THE MAINTENANCE OF FERTILITY.

FERTILITY STUDIES ON WOOSTER SOIL
BY THE
BUREAU OF SOILS
UNITED STATES DEPARTMENT OF AGRICULTURE

OHIO
Agricultural Experiment Station.

WOOSTER, OHIO, U. S. A., OCTOBER, 1905.

BULLETIN 167.

ORGANIZATION OF THE

OHIO AGRICULTURAL EXPERIMENT STATION.

BOARD OF CONTROL.

STATION STAFF.

CHARLES E. THORNE, M. A. S. .... Director
WILLIAM J. GREEN .... Horticulturist and Vice-Director
(Superintendent of Orchards, Gardens and Greenhouses.)
AUGUSTINE D. SELBY, B. Sc. .... Botanist
(In charge of botanical and plant physiological and pathological investigations)
C. G. WILLIAMS .... Agriculturist
(Superintendent of Farm.)
JOHN W. AMES, B. Sc. .... Chemist
L. H. GODDARD .... Experimentalist
H. A. GOSSARD, M. S. .... Entomologist
B. E. CARMICHAEL, B. S. .... Animal Husbandry
WILLIAM H. KRAMER .... Bursar
CLARENCE W. WAID, B. Sc. .... Assistant Horticulturist
(In charge of Greenhouses.)
F. H. BALLOU .... Assistant Horticulturist
(In charge of Orchards.)
J. S. HOUSER, B. S. .... Assistant Entomologist
J. M. VAN HOOK, A. M. .... Assistant Plant Pathologist
F. A. WELTON, B. S. .... Assistant Chemist
TRUE HOUSER .... Assistant in Plant Breeding
WILLIAM HOLMES .... Farm Foreman
CHARLES A. PATTON .... Meteorological Observer
CARY WELTY .... Mechanic
FAYE BLAYNEY .... Mailing Clerk
MARY M. LEE .... Stenographer
FRANK W. GLASS .... Printer

EDWARD MOHN .... Supt. Northeastern Test-farm, Strongsville
HENRY M WACHTER .... Supt. Southwestern Test-farm, Germantown
LEWIS SCHULTZ .... Supt. Southeastern Test-farm, Carpenter

The Bulletins of this Station are issued at irregular intervals. They are paged consecutively and an index is included with the Annual Report, which constitutes the final number of each yearly volume.

BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 167. OCTOBER, 1905.

FERTILITY STUDIES ON WOOSTER SOIL.

PREFACE.

When modern chemistry had demonstrated that certain elementary substances which are found in plants are derived from the soil, and that the growth of plants is dependent upon the supply of these substances in the soil, it was assumed that it would be possible easily to determine the capacity of a given soil for crop production by means of chemical analysis, and that such analysis would at once indicate what particular substances it might be necessary to add to a given soil in order to restore or increase its fertility.

This idea is still prevalent in the popular mind, and no request comes to this Station more frequently than the one that it should analyse a particular sample of soil, and on the basis of such analysis prescribe a formula for the fertilization of the field or farm from which the sample has been taken.

But chemists have long since learned that the amount of potential plant food actually present in a given soil, as revealed by the methods of the chemical laboratory, may be no indication of the quantity which the plant will be able to extract from the soil. A single illustration may make this point clear: The element potassium is absolutely essential to plant life, and a granite sand may contain as much potassium as an equal weight of wood ashes, yet the potassium of the sand is locked up in such an insoluble condition that ordinary plants can barely mantain an existence upon it, while the potassium of ashes is so easily dissolved that on a soil containing more than a very small percentage of ashes the same plants would be destroyed by the strength of the potassic solution.

It is true that the analysis of the soil has given some very helpful suggestions toward its rational fertilization, and chemists are still working in the hope of extending the usefulness of the laboratory in this direction; but the most that has been accomplished as yet is the ability to base a few broad generalizations upon such analysis. Very recent work gives encouragement to hope that the question whether lime is required on a particular soil, and if so in what quantity, may be definitely answered in the chemist's laboratory. Certain muck soils have shown under analysis an extreme lack of potassium, and field experiments have confirmed the chemical diagnosis. Little by little progress is being made along this line; but no chemist is yet ready to undertake to prescribe for the needs of soils in general on the basis of laboratory diagnosis.

Chemical analysis having failed to furnish a satisfactory clue to the productive capacity of the soil, chemists have tried the culture of plants in pots of soil, to which different fertilizing compounds have been added. This method also has given some most useful results. It permits the use of an absolutely uniform soil, since it is practicable to thoroughly mix a sufficient quantity of soil to fill a considerable number of pots. It also permits control of moisture and temperature conditions, but it has the great defect that these artificial conditions of soil, moisture and temperature are not such conditions as prevail in the open field, and it is furthermore limited to the study of the smaller plants, such as wheat and oats, since no practicable pot experiment can deal with a sufficient uumber of individual plants of corn, potatoes or root crops to eliminate the factor of individuality; for plants, like animals and men, have their individual peculiarities, and they must be studied in sufficiently large numbers to counterbalance these peculiarities in a general average.

Because of the failure of the laboratory to furnish a reliable guide to the use of fertilizers, the field experiment has been devised, a mode of investigation which, like the pot test, is conducted by the application of different fertilizing materials to tracts or plots of land, selected for uniformity of soil conditions. This method, however, is by no means the simple affair that some suppose it to be. In the first place, the plots must contain a sufficient number of plants to eliminate the factor of individuality, which involves the use of plots of such size that more or less irregularity of soil, exposure or drainage is inevitable, and hence there must be a considerable duplication of plots in order to offset these various sources of irregularity. Moreover, different seasonal conditions vary greatly in their effect on vegetation. For example, the field experiments of this Station have demonstrated beyond question that the addition of acid phosphate to the soils upon which these experiments have been conducted produces, in the average, a large increase in the yield of wheat; yet there have been two seasons in which this carrier of phosphorus produced a marked diminution in yield of grain, although in both cases the straw was increased. Finally, the actual manipulation of the field experiment, if its results are to be trustworthy, must be, in its way, as exact and careful as that carried on in the chemist's laboratory, but such exactness of manipulation is far more difficult in the operations of the field than in those of the laboratory.

In the field test the conditions of temperature, moisture, exposure, aeration and subsoil influence are the same as those with which the farmer has to deal, and for this reason this test is and must ever remain the criterion by which all other methods of soil investigation are measured; yet each of the methods above mentioned has its points of usefulness, and all must be employed when a thorough study of the soil is undertaken.

The Bureau of Soils of the United States Department of Agriculture has recently devised a modification of the pot system of soil study, which possesses such superiority in convenience and rapidity of manipulation that, if its results prove to be trustworthy, it will be found an agency of very great value in the pursuit of this line of investigation. In order to determine more fully the value of this method the Chief of the Bureau, Prof. Milton Whitney, detailed a party who came to this Station on February 1, 1905, and have spent seven months in testing it upon certain soils of the Station farms which have received a definitely known treatment for ten to twelve years past. The outcome of this work has been that results obtained in two or three weeks' time, are in general agreement with field tests which required an entire season for their execution.

The field experiments of this Station have demonstrated, as has been shown above, that in some cases the apparent effect of a single application of a fertilizing material may be entirely misleading. Under some conditions such materials have a marked cumulative effect, the increase from a fertilizer, which is systematically used upon the same land, growing gradually larger, year by year; while under other conditions the opposite effect is sometimes observed. Much is yet to be done in the study of the causes of these variations. This much is sure, that no single season's field work on a particular soil is a sufficient basis on which to formulate a definite prescription for the fertilization of that soil, and it is highly probable that we shall find the same law holding good in the conduct of the method of investigation described in the following pages. All that can be said of this method at present—and this is much—is that it promises to be a very useful help in one of the most intricate lines of investigation Science has yet undertaken—that of the maintenance of soil fertility.

CHAS. E. THORNE.

FERTILITY STUDIES ON WOOSTER SOIL

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

OUTLINE.

I. INTRODUCTION.

II. DESCRIPTION OF WOOSTER SOIL.

III. CULTURE EXPERIMENTS WITH WOOSTER SOIL.

1. STUDIES ON THE SOIL ITSELF.
   - (*a*) EFFECT OF FERTILIZERS, MANURE, AND LIME.
   - (*b*) ACIDITY OF THE SOIL.
2. STUDIES ON THE SOIL EXTRACT.
   - (*a*) THE GENERAL PROBLEM.
   - (*b*) RESULTS OF EXPERIMENTS.
   - (*c*) DISCUSSION OF RESULTS WITH EXTRACT.

IV. COMPARISON OF RESULTS OF CULTURE EXPERIMENTS WITH THOSE OF PLOT EXPERIMENTS.

1. FERTILIZER PLOTS.
2. LIME PLOTS.
3. MANURE PLOTS.

V. CONCLUSION.

I. INTRODUCTION.

For many years plot experiments on the problems of productiveness in agricultural soils have been in progress at Wooster, Ohio, on the farm of the Ohio Agricultural Experiment Station. These experiments, carried on under the direct supervision of Prof. C. E. Thorne, have been so carefully planned and have extended over so long a series of years that the recorded results are very valuable for comparative studies.

The Bureau of Soils, desiring to determine whether the results obtained by its wire-basket and aqueous-extract methods of studying the productiveness and manurial requirements of soils[1] were in accord with those secured through plot experiments, found in the records of the Wooster experiments a valuable means to this end.

Accordingly, arrangments were made with Director Thorne for a co-operation between his station and the Bureau of Soils in the study of the Wooster soil, and a party from the Bureau took up this work at the Ohio Experiment Station on February 1, 1905. The aim of this work has been to determine how nearly the results given by the Bureau's methods mentioned above, when applied to the Wooster soil, can be correlated with those obtained by Director Thorne in his crop-rotation studies in the field. The results obtained, together with a comparison of these with Director Thorne's results from his five-year rotation experiments, and some theoretical discussion of the properties of the Wooster soil, make up the present paper.

An excellent general agreement is shown between the results obtained by the basket and aqueous-extract methods on the one hand and those of the plot experiments on the other. While this is so and while the new methods promise to be of very great value in rapid preliminary studies and in planning experiments to be carried out in the field, it is believed that the latter method should always be resorted to for conclusively answering questions on soil productiveness and soil management.

II. DESCRIPTION OF WOOSTER SOIL.

The following description of Wooster soil is quoted from Director Thorne:[2] "The soil here (the Station farm at Wooster) is a yellow, somewhat sandy clay, lying upon the upper rocks of the

[1]For description of this method, the reader is referred to Bulletin 23, Bureau of Soils, United States Department of Agriculture.

[2]Ohio Agricultural Experiment Station, Bulletin 110, 1899, Page 4.

Waverly series; it is of glacial drift origin, but is largely modified by the soft, sandy shales upon which it lies, and which have been ground up and mixed with materials derived from granites and limestones to the northward. The native rock is abundantly streaked with iron, and a liberal percentage of iron is found in the soil, as shown by its analysis.

"The original forest growth of this region was chiefly whit oak (*Quercus alba L.*), with a little admixture of red, scarlet and black oaks, and an occasional chestnut (*Castanea vesca L.*). The most striking arboreal feature is the thick undergrowth of dogwood (*Cornus florida L.*) which belts the forest with its white blossoms in early May.

"The topography of the country is rolling, due entirely to erosion, as the rocks lie in level strata. When the forest was cleared away the slowly decaying roots of the deep-rooting white oak furnished channels of drainage through the thin sheet of clay to the loosely stratified rocks below, and through their rifts and seams the drainage waters percolate to feed the multitude of springs for which the region is famous. But as the roots decayed more completely the plow and the trampling of teams and pastured stock obliterated these natural channels, and artificial drainage became necessary."

This soil has been mapped and described, under the name of Volusia silt loam, by Caine and Lyman, in Field Operations of the Bureau of Soils, U. S. Department of Agriculture, 1904. It has also been described, under the name of Wayne silt loam, by Selby and Ames, in Bulletin 150 of the Ohio Agricultural Experiment Station.

Data from mechanical and chemical analyses of this soil are given by Director Thorne in Bulletin 110, just cited, pages 6 and 7, and more complete data by Selby and Ames in Bulletin 150, pages 100—103.

A large section of the Station farm has been devoted to experiments upon the effect of systematic crop rotation, extending over a long term of years. At the same time other experiments have been carried on to test the effect of various fertilizer ingredients alone and in different combinations, attention being given especially to the relative value of the various carriers of nitrogen and phosphoric acid. The effect of lime upon these soils has also been carefully investigated, and the results thus far obtained, both by field and culture methods, indicate that very marked results may be expected from the use of this substance.

The five-crop rotation experiments, with the results of which the present work has to deal, occupy sections of the "East Farm". These plots were prepared in 1893 and have been in continuous rotation since that year. The rotation used is corn, oats, and wheat, each one year, followed by clover and timothy, two years.[1] Fertilizers are applied only upon the first three crops; "the clover and timothy follow as gleaners".[2] For a full description of the method of treatment and study, the reader is referred to Bulletin 110 of the Ohio Station.

III. CULTURE EXPERIMENTS ON WOOSTER SOIL.

I. STUDIES ON THE SOIL ITSELF.

(*a*). Effect of fertilizers, manure and lime. The samples used in the basket culture experiments were taken from a small area of about one acre which had been used for several years past in a variety test of grasses. The area was in sod at the time the samples were collected, and had just received an application of about 8 tons of manure per acre. Prior to this time it had not received any fertilization, with the exception of an undetermined quantity of manure applied five years before.

A composite sample was taken by cutting out a section one foot square and seven inches deep from four different places in the area. The soil, which was covered with snow and frozen to a depth of 7 nches at the time of sampling, was thawed out in the green-house and allowed to dry sufficiently to permit of thorough pulverizing and mixing. The sods which were taken with the soil were finely ground in a food cutter and mixed evenly throughout the entire sample.

A preliminary determination of the optimum water content for the soil under experiment showed it to be about 20 per cent. Thirty wheat seedlings were grown by the basket method for a period of nineteen days, from February 16 to March 13, in each of 3 samples of soils, one containing 16 per cent of water, another 20 per cent, and the third 22 per cent. The total transpiration of these cultures for the last nineteen days of the period were: for the first, 636 grams; for the second, 663 grams, and for the third, 636 grams. Total transpiration being a fair measure of the growth of wheat in such cultures,[3] this experiment points clearly to the fact that 20 per cent of moisture is about the optimum for wheat in this soil.

[1] C. E. Thorne, Bulletin 110, Ohio Agricultural Experiment Station, page 3.

[2] C. E. Thorne, Loc. cit.

[3] Livingston. B. E., Relation of transpiration to growth in wheat, Bot. Gaz. 40, 178-195, 1905.

The first series of baskets was planned to determine the effect of the three most important fertilizer constituents; nitrogen, potash, and phosphorus, and of lime and stable manure. All these substances were used alone and in combination with one another. The fertilizers used were, in all cases, taken from the stock commercial fertilizers used at the Experiment Station, and the names used are those familiar to the trade. Nitrogen was applied in the form of nitrate of soda, potash in the form of sulphate of potash, and phosphoric acid in the form of acid phosphate. The amount of these used was 100 parts per million by weight, calculated upon soil containing 10 per cent of water. This is approximately equivalent to an application of 200 pounds per acre, (the calculated weight of soil to 7 inches in depth, being 2,000,000 lbs. per acre.) an amount often applied in practice. The lime used was taken from a sample of ground quick-lime which had been standing in the air for several months, so that a large percentage of it had undoubtedly passed into the carbonate form. The sample of manure was taken from the bottom of a pile of horse-stable manure which had lain for some time in an open yard, but was not thoroughly decomposed. The sample was dried, finely ground, and applied in the solid form. The results of this series are given in Table I.

The cultures grew from February 15 to March 13, transpiration being taken after February 21. Five baskets, each containing 6 wheat plants, were used for each treatment. In the table the first column shows the number of the series; the second the treatment of the soil; the third the total amount of water lost by transpiration during the period, expressed in grams; the fourth the percentage variation of the transpiration from the transpiration of the cultures in untreated soil, the latter being considered as unity; the fifth the green weight of tops at the end of the culture, these being cut off at the surface of the soil, and the sixth, the percentage variation of green weight computed on the green weight of the culture in untreated soil considered as unity.

From these data the following conclusions may be drawn:

1. Neither acid phosphate (No. 2, Table I.) nor sulphate of potash (No. 3, Table I), in the proportion used, is distinctly beneficial in itself.

2. Nitrate of soda when used in combination with one or both of the above named salts (Nos. 4, 5, 6, Table I), produces a well marked increase in growth, the improvement amounting to from 29 to 42 per cent by transpiration and from 46 to 62 per cent by green weight. It is to be noted that the greatest beneficial effect was exhibited in the case where all three fertilizers were combined.

TABLE I.—Total transpiration, and green weight of tops of 30 wheat plants grown in Wooster soil untreated and with various manurial treatments.

No. of series.	Treatment of soil.	Total transpiration.	Increase over untreated soil.	Green weight of tops	Increase in weight, treated over untreated soil
		grams	per cent	grams	per cent
1	Untreated.	592	..	5.80	..
2	Acid phosphate, 100 p. p. m.	562	—5.1	5.79	—0.2
3	Acid phosphate and sulphate of potash, each 100 p. p. m.	616	4.1	6.60	13.8
4	Acid phosphate and nitrate of soda, each 100 p. p. m.	766	29.4	8.50	46.5
5	Sulphate of potash and nitrate of soda, each 100 p. p. m.	795	34.3	8.45	45.7
6	Acid phosphate, sulphate of potash and nitrate of soda, each 100 p. p. m.	843	42.4	9.40	62.0
7	Lime, 1000 p. p. m.	708	19.6	7.00	20.7
8	Lime, 2000 p. p m.	866	46.3	10.35	78.4
9	Lime, 1000 p. p. m; acid phosphate, 100 p. p. m.	728	22.9	7.10	22.4
10	Lime, 1000 p. p. m; acid phosphate and sulphate of potash, each 100 p. p. m.	708	19.6	7.60	31.0
11	Lime, 1000 p. p. m; acid phosphate and nitrate of soda each, 100 p. p. m.	978	65.2	11.30	94.8
1	Lime, 1000 p. p. m; sulphate of potash, and nitrate of soda, each 100 p. p. m.	923	55.9	10.30	77.5
13	Lime, 1000 p. p. m; acid phosphate, sulphate of potash, and nitrate of soda, each 100 p. p. m.	892	50.7	10.20	75.8
14	Manure, 10000 p. p. m.	756	28.8	8.80	51.8
15	Manure, 10000 p. p. m, acid phosphate, 100 p. p. m.	717	21.1	8.10	39.6
16	Manure, 10000 p. p. m; acid phosphate and sulphate of potash, each 100 p. p. m.	717	21.1	8.10	39.6
17	Manure, 10000 p. p. m; acid phosphate and nitrate of soda, each 100 p. p. m.	892	50.7	10.00	72.4
18	Manure, 10000 p. p. m; sulphate of potash and nitrate of soda, each 100 p p. m.	874	47.6	11.40	96.5
19	Manure, 10000 p. p. m; acid phosphate, sulphate of potash and nitrate of soda, each 100 p. p. m.	846	42.8	11.00	89.6
20	Manure, 10000 p. p m; lime, 1000 p. p. m.	943	59.3	10.80	86.2
21	Manure, 10000 p. p. m; lime, 1000 p. p. m; acid phosphate, 100 p p. m.	796	34.6	9.60	65.5
22	Manure, 10000 p. p. m; lime, 1000 p. p. m; acid phosphate and sulphate of potash, each 100 p. p. m.	759	29.3	9.30	60.3
23	Manure, 10000 p. p. m; lime, 1000 p p. m; acid phosphate and nitrate of soda, each 100 p. p. m.	958	61.8	12.10	108.5
24	Manure, 10000 p. p. m; lime 1000 p. p. m; sulphate of potash and nitrate of soda, each 100 p. p. m.	973	64.3	11.30	94.8
25	Manure, 10000 p p. m; lime, 1000 p. p. m; acid phosphate, sulphate of potash and nitrate of soda, each 100 p. p. m.	862	43.9	6.50	12.1

3. Lime applied in the proportion of 1000 parts per million, or about 1 ton per acre, (No. 7, Table I) produced an increase in growth of about 20 per cent by transpiration and 21 per cent by green weight, while an application of 2000 parts per million (No. 8, Table I) gave an increase of 46 per cent by transpiration and 78 per cent by green weight.

4. When lime is used in combination with acid phosphate (No. 9, Table I), or with acid phosphate and sulphate of potash (No. 10, Table I), the beneficial effect produced is not markedly greater than that obtained from the use of lime alone.

5. When lime is applied with nitrate of soda, and either acid phosphate (No. 11, Table I), or sulphate of potash (No. 12, Table I), a very marked beneficial effect is manifest, an effect which is not increased when both acid phosphate and sulphate of potash (No. 13, Table I) are used.

6. Stable manure of the particular sample used, when applied at the rate of 10,000 parts per million, or approximately 10 tons per acre-foot (No. 14 Table I), gave an increase in growth of about 29 per cent by transpiration and 52 per cent by green weight. This is about the same as the increase obtained from the application of nitrate of soda together with acid phosphate (No. 4, Table I) or sulphate of potash (No. 5, Table I), each at the rate of 100 parts per million or 200 pounds per acre foot.

7. The same application of manure accompanied by acid phosphate either alone (No. 15, Table I) or with sulphate of potash (No. 16, Table I), each in the proportion of 100 parts per million, gave an increase of only about 21 per cent by transpiration and 40 per cent by green weight. It is evident therefore that these fertilizers do not increase the beneficial effect produced by manure alone and that they may even decrease this effect, although the differences noted are hardly large enough to be considered.

8. On the other hand the three treatments in which manure was used in the same proportion, but with nitrate of soda together with acid phosphate (No. 17, Table I), sulphate of potash (No. 18, Table I), or both (No. 19, Table I), the fertilizers being applied at the rate of 100 parts per million, exhibit a very marked increase in growth above the treatment with manure alone. No considerable differences are evident in these three combinations, the average increase of growth of the three being 47.03 per cent by transpiration and 86.16 per cent by green weight. It will be observed that this increase is considerably less than the sum of the increases obtained from application of manure alone and of sodium nitrate with acid phosphate or sulphate of potash or both.

9. The same application of manure accompanied by lime in the proportion of 1000 parts per million (No. 20, Table I) gives a much greater acceleration of growth than does the manure when used alone, the increase amounting to about 59 per cent by transpiration

and 86 per cent by green weight. Furthermore, when manure and lime are used together the resulting increase in growth is considerably larger than the summation of the increases when the two are used separately. The sum of the separate increases due to manure and to lime (Nos. 14 and 7, Table I) is 48.4 per cent by transpiration and 72.5 per cent by green weight.

10. The increase due to the combined use of manure and lime is apparently not magnified but seems to be diminished by the addition of acid phosphate (No. 21, Table I) or acid phosphate and sulphate of potash (No. 22, Table I).

11. The increase due to combined manure and lime is not markedly affected by the addition of nitrate of soda together with acid phosphate (No. 23, Table I), or sulphate of potash (No. 24, Table I), but it is apparently diminished by the addition of nitrate of soda together with both of the other salts (No. 25, Table I).

From these results it appears that lime, stable manure, and nitrate of soda (used with acid phosphate, sulphate of potash, or both) are markedly beneficial upon Wooster soil; that a greater effect may be obtained by using any two of the beneficial substances in combination, but that the use of all three in combination produces an increase only about as great as the combined effect of two. We may also conclude that acid phosphate and sulphate of potash have no marked beneficial effect upon the basket cultures and that when used in combination with the other substances which do have a good effect they fail quite uniformly to magnify the effect already produced. From another experiment on the same soil it was found that, while lime is much more effective in the proportion of 2000 than in that of 1000 parts per million, when used at the rate of 4000 parts per million it ceases to be beneficial and may even be injurious.

(*b*) Acidity of the soil. An examination of the Wooster soil indicates that its acidity is apparently due not to a mineral but to an organic acid. The soil itself is decidedly acid to litmus paper, and to a slightly alkaline solution of phenolphthalein, but not to methyl orange. The aqueous solution of the soil is only slightly acid,[1] as compared with the soil itself, showing that the acid substance is removed to only a small extent by treatment with water.

[1]This slight acidity of the soil extract is more easily recognized with a slightly alkaline solution of phenolphthalein than with litmus, but this is due to the greater sensitiveness of the former indicator. When a carefully prepared neutral litmus solution is used as an indicator, with a sufficiently large amount of soil extract, the acid reaction is readily and definitely shown Litmus paper contains always a trace of alkali, and is therefore not sensitive to small amounts of acid.

This acidity, though relatively slight, persists even after boiling for a considerable time, or after concentrating the solution to one-tenth of its original volume, which is evidence that the reaction is not due to carbonic acid. Since the solution, either in its diluted or concentrated form, does not show an acid reaction with methyl orange, it follows that the acid present belongs to the class of weak acids, being either some organic acid or possibly an acid phosphate. On heating the soil to redness for a sufficient length of time to burn out the organic matter and then treating with water containing litmus or phenolphthalein, the soil does not show an acid reaction, but, on the contrary, an alkaline one, indicating that theacidity of the soil is probably due to an organic acid and not to an acid phosphate.

Considering the acidity of the soils of the Wooster farm, it seemed possible that this property might be the cause, or associated with the cause, of their lesser fertility, in a natural state and that the good effect of lime might be due to the power of this substance to neutralize the acid. In order to determine whether or not this is the case, an experiment was carried out to determine the effect of increasing the acidity of the soil and also that of neutralizing this acidity with other alkalies than lime. A sample of the original soil was treated with 250 parts per million of sulphuric acid (about 500 pounds per acre) and another sample received tartaric acid in the same proportion. A third sample was treated with sodium carbonate, and a fourth with sodium hydrate, both substances being added in the proportion of 1000 parts per million (about 1 ton per acre). These four treatments were compared with the untreated soil by basket cultures. The seeds were planted February 16, and the transpiration taken from February 22 to March 13. Five baskets were used in each case, each containing six seedlings. The data are given in Table II. Since the percentage variations from the control series with untreated soil are alone of interest in these discussions, the actual figures for transpiration and green weight are omitted from this and the following tables:

TABLE II.—Percentage variations in total transpiration and green weight of 30 wheat plants grown in variously treated Wooster soil, as compared with transpiration and green weight of the same number of plants in untreated soil.

No. of series.	Treatment of soil.	Percentage variation	
		In total transpiration.	In green weight.
1	Untreated	....	....
2	Sulphuric acid, 250 p. p. m.	4.9	12.5
3	Tartaric acid, 250 p. p. m.	—6.7	—6.6
4	Sodium carbonate, 1000 p. p. m.	8.7	13.2
5	Sodium hydrate, 1000 p. p. m.	5.4	19 1

From the results presented in this table it is apparent that a large application of either sulphuric or tartaric acid has no marked effect upon the growth of wheat seedlings in this soil. Therefore, since increase in the soil acidity by either a mineral or organic acid has no marked deleterious effect, the acidity of the soil cannot be considered as the chief cause of its unproductiveness. Furthermore, an application of either sodium carbonate or sodium hydrate has produced only a moderate increase. Since the order of these two increases by one criterion is the reverse of what it is by the other, it is probably fair to average the increases from the two treatments for each criterion. This gives an average increase by transpiration of 7.05 per cent and by green weight of 16.15 per cent. From Table I (7) it appears that an application of lime at the rate of 1000 parts per million, produces an increase of about 20 per cent by green weight. It thus appears that lime is considerably more effective than sodium carbonate and sodium hydrate. Since sodium is not toxic in such concentration, and since the two sodium alkalies have considerably greater power to neutralize acid than is possessed by lime, it must be concluded that the effect of the lime is not mainly due to neutralization of the soil acid. This corroborates the conclusion reached from the direct application of acid as stated above.

(2) STUDIES OF THE SOIL EXTRACT.

(*a*) THE GENERAL PROBLEM. The next step in the examination of this soil was to determine whether or not the causes of a lowered productiveness are transmitted to the aqueous extract, and if so, whether these can be corrected by the various treatments found to be effective in the soil itself. It has been found in the case of a number of soils that the causes of a low fertility are transmitted to an aqueous extract of the soil[1]. When this is the case, a means of studying the causes of unproductiveness is offered, which is often much more satisfactory than are studies made upon the soil itself. Where water cultures grown in soil extract show the same retarded growth as those in the soil, and where a fertilizer beneficial in the soil is also beneficial in the extract, it follows that some factor or factors other than the mechanical condition are effective in causing a low productivity. The hypothesis so often proposed in regard to poor soils, namely, that fertilizers exert an indirect influence upon plant growth by bringing into solution, and thus making available for plants, mineral nutrient material not otherwise dissolved does

[1]On this subject see Bulletins Nos. 23 and 28 of the Bureau of Soils; also Breazeale, J. F., Effect of certain solids upon the growth of wheat in water cultures. Bot. Gaz , 1905 and Livingston, B, E. Loc. cit.

not come into consideration in water cultures. Furthermore, it has been found that the infertility of several soils already studied is due to toxic substances which can be altered or removed by various treatments and that these substances are transmitted to an aqueous extract of the soil and are best studied by means of water cultures in the extract. From such studies it appears that the theory of de Candolle, published over one hundred years ago, which supposes exhausted soils to contain substances toxic to plants, may in a more or less modified form be found to have considerable truth in it.

(*b*) EXPERIMENTS AND RESULTS: The results of a considerable amount of work upon the growth of wheat in variously treated aqueous extract of Wooster soil will now be presented. The method employed was that described in Bulletins Nos. 23 and 28 of the Bureau of Soils.

One thousand grams of air-dry soil was shaken for three minutes with 1,250 cc. of distilled water, allowed to stand for 20 minutes, and then filtered under pressure through a Pasteur-Chamberland filter. The distilled water used was prepared in a small tin-lined copper still, and was found, in itself, to be very toxic to the roots of wheat seedlings. This toxic effect of the distilled water was found to be removed by shaking it with a small quantity of carbon-black, and then refiltering through a Pasteur Chamberland filter.[1] Accordingly, all the distilled water used in preparing the soil extract was first treated with carbon-black in this manner, so that any effect which has been obtained by treatment of the soil extract can only be considered as an effect upon the extract, and not upon the water which was used in its preparation.

The cultures were grown in wide-mouthed bottles of dark opaque glass, capacity about 60 cc., four seedlings previously sprouted in sand being placed in each; these were fixed in notches cut in the sides of the cork stopper so that the seeds were just above the solution while the roots were immersed in it. A group of three of these bottles constituted a culture unit and were weighed together in determining transpiration. The solutions were removed and replaced by fresh ones at intervals of two or three days, weighings for transpiration being made at these times.

Several experiments were carried out to determine whether this soil extract responds to treatment with fertilizers in the same way as does the soil itself, the same commercial materials being used as in the case of the experiments with soil, unless otherwise

[1]The effect of this treatment of toxic distilled water has been pointed out by Brazeale, J. F., Effect of certain solids upon the growth of wheat in water cultures. Bot. Gaz., 1905.

stated. One of these experiments ran for 9 days, from March 30 to April 8, 1905. Certain salts were added to the extract alone or in combination. The results of the experiments are given in Table III, which shows the several treatments and the percentage variations in transpiration as compared with the untreated extract. 36 plants were used in each treatment.

TABLE III.—Percentage variations in total transpiration of 36 wheat plants grown in extract of Wooster soil, with addition of fertilizer salts.

Treatment.	Percentage variations in total transpiration
Calcium carbonate, in excess	11.7
Nitrate of soda, 50 p. p. m.	6.6
Calcium carbonate in excess and nitrate of soda, 50 p. p. m	22.3

From these results it appears that the extract is markedly improved by calcium carbonate and by nitrate of soda, either alone or together. Other experiments showed a greater improvement due to nitrate of soda than was effected in this case.

Another experiment lasting from April 27 to May 11, 1905, with 36 plants for each treatment showed an increase due to calcium carbonate in excess and acid phosphate, 50 p. p. m., of 15.6 per cent by transpiration and 8.5 per cent by green weight. It appears then that the effect of calcium carbonate is not markedly increased by addition of acid phosphate.

More comprehensive experiments carried on with extract of another sample of this soil, taken from a strip along the ends of the plots devoted to the five-year rotation experiment, gave further valuable results. This soil sample was compared by means of basket cultures with the one described and used in the experiments already detailed, and produced approximately the same growth as the latter. The results given in Table IV are therefore comparable with those just given.

TABLE IV.—Percentage variation in total transpiration and green weight of 36 wheat plants grown in extract of Wooster soil with the addition of various fertilizer salts.

Treatment.	Percentage variation.	
	In total transpiration	In green weight.
Nitrate of soda	32.2	32.0
Acid phosphate, 50 p. p. m.	13.6	8.0
Sulphate of potash, 50 p. p. m.	10.5	29.0
Potassium nitrate, 50 p. p. m	36.5	57.0
Potassium acid phosphate. 50 p. p. m	34.2	35.0
Calcium nit. and potassium acid phos., each 50 p. p. m.	18.2	29 0

Nitrates seem to be very beneficial in this experiment, and the effect of calcium nitrate is also improved by addition of potassium acid phosphate. The effect of calcium phosphate is relatively not nearly so great and that of sulphate of potash is not large, the latter salt being actually injurious by the criterion of transpiration. The only treatment in the experiment wherein the extract seems to differ from the soil itself similarly treated is that of potassium acid phosphate, which gives a very marked increase, both by transpiration and green weight.

Soil from Plot 1 of the five-year rotation experiment was also studied by means of the extract. Basket cultures showed this soil to have very nearly the same productive power as the first sample used. This experiment ran from March 1 to March 17, with 36 plants in each treatment. The results are given in Table V.

TABLE V.—Percentage variation in total transpiration and green weight of 36 wheat plants grown in extract of Wooster soil with the addition of various fertilizer salts.

Treatment.	Percentage variation.	
	In total transpiration.	In green weight.
Sulphate of potash, 50 p. p. m.	1.1	10.6
Acid phosphate, 60. p. p. m	20.2	5.3
Sulphate of potash, 50 p. p. m. and acid phosphate, 60 p. p. m	35.8	27.4
Nitrate of soda, 50 p. p. m	57.6	25.7
Sulphate of potash, 50 p. p. m. and nitrate of soda, 50 p. p. m.	61.1	44 2
Nitrate of soda, 50 p. p. m. and acid phosphate, 60 p. p. m.	68.8	30.1
Lime,[1] 87 p. p. m. and manure extract, 2,500 p. p. m.	54.7	29.2

[1]As lime water.

From this series it appears that potassium sulphate is again without effect. Acid phosphate here shows a much more marked effect than is shown in the cultures with soil. The results in the extract agree well with those in the soil, in that nitrate and lime with manure produce a very marked improvement.

While it is evident from an analysis of the results of these experiments with basket and aqueous-extract cultures that the soil extract fails to show exactly the same improvement shown by the soil under any given treatment, we are warranted in drawing the general conclusion that the property inhibiting productivity is possessed by the extract in about the same degree as by the soil, and that the fertilizers which are decidedly beneficial in the latter are also markedly beneficial in the former. This being the case, a study of the properties of the soil extract promised to throw considerable light on the causes of low productivity in the soil. Recent investigations by the Bureau of Soils[1] lead to the conclusion that the low productivity of Takoma lawn soil is due to the presence of toxic substances, probably organic in their nature. The extract of the soil, as well as the soil itself, was found to be greatly improved for the growth of wheat by the addition of pyrogallol, which seems to act in some way upon the toxic bodies, rendering them, to a large extent, innocuous. It was also discovered that several insoluble bodies, most important among them calcium carbonate, carbon-black, and ferric hydrate, when applied in very finely divided form to both the soil and the extract, had the same effect, it is believed either through the alteration of the deleterious substances or through their removal by absorption. To determine whether the same effect might be produced upon an extract of Wooster soil by pyrogallol and the above named solids, several experiments were performed.

The carbon-black used was the some as that used on Takoma lawn soil. It had been prepared from burning petroleum and was thoroughly washed with hot water so as to be practically free from soluble matter. The ferric hydrate was prepared from ferric nitrate and ammonia and was likewise thoroughly washed. It contained only the faintest traces of ammonia and soluble iron.

TABLE VI.—Percentage variations in total transpiration and green weight of 32 wheat plants grown in extract of Wooster soil with the addition of pyrogallol, calcium carbonate, carbon-black, and ferric hydrate.

Treatment.	Percentage variation.	
	In transpiration	In green weight.
Pyrogallol, 20 p. p.m.	12	5.3
Calcium carbonate	44	30.9
Carbon-black	19	11.9
Ferric hydrate	29	13.3

Table VI presents the results of an experiment on the effect of the above mentioned bodies, using an extract of the first soil sample described in this paper. In using carbon-black 3 grams of the dry substance were added to each 360 cc. of extract. In the case of calcium carbonate 5 grams were used for the same amount of extract, and in the case of ferric hydrate an amount of this substance, still wet from the washing, equivalent to 5 grams in the air-dry condition. The experiment ran from May 1 to May 19. Two cultures of 16 plants each were made for each treatment. Table VI presents as usual the percentage variations in total transpiration. The variations in green weight are based in this case on the final weights of the entire plants and not upon those of the tops alone.

[1]Bul. No. 28, Bureau of Soils, U. S. Dept. Agr. 1905

It thus becomes evident that of these substances pyrogallol has the least beneficial effect and that the three solids have a marked effect, calcium carbonate being the most beneficial, ferric hydrate next and carbon black least so. The effect of calcium carbonate here agrees very well with the effect of lime when used on the soil directly. Ferric hydrate and carbon-black are always effective in producing a much greater development of roots, in proportion to that of the tops, than is obtained in the untreated extract.

Another experiment on extract of the same soil, lasting from May 15 to May 23, 1905, is presented in Table VII. Here pyrogallol was used in several different concentrations while carbon-black and ferric hydrate were combined. Sodium nitrate was added to the series for comparison.

TABLE VII.—Percentage variations in total transpiration and green weight of 3o wheat plants grown in extract of Wooster with the addition of pyrogallol, carbon-black and ferric hydrate, and sodium nitrate.

Treatment.	Percentage variation	
	In transpiration.	In green weight.
Pyrogallol, 20 p. p. m	4 2	10 5
Pyrogallol, 40 p. p. m	18.3	4.6
Pyrogallol, 60 p p. m	21.2	0 0
Carbon-black and ferric hydrate	32.5	58 1
Nitrate of soda, 100 p p. m	35.8	59 3
Pyrogallol, 20 p. p. m. and nitrate of soda, 100 p. p. m	41 6	65 1

Increasing the amount of pyrogallol above 20 parts per million, while it seems to produce a considerable increase by transpiration, fails to produce a like increase by green weight. Thus it is impossible to consider this chemical as producing a definite beneficial effect upon the soil. The two solids combined have an effect a little greater than that found in the last experiment for ferric hydrate alone. Nitrate of soda is markedly beneficial and the good effect is apparently increased by the use of pyrogallol in combination with it. It is to be noted in passing that the effect of the two solids used together is practically identical with that of nitrate of soda used at the rate of 100 parts per million,and that the effect of this salt upon the extract is slightly greater than it appeared to be on the soil itself.

Results from still another experiment on the same extract, involving pyrogallol, 5 parts per million, ferric hydrate and carbon-black in combination, acid phosphate, and calcium sulphate are given in Table VIII. The experiment lasted from April 27 to May 11, 1905, and comprised 36 plants for each treatment.

TABLE VIII.—Percentage variations in total transpiration and green weight of 36 wheat plants grown in extract of Wooster soil, with the addition of pyrogallol, carbon-black and ferric hydrate, acid phosphate, and calcium sulphate.

Treatment.	Percentage variation	
	In transpiration.	In green weight.
Pyrogallol, 5 p. p. m.	2.9	10.2
Carbon-black and ferric hydrate	36.2	15.0
Acid phosphate, 100 p. p. m.	2.5	18.6
Calcium sulphate, 150 p. p. m.	15.0	13.5
Calcium sulphate, 150 p. p. m., and pyrogallol, 5 p. p. m.	6.0	1.6

It is seen from Table VIII that pyrogallol in still smaller amount than that used in the previous experiments has about the same effect. The two solids also have practically the same effect as that obtained before by the same treatment. Acid phosphate, although it has produced an increase of 18.6 per cent by green weight, has been markedly injurious according to the transpiration figures and must be considered as of doubtful benefit. Calcium sulphate shows a well-marked gain but this is not nearly so great as that obtained from calcium carbonate in this same extract. Finally, pyrogallol, 5 parts per million, fails to increase the effect of calcium sulphate, but on the contrary almost destroys that effect.

In an experiment on the extract of Plot 1 of the five-year rotation experiment, lasting from February 9 to February 27, 1905, and cantaining 36 plants for each treatment, the extract was shaken with carbon-black and the solid filtered out and the filtrate compared with the untreated extract by water cultures. The result showed that by this treatment the extract was improved 8.4 per cent by transpiration and 2.9 per cent by green weight.

(*c*) DISCUSSION OF RESULTS WITH EXTRACT.

From the experiments on wheat cultures in extract of Wooster soil it may be concluded that the addition of the following substances to the extract accelerates the growth of the plant to a marked degree; nitrates of soda, potash and calcium; calcium carbonate; carbon-black, and ferric hydrate. Various combinations of these substances in pairs have a marked beneficial effect, this effect being considerable greater than that of treatment by either substance singly, and sometimes approximating the summation of the separate effects of the two.

The effect of the nitrates would naturally be explained at first thought on the ground that these increase the amount of nutrient materials in the extract. However, practically as good results are obtained both in the soil and in its extract, with calcium carbonate, and the combination of carbon-black and ferric hydrate gives nearly as good results in the extract as calcium carbonate. The effect of calcium carbonate cannot be explained by the fact that since it is slightly soluble it increases the amount of calcium in the solution; for the extract itself contains about 10 parts per million of calcium, which amount is amply sufficient for the growth of the seedlings. Neither can it be explained by supposing the rôle of the calcium salt to be that of neutralizing the slight acidity of the extract, for calcium carbonate has the same effect in the soil and here the mere neutralizing of the acidity has been already shown to have but little effect in accelerating growth. The beneficial results derived from the use of carbon-black and ferric hydrate do not suggest any explanation on the ground of changes in the nutrient value of the solution. It is well known that such solids are great absorbents and if they were to affect the solution in this way at all they should remove from solution some of the salts originally present. Their absorbent power for salts is probably rather slight, however, and it is not probable that they have any marked effect in this way.

The only other possible explanation of the action of calcium carbonate, and the only possible explanation of the action of ferric hydrate and carbon-black, seems to be that given in the case of Takoma lawn soil already cited, namely, that there is present in the soil and in the extract some toxic substance or substances which are absorbed or changed by these solids so as to lose their power of retarding plant growth. The calcium salt may act chemically upon the toxic bodies as well as by absorbing them; indeed, the process of absorption itself may bring about chemical changes of far-reaching importance. That calcium sulphate in solution has a considerable beneficial effect makes it appear as if toxic bodies which may be present in the soil were acted upon by this salt. The beneficial effect of calcium sulphate cannot be explained on the supposition that it increases the amount of plant nutrient salts in the solution, for such consideration in regard to calcium is ruled out of account by the argument given above for the carbonate, and increase in the sulphate has been shown by the experiments to have no good effect.

Therefore it appears that the evidence from these investigations is in favor of the conclusion that Wooster soil contains substances which are deleterious to plant growth. These substances are apparently similar to those of the Takoma lawn soil in some respects. They seem to be largely corrected by the use of calcium carbonate, ferric hydrate, and carbon-black. They are accompanied by an acid reaction of soil and solution, but the acidity does not appear to be the injurious factor. On the other hand these toxic bodies seem to differ from those of the Takoma lawn soil in that, while the latter soil is markedly improved by pyrogallol, Wooster soil fails to show any such definite effect with this chemical.

The hypothesis of toxic substances in this soil is supported by a fact observed in experimenting with the extract, that diluting this solution to 2, 4, and even 10 times its original volume produces no marked effect either beneficial or deleterious. Neither does concentrating the extract to one-tenth its original volume have any marked effect. It would appear from this that the toxic bodies are present in minute quantities, and that they are nearly equally active over a wide range of concentration.

IV.—COMPARISON OF RESULTS OF CULTURE EXPERIMENTS WITH THOSE OF PLOT EXPERIMENTS

(1.) FERTILIZER PLOTS.

The five-year rotation experiments of the Ohio Agricultural Experiment Station were begun in 1893. In making a comparison of these with the results here reported from cultures in baskets and in soil extract it seems best to consider only the yield of wheat obtained from the plots for the first year. It appears from Director Thorne's work with this soil that the effect of several of the fertilizer salts, especially phosphate, is cumulative, and that soils treated with these gradually improve during a number of years.[1] For this

[1]This cumulative effect of the fertilizers is shown by the following comparison of the total amounts of increase in yield per acre of the several crops at Wooster for the two 5-year periods 1894-1898 and 1899-1903.

COMPARISON OF TOTAL INCREASE IN YIELD, IN POUNDS PER ACRE, ON WOOSTER SOIL FOR THE PERIODS 1894-1898 AND 1899-1903.

Plot No.	Fertilizer treatment.	Indian corn		Oats		Wheat		Clover		Timothy	
		1894-1898	1899-1903	1894-1898	1899-1903	1894-1898	1899-1903	1894-1898	1899-1903	1894-1898	1899-1903
2	Acid phosphate...	280	969	254	622	614	1478	389	273	186	67
3	Muriate of potash......	261	647	77	265	287	131	113	36	336	35
6	Acid phosphate and nitrate of soda	892	1720	563	1402	1301	2435	930	834	517	786
8	Acid phosphate and muriate of potash	790	1577	497	932	778	1678	690	420	337	441
9	Muriate of potash and nitrate of soda	265	762	192	481	340	463	342	465	225	501
11	Acid phos mur of potash and nitrate of soda .	1073	2094	1022	1753	1975	3009	989	1165	819	960

The cereal crops show a greater increase during the second period than during the first in every case excepting that of wheat on Plot 3, while these crops invariably show the same order of effectiveness for the different fertilizing applications, an order in which phosphorus alone ranks higher than potassium and nitrogen, and this combination higher than potassium alone. With clover, however, the increase (and total yield as well) is lower during the second period than during the first in every case excepting on Plots 9 and 11. With timothy, it is lower on Plots 2 and 3. These results on clover and timothy are apparently due to the increasing need of lime for these plants on this soil, and it is probably due to this need that the order of effectiveness is less regular for these crops than for the cereals.

reason the later results obtained in his experiments should not be compared with those obtained in the basket and bottle cultures. The soil used in the culture experiments is probably very similar to the soil of the five-year rotation plots at the time of the beginning of this experiment. While the treatments employed in the basket and bottle cultures were not identical with those used upon the plots in the fields, yet the former treatments were so arranged as to test the relative efficiencies of the same fertilizer ingredients as were used in the field work. Thus comparison is possible between the effects produced by nitrogen, potash, and phosphoric acid, as indicated by the two methods.

The yields of wheat obtained from variously treated plots of the five-year rotation experiment, which were in this cereal for the season 1893- 1894, are shown in Table IX, the data being given in bushels per acre for grain and in pounds per acre for straw.[2] The table also gives the percentage variation from the average yield of the five untreated plots.

TABLE IX. Yield of wheat on variously treated plots of Wooster soil for the season 1894.

Plot No.	Treatment of soil, Pounds per acre.	Yield.			
		Grain.		Straw.	
		Bushels per acre.	Per cent variation.	Pounds per acre.	Per cent variation.
1	Unfertilized	13.54	....	1,437	....
4	"	22 17	....	2,620	....
7	"	20 95	....	2,642	....
10	"	18.04	....	1,967	....
13	"	20.79	....	2,352	....
	Average of five unfertilized plots	19.1	....	2,036	....
2	Superphosphate, 160 lb.	13.62	—28 7	2,382	8.0
3	Muriate of potash, 100 lb.	24.92	30 4	2,805	27.7
6	Superphosphate, 160 lb., Dried blood, 40 lb., Nitrate of soda, 120 lb.	16 71	—12.6	2,847	29.1
8	Superphosphate, 160 lb., Muriate of potash, 100 lb.	18.87	—1.2	2,467	11.9
9	Muriate of potash, 100 lb., Dried blood, 40 lb., Nitrate of soda, 120 lb.	22.54	18.0	2,497	13.3
12	Superphosphate, 160 lb., Muriate of potash, 100 lb., Dried blood, 40 lb., Nitrate of soda, 200 lb	20.29	6.2	3,382	53.4

It will be noted at once that the percentage variations in the yield of the grain are not at all what should be expected from the

[1]These data are taken from Bulletin 110, Ohio Agricultural Experiment Station, December 1899, pages 8, 10, and 74. The percentage figures are calculated from them.

treatments. The negative results obtained in the yields of grain from Plots 2, 6, and 8, must be attributed to factors other than the fertilizers used. It is well known that the nature of the season affects the production of fruit or seed much more markedly than it affects vegetation growth. and seasonal peculiarities may be the cause of the negative yields noted. This question cannot be settled by a study of the data furnished by the following years, for the years 1895 and 1896 gave abnormally low yields on all plots, so low that these data have no comparative value, and the yields of 1897 already show in a marked degree the cumulative effect of phosphate above noted. Therefore the only data at hand upon the first effect of application of fertilizers to wheat on Wooster soil are embodied in the results of 1894.

In the case of the yield of straw the percentage figures appear to be more consistent with the treatments. Phosphate alone and the same in combination with the muriate of potash gave very small increases above the average yield of the untreated plots. Muriate of potash alone has a marked beneficial effect, amounting to 27.7 percent.[1] Phosphate in combination with the nitrogen-bearing materials, nitrate of soda and dried blood, gave 29.1 per cent increase, while muriate of potash in combination with the same materials gave 13.3 per cent increase. The treatment with all three fertilizer constituents, phosphate, potash, and nitrogen, gave by far the greatest increase, amounting to 53.4 per cent.

In the fertilizer experiments carried on by the Station, acid phosphate has caused a *decrease* in the yield of grain in wheat in 1891 at Columbus and in 1894 at Wooster, but in both instances the total crop has shown an increase. This is shown by the data given in Table X.

TABLE X. Effect of acid phosphate on wheat at Columbus in 1891 and at Wooster in 1894.

Plot No.	Fertilizer treatment.	Increase + or decrease — in pounds per acre					
		Grain.		Straw.		Total.	
		Col's 1891	Wooster 1894	Col's 1891	Wooster 1894	Col's 1894	Wooster 1894
2	Acid phosphate	—156	—168	+642	+550	+486	+383
3	Muriate of potash................	—102	+338	—427	+579	—529	+917
6	Acid phosphate and nit. of soda..	—180	—279	+1183	+212	+1003	— 57
8	Acid phos. and mur. of potash...	—204	— 67	+557	+ 50	+353	— 17
9	Nit. of soda and mur. of potash	+ 48	+212	+598	+305	+646	+ 93
11	Acid phos. mur. of potash and nit. of soda,......	—150	— 25	+2047	+991	+1897	+966
12	As plot No. 11......	—102	— 25	+2298	+1158	+2196	+1133

[1]This apparent increase, however, was probably due to a variation in the soil of the plot, since no such increase is shown on the other four similarly treated plots of the experiment.

TABLE XI. Increase (+) or decrease (—) per acre in yield of Indian corn with fertilizer treatments on Wooster soil.

Plot No	Fertilizer treatment	1893		1894		1895		1896		Average	
		Ear corn bushels	Stover pounds	Ear corn bushels.	Stover pounds.	Ear corn bushels.	Stover pounds.	Ear corn bushels.	Stover pounds	Ear corn bushels	Stover pounds
2	Acid phosphate	+1 00	+ 43	+0.73	+ 13	+3.68	— 63	+1.26	—293	+1.67	— 75
3	Muriate of potash...	—1 30	—123	+0.38	+ 97	—0.93	—274	+3.63	— 67	+0.44	— 92
6	Acid phos and nit of soda	+4 20	+210	+2 07	— 13	+11.54	+ 83	+6.06	+183	+5 97	+141
8	Acid phosphate and muriate of potash..... .	+1.80	+ 93	+3 17	+ 93	+5.31	+213	+3.69	+247	+3 49	+161
9	Muriate of potash and nitrate of soda.... ..	+0.20	— 13	—1 89	— 73	—4.56	+197	+1.85	+263	—1.10	+ 93
11	Acid phos., mur. of potash and nit. of soda...	+1 80	+110	+0.20	+113	+10.45	+357	+14 71	+317	+6 79	+222

From the above considerations it appears that treatment with all three fertilizers, and with some combinations of two of them comprising nitrogen, results in a marked improvement. From treatment with muriate of potash the improvement is marked but from phosphate treatment it is practically nil. The high percentage increase in the case of the former substance may well be abnormal. In 1899 this treatment gave a low increase compared to those containing nitrogen, and from the average yields of the years 1894 to 1902 inclusive, the increase is only 19 percent upon grain and the same on straw.

Comparison of the field results on straw with those obtained from the basket cultures shows a fair agreement. In the case of the basket cultures it was pointed out that the greatest increases were produced when all three fertilizer constituents were used, and that when the fertilizers were used alone, or in combinations of two, only those treatments comprising nitrate of soda showed any marked increase. Thus the two methods disagree in the effect of potash, but as has been pointed out, the increase obtained from muriate of potash in the field was probably abnormally high in 1894.

Although, as has been stated, the only available data regarding the first effect of applying fertilizers to wheat on Wooster soil are those derived from the single season of 1894, yet four crops of Indian corn have been grown on such land in the progress of the rotation, in the seasons of 1893 to 1896 inclusive. The crop of 1893 was very poor and as some slight changes were made in the plan of fertilizing for 1894 and the following years, it has never been reported. The results upon corn for these four seasons furnish corroboration of the conclusions above derived from wheat for the season of 1894. These results are given in Table XI.

As has been remarked above, under the system of rotation followed upon the plots of the five-crop rotation experiment, the soil soon reaches a condition in which it responds very readily to the application of phosphorus, and the effect of continued application of this fertilizer constituent is undoubtedly cumulative. The treatment of soil from one of the check plots, or of the soil extract from the same, with acid phosphate, shows an increase in transpiration, but not such a marked increase as is obtained in the field, where applications have been made repeatedly. The experiments bringing out this point follow:

Extract of soil from Plot 12, which has received a complete fertilizer in the field, was compared by the culture method with extract of that from Plot 1, one of the untreated plots, the latter extract having various treatments. Table XII gives the total transpirations and percentage variations, compared with the untreated extract, each treatment being tested by 36 wheat seedlings, grown from March 1 to March 17, 1905.

TABLE XII.—Total transpiration and percentage variations with 36 wheat plants grown in extract of soil from Plot 1, with the addition of various salts, compared with the untreated extract of Plots 1 and 12.

Treatment.	Total transpiration.	Percentage variation.
	Grams	
Extract of Plot 1, untreated	340	......
Same + Nitrate of soda, 50 p.p.m	556	63.5
Same + Acid phosphate, 50 p. p m	418	22.9
Same +Sulphate of potash, 50 p. p. m	336	— 1 3
Same + Sulphate of potash and nit. of soda, each 50 p. p. m.	581	70.9
Same + Sulphate of potash and acid phos., each 50 p. p. m.	461	35 6
Same + Acid phos and and nitrate of soda, each 50 p p m.	608	78 8
Same + Acid phos., sulphate of potash and nitrate of soda.	619	82 0
Extract of Plot 12, untreated	413	21 4

It will be noted from the table that the extract from Plot 12, which receives a complete fertilizer in the field, produced very much better plants that the extract from Plot 1, which is an untreated plot. Also that the application of either acid phosphate, or nitrate of soda produced a substantial increase, which was considerably magnified when they were used in combination with each other, or with potash. No increase was obtained here with potash alone. The largest increase was obtained by the use of a complete fertilizer, as has been the case with all the plot work as well as with the other culture experiments.

Another test of the soil extracts from Plot 1 and Plot 12 gave, for 19 days' growth of 36 seedlings, 463 grams transpiration for the former extract and 505 grams for the latter, an increase of 9.1 per cent in favor of Plot 12, which has received applications of a complete fertilizer.

An experiment similar to the ones just described, but with the soil itself in baskets, was carried on from February 16 to March 13, 1905, with 30 seedlings for each treatment. The treatments and results are given in Table XIII.

TABLE XIII.—Total transpiration and percentage variation of 30 wheat plants grown in basket cultures of the soil of Plots 1 and 12, the former also with the addition of acid phosphate and with a complete fertilizer.

Soil and treatment	Total transpiration	Percentage variation
	Grams	
Soil from Plot 1, untreated..................................	743	
Same+Acid phosphate, 100 p. p m.	798	7.4
Same+Acid phosphate, sulphate of potash, and nitrate of soda, each 100 p. p. m.	832	11 9
Soil from Plot 12, untreated..................................	794	6 9

The section of plots from which these soil samples were taken has produced a crop of wheat and two crops of grass since any fertilizer was applied. This probably explains the fact that by adding either acid phosphate, or the complete fertilizer, we have been able to produce better plants on Plot 1 with treatment than upon Plot 12, without treatment.

It will be noted that in every case, both in the extract and in the soil itself, much better growth has been obtained from Plot 12 than from Plot 1. It is also clear that the extract from Plot 1 responds to acid phosphate and to the complete fertilizer. These results agree very well, at least in the relative order of productivity for the different treatments, with the recent results obtained at the Station from the five-year crop rotation experiment. The results of the yield of wheat upon these plots for the year 1899 are given in Table XIV. They are taken from Bulletin 110 of the Station, page 74.[1] The percentage variations are derived from the average of the five nearest untreated plots in the. some manner as were those given in Table IX. The percentage variations obtained by similar treatment of soil extract from Plot 1 are brought from Table X and given here at the right for comparison:

[1]Similar results have been obtained in 1900 and 1901 and are published in Bulletin 124 of the Ohio Experiment Station.

TABLE XIV.—Yield of wheat on variously treated plots of Wooster soil for the season 1899.

Plot No.	Treatment of soil, pounds per acre.	Yield.				Per cent variation in similar treatments of soil extract of Plot 1. (See Table X.)
		Grain.		Straw.		
		Bushels per acre	percent variat'n	Pounds per acre	percent variat'n	
1	Untreated	4.42	....	635	....	....
4	"	7.67	....	1,140	....	....
7	"	5.83	....	810	....	....
10	"	5.33	....	770	....	....
13	"	6.25	....	725	....	....
	Average of 5 unfertilized plots	5.56	....	816	....	....
2	Acid phosphate, 160 lbs.	11.42	105.4	1,215	48.9	22.9
3	Muriate of potash, 100 lbs.	8.50	52.9	1,090	33.6	—1.3
6	Acid phosphate, 160 lbs., Dried blood, 40 lbs., Nitrate of soda, 120 lbs.	17.67	217.8	1,890	131.6	78.8
8	Acid phosphate, 160 lbs., Muriate of potash, 100 lbs.	15.08	171.2	1,535	88.1	35.6
9	Muriate of potash, 100 lbs., Dried blood, 40 lbs., Nitrate of soda, 120 lbs.	18.21	227.5	1,230	50.7	70.9
12	Acid phosphate 160 lbs., Muriate of potash, 100 lbs., Dried blood, 40 lbs., Nitrate of soda, 200 lbs.	24.67	343.7	2,820	245.6	82.0

TABLE XV.—Percentage variations in yield of wheat n variously treated plots of Wooster soil for the years 1894, 1899, and in the average yield from 1894 to 1902.

Plot number	Treatment.	Percentage variation in yield for years:					
		1894		1899		1894-1902 (Average)	
		Grain	Straw	Grain	Straw	Grain	Straw
2	Superphosphate, 160 lbs.	—28.7	8.0	105.4	48.9	84.3	80.1
3	Muriate of potash 100 lbs.	30.4	27.7	52.9	33.6	19.6	19.3
6	Acid phos, 160 lbs. dried blood, 50 lbs., nitrate of soda 120 lbs.	—12.6	29.1	217.8	131.6	142.3	141.5
8	Superphosphate, 160 lbs. muriate of potash, 100 lbs.	—1.2	11.9	171.2	88.1	123.8	94.5
9	Mur. of pot, 160 lbs., dried blood, 50 lbs, nitrated soda, 120 lbs.	18.0	13.3	227.5	50.7	24.9	34.3
12	Acid phos., 160 lbs mur. of potash, 100 lbs., dried blood 50 lbs., nitrate of soda, 200 lbs.	6.2	53.4	343.7	245.6	194.1	187.4

[1]Some slight changes in the treatment of some of the plots have been made during the nine years, but these are not important in this connection.

This comparison between the results obtained by the field and culture methods will be completed by the presentation of the average increases in yield due to the different fertilizers and fertilizer combinations for a period of nine years from 1894 to 1902. These figures have been obtained in the manner used for Tables IX and XII, from Bulletin 141 of the Ohio Agricultural Experiment Station. Since the percentage variations are alone of interest here, they alone will be given, and since these are mainly valuable in comparison with similar results already given for the single years 1894 and 1899, these two sets of data are brought from Table IX and XIV and are given in Table XV, together with the data on the average for nine years just mentioned.

It is at once seen that the percentage variations on grain and straw exhibit a much better agreement in the results from the average yields for the long period than in those from the yearly yields. This should be expected from the supposition that the discrepancies noted in the latter case are probably due to seasonal peculiarities, these tending to disappear in the average as time elapses. By arranging the treatments in the order of their beneficial effects as these are shown, on the one hand by field results from nine years work, and on the other by the results of the experiments with extract, some interesting information as to the relative efficiency of the methods is obtained. Such an arrangement is presented in Table XVI. The number of the plot is given in the first column and the treatment in the second column, and the figures placed opposite them in the three columns following are the serial numbers of these treatments when arranged in order of their effectiveness from the least to the most beneficial.

TABLE XVI.—Parallel arrangements of treatments numbered according to efficiency, as obtained from the field methods for nine years and from bottle cultures (Table X).

Plot number	Treatment.	Order of effectiveness of treatments.		
		In field method 1894-1902		In bottle cultures (See Table X.)
		Grain	Straw	
2	Phosphate	3	3	2
3	Potash	1	1	1
6	Phosphate and nitrogen	5	5	5
8	Phosphate and potash	4	4	3
9	Potash and nitrogen	2	2	4
12	Phosphate, potash, and nitrogen	6	6	6

From this table it is seen that the two methods agree in giving potash (Plot 3) the lowest place; in giving the fifth place to phosphate and nitrogen (Plot 6), and in giving the highest place to the complete fertilizer treatment (Plot 12). The treatment with phosphate (Plot 2) is given second place by the culture method instead of third as obtained from the field work, and that with phosphates and potash is given third place instead of fourth. This is very good agreement considering the nature of the work. The only considerable discrepancy is shown in the case of the treatment with potash and nitrogen (Plot 9), which is given fourth place by the bottle cultures and second place by the field experiments. It is impossible to explain this difference from any data at hand. On the whole, however, the agreement of the two methods is as perfect as is usually obtained with growing plants, the growth of which is greatly influenced by many factors which we are not as yet able to measure and control.

It appears from these considerations that, while, as in the case of all work of this kind, there are a few discrepancies, the general conclusions from the field experiments, both at the beginning in 1894 and in their more advanced stages, are in agreement with those from the experiments carried on by the methods of basket cultures and cultures in soil extract.

(2) LIME PLOTS.

The west half of each plot of the five-crop rotation experiment at the Station was limed in 1900, using slacked lime at the rate of 1 ton per acre. It will be noticed that this treatment gives the fertilizer of each plot with and without lime. Thus the results show the effect of lime when used with each of the fertilizers separately and with various combinations, and also the effect of lime upon the unfertilized soil. The effect of lime has been studied by Director Thorne since that time. He makes the following statement of the results of liming Wooster soil as shown by the wheat crop:[1] "Taking the first four unfertilized plots of Section E, on which this test was begun, we find that the average yield of the limed ends exceeded that of the unlimed by 7.50 bushels of wheat in 1902, and there were similar differences in the yields of the fertilized plots lying between. That these differences were not altogether due to natural superiority of the soil on the limed ends of the plots has been gradually brought out by the successive corn crops. Of the 120 plots on which the corn has been separately harvested in this test, only

[1]Ohio Agricultural Experiment Station, Bulletin 159, p. 185, 1905.

8 show as large a yield on the unlimed as on the limed portions. Moreover, other tests, with corn and wheat, are adding further evidence of the improvement in yield following the use of lime."

It thus appears that the results with lime obtained by means of the culture methods agree very well with those obtained by the field plots.

(3) MANURE PLOTS.

Barnyard manure chiefly from horses has been used on wheat on Plots 18 and 20 of the five-crop rotation experiment. On Plot 18 manure was added at the rate of 8 tons per acre, and on Plot 20 at the rate of 4 tons per acre. Plot 19, an untreated plot, lies between these two and is considered as a control experiment. The average results from the six years experiment, from 1894 to 1899, are given in Table XVII.[1]

TABLE XVII.—Results of plot experiments with manure on wheat. Average of six years.

Number of plot.	Treatment of soil. Pounds per acre.	Yield.			
		Grain.		Straw.	
		Bushels per acre	Percentage variation	Pounds per acre	Percentage variation
18	Horse manure, 16,000	13.18	62.7	1,642	95.0
19	Untreated	8.10	....	842	....
20	Horse manure, 8.000	11 81	45.8	1.394	65.5

These figures show clearly that in the case of yard manure, also, the results obtained by plot experiments agree perfectly with those obtained by the cultures. (See Table I.)

It thus becomes evident that the results of this work by the methods of wheat cultures in wire baskets and in soil extracts, lasting altogether only six months, are as consistent throughout with one another and with those obtained by the plot method at the Station for eleven years as the latter are among themselves. As was remarked in the introduction, this must not be considered to mean that these newer methods can in any way supplant that of field plots; the older methods must ever remain the source of final answers to questions of soil management and fertilizer practice. But the method of basket cultures and that of soil extracts should be of very great value in the solution of soil problems on account of their simplicity and the expedition with which they can be carried out.

[1]These data are taken from Bulletin 110, Ohio Agricultural Experiment Station, page 74.

EFFECT OF CONTINUOUS CROPPING AND ROTATION OF CROPS.

An experiment was carried out to determine whether or not the relative values of different crop rotations would be shown by the basket method. The soil used in this experiment was subjected to a three crop rotation, as follows: No. 1, wheat, clover, clover; No. 2, wheat, cowpeas, corn; No. 3, wheat, corn, oats; No. 4, wheat, oats, cowpeas; No.5, wheat, wheat, clover; No. 6, wheat, wheat, corn; No. 7, wheat, wheat, wheat.

The soil, which had previously been limed at the rate of 1500 parts per million, or approximately 1½ ton per acre, was placed in large wire baskets, each of which contained sufficient soil to fill five of the small wire baskets used in transpiration experiments. The first crop was planted March 9, and grew until April 4. The coarse roots were sifted out of the soil before planting the second crop, but nothing was applied, except in the case of No. 7, which received acid phosphate at the rate of 500 parts per million.

The second crop was cut on May 15, and the third crop planted without further treatment of the soil, with the exception of sifting out the coarse roots. This crop was cut on June 23, and the soil removed from the baskets.

On July 8 the soil from each rotation was put into five small baskets and planted with wheat in the usual manner, in order to determine the relative fertility by the transpiration method. Transpiration was taken from July 14 to July 29, and the data obtained are given in the following table:

Treatment				Transpiration	Green weight of plants
Basket No. 1,	wheat	clover	clover	670.5	5.30
" " 2,	wheat	cowpeas	clover	629.0	4.70
" " 3,	wheat	corn	oats	492.3	3.30
" " 4,	wheat	oats	cowpeas	646.8	5.20
" " 5,	wheat	wheat	clover	630.9	4.80
" " 6,	wheat	wheat	corn	510.2	3.80
" " 7,	wheat	wheat	wheat	522.0	4.80

It is to be noted that in every case in which a leguminous crop was included in the rotation, better plants were produced. The sample of soil which grew wheat continuously gave a trifle better results than the rotation of wheat with corn and oats, but this is no doubt due to the fact that the soil used for continuous culture received a heavy application of acid phosphate.

The results of this experiment, in addition to showing the value of leguminous crops, and the fact that the basket method is adequate to demonstrate this value, emphasize the necessity of knowing something in regard to the previous cropping of a sample of soil which is to be tested.

V. CONCLUSION.

The experiments carried on at the Ohio Agricultural Experiment Station during eleven years by the plot method and those carried on during the last six months by the culture methods of soil in wire baskets and of soil extract in bottles, agree in showing that the best results which have been obtained are those following the application of nitrate of soda in combination with acid phosphate, the application of lime or the application of manure. Being submitted to a five-crop rotation, this soil soon responds markedly to applications of phosphoric acid, and the effect of the continued application of this fertilizer is undoubtedly cumulative. This point being brought out equally well by both field and culture methods.

Additional conclusions brought out by the basket and bottle cultures are as follows:

1. The character of the soil, as far as its ability to produce plants is concerned, is transmitted to its extract, as is shown by the fact that the same results may be obtained by growing plants in the extract as are obtained by growing them in the soil itself.

2. The soil is acid, probably with an organic acid, but its present low productivity is not due to the acidity.

3. The beneficial effect of lime is probably due in great measure at least to other causes than its power to neutralize the soil acidity.

4. The evidence points strongly to the conclusion that this soil contains some toxic materials somewhat similar to, but still differing in some of their properties from, those found in the Takoma lawn soil investigated by the Bureau of Soils of the U. S. Department of Agriculture. It seems probable that the effect of lime on Wooster soil is largely due to its action, in some way as yet undetermined, upon these toxic bodies, and it may be that a large part of the effect produced by fertilizers and stable manure is due to some similar action on the part of these latter substances.

This page intentionally blank.