) on the amounts of plant food recoverable from field soils gives us the most valuable data on this subject. King compared the amounts of plant food recovered from fresh soil, soil air-dried, and soil dried in an oven at 110° C. He found more nitrates, phosphates, sulfates, bicarbonates, and silica, but less chlorides, recoverable from an oven-dried than from the fresh sample. The increase was greater than by washing the fresh sample with five times its weight in water. He considers that the increase may be partly due to the releasing of the salts locked up in the organic matter. Another cause may be what he calls the "fixing" power of soil grains, causing a concentration near the surface of the soil particles which when dried are covered with the residues of evaporation and allow a greater solution than in the fresh soil. He also considers that the granular condition of the soil would allow a large amount of water to be carried within the granules, the subsequent drying bringing the salts to the surface and making them more accessible to solution.

Leather (1912) found an increase in the nitrates in soils that had been dried in the sun at Pusa, India, the increase being four times as great as in the fresh sample.

Kelley and McGeorge (1913) studied the effect of drying on the

[2] Dates in parentheses refer to bibliography at end of paper.

mineral constituents of Hawaiian soils. On the average, drying the soils at 100° C. increased the water-soluble carbonates, phosphates, manganese, calcium, magnesium, potassium, aluminum, sulphates, and silica over the air-dried soil. They consider that the causes involve many factors, both chemical and physical, as flocculation, dehydration, oxidation, and the altering of the film pressure.

Investigations have shown that drying a soil has an effect on its biological condition. These changes must be studied in relation to the chemical changes produced and may be considered biochemical. Early bacteriologists considered that the soil was merely sterilized when heated. In recent investigations soils heated to temperatures lower than 100° C. have been considered as partially sterilized. The drying of a soil may therefore be considered as a partial sterilization.

Russell and Smith (1905) find that nitrifying organisms can be easily killed by an insufficient amount of moisture or by drying at 100° C.

Rahn (1907) has made the most extensive investigations on the effect of drying soils on their physiological condition. From studies on carbon dioxid and acid production in sugar solutions and ammonia production in peptone solutions he finds a greater bacteriological activity in a soil previously dried at room temperature than in the same soil kept moist. Greater differences were found in a rich garden soil than in a sandy soil. The number of bacteria were decreased, and this he considers difficult to explain if the effect is on the bacterial activity. He believes that the effect can not be physical as an extract of the soil or a water suspension shows the same order of differences; nor can it be the decomposition of the soil constituents because when phosphates and asparagin were added the same differences resulted. Mustard grew better on a soil previously dried.

Pickering (1908) found that the heating of soils inhibited the germination of certain seeds, and that the alteration of the soil began at temperatures as low as 30° C. No appreciable destruction of the detrimental substance occurred when the soil was kept for several months in a moderately dry condition.

Further experiments by Pickering (1908) show an increase in the soluble organic material in soils heated to 30°, 60°, and 80° C. and then exposed to the air for two months at summer temperatures and watered occasionally. At higher temperatures a decrease was obtained.

Russell and Hutchinson (1909) (1913) have studied the effect of partial sterilization by heating with steam. They find an increased availability in plant food and an increased plant growth. This they believe is related to a change in the bacterial flora, the larger phagocytic organisms being killed and the beneficial bacteria being allowed to increase.

Howard (1910) recognizes this effect in the soils which are exposed to the intense sunlight of India. The fertility is increased, and he believes that this may be due to an inhibiting effect of partial sterilization on the protozoa, as reported by Russell and Hutchinson on the studies of soils heated in the laboratory.

Russell (1910) recognizes the observation made by Howard and believes that the soils exposed to sunlight may be dried and heated sufficiently to remove the factor which limits the productiveness of the soil. This is shown in further investigations by Russell and Hutchinson (1913). They exposed the soil to a temperature of 35–38° C. for varying intervals. Upon remoistening the samples, it was found that the factor which is detrimental to the fertility is temporarily inhibited by ten days' drying. Soil exposed to sunlight for ten days behaves in the same manner. The detrimental organisms are killed at 55–60° C. and suffer considerably at lower temperatures (40° C.). They conclude that drying a soil has the same effect as heating at low temperatures; that is, it only temporarily eliminates the detrimental factor.

Greig-Smith (1911) has shown that bacteriotoxins are destroyed at 94° C. He holds that upon remoistening the soil the more resistant bacteria multiply and become more numerous because of the absence of bacteriotoxins. Sunlight and air-drying the soil destroy the toxins.

Ritter (1912) made studies similar to those of Rahn and found that bacterial activity increased on drying a soil. A dried soil gave quicker and more intensive action. "Heavy" soil showed a greater difference than a "light" soil. A repeated drying and wetting caused a decrease in the activity. He concludes that the physical condition of a soil goes hand in hand with the physiological condition.

Fischer (1913) discusses the work of Rahn and Ritter and comments on their conclusions. He believes that more depends on the chemical composition than on the bacterial activity. Oxidation must be the principal factor, as the nitrates are increased on drying, yet the nitrifying organisms are killed. He thinks that colloids and surface tension must play an important part as a factor in this induced oxidation.

Sharp (1913) studied the effect of drying by investigating soils that had been dried and kept in tightly stoppered bottles for thirty years. These soils still contained an average of 358,000 organisms per gram. Ammonifying organisms were present, but nitrification occurred only feebly in two of the nine soils examined. The nitrogen-fixing power was maintained but the Azotobacter forms were absent in all except one soil. He concludes that there is no relation between numbers and physiological efficiency.

Russell and Petherbridge (1913) found that plants grown on soils heated to 55° C. show an acceleration in early growth succeeded by a steady growth. An increase in plant food in the soil and an increase in nitrogen, potassium, and phosphorus was found.

Lyon and Bizzell (1913) found that the drying of the soil during seasonal moisture changes has both increased and decreased the nitrates, depending upon the kind of crop grown. In an unplanted plot an increase in soil moisture after a dry period has in most cases increased the nitrates in the soil.

Experiment I. The Effect of a Previous Drying of the Soil to Different Moisture Contents on Plant Food in the Soil and Plant Growth.

The object of the investigation is to study the effect of drying the soil on its chemical and biological condition and on plant growth. Previous investigations on the drying of the soil show that changes occur in the soil that greatly affect its fertility. That the effect is neither physical, chemical, nor biological, but a combination of the three, has been generally accepted.

In the field the soil is continually being subjected to an intermittent wetting and drying. The length of drying and the moisture content depend upon the amount and variation of the rainfall in the region concerned.

In a humid region the period of drying is short and the moisture content to which the soil is dried is usually not very low. In an arid region the soil is sometimes air dry or nearly so and remains dry for some length of time.

With this in view the plan of the experiment was to [illegible] controlled conditions [illegible] drying [illegible] moisture content on plant food in the soil and on plant growth.

THE SOIL.

[illegible]

decompose. Some of the organic matter had not entirely decomposed. This caused some difficulty in preparing the soil for the pots, as the undecomposed organic matter would tend to mass together.

Method of Experimentation.

The two soils were brought in from the field December 9, 1911, thoroughly mixed and put in 3-gallon pots. Each pot contained 11 kilograms of wet soil. A moisture determination was made at this time and the pots were brought to complete saturation (40 per cent). All pots were removed to the field-house January 11, 1912. On February 28, 1912, the pots were brought in from the field-house. While the pots were in the field-house the soil was frozen and a number of them were broken. The remaining pots were then allowed to dry in the greenhouse until they reached their permanent moisture content, as shown in Table 1.

TABLE 1. *The Moisture Content of Pots Used in the Experiment.*

Soil No. 1				Soil No. 2			
Series 1 Unplanted.		Series 2 Planted at 25 Percent.		Series 1, Unplanted.		Series [illegible] Planted [illegible] Percent.	
Pot No.	Moisture Content.	Pot No.	Moisture Content.	Pot No.	Moisture Content.	Pot No.	Moisture Content.
	Percent.		*Percent.*		*Percent.*		*Percent.*
421	15	401	15	447	15	431	15
422	15	403	[illegible]	448	15	432	15
424	20	408	[illegible]	449	15	433	15
425	20	411	20	450	20	434	[illegible]
426	25	412	[illegible]	451	20	435	[illegible]
427	25	430	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
428	30	[illegible]	25	[illegible]	25	[illegible]	[illegible]
429	30	416	25	[illegible]	[illegible]	[illegible]	[illegible]
		417	25	[illegible]	[illegible]	[illegible]	[illegible]
		418	30	[illegible]	30	[illegible]	[illegible]
		419	[illegible]	[illegible]	30	[illegible]	[illegible]
		420	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	30	[illegible]	[illegible]
				[illegible]	40	[illegible]	[illegible]
						[illegible]	[illegible]

The pots of the highest water content were at saturation. In soil No. 1 the highest water content was at 35 percent, but after a few months the water stood on the surface of the soil and it became necessary to drop this water content to 30 percent. Just the opposite condition was found in soil No. 2, and the highest water content of 35 percent was raised to 40 percent. The moisture content as shown in Table 1 gives this corrected percentage for the pots kept at saturation.

The pots were kept at the different moisture contents as shown in

Table 1 until December 19, 1912. They were then divided in two series. One series was prepared for planting by bringing all pots to 25 percent moisture content, while the second series was kept bare at the different moisture contents. The division of the pots in two series is shown in Table 1.

On January 14, 1913, all pots of series 1 were planted to Galgalos wheat. Forty seeds were planted in each pot. A good germination was secured and the seedlings were thinned to 12 plants.

Effect of Previous Moisture Content on Plant Growth.

At an early stage soil No. 1 allowed a better growth. On April 29, 1913, the pots that had been previously held at a high moisture content showed a poorer growth than those held at a low moisture content. At the time of heading the plants in pots 440, 441, and 442 were much smaller than others of the same series. On June 4, the plants in pots 437, 438, and 439 were making the best growth.

On May 22, it could be seen that the drying out of a soil to a low moisture content previous to planting was having a beneficial effect on plant growth. In soil No. 2 the pots which had been held at 30 percent moisture content previous to planting showed a poorer growth than the ones previously held at 40 percent.

A more luxuriant growth was obtained on soil 2, the great difference evidently being due to the greater amount of organic matter in soil No. 2 or to some factor depending upon the organic content.

On June 17, the plants were fully headed but were not entirely ripe. It was necessary to harvest on this date, however, owing to attacks made upon the plants by rodents in the greenhouse. The plants on soil No. 1 were somewhat nearer maturity than those on Soil No. 2. The plants from all pots were hung in the greenhouse and allowed to ripen completely.

Millet was immediately planted, but a very poor growth of the seedlings was obtained. It was therefore replaced by buckwheat.

The pots containing soil No. 1 had become so compact that it was necessary to lower the water content from 25 percent to 22 percent. During the growth of the buckwheat little difference could be observed. It was evident that the pots had reached a point where the previous moisture content had little effect, or that buckwheat was not appreciably affected by changes in the moisture content.

Effect of Previous Moisture Content on the Morphology of Wheat.

A study of the effect of drying a soil to different moisture contents on the morphology of wheat is shown in Table 2. The results with soil No. 1 do not show a great difference in the first three water contents (15, 20, and 25 percent). A great decrease will be noted in pots 418, 419, and 420 in the number of culms per pot, but only a slight difference in the other characters. These pots were held at saturation before planting and a poor physical condition of the soil was noticeable.

TABLE 2.—*Effect of Previous Moisture Content on the Morphological Characters of Wheat.*

Pot No.	Previous Moisture Content.	Culms per pot (12 Plants).	Length of Culm.	Length of Head.	Grains per Head.	Empty Spikelets.	Spikelets with one Grain.	Spikelets with two Grains.	Spikelets (Total.)	Nodes per Culm.
				Soil No. 1						
	P. ct.		*Inches*	*Inches*						
401	15	25	34.7	3.08	16.8	2.8	7.2	4.8	—	4.0
403	15	25	34.7	3.00	13.4	3.4	7.0	4.0	—	3.7
408	15	25	37.3	3.30	16.5	2.7	6.0	5.2	—	3.3
Ave.	15	25	35.6	3.12	16.0	3.0	6.7	4.7	14.4	3.7
411	20	26	33.5	3.20	15.4	2.3	7.1	4.2	—	3.9
412	20	20	42.5	3.20	17.0	2.4	6.5	5.1	—	4.0
430	20	26	36.0	3.20	16.3	3.1	7.0	4.8	—	3.9
Ave.	20	24	37.5	3.20	16.0	2.6	6.8	4.7	14.1	3.9
415	25	25	34.8	2.80	14.7	2.5	7.0	4.1	—	4.0
416	25	22	35.3	3.00	13.8	3.0	7.1	3.3	—	3.6
417	25	19	34.0	2.80	13.0	3.0	7.0	3.2	—	3.6
Ave.	25	22	34.7	2.95	14.0	2.8	7.0	3.5	13.3	3.7
418	30	12	31.3	2.40	10.5	3.3	6.3	2.0	—	4.0
419	30	13	34.5	2.50	12.0	2.9	6.1	3.0	—	3.7
420	30	13	31.6	2.45	10.3	1.6	6.3	2.2	—	3.5
Ave.	30	13	35.8	2.45	11.0	2.5	6.2	2.4	11.1	3.7
				Soil No. 2						
431	15	36	30.5	3.36	19.0	2.6	5.4	6.4	—	3.4
432	15	34	30.3	3.50	18.3	2.4	6.0	6.3	—	3.5
433	15	44	34.4	3.40	17.0	2.5	5.3	5.8	—	3.5
Ave.	15	38	31.7	3.40	18.1	2.5	5.6	6.2	14.3	3.5
434	20	30	28.5	3.20	14.1	2.2	5.2	6.0	—	3.7
435	20	34	29.6	3.20	16.8	2.2	5.5	5.5	—	3.5
436	20	34	30.0	3.60	16.9	2.0	5.0	7.3[1]	—	3.5
Ave.	20	33	29.4	3.30	15.9	2.1	5.2	6.3	13.6	3.6
437	25	33	32.4	3.60	18.6	2.0	5.2	6.6	—	3.7
438	25	35	30.6	3.40	18.5	2.0	6.0	6.3	—	3.6
439	25	27	34.3	3.40	16.6	1.7	5.2	6.5	—	3.9
Ave.	25	32	32.4	3.50	17.9	1.9	5.5	6.5	13.9	3.7
440	30	17	34.2	3.40	17.7	2.1	4.0	6.7[2]	—	3.6
441	30	17	23.2	2.50	13.0	2.3	4.4	4.4	—	3.2
442	30	13	22.7	2.30	9.0	3.5	5.0	2.0	—	3.0
Ave.	30	16	26.7	2.70	13.2	2.6	4.5	4.4	11.5	3.3
443	40	34	27.7	3.00	14.5	2.4	6.5	4.0	—	3.3
444	40	41	30.0	3.10	18.4	2.7	6.2	6.0	—	3.7
445	40	41	30.3	3.40	16.8	3.2	6.2	5.2	—	3.5
Ave.	40	38	29.3	3.20	16.8	2.8	6.3	5.1	14.2	3.5

[1] Also 5 three-grained spikelets.

[2] Also 7 three-grained spikelets.

In soil No. 2, greater differences in the morphological characters due to the effect of the previous moisture content could be noted. Here, as in the plant growth, the soil that had been held at 30 percent moisture content shows the poorest results. There is a similarity between the pots which had been held at 15 percent and those at 40 percent, the average number of culms per pot being as great in the 40 percent as in the 15 percent pots.

Comparing the two soils, we find a greater number of culms per pot in soil No. 2, but the length of culms is somewhat less in this soil. The greater number of spikelets with one grain were found on the plants in soil No. 1, and the greater number with two grains were found on the plants in soil No. 2. It will be seen that in soil No. 1 there was a decrease in the number of grains per head as the moisture content was increased, while in soil No. 2 there was little difference as affected by the different moisture contents.

Effect of Previous Moisture Content on Crop Yield.

A large number of investigators have studied the effect of different moisture contents on crop yield. They do not, however, consider the possible influence of the moisture condition of the soil before planting.

In this investigation the soil was kept at the different moisture contents for ten months before planting. At the time of planting all pots were brought to an optimum water content and the weights recorded. During plant growth the pots were kept at this content by adding distilled water every day and bringing the pots to standard weight. Under this plan any differences in the amount of dry matter produced by the crop would be due to the effect of the previous moisture content and not to differences during the growth of the plants.

As the two soils differ only in organic content, a comparison of the results shows also the influence of organic matter on the factors affecting the previous drying out of a soil to various moisture contents. The effect of the previous condition of soil moisture on the productiveness [illegible] is shown in Table 3.

In soil No. 1, the greatest weight of dry matter in the first crop, [illegible], is found in the soil that had been previously [illegible] 15 percent [illegible] at 20 percent and [illegible] at 30 percent. The soil that was [illegible] percent [illegible] at the time of planting [illegible] was found in soil No. 2, except that [illegible] there is a decided increase over the 30 percent. [illegible] soil that was held at 30 percent was [illegible] percent at the time of drying.

In soil No. 2, a moisture content of 40 percent must be compared to the content of 30 percent in soil No. 1, as in both cases we have complete saturation for each soil. In the clay loam pots which had been previously held at saturation the yield of dry matter is smallest, but in the organic clay loam pots which had been held at saturation the yield is as large as those with the lowest moisture content. If we consider that the lowering of the moisture content in the pots at 40 percent moisture content is an effective drying out previous to planting, there is decided increase due to drying just before planting.

TABLE 3.—*Effect of Previous Moisture Content on Weight of Dry Matter of Wheat and Buckwheat Produced.*

Soil No. 1					Soil No. 2				
Pot No.	Previous Moisture Content.	Wheat. Grain.	Wheat. Straw.	Buckwheat.	Pot No.	Previous Moisture Content.	Wheat. Grain.	Wheat. Straw.	Buckwheat.
	P. ct.	*Grams*	*Grams*	*Grams*		*P. ct.*	*Grams*	*Grams*	*Grams*
401	15	18.2	30.3	5.0	431	15	20.5	[illegible]	[illegible]
403	15	17.4	28.7	4.5	432	15	17.0	[illegible]	[illegible]
408	15	19.1	31.8	4.7	433	15	23.2	[illegible]	[illegible]
Ave.	15	18.2	30.3	4.7	Ave.	15	20.2	[illegible]	[illegible]
411	20	18.5	29.5	4.5	434	20	15.8	[illegible]	[illegible]
412	20	15.8	26.6	4.9	435	20	16.3	[illegible]	[illegible]
430	20	20.0	33.2	4.0	436	20	21.7	[illegible]	[illegible]
Ave.	20	18.1	29.8	4.5	Ave.	20	17.8	[illegible]	[illegible]
415	25	16.6	[illegible]	[illegible]	437	25	[illegible]	[illegible]	[illegible]
416	25	13.9	25.1	[illegible]	438	25	[illegible]	[illegible]	[illegible]
417	25	11.4	[illegible]	5.5	439	25	14.1	[illegible]	[illegible]
Ave.	25	14.0	[illegible]	[illegible]	Ave.	25	[illegible]	[illegible]	[illegible]
418	30	4.0	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]
419	30	5.2	[illegible]	[illegible]	441	30	[illegible]	[illegible]	[illegible]
420	30	6.3	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]	[illegible]
Ave.	30	5.5	[illegible]	[illegible]	Ave.	30	[illegible]	[illegible]	[illegible]
					443	40	[illegible]	[illegible]	[illegible]
					444	40	[illegible]	[illegible]	[illegible]
					445	40	[illegible]	[illegible]	[illegible]
					Ave.	40	[illegible]	[illegible]	[illegible]

This, however, is not the case in the 40 percent moisture content pots which have also been lowered to 25 percent before planting.

The effect of drying to lower moisture contents previous to planting has been to increase the crop yield, as is conclusively shown in soil No. 1 and also in soil No. 2, if the lowering of the 40 percent moisture content before planting be so considered.

With the second crop, buckwheat there has been little effect. There is, however, a greater increase in the yield of soil No. 2 over soil No. 1 than in the first crop.

Effect of Previous Moisture Content on the Total Nitrogen in the Crop.

The results obtained in the determination of the total nitrogen in the dry matter of the grain and straw are shown in Table 4. It has been repeatedly shown that plants grown under different moisture conditions show a variation in the amount of plant constituents found in the dry matter. A greater crop growth usually causes a smaller percentage of nitrogen in the plant. On the other hand, if the available nitrogen in the soil is increased by an increase in the moisture content, an increase may be found in the percentage of nitrogen in the crop. The chemical constitution of the soil must be a factor, more especially in the soluble organic matter.

TABLE 4.—*Effect of Previous Moisture Content on Total Nitrogen in the Crop.*

Soil No. 1.									Soil No. 2.								
		Total Nitrogen.									Total Nitrogen.						
		Wheat.				Buckwheat.					Wheat.				Buckwheat.		
Pot No.	Previous Moisture Content.	Grain.	Ratio.	Straw.	Ratio.	Total.	Ratio.		Pot No.	Previous Moisture Content.	Grain.	Ratio.	Straw.	Ratio.	Total.	Ratio.	
	Per-cent.	*Per-cent.*		*Per-cent.*		*Per-cent.*				*Per-cent.*	*Per-cent.*		*Per-cent.*		*Per-cent.*		
[illegible]	15	1.49	—	.27	—	1.63	—		431	15	3.26	—	1.02	—	2.07	—	
403	15	1.68	—	.26	—	1.62	—		432	15	3.30	—	1.13	—	2.25	—	
408	15	1.60	—	.25	—	—	—		433	15	3.26	—	1.18	—	1.84	—	
Ave.	15	1.59	100	.26	100	1.63	100		Ave.	15	3.27	100	1.11	100	2.05	100	
411	20	1.73	—	.26	—	1.74	—		434	20	3.24	—	1.17	—	2.30	—	
412	20	1.60	—	.26	—	1.82	—		435	20	3.25	—	1.16	—	2.10	—	
430	20	1.48	—	.29	—	1.81	—		436	20	3.26	—	.95	—	2.04	—	
Ave.	20	1.60	100	.27	103	1.79	109		Ave.	20	3.25	99	1.09	98	2.15	104	
415	25	1.63	—	.26	—	—	—		437	25	3.32	—	1.15	—	2.09	—	
416	25	1.67	—	.25	—	1.45	—		438	25	3.27	—	1.18	—	2.15	—	
417	25	1.72	—	.27	—	1.62	—		439	25	3.43	—	1.12	—	2.18	—	
Ave.	25	1.67	104	.26	100	1.53	94		Ave.	25	3.34	102	1.15	103	2.14	104	
418	30	1.88	—	.30	—	1.66	—		440	30	3.06	—	1.60	—	2.35	—	
419	30	1.71	—	.39	—	—	—		441	30	2.88	—	1.60	—	2.40	—	
420	30	1.53	—	.28	—	1.71	—		442	30	3.26	—	1.60	—	2.42	—	
Ave.	30	1.71	107	.32	107	1.68	103		Ave.	30	3.07	93	1.60	145	2.39	116	
									443	40	3.36	—	1.25	—	2.22	—	
									444	40	3.31	—	.88	—	1.56	—	
									445	40	3.34	—	.92	—	1.49	—	
									Ave.	40	3.34	102	1.01	91	1.46	71	

The results presented in Table 4 show that there has been no effect on the nitrogen of the crop resulting from a difference of the previous moisture content. A comparison of the two soils shows on the average twice as much nitrogen in the plants grown in the soil high in organic matter as in the same soil low in organic content. As these soils differ only in organic content and the results show practically no difference due to water content, the difference in the percentage of nitrogen in the dry matter must be caused through some factor due to the organic matter.

Effect of Previous Moisture Content on Water Soluble Matter.

It has been shown by a number of investigators that the complete drying of the soil causes an increase in the soluble salts recoverable from a water extract. However, in this investigation the soil has in no case been dried to an air-dry condition.

The results presented in Table 3 show that a lowering of the moisture content previous to planting has caused an increase in the plant growth. In order to determine whether this increase was related to an increased amount of plant food, determinations were made on the total solids, nitrates, potassium, and calcium in the water extract and phosphorus in a fifth-normal acid extract.

It might be expected that the greater plant growth in the soil high in organic matter would result from the large amount of plant food carried in the organic material. Water extracts were made from soils from all the pots immediately after the second crop was harvested, by adding 500 c.c. of distilled water to 100 grams of the soil and filtering through a Pasteur-Chamberlain water filter.

Total Solids.—Table 5 shows the results obtained in the determination of the total solids from a water extraction of the soil sample. It will be seen from this table that low water content reduces the total solids in the unplanted clay loam, while in the planted series of this soil there is little difference in the results. The results with the soil high in organic matter show an increase in the total solids in both the planted and unplanted series with an increased moisture content.

Considering the effect upon the clay loam, it is evident that drying the soil to a lower moisture content has increased the water-soluble matter. The planted series of this soil shows this same increase, although at the time of planting all pots were brought to the same moisture content. The opposite effect in the organic clay loam must be attributed to the greater amount of organic matter. It is evident that the lowering of the moisture content has had no effect on the total solids recovered, as the amounts increase with the increased water content.

TABLE 5.—*Effect of Previous Moisture Content on Soluble Salts in the Soil (Total Solids in Water Extract Expressed in Parts per Million).*

Soil No. 1.								Soil No. 2.							
Series 1, Planted.				Series 2, Unplanted.				Series 1, Planted.				Series 2, Unplanted.			
Pot No.	Previous Moisture Content.	Total Solids.	Ratio.	Pot No.	Previous Moisture Content.	Total Solids.	Ratio.	Pot No.	Previous Moisture Content.	Total Solids.	Ratio.	Pot No.	Previous Moisture Content.	Total Solids.	Ratio.
401	15	[illegible]	—					431	15	517	—	447	15	1226	—
403	15	305	—	421	15	874	—	432	15	704	—	448	15	747	—
408	15	[illegible]	—	422	15	800	—	433	15	438	—	449	15	1510	—
Ave.	15	[illegible]	100	Ave.	15	837	100	Ave.	15	553	100	Ave.	15	1198	100
[illegible]	20	[illegible]						434	20	915	—				
[illegible]	20	[illegible]	—	424	20	890	—	435	20	687	—	451	20	882	
[illegible]	20	[illegible]	—	425	20	690	—	436	20	473	—	452	20	2222	—
Ave.	20	[illegible]	[illegible]	Ave.	20	790	94	Ave.	20	691	124	Ave.	20	1550	131
[illegible]	[illegible]	[illegible]						437	25	700	—	453	25	1613	—
[illegible]	25	341		[illegible]	25	666	—	438	25	870	—	454	25	1584	—
[illegible]	[illegible]		—	[illegible]	25	404		439	25	740	—	455	25	1323	—
Ave.	25	[illegible]	91	Ave.	25	565	67	Ave.	25	792	143	Ave.	25	1507	127
[illegible]	30	[illegible]						440	30	941		456	30	1456	—
[illegible]	30	362		[illegible]	30	[illegible]	—	441	30	960		457	30	1364	
[illegible]	30	[illegible]		[illegible]	30	[illegible]	—	442	30	605		458	30	2352	
Ave.	30	[illegible]	95	Ave.	30	525	62	Ave.	30	835	151	Ave.	30	1724	140
								443	40	741	—	459	40	2450	—
								445	40	938	—	460	40	1467	—
								Ave.	40	863	156	Av.	40	1808	[illegible]

It would seem that the lowering of the water content as affecting the water soluble matter depends entirely upon the types of soil used.

Nitrates. In order to ascertain what effect the lowering of the moisture content may have upon the nitrification in the soil, the nitrates were determined on samples from all the pots after the second crop had been harvested. The samples were brought to the laboratory and the moisture and nitrate determinations were made within sixteen hours after sampling. The nitrates were determined colorimetrically by the phenol disulphonic-acid method. The results are presented in Table 6.

If a comparison of series 1 and 2 of both soils is made it will be seen that a reduction of the nitrates was caused by plant growth. The analyses also show that the nitrates are less in the planted series of soil No. 1 than in the same series of soil No. 2. This may be due to the greater amount of nitrates present in the organic clay loam before planting, there being more than necessary to satisfy the requirements of the plants. From Tables 3 and 4 it will be seen that a greater growth and a greater amount of total nitrogen in the crop were obtained in the organic clay loam. A decrease is found in the nitrates of the planted series due to the previous lowering of the moisture content, this decrease being more decisive in the clay loam. Under the unplanted series of both soils the results would tend to show that there has been little effect on the nitrates due to a lowering of the moisture content. A reduction may be expected in the planted series, as pots at the previous low moisture contents gave much greater growth.

TABLE 6.—*Effect of Previous Moisture Content on Nitrates in the Soil.*

Soil No. 1.								Soil No. 2.							
Series 1 Planted.				Series 2 Unplanted.				Series 1. Planted.				Series 2 Unplanted.			
Pot No.	Previous Moisture Content.	Nitrates.	Ratio.	Pot No.	Previous Moisture Content.	Nitrates.	Ratio.	Pot No.	Previous Moisture Content.	Nitrates.	Ratio.	Pot No.	Previous Moisture Content.	Nitrates.	Ratio.
	P.ct.	*p.p.m.*			*P.ct.*	*p.p.m.*			*P.ct.*	*p.p.m.*			*P.ct.*	*p.p.m.*	
401	15	14.0	—	421	15	421	—	431	15	204	—	447	15	861	—
403	15	22.0	—	422	15	183	—	432	15	140	—	448	15	688	—
408	15	21.3	—					433	15	110	—	449	15	502	—
Ave.	15	19.0	100	Ave.	15	302	100	Ave.	15	151	100	Ave.	15	685	100
411	20	16.8	—	424	20	341	—	434	20	159	—	450	20	1047	—
412	20	26.4	—	425	20	183	—	435	20	222	—	451	20	242	—
430	20	54.9	—					436	20	186	—	452	20	801	—
Ave.	20	32.7	173	Ave.	20	262	87	Ave.	20	182	132	Ave.	20	896	131
415	25	74.4	—	426	25	496	—	437	25	522	—	453	25	697	—
416	25	26.8	—	427	25	130	—	438	25	164	—	454	25	485	—
417	25	37.2	—					439	25	244	—	455	25	454	—
Ave.	25	46.1	242	Ave.	25	313	103	Ave.	25	310	205	Ave.	25	545	80
418	30	78.0	—	428	30	767	—	440	30	405	—	456	30	560	—
419	30	61.5	—	429	30	83	—	441	30	193	—	457	30	752	—
420	30	26.4	—					442	30	339	—	458	30	432	—
Ave.	30	55.3	290	Ave.	30	420	134	Ave.	30	312	205	Ave.	30	581	85
								443	40	372	—	459	40	760	—
								444	40	—	—	460	40	752	—
								445	40	185	—				
								Ave.	40	278	184	Ave.	40	756	110

Why the lowering of the moisture content in the unplanted series had no effect is hard to explain, as an aeration of the soil under the low water content would be expected to increase the nitrates, yet it is evident that the results are influenced by other factors which tend to equalize this effect.

It was thought that a study of the nitrate producing power of the soil might throw some light on the effect of drying soil on the nitrifying organisms of the soil. At the time the nitrates were determined in the soil, another 100-gram sample was taken, placed in a bottle, plugged with cotton, and incubated for seven days at 30° C. Nitrate determinations were then made as shown in Table 7.

A comparison of the nitrates in the soil as shown in Table 6 with the nitrates after incubation as shown in Table 7 will show that in nearly all cases denitrification has taken place. It can be seen from the tables that the variation in the samples from pots under the same treatment are too great to warrant any conclusions on the effect of lowering the moisture content on the power of the nitrifying organisms of the soil.

TABLE 7. *Effect of Previous Moisture Content on Nitrates Produced by Incubation for Seven Days at 30° C.*

Soil No. 1.								Soil No. 2.							
Series 1, Planted.				Series 2. Unplanted.				Series 1, Planted.				Series 2. Unplanted.			
Pot No.	Previous Moisture Content.	Nitrates.	Ratio.	Pot No.	Previous Moisture Content.	Nitrates.	Ratio.	Pot No.	Previous Moisture Content.	Nitrates.	Ratio	Pot No.	Previous Moisture Content.	Nitrates.	Ratio.
	P. ct.	*p. p. m.*			*P. ct.*	*p. p. m.*			*P. ct.*	*p. p. m.*			*P. ct.*	*p. p. m.*	
401	15	39	—	421	15	240	—	431	15	124	—	447	15	433	—
403	15	64	—	422	15	—	—	432	15	144	—	448	15	672	—
408	15	56	—					433	15	88	—	449	15	672	—
Ave.	15	53	100	Ave.	15	240	100	Ave.	15	118	100	Ave.	15	593	100
411	20	59	—	424	20	222	—	434	20	264	—	450	20	1152	—
412	20	48	—	425	20	184	—	435	20	176	—	451	20	370	—
439	20	34	—					436	20	96	—	452	20	704	—
Ave.	20	47	89	Ave.	20	203	84	Ave.	20	178	153	Ave.	20	778	131
415	25	37	—	426	25	200	—	437	25	200	—	453	25	608	—
416	25	34	—	427	25	100	—	438	25	144	—	454	25	576	—
417	25	40	—					439	25	168	—	455	25	336	—
Ave.	25	37	70	Ave.	25	180	75	Ave.	25	171	145	Ave.	25	507	85
418	30	50	—	428	30	21	—	440	30	352	—	456	30	480	—
419	30	34	—	429	30	84	—	441	30	276	—	457	30	572	—
420	30	59	—					442	30	360	—	458	30	448	—
Ave.	30	44	83	Ave.	30	52	20	Ave.	30	329	278	Ave.	30	500	84
								443	40	144	—	459	40	528	—
								444	40	—	—	460	40	526	—
								445	40	152	—				
								Ave.	40	148	125	Ave.	40	527	89

Potassium, Calcium, and Phosphorus.—Determinations were made of the potassium and calcium in the water extracts and of the phos-

TABLE 8.—*Effect of Previous Moisture Content on the Potassium, Calcium and Phosphorus in the Soil.*

Series 1, Planted.				Series 2. Unplanted.					
Pot No.	Previous Moisture Content.	K.	Ca.	Pot. No.	Previous Moisture Content.	K.	Ca.	P_2O_5.	Lime Required (CaO).
SOIL NO. 1									
		p.p.m.	*p.p.m.*			*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
401	15	42.2	9.0	421	15	12.0	18.5	—	
403	15	21.3	12.2	422	15	43.1	21.4	13.7	
408	15	12.6	10.1						
Ave.	15	23.3	10.4	Ave.	15	27.5	20.0	—	
411	20	30.4	7.3	424	20	14.7	21.5	—	
412	20	21.1	13.6	425	20	41.8	25.4	13.1	
430	20	11.7	11.8						
Ave.	20	21.1	10.9	Ave.	20	27.6	23.4	—	None
415	25	21.3	9.7	426	25	16.4	20.3	—	
416	25	11.6	12.1	427	25	20.3	18.8	14.6	
417	25	26.4	8.6						
Ave.	25	19.8	10.1	Ave.	25	18.3	19.6	—	
418	30	24.4	—	428	30	12.7	22.0	—	
419	30	21.4	14.6	429	30	32.3	12.6	15.0	
420	30	22.2	8.4						
Ave.	30	23.7	11.4	Ave.	30	22.5	17.3	—	
SOIL NO. 2									
431	15	28.3	13.1	447	15	74.4	23.2	14.3	1,400
432	15	19.2	17.6	448	15	84.2	27.1	—	—
433	15	62.2	9.9	449	15	60.0	29.6	—	—
Ave.	15	36.6	13.5	Ave.	15	72.6	26.6	—	—
434	20	38.4	19.0	450	20	144.3	32.7	13.4	1,100
435	20	29.6	15.1	451	20	84.4	18.6	—	—
436	20	34.3	14.6	452	20	55.8	32.3	—	—
Ave.	20	34.1	16.2	Ave.	20	91.5	27.9	—	—
437	25	14.6	17.3	453	25	104.0	27.5	18.1	1,275
438	25	29.0	13.4	454	25	41.6	19.8	—	—
439	25	38.1	20.3	455	25	111.3	25.0	—	—
Ave.	25	27.2	17.0	Ave.	25	85.6	24.0	—	—
440	30	45.2	21.0	456	30	112.0	22.8	11.8	1,200
441	30	61.0	17.2	457	30	61.8	25.9	—	—
442	30	41.4	22.8	458	30	—	24.9	—	—
Ave.	30	49.2	20.0	Ave.	30	86.9	24.5	—	—
443	40	22.9	19.4	459	40	96.6	24.8	15.2	1,075
444	40	105.2	13.4	460	40	79.0	27.0	—	—
445	40	9.2	12.3						
Ave.	40	46.4	15.0	Ave.	40	87.8	25.9	—	—

phorus in a fifth-normal nitric acid extraction of the soils. The calcium was determined by the turbidity method and the potassium by the colorimetric method of the Bureau of Soils.[3] The phosphorus

[3] Schreiner, Oswald, and Failyer, George H., Colorimetric, Turbidity and Filtration Methods Used in Soil Investigations, U. S. Dept. Agr., Bur. Soils Bul. No. 31, 1906.

was determined colorimetrically according to the method of Fraps.[4] The results are shown in Table 8.

From a study of Table 8 it may be seen that there has been very little effect due to the different moisture contents. A reduction of the potassium and the calcium was found in the planted series of soil No. 2. The phosphorus was determined in the unplanted series of both soils and no differences were found due to differences of moisture content.

It must be concluded from these data that the reduction of the moisture content has no appreciable effect on the potassium, calcium, and phosphorus in the soil.

Lime Requirement. In order to determine whether the lowering of the moisture content had any effect on soil acidity, lime requirement determinations were made according to the method of Bizzell.[5] These results are presented in Table 8. The clay loam shows no lime requirement, the organic clay loam an average of 1,200 p.p.m. CaO. No differences are shown due to the lowering of the moisture content.

Summary of Experiment 1.

1. The drying of soil previous to planting has a beneficial effect on plant growth.

2. The factor which causes this beneficial condition due to drying is affected by the organic matter in the soil, as is shown from the results of the two soils used, which differ only in organic content.

3. The previous drying of the soil has no effect on the total nitrogen in the dry matter of the crop.

4. The water-soluble matter is increased in the clay loam with a drying out of the soil, while in the same soil with a high organic content the opposite result occurs. The organic content must be the deciding factor.

5. In the planted series of both soils a decrease in the previous moisture content has resulted in a decrease in the nitrates in the soil. In the unplanted series no effect has been found.

6. A denitrification was found in the soil samples when incubated at 30° C. for seven days. The great variation in the test allows no conclusions from the effects of drying the soil.

7. The drying out of the soil has little effect on the available potassium, calcium, or phosphorus in the soil.

[4] Fraps, G. S., Active Phosphoric Acid and Its Relations to the Needs of the Soil for Phosphoric Acid in Pot Experiments, Tex. Agr. Exp. Sta. Bul. No. 126, 1909 (1910).

[5] Bizzell, J. A., and Lyon, T. L., Estimation of the Lime Requirements of Soils, Journ. Indus. Engin. Chem., 5: 1011–1012, 1913.

Experiment 2. The Effect of Drying a Soil on its Physiological Condition as Measured by the Carbon Dioxid Production and Nitrification.

As a study of the effect of drying and wetting a soil on its bacterial activity, the carbon dioxid formation has been determined. A study of the effect on nitrification has also been made by determining the nitrates in the soil and its nitrifying power. It has been shown by previous investigators that the bacterial activity of the soil may be measured by the carbon dioxid production. It can not be said that this determination gives a complete measurement of the bacterial activity, yet sufficient data have been obtained to show that the effect of drying a soil on its bacterial activity may be determined in this way. As a check on the carbon dioxid determination and because of the importance of the nitrifying organisms, the nitrates and the nitrifying power were determined.

When the pots that had been kept in the field-house for two months were returned to the greenhouse, it was found that a number of them had been broken. The clay loam (soil No. 1) from six of these broken pots was transferred to new pots, and the soil brought to an optimum moisture content.

After the pots were held at an optimum moisture content for fourteen months, they were submitted to a treatment as shown in the following plan:

Pot 1. Original soil. Determinations made on wet soil.
Pot 2. The soil taken from the pot and dried in the drying room at 30-35° C. for ten days and determinations made on the dry soil.
Pot 3. Soil dried as above, but it was again brought to an optimum water content (25 per cent.) and held for sixteen days before determinations were made.
Pot 4. Treated as pot 3, but held thirty-five days before determinations were made.
Pot. 5. Treated as pot 4, but again dried and held eleven days at optimum moisture content before making determinations. (Two dryings.)
Pot 6. Treated as pot 5, but again dried and wet again fourteen days before making determinations. (Three dryings.)

Carbon Dioxid Produced on Drying and Wetting a Soil.

The method used to study the amount of carbon dioxid produced in a soil was a modification of Stoklasa.[6] A diagram and description of the apparatus is presented in figure 3.

The soil sample was well mixed and 500 grams (on dry basis) placed in the glass cylinder. The cylinders were kept in an incubator,

[6] Stoklasa, J., in Handbuch der Biochemischen Arbeitsmethoden (Alberhalden), Band 5, Teil 2, p. 869, 1912.

held at a temperature of 30° C. The air free of carbon dioxid was drawn through the soil in the cylinders, the rate of flow being regulated at "*k*" on the aspirator. By making some preliminary experiments the maximum rate of flow necessary was found. The carbon dioxid produced was measured daily for ten days, except in the case of the air-dry soil, which ceased production after the seventh day. All determinations were made in triplicate. The results for each soil are presented in Table 9.

TABLE 9.—*Daily Production of Carbon Dioxid in Parts per Million from a Soil Variously Treated as to Moisture Content.*

Sample No.	Parts per Million of Carbon Dioxid. Day. 1	2	3	4	5	6	7	8	9	10	Total.
Pot 1. Original Soil—Not Dried.											
1	546	206	76	92	120	88	52	64	198	234	1,676
2	542	216	104	104	86	162	—	152	92	140	1,598
3	540	112	116	72	74	122	0	204	72	—	1,318
Average	544	178	99	90	93	124	26	140	120	187	1,601
Pot 2. Soil Dried and Not Wet Again.											
1	108	8	0	68	4	0	0	—	—	—	188
2	84	16	0	46	10	0	32	0	—	—	188
3	54	108	4	40	44	30	30	0	—	—	310
Average	82	44	1	51	19	10	20	0	—	—	229
Pot 3. Soil Dried and Wet again for Sixteen Days.											
1	396	228	174	246	158	224	276	236	164	268	2,370
2	328	316	184	208	58	206	294	52	168	158	1,972
3	648	104	184	232	68	220	252	96	168	188	2,160
Average	457	216	181	228	94	217	274	128	166	205	2,166
Pot 4. Soil Dried and Wet again for Thirty-five Days.											
1.	486	276	216	216	240	240	132	168	24	0	1,998
2	200	220	224	186	224	162	2	62	164	124	1,561
3	128	244	140	156	244	178	0	74	142	30	1,336
Average	271	247	193	186	236	193	45	101	110	53	1,635
Pot 5. Soil Dried Twice and Wet again for Eleven Days.											
1	260	554	202	168	196	166	142	166	—	—	1,854
2	1112	402	374	164	682	66	196	76	—	—	3,072
Average	686	478	288	166	439	116	169	121	—	—	2,463
Pot 6. Soil Dried Three Times and Wet again for Fourteen Days.											
1	414	296	186	0	400	160	100	152	216	276	2,206
2	600	284	322	262	244	204	162	110	264	190	2,642
Average	507	290	254	134	322	182	131	131	243	233	2,427

By a study of the tables it will be seen that the bacterial activity was greatly increased by a previous drying of the soil. In the soil that was not wet again after drying, the bacterial activity was greatly inhibited, and after seven days the carbon dioxid production had completely stopped.

One drying of the soil greatly increases the activity over the original soil. In the soil held at an optimum moisture content for 35 days after drying the production of carbon dioxid becomes normal again, as shown by a comparison of Pots 1 and 4 (Table 9). A soil dried twice does not show a much greater activity than when dried once, while three dryings show no increase over two dryings. Evidently the factor that causes the increase is not greatly affected after the first drying of the soil.

The Effect of Drying and Wetting a Soil on the Nitrates and Nitrifying Power.

The nitrates were determined colorimetrically in a water extract of the sample by the phenol disulphonic-acid method. Samples from each pot were taken at the time the carbon dioxid determination was made, one part being used for the immediate determination of the nitrates and the other for the determination of the nitrifying power. The nitrifying power was determined by incubating the samples for seven day at 30° C. The results are shown in Table 10.

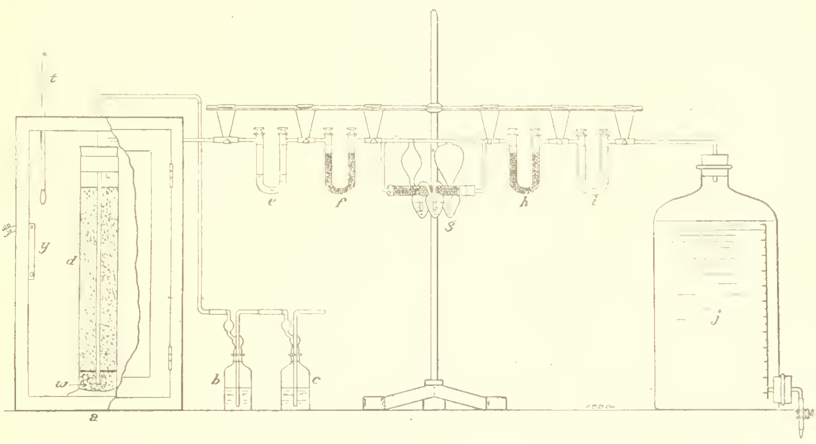

FIG. 3. Apparatus for determination of the carbon dioxid produced in a soil. Description of apparatus: *a*, Incubator; *b*, wash-bottle containing $Ba(OH)_2$; *c*, wash-bottle containing KOH; *d*, glass cylinder containing soil; *e*, U-tube containing H_2SO_4; *f*, U-tube containing $CaCl_2$; *g*, potash bulb; *h*, U-tube containing $CaCl_2$; *i*, U-tube containing H_2SO_4; *j*, aspirator bottle; *k*, stop-cock for regulating flow of air; *t*, thermometer; *w*, glass-wool in bottom of cylinder; *y*, thermostat.

TABLE 10.—*Effect of Drying and Wetting a Soil on the Nitrates and Nitrifying Power.*

Sample No.	Parts per Million of Nitrates in					
	Original Soil at 25 Percent Moisture Content (Pot 1).	Soil Dried Ten Days. Dry Soil (Pot 2).	Soil Dried Ten Days, Then Brought to 25 Percent Moisture Content and Held for Sixteen Days (Pot 3).	Soil Dried Ten Days, Then Brought to 25 Percent Moisture Content and Held Thirty-five Days (Pot 4).	Soil Treated as No. 4, Then Dried Ten Days, Then Wet Eleven Days (Pot 5).	Soil Treated as No. 5, Then Dried the Third Time and Wet Fourteen Days (Pot 6).
Nitrates in the Soil						
1	140	143	117	166	264	328
2	160	133	117	166	256	336
Ave.	150	138	117	166	260	332
Nitrifying Power after Incubation for Seven Days at 30° C.						
Series 1, Soil alone:						
1	208	183	184	136	368	400
2	200	160	[illegible]	136	384	384
Ave.	204	172	172	136	376	392
Series 2, Soil + 2 gr. dried blood:						
1	192	228	[illegible]	272	400	464
2	160	200	216	356	400	432
Ave.	176	214	[illegible]	304	400	448
Series 3, Soil + 0.5 gr. $(NH_4)_2CO_3$:						
1	224	190	[illegible]	288	672	416
2	208	228	224	304	640	416
Ave.	216	209	[illegible]	296	656	416

First considering the effects on the nitrates, we find that the drying of the soil has greatly reduced them, and as has been previously shown also has reduced the carbon dioxid production. The rewetting of the dry soil for a period of sixteen days has further decreased the nitrification. In this sample the opposite is found in the carbon dioxid production. In the soil held moist for thirty-five days after one drying and in those previously dried twice and three times, an increase in nitrification is found. This increase corresponds with the carbon dioxid production in these samples. Why sample 3 has shown a decrease is not altogether clear.

The results from the nitrate determinations as compared with the carbon dioxid production show that the nitrification as effected by the drying of the soil is for the most part biological, but there must be factors other than biological which influence this change. These will be discussed later.

The nitrifying power of the soil was determined in three series in order to observe the effect of the addition of organic and inorganic nitrogen on nitrification. Samples of 100 grams of soil were used in each case. The three series were as follows:

Series 1. Untreated.
Series 2. 2 grams of dried blood added to the sample.
Series 3. 0.5 gram of $(NH_4)SO_4$ added to the sample.

It will be seen from Table 10 that the addition of nitrogen either in organic or inorganic form has increased the nitrification. However, the results from each treatment as compared with the nitrates before incubation show, in the main, the same order of difference.

Considering the effect of drying of the soil on the nitrifying power, the original soil shows an increase of 54 p.p.m. when the soil has been incubated alone. Series 2 and 3 of the same sample gave an increase of 26 and 66 p.p.m. respectively. In the dry soil the nitrates are increased in about the same ratio, but here there is an error due to the wetting of the soil on incubation, and the same results are obtained as in sample 3. If the nitrifying power of the dry soil had been determined, it is very probable that no nitrifying power would have been obtained. In sample 3 there was an increase of 55, 95, and 111 p.p.m. in series 1, 2, and 3 respectively. This shows that the effect of previously drying a soil is to increase the activity of the nitrifying organisms. In sample 4 the incubation of the soil has shown a decrease, but an increase of 138 and 130 p.p.m. was found in series 2 and 3 of this sample. In the carbon dioxid determination the rewetting of the soil for a period of thirty-five days gave a result similar to the original soil. Soils dried two and three times have increased the nitrifying power over the samples dried once. From the table it can be seen that the maximum is reached at two dryings. These results would show that the activity of the nitrifying organisms is increased by a previous drying of the soil, but reaches a maximum at two dryings.

Summary of Experiment 2.

1. The bacterial activity as measured by the carbon dioxid production is increased by a previous drying of the soil.

2. The carbon dioxid production is very low in a dry soil, the production ceasing after seven days.

3. The activity is increased by two dryings, the third drying showing only very slight increase over the second.

4. A soil held moist for thirty-five days after one drying assumes its normal condition, the activity being only slightly greater than in the original soil.

5. The previous drying of the soil increases nitrification.

6. The dry soil shows a reduction in nitrates, as in the carbon dioxid production.

7. The nitrification is increased by two dryings and again in the soil dried three times.

8. The nitrifying power of the soil is increased by a previous drying.

9. The nitrifying power continues to increase with two dryings, but probably reaches its maximum at three dryings.

10. The effect of adding organic or inorganic nitrogen to the samples is shown by a marked increase in the nitrates produced. The increase in the determinations is in the same ratio as in the sample with no nitrogen added.

Discussion and Conclusions.

The foregoing results show that the drying of soil has an effect on its fertility, which results in an increased plant growth. The crop growth is increased by a previous lowering of the moisture content, but the difference in the organic content as shown in the two soils used, has influenced the changes which are produced.

In Experiment 1 there is a drying out of the soil by a lowering of the moisture content, but in no case do we have a soil completely air-dried. This experiment represents a condition that takes place in a humid region where the soil rarely reaches an air-dry condition. In a consideration of the results from Experiment 1 this must be kept in mind.

While the effects of drying on the physical changes have not been definitely studied, a discussion of the subject will necessarily include the physical factors which are acting through a change in the soil moisture.

The drying out of the soil increases the granulation, which is in the most part due to an alteration of the colloidal material. The increased granulation allows a greater amount of soluble salts to be carried in the granules, which on subsequent wetting allows a greater amount to go into solution. Referring to the results obtained on the amounts of water soluble material found in the two soils under different moisture contents, we find that the drying out of the clay loam has caused an increase in the water soluble material, while in the organic clay loam the opposite occurs. As these soils differ only in the organic content, the factor which influences the solubility of the soil constituents must be due to the difference in the organic matter of the two soils. If in the clay loam a granulation due to drying has caused a greater alteration of the colloidal material, this would allow the water greater access to the soil particle; and if the concentration of the salts on the surface of the particle has resulted from an increased film pressure around the particle, a greater amount of soluble material will be recovered by a subsequent wetting of the soil. However, in the organic clay loam the decrease found in the soluble matter on drying would tend to show that the great amount of material soluble when the soil is held at high water content overcomes any increase that may be due to a drying of the soil.

Again, as the organic clay loam shows a lime requirement of 1,200 p.p.m. CaO, the acidity which is due to the organic matter would deflocculate the colloidal material, resulting in a less amount of surface being exposed to the solvent than in the clay loam. It has been shown by previous investigators that a soil high in organic matter has a great absorptive power. This absorptive power would increase the plant food held by the soil and result in an increase of the soluble matter when the soil was dried; but if the soil was not dried to a low enough water content to alter this absorptive power, no increase would result. The resinous and fatty material of the organic matter may surround the mineral particles and allow no greater solubility even if more soluble salts are exposed to the solvent after a drying of the soil. It has been considered by some investigators that the water-soluble material forms a colloidal film around the soil particle. On drying a soil this film will be altered and allow a greater solubility of the soluble salts. This may partly account for the increase in the water-soluble material in the clay loam when dried to a 15 percent moisture content, but in the organic clay loam it may be that the large amount of organic matter soluble would strengthen this colloidal film and a greater drying be necessary to alter the pressure of the film.

Other factors, mainly chemical, must be considered in a discussion of the effects of drying soil. The dehydration of the silicates, deoxidation of the oxids, and oxidation of many of the compounds are some of the important chemical changes which take place in the soil on drying. However, in Experiment 1 the soil has not been dried below a moisture content of 15 percent, and these factors cannot exert any marked influence on the changes produced.

The drying out of the soil causes an increase in the nitrification in the planted series, but no effect is observed in the unplanted series. Why this occurred is not clear. The biological factors that are at work here may sufficiently alter the results so as to eliminate any difference due to the changes in moisture. This will be discussed further under the results of Experiment 2.

Turning to the determinations of potassium, calcium, and phosphorus, as affected by the lowering of the moisture content, it was found that there is no increased solubility of these elements. This would show that the beneficial effect on plant growth must be due to a great extent to an alteration of the physical condition of the soil and not to a greater amount of plant food being liberated.

The results from Experiment 1 show that the lowering of the moisture content previous to planting has a beneficial effect on plant growth. Of the changes produced in the soil, the physical, chemical, and biological factors must be considered, but in the results obtained from Experiment 1, it would seem that the change in the physical condition is the principal factor.

In Experiment 2, the results of drying a soil are studied in connection with the biological changes. The effects on the biological factors have been measured by the biochemical changes produced. This experiment differs from Experiment 1 in that the soil was dried in a drying room at a temperature of 30° C. and may be considered as air-dried.

Before discussing the effects of drying on the physiological changes produced as measured by the carbon dioxid production, it will be well to consider whether the carbon dioxid produced is a correct measure of the bacterial activity. The most important objection to this method is that the amount obtained in some cases appears to be too high to attribute to bacterial action. The chemical changes produced on drying may be partly responsible for the increase in carbon dioxid. It can not be said that all the organisms in the soil evolve carbon dioxid; but if the most important soil organisms produce carbon dioxid and if the changes produced by drying act similarly on these organisms, the measuring of the carbon dioxid production should give a relative measurement of the bacterial activity.

The results of the experiment show that a previously dried soil gives a greater bacterial activity as measured by the carbon dioxid production and nitrification in the soil. There are a number of possible reasons to be considered in a discussion of the effect of drying on the physiological condition of the soil.

It has been shown by many investigators that the organisms in the soil, except the nitrifiers, are resistant to drying. If the nitrifying organisms are destroyed on drying the soil, then the increased nitrification must be accounted for through chemical changes produced in the soil. The drying of the soil alters the colloidal material and allows a greater amount of oxygen to enter the soil. After the soil has been wet again an increase is found in the nitrates, which would be due to the induced oxidation.

If in drying a soil a greater amount of plant food is made available, the bacteria would be able to obtain a greater supply of food. According to Greig-Smith, the drying of the soil would destroy the waxy substance surrounding the soil particle and allow the more resistant bacteria a greater food supply.

The resistance of the organisms to drying may be due to the formation of spores. As it is known that the nitrifying bacteria do not produce spores, we may consider that the decrease in the nitrifying organisms and the increase of the other organisms on drying may be due to the ability of the latter to form spores. In a discussion of the causes of the beneficial effect due to drying it is necessary to consider the hypothesis of Russell and Hutchinson. Considering that the drying of the soil is a partial sterilization, they believe that the drying of soils destroys or inhibits the action of the phagocytic organisms, and an increase in the ammonifying bacteria results, which is beneficial to the productiveness of the soil.

In an air-dried soil the hygroscopic water may be sufficient to satisfy the requirements of the bacteria. The hygroscopic water is held around the soil particle as a thin film. This film exerts a very great pressure, which, it seems, would not allow the organisms to obtain the water or the food enveloped in it; but if the bacteria themselves were included within this film, then sufficient food might be obtained.

From the results obtained in this investigation and by other workers it would seem that the increase in bacterial activity on drying a soil is not a question of bacterial numbers, but depends upon the relative resistance of the important soil organisms.

In a consideration of the effect of drying a soil on the physiological condition of the soil, no definite conclusions can be drawn until more knowledge is obtained relating to the effect on the different groups of organisms. The subject is very complex and must include many factors both chemical and physical, as, for example, an alteration of the colloidal material which would allow a greater oxidation.

The results of these studies show that the drying of soil affects the physical, chemical, and biological factors, resulting in an increased plant growth. The increased crop growth on a soil that has been previously dried is of importance to the practical question of soil management, more especially in the arid regions where the soil is often air-dried.

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