EFFECT OF SULFUR AND MANURE ON AVAILABILITY OF ROCK PHOSPHATE IN SOIL

BY P. E. BROWN
AND A. R. GWINN

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

AGRONOMY
Soil Chemistry and Bacteriology

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THE EFFECT OF SULFUR AND MANURE ON THE AVAILABILITY OF ROCK PHOSPHATE IN THE SOIL.

BY P. E. Brown and A. R. Gwinn.*

The use of phosphorus fertilizers is now a recognized necessity in all systems of permanent agriculture. However well supplied naturally, all soils gradually become depleted in phosphorous thru the removal of crops and this element must be returned if crop production is to continue satisfactory. Many soils, especially those under long continued cultivation, have been found to respond very profitably to phosphorus fertilization while even the newer, more fertile soils are approaching a condition where phosphorus will soon become the controlling factor of growth. The interest in phosphorus fertilizers is therefore becoming more widespread and the use of these materials is assuming much economic importance.

In this country there are two general sources of phosphorus for fertilizers, the bones of animals and certain minerals. Bones were first used to provide phosphate fertilizers and they are still used to a limited extent. Bone meal, however, is produced in such comparatively small amounts that it is of little importance in a general consideration of phosphorus fertilization. Mineral phosphates, of which there are vast deposits in this country, are the chief source of phosphorus in American agriculture. They are used either in the natural form, known as "rock phosphate," "raw rock phosphate" or "floats," or in the commercially prepared form of "acid phosphate." This latter material is produced by treating one ton of the raw rock with one ton of sulfuric acid and it contains approximately one-half as much of the element phosphorus as the untreated material. In raw rock phosphate, however, the phosphorus is in a form which is very slowly available for plants while in acid phosphate it is immediately available. The greater cost of the phosphorus in acid phosphate makes its use in preference to rock phosphate inadvisable unless crop yields are increased sufficiently to offset the greater expense involved.

The relative merits of these two fertilizers will not be discussed here as the question is not involved in the present work.

*Formerly research fellow in soil fertility.
The evidence from field experiments along this line is still far from conclusive, much conflicting data having been secured in different states under a wide variety of conditions.

The comparative cheapness of floats has led to many experiments to devise methods of treatment on the farm prior to use, or methods of application which would make the phosphorus more readily available. Composting with decaying organic matter has been tried again and again by many investigators but the data secured in these tests are conflicting. Increases in availability have been found in some cases while in others decided decreases occurred. No practical method has been devised for producing available phosphorus on the farm. The turning under of farm manure or of a green manure crop when rock phosphate is applied to the soil has been the method recommended for making the phosphorus available in the soil. While beneficial effects on crops from such a method of application have been noted in many cases, there are practical difficulties to be met, such as lack of farm manure or the loss of time and the cost involved in growing green manure crops and the results secured have also often been very unsatisfactory.

These facts, together with the increasing cost of acid phosphate, led Lipman to suggest the use of elementary sulfur for the purpose of making inert phosphates available. The studies of American and European investigators had shown the rapidity of the oxidation of sulfur, or sulfofication, in soils thru the action of microorganisms. Lipman purposed to use this reaction to bring about the production of sulfuric acid from sulfur and this acid reacting with the insoluble phosphate would presumably make it available in exactly the same way as is the case in the manufacture of acid phosphate.

The experiments reported along this line by Lipman, McLean and Lint (2) show that the assumption was correct. Large increases in water-soluble and citrate-soluble phosphorus were found when sulfur was added to soil along with rock phosphate.

The experiments were carried out in the laboratory with three soils for a period of 30 weeks and while increases in available phosphorus occurred in all cases throughout the experiment, the greatest gains were found after different incubation periods with the various soils. The oxidation of the sulfur in all cases paralleled the increase in available phosphorus and the acidity determinations showed very definitely that the production of sulfuric acid by sulfofication preceded the increases in available phosphorus. It was concluded, therefore, that composting under farm conditions one part of sulfur and two parts of floats might
constitute a satisfactory combination for the production of available phosphorus. It is suggested also that "in field practice, inert phosphates may probably best be made available by sulfur oxidation in a relatively concentrated medium, e. g., in a compost heap containing a relatively large proportion of both phosphorus and sulfur."

There is contained in this report of the work of Lipman, McLean and Lint a complete bibliography along the line of composting experiments with rock phosphate, the production of available phosphorus by the action of microorganisms and of salts on rock phosphate, sulfofication, and the early patents on the use of sulfur with rock phosphate in the field to increase its value. No references on these subjects will therefore be given here.

The purpose of the experiments reported in this bulletin was to determine the effect of sulfur and of farm manure on the availability of raw rock phosphate when the last two materials were applied in the amounts usually employed in ordinary farm practice and the sulfur in the proper proportion to react with all the rock phosphate used.

The relation between soluble phosphate production, the formation of sulfates and the sulfofying powers of the soils were also to be ascertained, with a view to throwing further light on the general occurrence of the process. The experiments were conducted in the greenhouse in order to obtain some idea of the results which might be expected in the field from the practical application of the process.

**EXPERIMENTAL.**

Two soils were employed in the experiment, both being obtained from the Wisconsin drift soil area. One was the dark brown to black loam on yellow clay loam, named Carrington loam by the Bureau of Soils, and comparatively high in organic matter. The other was the light brown to gray loam on yellow sandy clay loam, called Miami loam, and rather low in organic matter. The analyses of these soils for total and \( \frac{N}{5} \) HNO\(_3\) soluble phosphorus and for sulfur and sulfates showed the following percentages.

<table>
<thead>
<tr>
<th></th>
<th>Per cent Total P.</th>
<th>Per cent Soluble P.</th>
<th>Per cent Sulfur</th>
<th>Per cent Sulfates</th>
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<tbody>
<tr>
<td>Carrington Loam</td>
<td>.0873</td>
<td>.0324</td>
<td>.0490</td>
<td>.0032</td>
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<tr>
<td>Miami Loam</td>
<td>.0513</td>
<td>.0227</td>
<td>.0415</td>
<td>.0027</td>
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Thirty-two pots, each one gallon in size and with an opening at the bottom, were filled with nine pounds of soil, the Carrington loam being used in 16 pots and the Miami loam in the other 16. The experiment was then divided into two series: Series A, Carrington loam, and Series B, Miami loam. The treatments of the soils in the two series were identical, as follows:

**Pot Nos.** | **Treatment**
---|---
1, 2 | Check
3, 4 | 12 tons horse manure per acre.
5, 6 | 2000 lbs. rock phosphate per acre.
7, 8 | 500 lbs. sulfur per acre.
9, 10 | 12 tons horse manure and 2000 lbs. rock phosphate per acre.
11, 12 | 12 tons horse manure and 500 lbs. sulfur per acre.
13, 14 | 2000 lbs. rock phosphate and 500 lbs. sulfur per acre.
15, 16 | 2000 lbs. rock phosphate and 12 tons horse manure and 500 lbs. sulfur per acre.

The pots were all kept bare to allow of sampling for analytical work. After filling, sufficient water was added to each pot to bring the moisture content up to the optimum. The pots were then weighed and additions of water were made at regular intervals during the experiment to maintain a constant weight.

Samples of soil were drawn at the end of 3, 6, 9, 12, 15 and 20 weeks and the soluble phosphorus and sulfates determined. Three determinations of the sulfofying power of the soils were made at different intervals on both soils. The Carrington loam was sampled at the end of 6, 12 and 16 weeks and the Miami loam at the end of 16, 20 and 24 weeks. In order to secure representative samples, the entire contents of the pots were removed and thoroughly mixed before the samples were drawn. For the sulfofication tests, the usual precautions were observed to prevent contamination.

The available phosphorus was determined colorimetrically by a modification of the method of Truog (4).

Fifty grams of air-dry soil was shaken with 500 c. c. of N/5 nitric acid for five hours and immediately filtered. A known amount of the filtrate was evaporated to dryness, 25 c. c. of distilled water were added and a slight excess of a 10% NaOH solution. This was heated for a few minutes on the water bath and then all organic matter was oxidized by means of bromine water. Enough dilute nitric acid was then added to remove the excess of bromine. After allowing the solution to heat for a few minutes while covered with a cover glass it was taken to dryness. The evaporating dish was then placed in the oven at 110° C. for two hours. This residue was treated with 5 c. c. of
nitric acid (sp. gr. 1.07) and a little distilled water. The solution was filtered and the evaporating dish and filter paper washed with distilled water until the filtrate measured about 40 c. c., the filtrate being caught in a 50 c. c. volumetric flask. Four c. c. of ammonium molybdate solution were added and the filtrate made up to 50 c. c. After allowing the solution to stand for 20 minutes, it was read against the standard colorimetric solution.

The analyses for sulfates were made by the use of the sulfur photometer as advocated by Brown and Kellogg (1). One hundred grams of air-dry soil were shaken with 200 c. c. of distilled water for seven hours. After filtering, an aliquot was drawn off, barium chloride and oxalic acid added and the amount of sulfate present ascertained in the photometer. The sulfonation tests were carried out by weighing out 100 gm. portions of fresh soil in tumblers. One hundred milligrams of sulfur were then added and thoroughly mixed with each 100 gms. of soil. The moisture content was adjusted to the optimum and the tumblers incubated at room temperature for fourteen days. At the end of that time the sulfates were determined photometrically.

**AVAILABLE PHOSPHORUS.**

The term "available phosphorus" is used here to refer to that portion of the total phosphorus which is soluble in fifth normal nitric acid. It is realized, of course, that this does not strictly represent available phosphorus. Indeed, it is extremely doubtful if any of the methods in use at the present time do show available phosphorus. Fifth-normal nitric acid extracts somewhat larger amounts of phosphorus than other solvents for available phosphorus and the results given here are therefore undoubtedly too high. They are comparative, however, and as the differences are brought out very distinctly, the assumption seems well warranted that they indicate the actual differences in available phosphorus.

The results of the analyses for available phosphorus in Series A with Carrington loam are given in table I while those in Series B with Miami loam are given in table II. The results are also shown graphically in plates I and II.

Considering the results with the Carrington loam given in table I it will be seen that in the case of the check pots there was a gradual increase in the availability up to and including the ninth week after which there was a decline in every case up to the termination of the experiment. The manured pots showed
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TABLE II.—MIAMI LOAM: PER CENT PHOSPHORUS SOLUBLE IN N/5 NITRIC ACID.

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Plate I. Graph of results of analyses for available phosphorus in Series A.

Plate II. Graph of results of analyses for available phosphorus in Series B.
a somewhat higher availability than the check, but as before there was an increase up to the ninth week followed by a gradual decrease at the succeeding samplings. Where rock phosphate alone was applied there was a greater gain than where manure was added, the availability again increasing up to the ninth week and then decreasing at the following periods. The per cent that was soluble at the twentieth week was considerably higher than at the end of three weeks, while in the case of the check and manured pots the amount of decrease after nine weeks just about equalled the increase up to this point. Where sulfur alone was used, the percentage of soluble phosphorus at the end of the three and six weeks periods was about the same as in the check pots. At the end of nine weeks, however, the pots receiving sulfur were considerably higher in available phosphorus.

The results secured where the materials were used in combinations are somewhat more difficult to interpret. The pots receiving manure and rock phosphate showed a higher availability in all cases than those receiving rock phosphate alone. From this it is quite evident that the action of the decaying organic matter had been instrumental in producing soluble phosphorus. These results are quite in accord with those of Tottingham and Hoffman (3). In their work they found that although fermentation over periods of four to six months caused a decrease in soluble phosphorus in mixtures of manure and rock phosphate, very favorable results were secured when these two materials were applied to the soil. In other words, the conditions which prevail in the manure heap are quite different from those in the field.

The results with rock phosphate and manure at the various samplings, as in the case of the single treatments, showed an increase up to the ninth week and then a decrease. Manure and sulfur gave somewhat higher results than the manure alone, but as was to be expected, the increase was not great. At the ninth week again, the greatest solubility was found.

Examining the analyses of the rock phosphate and sulfur pots, it will be seen that the availability of the rock phosphate was accelerated by the use of sulfur. The gain over the check was greater than where manure was applied in connection with the raw rock. From these results it is apparent that the oxidation of sulfur was much more effective in producing soluble phosphorus from rock phosphate than was decaying organic matter. The per cent of available phosphorus increased up to the ninth week and then declined until at the end of the experiment...
it was practically the same as at the end of the three weeks' period.

Where all three materials were applied the greatest availability was secured. As in all previous cases, the availability increased up to the end of the ninth week and was followed by a decrease. The greatest effect of the sulfur, therefore, occurred at the nine weeks period. These results show that the combined action of manure, sulfur and rock phosphate brought about an increase in availability of the latter. The presence of the fresh organic matter and sulfur seemed to stimulate the organisms concerned to greater activity.

The decrease in soluble phosphorus after the ninth week can probably be explained by bacterial assimilation whereby it is either held within the bodies of the bacteria in a form which cannot be extracted by fifth-normal nitric acid or it is transformed into some insoluble compound of phosphorus.

Table II shows that somewhat similar results were secured with the Miami loam as were obtained where the Carrington loam was used.

In the check pots the per cent of availability increased slightly up to the ninth week after which there was a gradual decline. Where manure was added there was an accumulation of soluble phosphorus over the check. This increase was greater with this soil than it was with the Carrington loam which had a higher organic matter content. There was a slight gain up to the ninth week, then a decrease. The rock phosphate alone brought about an increase in soluble phosphorus over the manured pots. The availability remained about the same, up to the ninth week, after which there was a gradual diminution. Where sulfur was applied, the availability increased up to the ninth week, remained about the same at the twelfth week, and after that there was a decrease until at the end of twenty weeks the per cent of soluble phosphorus was lower than at the end of three weeks. This corresponds to what occurred in the other soil, except that the decrease was not so great in that case.

The manure and rock phosphate together brought about an increase over the rock phosphate alone. The greatest availability in this case was at the end of the first three weeks. After this there was a gradual decrease until the termination of the experiment. The increase over the rock phosphate alone was about the same as was noted in the case of the former soil. The manure did not seem to be any more effective on the light soil than on the one originally high in organic matter but the great-
The production of available phosphorus occurred in a much shorter time. The manure and sulfur showed a slight increase over the manure alone. The per cent of soluble phosphorus remained about the same up to the twelfth week, a decrease following at the last two samplings. The rock phosphate and sulfur when used together showed a marked superiority over the rock phosphate and manure. As was pointed out in the case of the former soil, the oxidation of sulfur was much more effective than the decaying organic matter in increasing the availability of the phosphorus. There was a gradual decrease in availability after the third week. This decline was not very great up to the fifteenth week, but there was a very pronounced drop at the last sampling. As before, the greatest availability of the phosphorus was secured when all three materials were applied. The largest production of soluble phosphorus was found at the end of three weeks after which there was a gradual decrease. The differences were not great, however, until after twelve weeks.

Altho the percentages of soluble phosphorus in Series B were not as high as in Series A, the per cent increases over the check due to the various treatments were greater. The lighter colored soil responded more readily to treatment than the one already high in organic matter. However, the latter was originally richer in total phosphorus and nitrogen, as well as in available phosphorus. From the results obtained with these two soils it is apparent that sulfur applied to the soil with manure and rock phosphate brings about a large increase in available phosphorus. This increase became gradually larger up to nine weeks after application in the case of the Carrington loam and then decreased slightly, while with the Miami loam the greatest effect occurred earlier. Evidently the rapidity of action depends on the soil employed in the test and will vary with different soils.

**SULFATES.**

The results of the sulfate analyses will be found in Tables III and IV and they are shown graphically in Plates III and IV. In a general way, it may be said that the amount of sulfates found may be correlated with the amounts of available phosphorus already discussed.

It will be seen in Series A that the pots receiving no additions of sulfur but treated with manure and rock phosphate alone showed practically the same sulfate content as the check
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pots. On the average the pots receiving rock phosphate were slightly higher in sulfates than either the check or manured pots but the differences are too small to be distinctive. For these three treatments, there is very little variation throughout the experiment.

Where sulfur alone was added the sulfates were much higher in all cases, as would of course be expected. The amounts were considerably higher at six weeks than they were at three, but after this time there was a continuous decrease at all succeeding samplings.

The manure and rock phosphate treated pots showed practically the same amount of sulfates in all cases as the check, being only slightly higher on the average. Where manure and sulfur were applied, a larger amount of sulfates were found than where sulfur was used alone. The organic matter seemed to stimulate sulfur oxidation in this soil, altho it was already high in organic material. As before, the greatest amount of sulfates was found at the end of six weeks, after which there was a gradual decline. Where rock phosphate was used in connection with the sulfur, the amount of sulfates was a little lower on the average than where manure was used. The greatest amount of sulfates was found at the end of six weeks and as before this was followed by a steady decrease at the following periods.

Where all three materials were used the amount of sulfates was still lower than where sulfur and rock phosphate were applied. As an average they were slightly higher than where sulfur was added alone, the greatest production of sulfates occurring at the second sampling, at the end of six weeks. The greatest availability of phosphorus where the three materials were applied occurred at the following period. It is very interesting to note that the period of the greatest production of sulfates preceded the period of the greatest availability of phosphorus. It would not be expected that these two periods would coincide exactly for after the sulfur has been oxidized to sulfuric acid some time would be required for its action on the raw rock before any change in the solubility of the latter could be brot about.

By referring to table IV, it will be observed that quite similar results as regards sulfates were secured with the Miami loam as with the Carrington. It is not necessary, then, to take up a discussion of these results in detail. As with the Carrington loam when the three materials were applied the greatest production of sulfates was at the end of six weeks. There was
then a gradual decline in the amounts to the termination of the experiment.

With this soil, when sulfur, rock phosphate and manure were applied the greatest availability of phosphorus occurred at the end of three weeks. The greatest availability might have occurred at some time between the three and the six weeks' period; likewise the greatest production of sulfates might have occurred between those two dates of sampling. So in this case, while the results do not show the greatest production of sulfates preceding the largest production of available phosphorus, analyses at the fourth or fifth week or preceding the three weeks test might have yielded more definite results. The action in this soil was evidently more rapid than in the other and the results should not to be considered to disprove the relation between sulfate production and available phosphate production.

It is interesting to note that in every case where rock phosphate was used in connection with sulfur, the production of sulfates was increased over the production where the sulfur was used alone. This bears out previous observations that phosphorus stimulates sulfur oxidizing organisms of the soil.

Considering the data for both soils it seems that the production of available phosphorus from the insoluble raw rock phosphate may be the result of the action of sulfuric acid on this raw rock. It is possible, however, that the increased production of available phosphorus may be the result of a direct action of bacteria on the raw phosphate but there is nothing in this experiment to disprove the claim that the action is due to sulfuric acid production entirely.

**SULFOFICATION.**

In table V are given the results of the tests of the sulfifying power of the variously treated soils. Plate V shows these results graphically. It can be seen readily that changes are brought about in the sulfifying power of the soil by different treatments. These changes may be due to alterations either in the physical or in the chemical composition of the soil. In some way the conditions of growth of the sulfifying organisms were affected and consequently the efficiency of the organisms was influenced.

With the Carrington loam it will be seen that where the soil was untreated the sulfifying power was the weakest just as was the case with available phosphorus and sulfur. Manure increased sulfosication slightly. Rock phosphate and sulfur in-
TABLE V.—SULFOFICATION:
†MGS. SULFUR OXIDIZED BY SOIL.

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<td>23</td>
</tr>
<tr>
<td>Phosphorus and Sulfur</td>
<td>174</td>
<td>96</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Manure, Phosphorus and Sulfur</td>
<td>182</td>
<td>110</td>
<td>41</td>
<td>47</td>
</tr>
</tbody>
</table>

†Average of three determinations

creased the sulfofying power to the same extent. This bears out previous observations that additions of phosphorus stimulate the activities of the sulfur oxidizing organisms. Where rock phosphate was applied, as has been pointed out, there was a marked increase in available phosphorus. This increase in soluble phosphorus may be attributed in part at least to the increased sulfofying power of the soil and hence a greater production of sulfuric acid. With a greater production of sulfuric acid, more available phosphorus would of course be produced.

Additions of manure and phosphorus together stimulated sulfofication still further. The effect was greater than that brought about either by manure or by rock phosphate alone. As was pointed out earlier, this application also caused an increase in available phosphorus. Where manure and sulfur were added together, there was no increase in sulfofying power over that produced by sulfur alone. Sulfofication was greatly accelerated by the application of rock phosphate and sulfur together.

By the oxidation of the sulfur, available phosphorus was eventually produced which apparently in turn stimulated the sulfur oxidizing organisms to further activity. There was also a great increase in soluble phosphorus where these two materials were used together.

As was the case with available phosphorus, the greatest activity of the sulfur oxidizing organisms was brought about where all three materials, manure, rock phosphate and sulfur were applied.

From this it seems quite evident that there was a relationship between the sulfofying power of the soil and the amount of available phosphorus produced. Where the sulfofying power
of the soil was increased by the different treatments, as has been pointed out, the production of available phosphorus was accelerated. Reciprocally, the production of available phosphorus increased the sulfofying power of the soil. The oxidation of sulfur to sulfuric acid, therefore, evidently is responsible for the production of much of the available phosphorus. It seems quite reasonable to assume that the use of sulfur may aid materially in making phosphorus available for plant use.

The results with the Miami loam differ in degree rather than in kind from those with the soil high in organic matter. Here again the untreated soil showed the lowest sulfofying power. Manure increased it more in the case of the light soil than with the dark soil. The former responded more readily to applications of organic material, as would be expected. The increases in sulfofication due to the addition of rock phosphate and sulfur alone were, however, not as great with this soil. The other results secured were practically the same as in the case of the Carrington loam. It is interesting to note that in every case except one where manure was added, the sulfofying power was increased more with the Miami loam than with the one originally high in organic material.

This correlation between the sulfofying power and the production of soluble phosphorus is not, then, a distinctive property of only one soil, but was found to exist in the case of two soils differing widely in chemical and physical composition.

DISCUSSION.

It has been shown in the foregoing work that under greenhouse conditions the availability of rock phosphate can be increased by applying either manure or sulfur with it. It also seems quite reasonable to assume from the experimental data that the rock phosphate is made available with sufficient rapidity to supply the needs of any growing crop. As an average, the increase in available phosphorus where sulfur was applied with the raw rock over that where the raw rock was applied alone was about 80 pounds per acre, where 2,000 pounds of rock phosphate were applied. This is more than is required for three one-hundred bushel crops of corn. These figures, of course, are based on results secured in a period of twenty weeks.

The increase in available phosphorus due to the action of the manure was not as great as that due to the action of sulfur. Sulfur oxidation, then, is more effective in producing available phosphorus than is the action of decaying organic matter.
Concluding then that such practices do increase the availability of rock phosphate to a sufficient extent for good crop production, the next question that arises is, “Can this be done profitably, or can the acid phosphate which already has its phosphorus in an available form be purchased and applied for less money?"

In the manufacture of acid phosphate, one ton of the raw rock phosphate is treated with approximately one ton of 60% sulfuric acid to produce two tons of acid phosphate. In one ton of 60% sulfuric acid, there is a little less than 400 pounds of sulfur. Now if all the free sulfur that is applied to the soil is oxidized, it will require only about 400 pounds to produce enough sulfuric acid to convert one ton of raw rock phosphate into an amount of acid phosphate containing the same amount of available phosphorus as is present in two tons of commercial acid phosphate.

Assuming that the raw rock will cost about $10.00 per ton, acid phosphate $20.00 per ton, and sulfur $40.00 per ton, the proposition can be considered from an economic standpoint.

The cost of the one ton of rock phosphate and the 400 pounds of sulfur which are necessary to produce the equivalent of the available phosphorus contained in two tons of acid phosphate would be $18.00. Two tons of acid phosphate would cost about $40.00, or more than twice as much as the rock phosphate and sulfur. Where the two materials are applied there would not of course be as much phosphorus available at any one time as if the acid phosphate were applied, but it has been pointed out that the phosphorus is made available from the mixture with sufficient rapidity to supply crop needs.

There is also another advantage in using the two materials. Sulfur has been found to be deficient in some soils, so this element itself may bring about increased production. Sulfur has also been found to stimulate the activities of certain micro-organisms in the soil. By these increased activities other insoluble plant foods may be converted into forms that are utilisable.

Manure was found to increase the availability of rock phosphate to an appreciable extent. Any fresh organic material would, no doubt, act in a similar manner. If sufficient quantities of manure are not available, the turning under of green manure crops would be very effective in bringing about a production of soluble phosphorus.

From the data at hand it appears that the use of sulfur in conjunction with raw rock phosphate, as well as applying ma-
nure with it, would be a profitable practice. Specific experiments in the field are necessary, however, before definite recommenda-
tions along this line can be made.

CONCLUSIONS.

The conclusions which may be drawn from the experiments with these two soils as to the effect of sulfur and manure on the availability of rock phosphate are as follows:

1. The addition of sulfur to the soil greatly increased the availability of raw rock phosphate.

2. Applications of manure increased the availability of rock phosphate, but the increase was less than where sulfur was applied.

3. There was a gain in availability with all treatments, but where sulfur and manure were both used with the rock phosphate, the gain was greatest, the time of greatest availability varying with the soil used.

4. In a general way, the production of sulfates paralleled the production of soluble phosphorus. With one soil the greatest production of sulfate preceded the largest production of soluble phosphorus, while with the other the tests were not made at the proper time to prove this point. They do not disprove it, however.

5. The physical and chemical composition of the soil greatly influenced the production of available phosphorus and sulfur.

6. Different treatments markedly affected the sulfofying power of the soil.

7. Phosphorus and manure increased sulfofication.

8. A rather definite relationship existed between the sulfofying power of the soil and the production of available phosphorus.

9. The type of soil affected the sulfofying power of that soil.

10. These conclusions should be confirmed by field experiments before application to general agricultural practice. However, so far as the results of pot experiments indicate conditions in the field, the results secured by applying sulfur and manure to the soil with rock phosphate appear to be of economic value.

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