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FERTILITY STUDIES ON STRONGSVILLE SOIL
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OHIO AGRICULTURAL EXPERIMENT STATION

BULLETIN

OF THE

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PREFACE.

The value of long time plot experiments is now being recognized the world over as one of our most valuable methods of soil investigation. It is therefore a cause for congratulation that several of our American State Experiment Stations have been able to maintain such experiments over considerable terms of years, and it is to be earnestly hoped that the authorities of the several institutions having in charge plots, whose crop history and management are well known, will guard them with a jealous care as among the most valuable assets the country possesses for the bettering of our knowledge of soil control.

The Ohio State Experiment Station is peculiarly fortunate in having in the Wooster plots and the Strongsville plots two widely different sets of soil conditions under observation. In both stations the soils represent widely distributed areas and consequently have a great economic importance to the state. But they have an even greater importance to the country at large in that while at Wooster the improvement and maintenance of the crop producing power of the soil seems to be mainly a problem of soil chemistry, at Strongsville the problem presented is mainly one of soil physics. Any interruption of the studies being made at this latter station especially would be more than a local or state loss, and would in fact be a national loss of no mean proportions. The plots at Wooster and at Strongsville have been laid out in an unusually advantageous manner, and their management and history have been recorded with a carefulness beyond criticism. They have offered, therefore, an exceptionally favorable opportunity for the testing of the paraffin pot methods of investigation recently devised in the Bureau of Soils. The Bureau accepts the responsibility for the actual results obtained by its agents with its methods, but the credit for the conclusions reached must be given to the Ohio Station which assumed the direction of the work.

The results of the two investigations at Wooster and Strongsville leave no reasonable doubt that the paraffin pot method does give results in harmony with the average results obtained by the much longer timed experiments in the field. It thus has an unquestionable value as a practical method for investigating the manurial requirements of a soil. But it has also been shown to be a valuable instrument of research which will probably enable plot experimenters in the future to save many years of labor, although in no way can it be regarded as supplanting or depreciating the more certain results which long time plot experiments alone can furnish. The present bulletin showing the value of this method in demonstrating the physical requirements of the soil in comparison with the preceding bulletin showing the chemical requirements of the Wooster soil will undoubtedly prove valuable to all interested in the fundamental problems of agriculture.

MILTON WHITNEY, *Chief, Bureau of Soils,*
U. S. Department of Agriculture

FERTILITY STUDIES ON STRONGSVILLE SOIL.

BY A. H. SNYDER AND C. L. COOK.

OUTLINE.

DESCRIPTION OF SOIL.

The Strongsville Sub-station farm is in Strongsville township, Cuyahoga county, Ohio, and consists of a comparatively level area slightly broken by the erosion of streams. The original growth consisted largely of beech, sugar maple and oak, with an occasional tree like the chestnut, marking a strong local contrast in the soil character. The soils in question are marked, in their general behavior, by their resistance to culture, save at just the right period. They are commonly known as hard clay soils, although the actual clay percentage scarcely warrants such a designation. Four miles north there are the extensive quarries of the Berea sandstone, belonging geologically to the Waverly group. In the vicinity of Strongsville the soil is for the most part underlaid by one of the shales characteristic of this region. In the earlier geological reports there is some irregularity in the designation of this shale series. It appears we have here to do with the Cuyahoga shale; this shale was earlier designated in the Geological Report as the Waverly shale. It appears that the soils under study have derived their character from the Cuyahoga shale.[1]

In Bulletin No. 110 of the Ohio Experiment Station is the following statement concerning the Strongsville soil:—"The underlying rock here is the Cuyahoga shale; a gray, argillaceous shale, nearly impervious to water, which weathers into a cold, heavy, tenacious, white clay. Although this region lies within the glaciated area of the state, the underlying rock, which in the case of this test farm is usually less than ten feet from the surface, is the chief source from which the soil has been derived."

Mr. J. E. Lapham of the U. S. Department of Agriculture has furnished the following description: "The soil of the Strongsville farm has been mapped by the Bureau of Soils as the Miami clay loam and is fairly typical of that soil as found widely distributed over many of the counties of the central and northern portions of the state. The soil to a depth of from six to eight inches consists of a rather grayish brown, uniformly silty loam, containing enough clay to cause it to clod to some extent especially if worked when wet. The top two or three inches of the subsoil exhibits a marked contrast to the soil in color, being a light pale yellow, mottled with gray. The texture, however, remains rather silty until a depth of about fifteen inches is reached, where the clay content gradually increases, the color changing to a yellowish brown, slightly mottled. Below

[1]Bulletin No. 150, Ohio Agricultural Experiment Station, page 88.

eighteen inches the subsoil is somewhat mottled, brown, heavy, dense clay, which polishes under very light pressure between the thumb and finger, the maximum clay content being reached at about twenty-eight inches. A few irregular, angular rock fragments are scattered about at the surface and through the subsoil.

Fair surface drainage is secured through the gently sloping topography, but thorough underdrainage by artificial means is necessary to put the land in the best condition for crops.

The soil is derived from the material brought down during glacial times, modified to some extent by the residual soil derived from the underlying shale."

The farm at Strongsville from which the samples of soil were taken for this investigation is that upon which the Ohio Experiment Station has conducted an extensive series of plot experiments, covering a period of about ten years. On one series of plots a five-year rotation experiment has been carried on, the rotation consisting of corn, oats, wheat, each one year, and clover and timothy two years. In this rotation experiment plots treated with various amounts and various combinations of fertilizers are represented. The greater part of the work to be described in the present publication was conducted upon samples taken from the check or unfertilized plots.

DESCRIPTION OF METHOD.

The method of growing plants in the wire baskets is as follows: Five small wire baskets, three inches in diameter, by three and one-half inches deep, are used for each treatment. After the soil has been treated with its respective fertilizer and brought up to the optimum water content with distilled water, the equivalent of about 325 grams of dry soil is placed in each basket. The soil is firmly packed and six germinated kernels of wheat are planted in each basket. During the process of packing a small portion of the soil presses out through the wire mesh, but this is brushed off and returned to the interior of the basket, after which the basket is at once dipped into melted paraffin, which not only forms an intimate contact with the soil but produces a water-tight covering. An eighth to a quarter of an inch of washed quartz sand is now placed over the soil of each basket and its contents at once weighed and the weight recorded. In from three to five days the wheat plants have emerged from the soil and have a height of approximately one inch, at which time the surface of the basket is sealed; that is, covered with a piece of paper having a small opening in the center sufficiently large to permit the plants to pass through. The paper is dipped in paraffin just before placing it over the soil, and then a small amount of paraffin is run around the outer edge of the paper, thus forming contact with the side of the basket. In this way all evaporation from the soil is prevented, excepting the minute amount which may pass through the small opening immediately around the plants. The loss from this source is so slight in comparison to that which is transpired by the plants that no account is taken of it, but even if the loss were considerable it should be practically the same for all baskets. The weight of the basket is taken immediately before sealing, and immediately afterwards, in order to ascertain the weight which has been added to it in the process of sealing.

During the growth of the plants, which usually continues from eighteen to twenty-one days from the date of sealing, the basket are weighed at intervals of two or three days and watered with distilled water in order to retain a favorable moisture content for plant growth. By this method the loss of water or amount transpired by the plants is ascertained periodically and at the end of the experiment the total amount of water given off through the plants of each basket is obtained for comparison with the growth and green weight of the plants, which is ascertained by cutting and weighing the plants at the time the experiment is concluded.

All conditions of the experiment are so carefully controlled that the average result of five baskets rarely differs more than five percent from the average result of any other five baskets that have been treated throughout in precisely the same manner. Differences which occur beyond this amount may therefore safely be attributed to the different manurial treatments which have been given.

This method has several advantages over the growing of plants in open and porous pots. The method of coating the baskets with paraffin prevents any accumulation of roots between the soil and receptacle, a trouble which is so common in pot experiments. The complete sealing up of the soil also enables the experimenter to determine the amount of water which the plant has actually used and transpired in the process of growth, and this together with the small size of the baskets enables the moisture content and its fluctuations to be carefully controlled. When the plants have attained considerable size, the draft made upon the soil moisture is very great, and on warm days with bright sunshine the plants may use half of the moisture which the soil contains. The draft upon the soil that occurs during this period of growth, both as to moisture and mineral food constituents, is probably as great as that under field conditions by the removal of a large crop, providing we assume that the removal takes place to no greater depth than one foot, which in the case of wheat and other similar crops would be approximately correct. For example, the amount of green matter in the plants produced on soil from the unfertilized plot at Strongsville, which received no fertilizer before being placed in the pots, was at the rate of about 18,000 pounds to the acre-foot and the water removed was equal to about 24 percent of the weight of the soil. This yield, of course, is considerably greater than the yield obtained in the field from the unfertilized plots, but it serves to bring out one feature of the method which seems to be fairly well established and applies equally well to all pot experiments, viz., that the percentage increase secured by fertilizer treatment of clay soils in pots is usually less than the percentage increase secured from the same treatment in the field.[1] This fact is easily explained when we consider that the chief requirement of many clay soils, in order to render them fertile, is to place them in good physical condition, which condition is generally obtained in potting the soil. For this reason a portion of the effect of treatments which are valuable by virtue of their physical effect upon the soil is not shown by the direct results of pot experiments. The above statements apply more forcibly to soils of the clay types than to those of a more sandy nature, because the change produced in the physical condition of a clay soil in the process of potting is relatively greater than that produced in a sandy soil, and a change of physical condition is more frequently found beneficial with a clay soil.

By comparing the yields of the various crops in the fields at Wooster and Strongsville, we find that with the exception of the oat crop the yield at Wooster has always been the greater. The results of chemical analyses would indicate the Strongsville soil to be the richer. A comparison by the basket method of a sample from an unfertilized plot at Strongsville with a similar sample from an unfertilized plot at Wooster gave results agreeing with the relation between these soils exhibited by field cropping, but the difference between the yields obtained from the two soils in baskets is less than would have been expected from field results. This is in accordance with the foregoing statement concerning the relative improvement of clay and sandy soils in the process of potting, the Wooster soil being considerably lighter than that from Strongsville. These results indicate that the Strongsville soil would respond markedly to

[1]Circular No. 15, U. S. Dept. Agric , Bureau of Soils.

any treatment which will improve its physical condition. Further evidence in the same direction is found in considering the marked beneficial effect of lime, a substance known to be capable of changing the texture of soils through its flocculating tendency. Field work has shown that small applications of lime produce but little effect, while the effect of a large application, of about three tons per acre, is very marked.

REPLANTING.

Some very interesting and valuable features regarding the effect of various treatments are sometimes brought out by replanting the pots with wheat immediately after they have grown a crop. It is almost invariably true that an untreated sample of this soil which has been replanted without treatment will show a decrease in the growth of the second crop of 50 percent or more, although certain treatments may produce better plants in the second crop than they did in the first. Particularly is this true of green manure, which will be discussed later. The effect of replanting is shown by the fact that the transpiration of 30 wheat plants for a period of seventeen days on a second planting was but 58 percent of that obtained with a first planting, using the same number of plants during the same time. The actual amount of water transpired by the plants of the first crop was 660 grams as compared with 381 grams for the second, while the green weights of the plants for the two crops were 7.3 and 4.2 grams respectively.

VARIOUS AMOUNTS OF LIME.

In the following table are given the results obtained by treating samples from an unfertilized plot with various amounts of lime. The lime used in this experiment was taken from a sample of ground quick lime which had been kept in an open barrel in the barn for several months and a large percentage had undoubtedly passed into the carbonate form.

The cultures from which the data given under *A* were obtained grew from April 7 to April 24, and transpiration was taken after April 17. Five baskets, each containing six wheat plants, were used for each treatment. In the table the relative growth of the plants as indicated by their transpiration is expressed on the basis of 100 for the untreated soil. Under *B* the data were obtained from another experiment, the soil being kept at optimum water content for eight days previous to planting. The transpirations were taken from July 14 to July 25. Under *C*, the data were obtained from a third experiment, planted March 23, transpiration being determined for 17 days.

		Relative transpiration	Green weight
(*A*)	Untreated soil	100	
	Lime, 1,000 parts per million	114	
	" 2,000 " " "	112	
	" 3,000 " " "	110	
	" 4,000 " " "	115	
	" " " "	115	
(*B*)	Lime, 1,000 p. p. m. + $(NH_4)_2SO_4$ 200 p. p. m.	118	121
	" 1,000 p. p. m. + CaH_4PO_4 400 p. p. m.	130	121
	" 1,000 p. p. m. + H_2SO_4 200 p. p. m.	108	106
(*C*)	Lime, 1,000 + Manure, 10,000 p. p. m.	108	113

The results of these experiments indicate that if the soil were put in good physical condition one would not be justified in applying lime in larger amount than 2,000 pounds per acre, which corresponds to 1,000 parts per million, or the smallest amount tested in the experiment.

As has been previously pointed out, the beneficial results secured from the use of lime on the Strongsville soil are probably due in a great measure to the physical effect of this substance. That the effect of lime is not due to its action in neutralizing soil acidity is shown by an experiment carried on simultaneously with that designated as *A* in the above table, which brought out the fact that the addition of sodium carbonate or of sodium hydrate in the proportion of 1,000 parts per million was practically without effect, the former giving the same growth as the untreated soil and the latter a gain of only 9 percent. Since the soil in the baskets has been placed in good physical condition in the process of potting it is possible that a heavier application of lime than one ton per acre would give a sufficient increase in the yield to justify its use in the field. When the lime treatment is accompanied by a treatment of either ammonium sulphate or barnyard manure, the effect of the lime is not appreciably increased. The addition of sulphuric acid with lime, unquestionably producing calcium sulphate, or land plaster, appears to bring about a slight decrease as compared with lime alone. But the addition of calcium phosphate with lime produces a distinct improvement.

An experiment was conducted to determine the relative values of several different forms of lime. The results of this test are given in the following table:

TREATMENT	FIRST CROP Transpiration	FIRST CROP Green weight	SECOND CROP Transpiration	SECOND CROP Green weight
Untreated	100	100	58	58
Commercial quick lime 2 tons per acre	139	128	67	60
Commercial slaked lime 2 tons per acre	125	128	64	59
Pure lime 1 ton per acre	129	130	63	54

The data given in the above table represent the relative transpiration and green weight of 30 wheat plants grown in soil treated with the three kinds of lime named, the results being expressed on the basis of 100 for the first crop grown in untreated soil. The lime was applied at the rate of two tons per acre-foot, assuming that the soil weighs approximately 2,000,000 pounds for the top seven inches. Thirty plants were grown in each treatment. The quick lime and slaked lime were samples secured from consignments of the same that the Station has used in the field; the pure lime was a sample of chemically pure calcium oxide prepared in the laboratory of the Bureau of Soils.

A large sample of the Strongsville soil taken from an unfertilized plot was thoroughly mixed and a sufficient quantity to fill five of the wire baskets was weighed into each of three pans. The samples were treated with the different kinds of lime on June 2 and kept at the optimum water content for a period of ten days, being thoroughly stirred once or twice each day during that time.

On June 12 the first crop was planted, and transpiration was taken from June 20 to July 1. Owing to a large amount of cloudy and rainy weather during the growth of this crop, the daily transpiration was low, and the green weight of the plants can probably be more safely relied upon to show the relative growth obtained with the different treatments.

On July 7 wheat was again planted in this soil, the soil being left in the baskets and not disturbed in any way. This crop was allowed to grow from July 7 to July 27, the transpiration being taken after July 14. It will be noted that neither in the transpiration nor the green weights is there any marked difference in the effect produced by the three kinds of lime tested, although the pure lime was used in only half the amount that was applied in the case of the quick lime and hydrated lime. This, however, is what should be expected from the results of an analysis of these two kinds of lime made by the Chemist of the Station and reported in Bulletin No. 159, Ohio Agricultural Experiment Station, March 1905. This analysis shows 54.69 percent calcium oxide in the quick lime, and 61.32

percent for the hydrated lime. Thus we see that practically as much calcium oxide has been applied in the above experiment in the case of the pure lime as in that of the quick lime and the hydrated lime.

NITROGEN FERTILIZERS.

In order to test the effects of nitrate of soda and sulphate of ammonia two series of cultures were grown in samples of soil treated with these two carriers of nitrogen, using each salt alone and in combination with acid phosphate, lime, potassium sulphate, and manure. An unlimed soil was used throughout the entire series and the fertilizers were applied in solution, the chemically pure salt being used in every case. The lime was a hydrated sample from the lime extensively used upon the Wooster farm in the spring of 1905. These two series were carried out simultaneously with these designated respectively *A* and *C* in the preceding chapter. The results are given in the following table.

NITROGEN FERTILIZERS	Transpiration	Green weight
Untreated	100	100
(*A*) $NaNO_3$ 200 parts per million	131	112
$NaNO_3$ 700 p. p. m. + lime 2,000 p. p. m.	129	136
$NaNO_3$ 200 p. p. m. + $CaH_4(PO_4)_2$ 400 p. p. m.	88	90
$(NH_4)_2SO_4$ 200 p. p. m.	90	96
$(NH_4)_2SO_4$ 200 p. p. m. + lime 2,000 p. p. m.	118	121
$(NH_4)_2SO_4$ 200 p. p. m. + $CaH_4(PO_4)_2$ 400 p. p. m.	71	83
(*C*) $NaNO_3$ 100 p. p. m. + $CaH_4(PO_4)_2$ 100 p. p. m.	96	94
$NaNO_3$ 100 p. p. m. + $CaH_4(PO_4)_2$ 100 p. p. m. + K_2SO_4 100 p. p. m.	96	94

The data given in this table show that nitrate of soda at the rate of 200 parts per million or 400 pounds per acre-foot gives an increase equal to that obtained with lime at the rate of 2,000 parts per million or two tons per acre-foot. This increase remains the same when the two are used together. While an increase has been obtained by the use of nitrate of soda at the rate of 400 pounds per acre, only a slight increase, or none at all, has been obtained by its use in smaller amounts. The use of calcium phosphate together with sodium nitrate shows a considerable decrease in growth, indicating that the phosphate has more than counteracted the beneficial effects of the nitrate. When potassium sulphate is used together with sodium nitrate and acid phosphate the potash salts seem to have but little effect.

The use of sulphate of ammonia at the rate of 400 pounds per acre has shown a decrease in every case and the same has been already noted in the case of acid phosphate when used at the rate of 800 pounds per acre. This decrease is about doubled when the two are used together. The use of lime together with ammonium sulphate has much more than overcome the ill effects of the latter salt.

Since the application of sulphate of ammonia does not prove beneficial to this soil it seems probable that the soil is not deficient in nitrogen and that the increase obtained by a large application of nitrate of soda is due to some effect other than that of merely supplying available nitrogen.

The addition of 10,000 parts per million of stable manure together with 100 parts per million of sodium nitrate showed an increase of 14 percent by transpiration and 11 percent by green weight over the results obtained with the nitrate alone.

PHOSPHATIC FERTILIZERS.

Three series of baskets were planted to test the effect of phosphates on this soil. The calcium acid phosphate was taken from a sample of commercial fertilizer used by the Station. The sodium phosphate used was the chemically pure salt. The following table gives the transpirations and green weight of these series. The experiments were performed simultaneously with those given in the first table, the same letters being used to denote the separate tests.

PHOSPHATIC FERTILIZERS.		Transpiration	Green weight
	Untreated	100	100
(*A*)	$CaH_4 PO_4$ 400 p. p. m.	91	85
	$CaH_4 PO_4$ 400 p. p. m. + lime 2,000 p. p. m.	130	121
	$CaH_4 PO_4$ 400 p. p. m. + $NaNO_3$ 200 p. p. m.	88	90
	$CaH_4 PO_4$ + $(NH_4)_2 SO_4$ 200 p. p. m.	71	83
(*B*)	CaH_4PO_4 100 p. p. m.	92	96
	CaH_4PO_4 100 p. p. m. + 10,000 p. p. m. manure	115	116
(*C*)	CaH_4PO_4 100 p. p. m.	92	96
	CaH_4PO_4 500 p. p. m.	102	95
	CaH_4PO_4 100 p. p. m. + $NaNO_3$ 100 p. p. m.	96	94
	CaH_4PO_4 100 p. p. m. + K_2SO_4 100 p. p. m.	94	91
	CaH_4PO_4 100 p. p. m. + K_2SO_4 100 p. p. m. + $NaNO_3$ 100 p. p. m.	96	94
	Na_2HPO_4 100 p. p. m.	101	93
	Na_2HPO_4 500 p. p. m.	109	99

From the data given above it appears that calcium acid phosphate has no appreciable beneficial effect; rather that it has a slight depressing influence upon the soil. Sodium phosphate, however, does not seem to exert any depressing effect. Stable manure, when used with phosphate, not only overcomes the ill effect of the mineral fertilizer but produces a considerable increase.

As would be inferred from preceding statements, the depressing influence of calcium phosphate is increased by the addition of ammonium sulphate, and is apparently not markedly affected by the addition of sodium nitrate or potassium sulphate or both of these salts together, but the addition of lime produces a very good increase.

POTASH FERTILIZERS.

Two experiments were prepared to determine the values of potassium sulphate and of this salt together with acid phosphate, sodium nitrate and manure. These were carried out at the same time with those designated by the letters *B* and *C* in the first table.

The results are given below.

POTASH FERTILIZERS	Transpiration	Green weight
(*C*) Untreated	100	100
K_2SO_4 100 p. p. m.	91	95
K_2SO_4 500 p. p. m.	106	109
K_2SO_4 100 p. p. m. + CaH_4PO_4 100 p. p. m	94	91
K_2SO_4 100 p. p. m. + $NaNO_3$ 100 p. p. m.	96	94
(*B*) K_2SO_4 100 p. p. m.	91	95
K_2SO_4 100 p. p. m. + manure 10,000	115	121

Potassium sulphate used in the proportion of 100 parts per million appears to have a slight depressing effect, but a slight beneficial effect was produced when this salt was used in the proportion of 500 parts per million. As would be inferred from the statements made in connection with the nitrogen and phosphate fertilizers, the addition of acid phosphate together with potassium sulphate and of the latter salt together with sodium nitrate has shown no appreciable effect upon the action of the potash salt. Manure is markedly beneficial when used with potassium sulphate, but the effect is probably mainly due to the manure.

BARNYARD MANURE.

A test of the effect of barnyard manure and of manure together with lime, sodium nitrate and potassium sulphate, was made simultaneously with Experiment *B* of the first table. The sample of manure was taken in the open yard and decomposition was not far advanced. It was finely ground in a sausage grinder and thoroughly mixed with the soil. The results follow:

BARNYARD MANURE	Transpiration	Green weight
Untreated	100	100
Manure 10,000 p. p. m.	105	109
Manure 10,000 p. p. m. + lime 1,000 p. p. m.	108	113
Manure 10,000 p. p. m. + $NaNO_3$ 100 p. p. m.	109	114
Manure 10,000 p. p. m. + K_2SO_4 100 p. p. m.	115	121

From this table it appears that the beneficial effect of manure, as shown in the basket cultures, is only slight. As is well known, manure is often beneficial in improving the physical condition of soils and it may be that the increase in productiveness derived from this substance in the field is due to this manner of action. It has been noted that in preparing the baskets the soil is probably placed in a much better physical condition than exisits in the field, so that substances which act in the field by improving the physical properties of the soil may be almost without effect in the baskets. The most probable explanation of the rather large increase shown above for manure and potassium sulphate is that the soil of this particular set of baskets was not in as good physical condition as is usually obtained, so that the manure had an effect resembling that which would have been obtained had the soil been in the field condition.

SULPHURIC ACID.

Since it was found in the case of the Wooster soil that a rather large addition of sulphuric acid was without ill effect it seemed worth while to test the effect of this acid on the present soil. This experiment was carried out in connection with that described under *A* of the first table. The results are given below.

SULPHURIC ACID	Transpiration	Green weight
(*A*) Untreated	100	100
H_2SO_4 200 p. p. m.	80	90
H_2SO_4 500 p. p. m.	59	83
H_2SO_4 200 p. p. m. + lime 2.000 p. p. m.	108	108
H_2SO_4 200 p. p. m, + $NaNO_3$ 200 p. p. m.	83	94

An application of sulphuric acid at the rate of 400 pounds per acre gave a decrease of 20 percent, while a somewhat heavier application to the Wooster soil gave no decrease. An application in the proportion of 1,000 pounds per acre to the Strongsville soil gave twice as great a decrease as an application of 400 pounds, both by transpiration and green weight of plants. In the same series a test of the fertilizing value of magnesium sulphate showed a gain of 2 percent by transpiration and of 6 percent by green weight when this salt was used in the proportion of 1,000 parts per million. An application of 3,000 parts per million showed a decrease of 13 percent by transpiration and of 2 percent by green weight. It thus appears that magnesium sulphate is without appreciable beneficial effect. As has been shown, the same is true for potassium sulphate. Ammonium sulphate, both when used alone and in combination with acid phosphate, fails to exhibit any increase, but on the contrary has an ill effect.

From these facts it seems probable that the acid radical of sulphuric acid is not beneficial upon this soil and is even deleterious in some forms. Lime is apparently capable of wholly or partially counteracting the deleterious effect of the sulphate radical, while nitrate of soda does not seem to possess this power.

GREEN MANURE

The following table represents the relative transpiration and green weights of plants from three successive wheat crops grown in soil treated with green manure and lime, the results being expressed upon the basis of 100 for the first crop grown in untreated soil.

TREATMENT	1st Crop		2nd Crop		3rd Crop
	Relative transpiration	Green weight	Relative transpiration	Green weight	Relative transpiration
Untreated soil	100	100	58	58	42
Quick lime 2 tons per acre	139	128	67	60	Not
Hydrated lime 2 tons per acre	125	128	64	59	planted
Pure lime 1 ton per acre	129	130	63	54	
Quick lime 2 tons—green manure 5 percent	111	117	80	85	41
Hydrated lime 2 tons—green manure 5 percent	110	109	77	84	51
Pure lime 1 ton—green manure 5 percent	140	123	67	65	47
Quick lime 4 tons—green manure 5 percent	104	119	78	90	57
Hydrated lime 4 tons—green manure 5 percent	119	128	75	85	49
Pure lime 2 tons—green manure 5 percent	129	128	83	90	51
Green manure 5 percent	84	92	77	76	47

The green manure used was red clover and was finely ground in a food cutter and applied to the soil at the rate of 5 percent of green matter. Thirty wheat plants were grown in each treatment. The samples of soil were treated on June 2 and kept at optimum water content for a period of ten days, being thoroughly stirred once or twice each day during that time. On June 12 the first crop was planted and transpiration taken from June 20 to July 1. Owing to a large amount of cloudy and rainy weather during the growth of the first crop, the daily transpiration was low, and the green weights of the plants can probably be more safely relied upon. On July 7 wheat was again planted in this soil, the soil being kept in the baskets and not disturbed in any way. This crop was allowed to grow from July 7 to July 27, transpiration being taken from July 14 to July 27. The third crop was planted on July 29 and transpiration taken from Aug. 5 to August 22.

The effect of green manure alone upon the first crop was negative, which has frequently been found to be the case in pot experiments with other soils, where green manure has been applied in large quantities and the seed planted soon after its application. This is probably caused by the presence of substances in the soil due to the fermentation of the green matter; the addition of lime tends to counteract this effect of the green manure as will be seen by the table. A consideration of the second crop, however, shows that the effect of green manure was decidedly beneficial, amounting to approximately 30 percent, both by transpiration and by green weight. It does not appear, however, that lime in combination with green manure produced in general any increase in the second crop above that produced by the latter substance. In the third crop the green manure still gave a considerable increase as shown by the transpiration figures, the green weight of the plants not having been obtained.

Another experiment carried on in large wire baskets, each of which contained as much soil as five of the smaller form, gave further data upon the effect of green manure. On August 4 four of the larger baskets were filled with Strongsville soil and 30 germinated wheat seeds planted in each basket. Before placing them in the baskets the various samples of soil were treated as follows: No. 1, untreated; No. 2, red clover, 20,000 parts per million; No. 3, red clover, 20,000 parts per million and lime 2,000 parts per million; No. 4, sweet clover, 20,000 parts per million and lime 2,000 parts per million. It was desired to change the soil from the condition which exists in the field as little as possible before planting, but it was found impossible to incorporate the green manure and lime without placing the soil in good physical condition in the process. The first crop was allowed to grow from Aug. 4 to Aug. 28, when the plants were cut and their green weight obtained. On Sept. 2 thirty wheat seeds were again planted in each basket, the soil not having been removed or in any way disturbed since the planting of the first crop. The plants of the second crop were cut from the baskets and weighed on Sept. 23. The following table gives the green weights of the plants from the two crops.

TREATMENT	Green weight 1st crop	Green weight 2nd crop
Untreated soil	100	100
Red clover 20,000 parts per million	67	195
Red clover 20,000 p. p. m + lime 2,000 p. p. m.	54	163
Sweet clover 20,000 p. p. m. + lime 2,000 p. p. m.	61	255

From this experiment it appears that while the results from green manure and lime are negative in the first planting, a large increase has been secured in the second crop. The fact that green manure has a deleterious effect upon the crop planted in the pots immediately after its application, but is markedly beneficial upon subsequent crops may be accounted for in several ways.

In the first place, there may be substances present in the soil due to the fermentation of the green matter which are injurious to plant growth. This is probably not often encountered in the field owing to the time which elapses between the application of the green manure and the planting of the crop, allowing the deleterious substances to escape by leaching or otherwise. In the second place, we have shown that plants grown in pots by this method make practically as great a draft upon the soil as a large crop in the field, so that the green matter, after it has decomposed, may have value as a fertilizer by adding readily available plant food. The third and probably the most plausible explanation of the beneficial effect of green manure upon the second crop is found in its improvement of the physical condition of the soil. When the first crop is planted the soil in all the pots is in excellent physical condition, but during the growth of the first crop it gradually assumes the condition which exists in the field. This, however, is probably prevented in the pots which have been treated with green manure, so that during the growth of the second crop we find the soil of those pots in much better physical condition than that of the untreated soil.

The investigation upon the Strongsville soil must be considered as merely preliminary. It should also be stated that the experiments were conducted under somewhat unfavorable conditions, being carried on during the hottest months of the year, the most unsatisfactory time for growing wheat. The season was exceptionally rainy and it was necessary to keep the plants in a building for a considerable portion of the time, which interferred greatly with the growth and transpiration of the plants.

SUMMARY.

The results obtained by the basket method in studying the heavy clay soil of the test farm at Strongsville, Cuyahoga county, Ohio, and reported in this paper, may be summarized as follows:

1 The soil has been greatly improved by placing it in good physical condition such as is obtained in potting.

2 The soil is naturally fertile so far as plant food is concerned, as shown not only by the basket cultures but as indicated by the result of the chemical analyses reported in Bulletin 150 of the Ohio Agricultural Experiment Station.

3 The effect of replanting the untreated soil in pots with wheat immediately after a crop of wheat has been grown in the same is to reduce the growth of plants approximately 50 percent.

4 Lime appears to have some beneficial effect in the baskets. Heavier applications than the results in the baskets would seem to indicate have been found practicable in the field, probably owing to the physical effect which this substance has upon the soil.

5 No appreciable difference is detected between the results obtained with ground quick lime and hydrated lime.

6 Little if any beneficial effect has been shown from the application of mineral fertilizer salt to this soil after it has been placed in good physical condition, although an application of these salts, especially acid phosphate, gives a decided increase when the soil is in the condition found in the field.

7 Manure produces a small increase in the growth of plants in pots but not as great an increase as is secured from its application in the field. This is probably due to the fact that in the field its effect is mainly due to its physical action.

8 The effect of green manure is negative upon the crop planted immediately after it was applied, but gives a large increase in crops planted subsequently.

CONCLUSIONS.

1 The soil of the Strongsville test farm is sufficiently rich in the mineral constituents of fertility for abundant crop production, but such is not secured on account of the unfavorable physical condition of the soil.

2 An improvement of the physical condition of the soil, such as is obtained in the process of potting, or by the application of lime, barnyard manure or green manure, gives a marked increase in the growth of the plants and apparently, to a great measure, obviates the need of the addition of mineral fertilizers.