SULPHUR IN RELATION TO SOILS AND CROPS

OHIO Agricultural Experiment Station

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BULLETIN 292

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BULLETIN

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SULPHUR IN RELATION TO SOILS AND CROPS

J. W. AMES AND G. E. BOLTZ

All crop plants have a greater or less content of sulphur existing as organic and inorganic compounds. Whether the amount found in plants in excess of that which has been elaborated into organic forms is required or is present merely as an unnecessary surplus, has not been determined, so far as we know. A comparison of the sulphur content of crops and soils shows that some species of plants assimilate sulphur in excess of other so-called essential elements from a less abundant soil supply. The sulphur assimilated by leguminous plants may be, and often is, in excess of the phosphorus; ordinary cereals contain approximately half as much sulphur as phosphorus, and the Cruciferae contain an amount of sulphur which exceeds that of phosphorus. This relation between the sulphur content of soils and crops has led to considerable attention being directed to the necessity of supplying sulphur.

Sulphates may stimulate plant growth both directly and indirectly, by supplying sulphur required for metabolic processes and by interaction with mineral constituents of the soil, thereby furnishing more available supplies of plant food. Whether acid phosphate in comparison with carriers of phosphorus not supplying sulphates has, in addition to its phosphorus content, a value which may be attributed to calcium sulphate has been considered in the experiments reported in this bulletin. Tests with other forms of sulphur, and the effect of sulphur on the production of acidity and the solubility of phosphorus are also included, although they are not so extensive as those regarding the effect of sulphates on crop production.

THE SULPHUR SUPPLY OF SOILS

ADDITION OF SULPHUR TO SOILS

Fertilizers and manure.—Sulphur is one of the constituents incidentally supplied by the more commonly used fertilizing materials, including acid phosphate, sulphate of potash, sulphate of ammonia and barnyard manure. Some of these materials furnish sulphur in quantities about equal to the elements of which they are used primarily as carriers. As commercial acid phosphate is about one-half calcium sulphate, 100 pounds will furnish approximately 8 pounds of sulphur. Potassium sulphate contains 18 percent of sulphur. Each 100 pounds of ammonium sulphate will supply approximately 24 pounds of sulphur in the form of sulphate. Basic slag contains a small percentage of sulphur. Barnyard manure furnishes an appreciable quantity, depending upon the composition of the feed and bedding, and upon conditions under which fermentation of the manure has taken place.

Rainfall.—Atmospheric precipitations carry to the soil varying amounts of sulphur, depending upon the proximity of cities, industrial plants or natural sources of gases containing sulphur. Kossovich[1] found that the quantity falling with the precipitation on an acre annually varied from 9 pounds in the country to 72 pounds in the neighborhood of towns and industrial works. This author states that the continuous introduction of sulphur from the atmosphere is essential to vegetation and for maintaining a supply to offset the rapid depletion of the supply of sulphur in the soil by leaching. The data available concerning the amount of sulphur in precipitations, as determined at several localities in the United States, indicate that from 6 to 7 pounds per acre can be regarded as a more nearly correct average of the quantity of this element returned to the soil in this way.

SULPHUR CONTENT OF SOILS

Analyses of typical soils.—The average sulphur content of soils is relatively small. Soils which are characterized by a liberal supply of organic matter generally have a higher percent of sulphur than those containing less vegetable and animal residues. A study of the sulphur content of Kentucky soils reported by Shedd[2] shows that in almost all instances the sulphur content was low, and in many soils the phosphorus content exceeded that of the sulphur. Shedd found that in almost every instance phosphorus fertilizing without manuring depleted the sulphur supply, and that in some instances the decreased sulphur content of cultivated soils, as compared with that of corresponding virgin soil, was considerable.

Hart and Peterson[3] report about the same quantity of sulphur as of phosphorus in normal soils, and call attention to the fact that the amount of sulphur removed by ordinary farm crops is about two-thirds that of phosphorus.

Table I gives the sulphur content of some representative soils. Of the soils analyzed, that described as Wooster soil is found to be lowest in sulphur, while the black soils designated as Clyde clay and Miami black clay loam contain the largest amount of sulphur. In these soils the sulphur content follows the order usually observed; namely, that an increased sulphur content is associated with an increased amount of organic matter.

TABLE I.—Total sulphur content of soils

Plot	Treatment for one 5-year rotation	Depth	Quantity per acre
	SOIL FROM SECTION D, 5-YEAR ROTATION FERTILITY EXPERIMENTS, WOOSTER	Inches	Pounds
	Unfertilized soil (1896)	0–6	472
	Unfertilized soil (1912)	0–6	412
2	Acid phosphate 320 lb.	0–6	440
11	Acid phosphate 320 lb.; muriate potash 260 lb.; nitrate soda 440 lb.; dried blood 50 lb.	0–6	438
24	Acid phosphate 480 lb.; muriate potash 260 lb.; ammonium sulphate 320 lb.; dried blood 25 lb.	0–6	472
26	Treatment same as 11 but phosphorus supplied by bone meal	0–6	362
29	Treatment same as 11 but phosphorus supplied by basic slag	0–6	500
18	Manure 16 tons	0–6	464
	STRONGSVILLE CLAY		
	Unfertilized and uncultivated	0–6	800
	Unfertilized and uncultivated	6–12	330
	Unfertilized and cultivated	0–6	730
	CLYDE CLAY		
	Unfertilized	0–6	1 056
	Unfertilized	6–12	830
	Unfertilized	12–18	686
	Unfertilized	18–24	528
	MIAMI BLACK CLAY LOAM		
	Unfertilized	0–6	1 112
	Unfertilized	6–12	906

Effects of fertilization and cultivation.—For the purpose of ascertaining the effects of fertilization and cultivation upon the sulphur content of soils of known history, soil was analyzed from several of the plots in the 5-year rotation fertility tests at the Ohio Station, which at the time of sampling had been treated for 16 years as designated. Some slight variations occur in the results for the differently fertilized plots which may be due to the treatment. The soils from plots to which sulphur-carrying fertilizing materials were applied have a somewhat larger sulphur content than corresponding unfertilized soil. The plot treated with ammonium sulphate contained more sulphur than a similarly treated plot where nitrate of soda furnished the nitrogen. Plots 2 and 11 have received the same amounts of calcium sulphate in the like quantities of acid phosphate applied to both plots. Although larger crop yields have been obtained on Plot 11, the analysis of the soil from this plot shows about the same quantity of sulphur present as for Plot 2, which has been treated with acid phosphate only, while Plot 11 has received in addition nitrate of soda, dried blood and muriate of potash.

The results for Plot 26, which has received a complete fertilizer containing no appreciable amount of sulphur, show a smaller amount of sulphur in the soil than in the other similarly fertilized plots to which sulphates have been added. The amount is smaller than for the unfertilized soil, due undoubtedly to the greater depletion of the sulphur supply through the increased yields following the fertilizer treatment.

Where basic slag has been the carrier of phosphorus, the soil has the highest sulphur content, which may be due to the fact that the more basic condition of the soil following the treatment with basic slag has tended to conserve the sulphur supply. The variations observed are not consistent enough for any definite conclusions to be drawn from the results as to the effect of the fertilizer treatment on the total sulphur content of the soil.

Considering the differences in sulphur content of soils sampled in 1896 and again in 1912, it is found that small loss occurred during the 16-year interval.

Results from the Strongsville soils show a slight decrease in the sulphur content of cultivated and unfertilized soil as compared with adjacent soil which has not been under cultivation. While the loss is only slight, it indicates that there is a gradual depletion of sulphur supply following cultivation, and that the amounts of sulphur carried to the soil by atmospheric precipitation are not adequate to counterbalance the removal by crops and drainage.

Distribution in the soil.—Sulphur like phosphorus is found most abundantly distributed in the surface soil, the amount diminishing in proportion to the decrease of organic matter from the surface to lower depths of soil. In dark-colored soils or soils of which the Clyde clay and Miami black clay loam are representative, the line of demarcation between the surface soil and the subsoil, due to a decreased content of organic material, is not as sharply defined as in the case of soil having a small supply of organic matter. In soil of the former class there is not the marked decrease in sulphur content that is observed in soils containing only meager amounts of incorporated organic matter in the subsoil. Soils which are characterized by a high content of organic matter in the lower soil strata as well as in the surface 6 inches, contain more sulphur in the subsoil than is found in corresponding depth of clay soil, containing less organic matter.

The subsoil of the Clyde clay and Miami black clay loam contains sulphur in amounts closely approximating that in the surface 6 inches of the Strongsville clay, the subsoil of which has a greatly diminished sulphur content. The sulphur content of four depths of Clyde clay loam from 6 to 24 inches illustrates the decrease in sulphur content of the lower soil strata sampled. The decrease in the 6-inch depths from 12 to 24 inches is not as large as that occurring in the first and second 6 inches.

Soluble sulphur.—The amounts of sulphate found in the water extract of soils indicate that possibly an adequate supply of available sulphur is present, provided sulphates are a satisfactory form for supplying this element. The presence of sulphates in some soils may be neither necessary nor advantageous. Sulphates of iron and aluminum, if present in sufficient quantities, will be injurious to plant growth. Table II shows the water-soluble sulphur extracted from Wooster silt loam, Clyde clay and Strongsville clay. Differently treated plots of the Wooster silt loam were sampled; and samples of this soil collected in 1896 and again in 1912, 16 years later, were compared.

TABLE II.—Water-soluble sulphur content of soils
(Parts per 2,000,000 of soil)

Soil and treatment	Soluble sulphur	Total sulphur
Wooster silt loam—Unfertilized (1896)	58	472
Wooster silt loam—Unfertilized (1912)	64	412
Wooster silt loam (Plot 2)—Acid phosphate	67	440
Wooster silt loam (Plot 18)—Manure	48	464
Wooster silt loam (Plot 24)—Acid phosphate, muriate potash, ammonium sulphate	126	472
Clyde clay—Cultivated	74	1 056
Strongsville clay—Uncultivated	26	800

Soluble sulphur was determined by making repeated extractions of 200 grams of soil with distilled water until a total volume of 2,000 cubic centimeters was obtained. The solutions were first filtered through Berkfeld filters; some finely divided clay passed through the filters. This was removed by adding ammonium carbonate as a flocculating agent and by refiltering the solution. A 500 cubic centimeter aliquot of the filtrate was taken for determination of sulphur. After the solution was evaporated to dryness, the residue was slightly acidified with hydrochloric acid and filtered, and sulphates were precipitated in a volume of 50 cubic centimeters. A much larger amount of soluble sulphur was found than was considered soluble in water, and the results obtained by this treatment show there is an appreciable accumulation of sulphates in soils.

The amount present in the soil from the plot receiving ammonium sulphate is greatly in excess of that found in the other plots on the same soil. Treatment with ammonium sulphate has been continued for the last 20 years. Whether there will be an increased accumulation from further additions of ammonium sulphate is not known, although the larger amount in the soil at the present time as compared with soil not receiving this treatment indicates that there will be. Ruprecht and Morris,[4] found an increased amount of sulphates in the drainage water from plots treated with ammonium sulphate. They state that there is probably no accumulation of sulphates from this source in the soil.

The percentage of total sulphur soluble in water varies considerably for the different soils. The total sulphur content of the ammonium sulphate treated plot is only slightly in excess of the other plots on the same soil, but it will be noted that the soluble sulphur found in the ammonium sulphate treated plot is greatly in excess. The black clay soil, designated as Clyde clay, contains a large amount of total sulphur, which is evidently present in other forms than sulphates, since water has extracted only a relatively small proportion as compared with the amounts of soluble sulphur found in the case of silt loam soil which is deficient in organic matter. The same comparison applies to the Strongsville uncultivated soil which contains a fair amount of organic matter. The deduction is that sulphur exists in these soils chiefly in organic combinations.

A point which seems worth considering in relation to the sulphur requirements of plants and the possible deficiency in the soil is the greater availability of sulphur as compared with phosphorus, since a much larger amount of sulphur than phosphorus can be obtained in the water solution of most soils.

Another phase of this question, however, is that phosphorus is absorbed and retained in a more insoluble condition than sulphur, and the appreciable amount of sulphur as sulphates in drainage water indicates a more rapid depletion of sulphur, either naturally present or artificially supplied, from the soil.

SULPHUR AS A FACTOR IN CROP PRODUCTION

INFLUENCE OF SULPHATES

Sulphates have been added to soils through the use of fertilizers without any particular attention being given to the possible effect of sulphates incidentally supplied in this manner on soil conditions or on plant growth. The beneficial results attributed to gypsum, formerly used quite extensively on some soils, may have been due in part to the sulphate content. The superiority of fertilizing materials containing sulphates over other forms of phosphorus, potassium and nitrogen, depends largely upon the crop grown, the character of the soil and the nature of accompanying fertilizers.

EARLY EXPERIMENTAL RESULTS

Field experiments by Milburn[5] showed that sulphate of ammonia proved a better source of nitrogen for potatoes than did nitrate of soda, and the beneficial effect of sulphate of potash was greater than that from muriate of potash or kainit. Hunt[6] found that nitrate of soda gave better results as a source of nitrogen than did either dried blood or sulphate of ammonia. An acid condition proving especially injurious in later years to corn and clover resulted from the continued use of sulphate of ammonia.

Prainishnikow[7] concluded that ammonium sulphate in the presence of raw phosphate exerted two opposite influences: one positive, due to the solvent action resulting from the physiological acidity of the salt; the other negative, resulting from the injurious effects of an excess of acidity on plant growth. The acid reaction was reduced and the yield increased by the use of calcium carbonate.

Schneidewind[8] found that ammonium sulphate was as effective as sodium nitrate as a fertilizer for potatoes, while on some other crops the sodium nitrate was more effective.

Field experiments conducted at Woburn and Rothamsted[9] proved that the long continued use of sulphate of ammonia on soils poor in lime results in a sour soil. The acidity is supposed to be caused by certain microfungi in the soil which split the sulphate of ammonia in order to obtain the ammonia and consequently set free the sulphuric acid. The remedy, as demonstrated on the Woburn plots, is the addition of sufficient lime to maintain a neutral reaction.

Experiments conducted at the Massachusetts Experiment Station[10] with different carriers of potash showed that sulphate of potash gave a heavier yield of corn by 5 bushels and a lighter yield of stover by 600 pounds per acre than muriate of potash.

Takeuchi[11] found that, as a rule, gypsum decreased the yield when used with acid fertilizers and increased the yield when used in connection with alkaline fertilizers.

TESTS AT THE OHIO EXPERIMENT STATION

FIELD TESTS

Description and treatment of plots.—Included in the fertility experiments which have been conducted at this Station for the last 20 years are plots treated with fertilizing materials which have furnished a considerable supply of sulphur as sulphates of calcium, in comparison with plots on which the fertilizer treatment is such that very small quantities of sulphates are added to the soil. The yields obtained afford an opportunity for studying the response to sulphate treatment, in conjunction with phosphorus, potassium and nitrogen, of the several crop plants grown under favorable field conditions for an extended period on a soil containing less sulphur than phosphorus. The phosphorus found in cultivated and unfertilized soil is 670 pounds per acre 6 inches, while the sulphur content is approximately 470 pounds.

To four plots of the 5-year rotation fertility test the same quantities of nitrogen, potassium and phosphorus are added, phosphorus, however, being supplied in different forms. On Plot 11 acid phosphate furnishes phosphorus and calcium sulphate; Plot 27 has phosphorus and calcium sulphate supplied by dissolved bone black; Plot 26 is treated with bone meal, and Plot 29, with basic slag.

Seasonal differences influence crop production; consequently, if the yields for only 1 or 2 years are considered, variations in yield between the several plots compared may lead to erroneous conclusions, since the plot that produces higher yields one year, compared with a differently treated plot, may have a comparatively small crop the following year. Comparing the average yields for a number of years tends to minimize differences due to abnormal yields during exceptional seasons.

Crop yields at Wooster.—The 20-year average of Wooster 5-year rotation plots, compared in Table III, shows that the bone meal treated plot has produced smaller yields of corn, oats and wheat than plots to which sulphate was added incidentally with the fertilizing materials carrying phosphorus.

TABLE III.—Effect of sulphates on crop yields
Twenty-year average yields per acre in a 5-year rotation, Wooster*

Plot	Phosphorus carriers	Corn	Oats	Wheat	Clover	Timothy
		Bushels	Bushels	Bushels	Pounds	Pounds
11	Acid phosphate	46.95	48.80	26.88	3,194	3,554
26	Bone meal	44.46	45.70	23.40	3,352	3,640
27	Dissolved bone black†	46.79	48.20	25.63	2,968	3,449
29	Basic slag	47.10	46.19	24.33	3,194	3,808

*Fertilizer treatment per acre for each rotation: Nitrogen 76 pounds in nitrate of soda; potassium 108 pounds in muriate of potash; phosphorus 20 pounds in different carriers.
†Previous to 1910; since 1910 acid phosphate and nitrate of lime have been used.

The basic slag plot has produced only a slight increase of corn over the acid phosphate and dissolved bone black plots. Average yields of oats and wheat are less for the basic slag plot than where sulphates have been supplied. Timothy and clover have made a better growth on plots treated with bone meal and basic slag than on either the acid phosphate or the dissolved bone black plot.

The soil on which these plots are located is deficient in lime carbonate and responds to lime treatment, which accounts for the better growth of clover on the basic slag and bone meal plots as compared with plots where acid phosphate has furnished the phosphorus. The 20-year averages include yields for years previous to the time when lime was first applied to the soil, and for both the unlimed and limed halves of the plots since liming has been practiced. After the treatment with acid phosphate and dissolved bone black, the soil has shown a greater need of lime than where other carriers of phosphorus are used.

In Table IV average yields of crops on both the unlimed and limed halves of the same plots for the periods indicated are compared. The fertilizer treatment per acre for each rotation is indicated in Table III. The lime treatment will have neutralized any increased acid condition of the soil which may have been caused by the fertilizer treatment. It will be observed that on the limed soil larger yields of corn, oats and wheat have been secured from the plots where acid phosphate and dissolved bone black furnished the phosphorus than for the bone meal and basic slag plots.

TABLE IV.—Effect of sulphates on crop yields*

Average yields per acre for periods indicated, on unlimed and limed soil in a 5-year rotation, Wooster

Plot	Phosphorus carriers	Corn[1]		Oats[2]		Wheat[3]		Clover[4]		Timothy[5]	
		Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
		Bushels	Bushels	Bushels	Bushels	Bushels	Bushels	Pounds	Pounds	Pounds	Pounds
11	Acid phosphate..........................	49.06	55.73	49.61	47.61	30.70	30.82	2,796	3,631	3,507	4 389
26	Bone meal...............................	45.53	52.99	45.06	45.20	26.18	27.23	3,135	3,981	3,436	4 876
27	Dissolved bone black†....................	48.60	54.77	47.59	46.40	26.61	28.68	2,636	3 524	3,184	4,607
29	Basic slag............	48.71	52.07	45.66	44.54	27.87	26.46	3,072	3,579	3,837	4 567

[1]Average 12 years, 1900-1913 (excluding 1903 and 1913).
[2]Average 10 years, 1901 and 1905-1913, inclusive.
[3]Average 8 years, 1906-1913.
[4]Average 11 years, 1903-1913.
[5]Average 7 years, 1906-1913 (excluding 1909).
*Compiled from Tables I-V, Ohio Agr. Exp. Sta. Bul. 279, *The Maintenance of Fertility, Liming the Land*, C. E. Thorne.
†Previous to 1910; since 1910 acid phosphate and nitrate of lime have been used.

Any increase in crop yields obtained on the acid phosphate and dissolved bone black plots cannot be attributed with certainty to the increased supply of sulphates furnished the soil by these materials, for the greater availability of the phosphorus in these carriers may be the factor responsible for the advantage phosphorus carriers supplying sulphates appear to have over materials which do not supply sulphates.

The average yields of potatoes, wheat and clover grown in the 3-year rotation on Wooster soil, which are compared in Table V, show that bone meal has produced smaller yields of potatoes and of wheat, while the yield of potatoes on the basic slag plot is the same as for the dissolved bone black plot. The yields indicate that basic slag is superior to the other carriers of phosphorus on soil deficient in basic calcium compounds.

TABLE V.—Effect of sulphates on crop yields
Twenty-year average yields per acre in a 3-year rotation, Wooster*

Plot	Phosphorus carriers	Potatoes	Wheat	Clover
		Bushels	Bushels	Pounds
11	Acid phosphate	171.00	37.51	4,269
26	Bone meal	163.05	34.36	4,204
27	Dissolved bone black†	167.96	35.80	4,023
29	Basic slag	167.80	36.37	4,541

*Fertilizer treatment for each rotation: Nitrogen 38 pounds in nitrate of soda; potassium 83 pounds in muriate of potash; phosphorus 20 pounds in different carriers.
†Previous to 1910; since 1910 acid phosphate and nitrate of lime have been used.

Crop yields at Strongsville.—The yields from the acid phosphate, bone meal, dissolved bone black and basic slag plots of the 5-year rotation experiment on Strongsville soil, which has a considerably higher sulphur content than the Wooster soil, do not show as marked differences between the more available phosphorus carriers containing sulphates and the bone meal and basic slag plots as is shown by the yields obtained on similarly fertilized plots on the Wooster soil. The dissolved bone black used on Strongsville soil has been less effective than bone meal and basic slag.

Somewhat larger yields of corn, oats and timothy have been produced on the acid phosphate treated plot. A slightly smaller yield of wheat has been obtained from the dissolved bone black plot than from the other plots compared, which have about the same yield. The effect of other elements in the fertilizer may have obscured any influence of the sulphur supplied on the yields. Data for Strongsville soil are given in Table VI.

TABLE VI.—Effect of sulphates on crop yields

Nineteen-year average yield per acre in a 5-year rotation, Strongsville*

Plot	Phosphorus carriers	Corn	Oats	Wheat	Clover	Timothy
		Bushels	Bushels	Bushels	Pounds	Pounds
11	Acid phosphate	38.69	50.68	17.31	2,820	2,[illegible]56
26	Bone meal	35.96	48.13	17.43	2,963	2,[illegible]60
27	Dissolved bone black	34.36	40.23	16.49	2,659	2,989
29	Basic slag	35.88	47.04	17.46	2,732	2,605

*Fertilizer treatment per acre for each rotation: Nitrogen 76 pounds in nitrate of soda; potassium 108 pounds in muriate of potash; phosphorus 20 pounds in different carriers.

Crop yields at Germantown.—The yields of tobacco, wheat and clover from the fertility plots on Germantown soil are given in Table VII. Here the comparison is between muriate of potash and sulphate of potash, which have been used as carriers of potassium. As these plots have all been treated with acid phosphate, they have received sulphur in the form of calcium sulphate. In addition, Plots 23 and 25 have had an increased supply of sulphur furnished by the 190 pounds of potassium sulphate added during each 3-year period. This amount of potassium sulphate has furnished 34 pounds of sulphur in addition to approximately 38 pounds of sulphur in the acid phosphate. No beneficial effect has been observed from the increased amount of sulphate furnished, as the 10-year yields show that muriate of potash treated plots have produced more tobacco, wheat and clover than plots to which sulphate of potash has been added.

TABLE VII.—Effect of sulphates on crop yields

Ten-year average yields per acre in a 3-year rotation, Germantown*

Plot	Potassium carriers	Tobacco	Wheat	Clover
		Pounds	Bushels	Pounds
8	Muriate of potash	1,325	25.22	3,874
23	Sulphate of potash	1,186	22.71	3,511
26	Muriate of potash	1,193	24.59	3,592
25	Sulphate of potash	1,156	23.42	3,472

*Fertilizer treatment per acre for each rotation: Nitrogen 38 pounds in nitrate of soda; phosphorus 30 pounds in acid phosphate; potassium 75 pounds in muriate and sulphate.

While it is true that the muriate of potash and nitrate of soda used in connection with the phosphorus carriers will furnish some sulphur, this quantity is small as compared with that supplied by phosphorus fertilizers made by treating phosphate rock with sulphuric acid.

The data obtained from crops grown in field tests reported do not give conclusive evidence that the addition of sulphur in the form of sulphates to a soil having a naturally low sulphur content has increased the yields of general farm crops to any appreciable extent.

EXPERIMENTAL DATA

Plan of experiments.—During 1912 vegetation tests in pots and small field plots were started for the purpose of studying the effect of sulphates on the growth and composition of different crops. The pot tests were conducted under glass, the soil being placed in rectangular boxes the dimensions of which were such that each box contained 1 cubic foot of soil.

At the same time field tests were conducted in which the treatment given the pots was duplicated. In the field test the crops were planted on small areas 8 feet long and 1 foot wide, in which soybeans, millet and rape were grown in single rows to each plot. Soybeans were grown in the pot tests.

Chemically pure salts were used as the source of the materials supplied. Phosphorus was applied at the rate of 50 pounds per acre; potassium, 20 pounds; nitrogen, 12 pounds; sulphur, 100 pounds. Where calcium carbonate was used, it was applied at the rate of 4,000 pounds per acre. Phosphorus was supplied in the form of di-calcium phosphate. Nitrogen was furnished by sodium nitrate and ammonium sulphate. Potassium chloride and potassium sulphate were used as carriers of potassium. Sulphur was suplied in the form of calcium and magnesium sulphates in addition to ammonium sulphate and potassium sulphate.

The treatment given each plot is included in the tables which give the yield and composition of the crops grown. The difference between the total and sulphate sulphur,* is designated as organic sulphur.

Results for soybean hay grown in pot tests.—Results which are given in Table VIII show that where phosphorus, potassium and nitrogen were applied and calcium sulphate furnished the sulphur, there has been an increased weight of soybean hay, having a higher percentage of proteid nitrogen, total sulphur and inorganic sulphur than was found in the crops from similarly treated soil without the addition of calcium sulphate. With the same fertilization and the addition of calcium carbonate, calcium sulphate gave practically the same yield and a lower percent of total nitrogen than the pot to which no calcium sulphate was added, but the crop contained more total and inorganic sulphur.

*Sulphates were determined by the method outlined in Ohio Agr. Exp. Sta. Bul. 285.

TABLE VIII.—Soybean hay grown in pot tests (1912)

Treatment	Weight of crop	Total nitrogen	Non-proteid nitrogen	Proteid nitrogen	Total sulphur	Inorganic sulphur	Organic sulphur
	Grams	Percent	Percent	Percent	Percent	Percent	Percen
Check with $CaCO_3$	52	3.37	0.52	2.85	0.2708	0.0480	0.2228
Check without $CaCO_3$	61	3.03	.55	2.48	.3152	.1206	.1946
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$	65	3.19	.63	2.56	.2843	.0313	.2530
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $CaSO_4$	62	3.12	.75	2.37	.3050	.0784	.2266
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$	67	2.99	.56	2.43	.2721	.0616	.2105
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaSO_4$	87	3.30	.68	2.62	.3046	.0819	.2227
$Ca_2H_2(PO_4)$, K_2SO_4, $NaNO_3$, $CaCO_3$	66	3.11	.67	2.44	.2736	.0430	.2306
$Ca_2H_2(PO_4)$, K_2SO_4, $NaNO_3$, $CaCO_3$, $CaSO_4$	80	3.12	.66	2.46	.3025	.0721	.2304
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$	97	3.19	.87	2.32	.2709	.0587	.2122
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$, $CaSO_4$	75	3.07	.68	2.39	.3124	.0787	.2337
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $MgSO_4$	67	3.13	.72	2.41	.3076	.0787	.2289
$Ca_2H_2(PO_4)_2$, $CaCO_3$, $CaSO_4$	76	3.20	.58	2.62	.2695	.0589	.2106
$Ca_2H_2(PO_4)_2$, $CaCO_3$	86	3.11	.78	2.33	.2727	.0422	.2305
KCl, $CaCO_3$	60	3.03	.53	2.50	.3117	.0686	.2431
K_2SO_4, $CaCO_3$	70	2.88	.52	2.36	.2760	.0719	.2040
$(NH_4)_2SO_4$, $CaCO_3$	78	3.19	.57	2.62	.2961	.0597	.2364
$NaNO_3$, $CaCO_3$	80	3.06	.68	2.38	.3012	.0942	.2070
$CaSO_4$, $CaCO_3$	79	3.07	.70	2.37	.3298	.1476	.1822
$MgSO_4$, $CaCO_3$	87	3.15	.71	2.44	.3386	.1362	.2024

The addition of calcium sulphate to soil treated with phosphorus, potassium and nitrogen, both with and without the addition of calcium carbonate, has increased the amount of sulphur assimilated by the soybean plant. It appears, however, that this excess is present mainly as inorganic sulphur, since the increase of inorganic sulphur is greater than the increase of organic sulphur after the addition of calcium sulphate. Independent of any influence of sulphates, there is a decided difference in the inorganic sulphur content of the crops from pots where the only difference in treatment has been with regard to calcium carbonate. The untreated pot contains more inorganic sulphur than the pot treated with calcium carbonate. The addition of calcium sulphate to the pot on which potassium sulphate was used has given a larger weight of crop, slightly increased the total sulphur, and decidedly increased the inorganic sulphur, while the organic sulphur has not been changed.

Calcium sulphate added to soil where ammonium sulphate has been used as the nitrogen carrier has affected the total and inorganic sulphur in the same manner, and has also increased the percent of organic sulphur; the weight of the crop, however, is much less. Magnesium sulphate and calcium sulphate on otherwise similarly treated pots show closely agreeing figures both as to yield and as to composition of crops.

The results obtained from a study of one crop of soybeans grown in pot tests indicate that the addition of sulphates has had some influence on the sulphur content of the soybean hay.

Results for soybeans grown in plot tests.—One-half of the soybean crop grown on small plots was harvested as soybean hay at the stage when the plants were nicely podded, and the rest of the crop was allowed to mature in order that the yield of beans might be obtained. The yields of soybean hay from equal areas and the nitrogen and sulphur content are included in Table IX; the data for the beans harvested, in Table X. The untreated soil produced the most hay. Sulphates used with "complete" fertilizer treatment have had a favorable effect on the yield in some instances.

The addition of calcium sulphate to plots which had sulphur furnished by potassium sulphate or ammonium sulphate gave an increase in yield for both plots thus treated. Potassium sulphate compared with potassium chloride, and ammonium sulphate with sodium nitrate both increased the yield.

In general, the percents of total and inorganic sulphur are greater in the crop from plots to which sulphates were applied, when compared with plots similarly fertilized but receiving a smaller amount or no sulphates.

TABLE IX.—Soybean hay grown in plot tests (1912)

Treatment	Weight of crop	Total nitrogen	Non-proteid nitrogen	Proteid nitrogen	Total sulphur	Inorganic sulphur	Organic sulphur
	Grams	Percent	Percent	Percent	Percent	Percent	Percent
Check with $CaCO_3$	196	2.23	0.39	1.84	0.2350	0.1270	0.2080
Check without $CaCO_3$	227	2.24	.31	1.93	.2813	.0978	.1835
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$	173	2.05	.32	1.73	.3033	.1256	.1770
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $CaSO_4$	133	2.21	.36	1.85	.3520	.1489	.2033
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$	157	2.34	.34	2.00	.2835	.0950	.1885
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaSO_4$	192	2.01	.32	1.69	.3045	.1133	.1912
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$	117	2.52	.49	2.03	.2864	.0834	.2030
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$, $CaSO_4$	177	1.92	.34	1.58	.2809	.1571	.1238
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$	150	1.87	.36	1.51	.2991	.1400	.1591
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$, $CaSO_4$	193	1.90	.34	1.56	.2736	.1254	.1482
$Ca_2H_2(PO_4)_2$, KCl, $NaNo_3$, $CaCO_3$, $MgSO_4$	110	2.09	.32	1.77	.2761	.1056	.1705
$Ca_2H_2(PO_4)_2$, $CaCO_3$, $CaSO_4$	222	2.21	.38	1.83	.3125	.1160	.1967
$Ca_2H_2(PO_4)_2$, $CaCO_3$	213	1.83	.29	1.54	.2807	.1168	.1651
KCl, $CaCO_3$	122	1.74	.30	1.44	.3338	.1357	.1981
K_2SO_4, $CaCO_3$	217	1.88	.32	1.56	.2990	.1143	.1847
$(NH_4)_2SO_4$, $CaCO_3$	177	1.97	.30	1.67	.2900	.1018	.1882
$NaNO_3$, $CaCO_3$	144	2.02	.31	1.71	.2636	.1012	.1622
$CaSO_4$, $CaCO_3$	174	2.08	.31	1.77	.2780	.1235	.1545
$MgSO_4$, $CaCO_3$	178	2.24	.33	1.91	.2848	.1146	.1702

TABLE X.—Soybeans grown in plot tests (1912)

Treatment	Weight of crop	Total nitrogen	Nonproteid nitrogen	Proteid nitrogen	Total sulphur	Inorganic sulphur
	Grams	Percent	Percent	Percent	Percent	Percent
Check with $CaCO_3$	249	5.70	0.36	5.34	0.4667	None
Check without $CaCO_3$	256	5.78	.32	5.46	.4756	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$	142	5.62	.33	5.29	.5121	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $CaSO_4$	145	5.73	.31	5.52	.4603	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$	249	5.60	.33	5.27	.4931	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaSO_4$	246	5.69	.31	5.38	.4715	"
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$	263	6.38	.37	6.01	.4417	"
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$, $CaSO_4$	206	6.41	.40	6.01	.4719	"
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$	249	5.72	.36	5.36	.4743	"
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$, $CaSO_4$	97	5.77	.35	5.42	.4674	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $MgSO_4$	174	5.70	.37	5.33	.4630	"
$Ca_2H_2(PO_4)_2$, $CaCO_3$, $CaSO_4$	247	5.92	.34	5.58	.4575	"
$Ca_2H_2(PO_4)_2$, $CaCO_3$	184	5.95	.35	5.60	.4400	"
KCl, $CaCO_3$	178	6.05	.42	5.63	.4523	"
K_2SO_4, $CaCO_3$	239	6.02	.31	5.71	.4486	"
(NH_4) SO_4, $CaCO_3$	249	5.72	.31	5.41	.4796	"
$NaNO_3$, $CaCO_3$	232	5.56	.28	5.28	.4405	"
$CaSO_4$, $CaCO_3$	260	5.83	.33	5.50	.4410	"
$MgSO_4$, $CaCO_3$	176	5.87	.40	5.47	.4724	"

Plots treated with calcium carbonate uniformly gave a smaller yield than similarly treated plots to which calcium carbonate was not added. Calcium sulphate applied in addition to nitrogen, phosphorus and potassium fertilizers supplying no sulphur, has had practically no effect on the yield of beans, but the results show an appreciable reduction in the sulphur content of beans grown on soil treated with sulphates. Potassium sulphate and ammonium sulphate, used in comparison with potassium chloride and sodium nitrate, produced a larger yield of beans with a lower percent of sulphur. The addition of calcium sulphate to fertilizer supplying sulphates, however, decreased the yield of beans.

Calcium sulphate used with di-calcium phosphate and calcium carbonate produced a larger yield than the same treatment without the addition of this sulphate. Plots treated with potassium sulphate and ammonium sulphate produced more beans than plots where potassium chloride and sodium nitrate were used.

No inorganic sulphur was found in the seed from any of the differently treated plots, all sulphur being in the organic form. The results obtained show that the proteid nitrogen content of the beans has been increased somewhat in the crop from soils treated with sulphates. This increase, however, is not large enough to be of any practical importance.

Results for millet grown in plot tests.—Half of the millet crop was cut for hay when in bloom, and the rest allowed to mature for seed. Tables XI and XII give the data obtained for this crop. The weights of hay and seed from the several plots show considerable variation, which appears to be due to the treatment. Sulphates used with complete fertilizer and calcium carbonate have decreased the yield. Calcium sulphate in addition to fertilizer containing sulphates also decreased the yield. When potassium sulphate was used, the yield was larger than that produced on the plot treated with potassium chloride, the other treatment on these plots being the same. Ammonium sulphate as compared with sodium nitrate—both plots receiving phosphorus and calcium carbonate—also increased the yield of seed.

TABLE XI.—Millet hay grown in plot tests (1912)

Treatment	Weight of crop	Total nitrogen	Non-proteid nitrogen	Proteid nitrogen	Total sulphur	Inorganic sulphur	Organic sulphur
	Grams	Percent	Percent	Percent	Percent	Percent	Percent
Check with $CaCO_3$	306	1.26	0.34	0.92	0.2298	0.0720	0.1578
Check without $CaCO_3$	247	1.15	.45	.70	.2427	.0985	.1442
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$	391	.99	.28	.71	.1923	.0584	.1339
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $CaSO_4$	357	1.02	.27	.75	.2263	.0838	.1425
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$	420	1.01	.41	.60	.1832	.0643	.1189
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaSO_4$	502	.96	.41	.55	.2041	.0882	.1159
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$	470	.92	.28	.64	.1991	.0710	.1281
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$, $CaSO_4$	395	1.01	.27	.74	.2284	.0862	.1422
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$	439	.97	.29	.68	.2022	.0675	.1347
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$, $CaSO_4$	301	1.18	.35	.83	.2385	.1028	.1357
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $MgSO_4$	510	1.20	.42	.78	.2280	.0791	.1489
$Ca_2H_2(PO_4)_2$, $CaCO_3$, $CaSO_4$	429	1.05	.42	.63	.2271	.1166	.1105
$Ca_2H_2(PO_4)_2$, $CaCO_3$	358	1.05	.37	.68	.2278	.0967	.1310
KCl, $CaCO_3$	245	1.30	.43	.87	.2325	.0801	.1524
K_2SO_4, $CaCO_3$	244	1.29	.51	.78	.2154	.0853	.1301
$(NH_4)_2SO_4$, $CaCO_3$	196	1.39	.51	.88	.2286	.0879	.1407
$NaNO_3$, $CaCO_3$	202	1.24	.42	.82	.2198	.0693	.1505
$CaSO_4$, $CaCO_3$	273	1.21	.46	.75	.2722	.1260	.1462
$MgSO_4$, $CaCO_3$	195	1.20	.48	.72	.2649	.1447	.1202
Check	247	1.15	.45	.70	.2427	.0985	.1442

TABLE XII.—Millet seed grown in plot tests (1912)

Treatment	Weight of crop	Total nitrogen	Nonproteid nitrogen	Proteid nitrogen	Total sulphur	Inorganic sulphur
	Grams	Percent	Percent	Percent	Percent	Percent
Check with $CaCO_3$	87.1	2.32	0.12	2.20	0.2778	None
Check without $CaCO_3$	88.9	2.17	.10	2.07	.2397	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$	100.2	2.04	.10	1.94	.2824	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $CaSO_4$	99.1	2.36	.12	2.24	.2456	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$	135.5	2.24	.09	2.15	.2402	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaSO_4$	172.9	2.23	.09	2.14	.2435	"
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$	156.0	2.29	.12	2.17	.2473	"
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$, $CaSO_4$	102.5	2.03	.12	1.91	.2305	"
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$	150.7	2.31	.12	2.19	.2722	"
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$, $CaSO_4$	88.5	2.38	.11	2.27	.2576	"
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $MgSO_4$	122.5	2.06	.12	1.94	.2794	"
$Ca_2H_2(PO_4)_2$, $CaCO_3$, $CaSO_4$	123.1	2.47	.11	2.38	.2586	"
$Ca_2H_2(PO_4)_2$, $CaCO_3$	151.2	2.37	.11	1.26	.2876	"
KCl, $CaCO_3$	96.0	2.27	.13	2.14	.2458	"
K_2SO_4, $CaCO_3$	112.3	2.41	.12	2.29	.2636	"
$(NH_4)_2SO_4$, $CaCC_3$	89.5	2.42	.13	2.29	.2652	"
$NaNO_3$, $CaCO_3$	88.5	2.22	.14	2.08	.2306	"
$CaSO_4$, $CaCO_3$	103.5	2.25	.11	2.14	.2427	"
$MgSO_4$, $CaCO_3$	124.1	2.22	.12	2.10	.2498	"

An interesting point in connection with the sulphur content is that the application of sulphates has caused an increased accumulation of sulphur in the hay, while the seed in most instances has a higher sulphur content where sulphates were not included in the soil treatment. This same relation between the hay and the seed was found for the soybeans. The magnesium sulphate plot appears to be an exception, since the crop from this plot has an increased percentage of total sulphur in both the millet seed and hay. The millet seed from some of the sulphate treated plots contains a slightly increased amount of proteid nitrogen.

Results for rape in plot tests.—With certain conditions of treatment, sulphates have affected the yield and the composition of the rape crop. The results in Table XIII show that, when calcium sulphate was added to plots treated with di-calcium phosphate, potassium chloride and sodium nitrate, there has been an increased yield and the proteid nitrogen and the organic sulphur have been influenced, both where calcium carbonate was applied to the soil and where it was not.

Calcium sulphate in addition to complete fertilization supplying no sulphur and where the soil was not treated with calcium carbonate produced more rape than similarly fertilized soil to which calcium carbonate was added. This plot also produced more millet and soybeans than a like fertilized plot with calcium carbonate treatment. The addition of calcium sulphate to di-calcium phosphate and calcium carbonate increased the yield of rape as well as that of millet hay and soybeans. The plots having sulphur furnished by potassium sulphate and ammonium sulphate gave a less weight of crop than the plots treated with potassium chloride and sodium nitrate. The addition of calcium sulphate, however, to these plots having a small amount of sulphur furnished by the nitrogen and potassium carriers slightly increased the yield of rape.

The total sulphur content of the crops from plots receiving calcium sulphate in addition to phosphorus, potassium and nitrogen has been increased. The sulphur content of these plots, however, is less than that of the plots receiving no fertilizer salts or sulphates.

Increasing the sulphur supply has affected the sulphur content of the rape in a different manner than the soybean and millet hay, in that the increased amount of sulphur assimilated by the rape crop from plots having sulphur supplied in addition to phosphorus, potassium and nitrogen is present as organic sulphur, the inorganic sulphur content being less than that found where no sulphates were added, while the soybean and millet hay from the same plots contained a decidedly increased amount of inorganic sulphur. A different effect is noticed where calcium sulphate is added to the plots

TABLE XIII.—Rape from plot tests (1912)

Treatment	Weight of crop	Total nitrogen	Non-proteid nitrogen	Proteid nitrogen	Total sulphur	Inorganic sulphur	Organic sulphur
	Grams	Percent	Percent	Percent	Percent	Percent	Percent
Check with $CaCO_3$	359	2.76	1.62	1.14	1.1329	0.6782	0.4547
Check without $CaCO_3$	325	2.33	1.14	1.19	1.0495	.5851	.4644
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$	462	2.17	1.30	.87	.8719	.4780	.3939
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $CaSO_4$	473	2.23	1.19	1.04	.9024	.4533	.4491
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$	377	2.36	1.45	.91	.9575	.5517	.4058
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaSO_4$	494	2.19	1.09	1.10	.9658	.5385	.4273
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$	404	2.19	1.31	.88	.8335	.4204	.4131
$Ca_2H_2(PO_4)_2$, K_2SO_4, $NaNO_3$, $CaCO_3$, $CaSO_4$	412	2.12	1.32	.80	.9237	.5342	.3595
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$	362	2.11	1.28	.83	.9071	.4711	.4360
$Ca_2H_2(PO_4)_2$, KCl, $(NH_4)_2SO_4$, $CaCO_3$, $CaSO_4$	377	2.26	1.32	.94	1.0125	.6248	.3877
$Ca_2H_2(PO_4)_2$, KCl, $NaNO_3$, $CaCO_3$, $MgSO_4$	271	2.59	1.49	1.10	1.1180	.7034	.4146
$Ca_2H_2(PO_4)_2$, $CaCO_3$, $CaSO_4$	432	2.23	1.16	1.07	.9719	.4817	.4902
$Ca_2H_2(PO_4)_2$, $CaCO_3$	325	2.37	1.37	1.00	1.0195	.5829	.4366
KCl, $CaCO_3$	250	2.51	1.42	1.09	1.1431	.6707	.4724
K_2SO_4, $CaCO_3$	262	2.68	1.16	1.52	1.1940	.7556	.4384
$(NH_4)_2SO_4$, $CaCO_3$	218	2.74	1.52	1.22	1.1803	.7730	.4073
$NaNO_3$, $CaCO_3$	346	2.41	1.47	.94	1.1719	.7179	.4540
$CaSO_4$, $CaCO_3$	318	2.37	1.37	1.00	1.1371	.6728	.4646
$MgSO_4$, $CaCO_3$	227	2.32	1.37	.95	1.1573	.7230	.4343

receiving a small amount of sulphur in the potassium and ammonium sulphates used as the carriers of potassium and nitrogen; in the rape crop from these plots the inorganic sulphur is appreciably increased, while the amount of organic sulphur found is less than that in the crop from plots receiving a larger amount of sulphur. The organic sulphur in the soybeans from these two plots is also less.

The greater part of the total sulphur in the rape is present as inorganic sulphur. Potassium sulphate compared with potassium chloride and ammonium sulphate with sodium nitrate, no phosphorus or nitrogen being applied in the former case and no phosphorus or potassium in the latter, have increased the inorganic sulphur and caused a corresponding decrease of organic sulphur. Magnesium sulphate as compared with calcium sulphate has affected the sulphur content of the crop from two plots treated with it in the same manner as noted above.

The nonproteid nitrogen found in the rape plant grown under the condition of this experiment is in excess of the proteid nitrogen, except in the crop from three plots where the proteid nitrogen is slightly in excess. The plots treated with calcium sulphate in addition to phosphorus, potassium and nitrogen, both with and without calcium carbonate, have a slightly increased amount of proteid nitrogen. The crop from the plot treated with potassium sulphate and calcium carbonate contains more nitrogen than the plot treated with potassium chloride; the same is true of the ammonium sulphate treated plot as compared with that where sodium nitrate was used.

Plot tests of 1913-15.—To study the effect of sulphates on various crops under more satisfactory conditions, a series of small permanent plots were put under cultivation in 1913 on soil which had been uncultivated for about 20 years. The plots in this test are 6½ feet wide and 50 feet long, the plots being separated by paths 2 feet wide.

After the soil had been prepared for the first crop, one-half of each plot was treated with calcium carbonate at the rate of 6,000 pounds per acre. That part of the plot so treated is designated in the table of results as the limed plot, and the other as unlimed. The fertilizer materials used are indicated in Table XIV, which also shows the yields of rape, millet and wheat obtained for the 3 years during which this experiment has been conducted. Fertilizer treatment was applied for the rape crop in 1913; no additional fertilizer was applied for the millet and wheat; additional treatment will be made for the crop following the clover which is now growing on the plots.

TABLE XIV.—Fertilization and yield (in pounds) of rape, millet and wheat in plot tests

Plot	Treatment	Rape (1913)		Millet (1914)		Wheat grain (1915)		Wheat straw (1915)	
		Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed
6	Check	27.5	15.5	18.5	16.5	4.71	3.60	12.54	7.90
7	Potassium sulphate	26.5	14.0	17.5	16.5	4.69	3.51	12.18	7.99
8	Calcium sulphate	25.5	12.5	15.0	13.0	5.44	3.96	11.43	8.79
19	Magnesium sulphate	26.0	8.0	18.0	16.0	3.66	3.25	9.84	7.50
0	Ammonium sulphate	24.0	8.0	19.0	19.0	4.45	3.70	11.67	10.05
1	Calcium phosphate, potassium chloride, sodium nitrate	32.5	19.0	26.5	18.0	4.41	3.67	13.59	9.58
4	Calcium phosphate, potassium sulphate, sodium nitrate	39.5	20.5	21.5	18.5	4.89	3.61	15.73	4
2	Calcium phosphate, potassium chloride, sodium nitrate, calcium sulphate	38.5	19.5	18.5	17.5	5.32	3.70	14.55	10.55
3	Calcium phosphate, potassium chloride, sodium nitrate, magnesium sulphate	36.0	18.5	20.0	18.0	5.47	4.07	15.15	9.93
5	Calcium phosphate, potassium chloride, ammonium sulphate	34.5	18.0	17.0	16.0	4.15	3.76	13.85	8.49
11	Calcium phosphate	14.0	13.0	20.0	20.0	3.91	4.48	12.96	10.52
12	Acid phosphate 16 percent	14.5	14.5	20.5	21.5	4.36	4.62	14.76	10.63

The fertilizer salts were added to furnish the following amounts of the elements per acre: phosphorus 25, potassium 40, nitrogen 24, and sulphur 100 pounds as sulphates of calcium and magnesium. Potassium and ammonium sulphates, when used as carriers of potassium and nitrogen, supplied sulphur at the rate of 16 pounds per acre. Di-calcium phosphate was the carrier of phosphorus except on one plot where commercial acid phosphate was used.

Since the soil has been distinctly acid in its reaction, the application of calcium carbonate has influenced the crop yields more decidedly than has the fertilizer treatment including sulphates. The rape crop appears to have been benefited more by the addition of calcium carbonate than were the succeeding crops of millet and wheat. This may have been due to the fact that a heavy sod was turned under, with the result that a larger amount of available nitrogen has been formed from the organic nitrogen following the treatment with calcium carbonate. This effect would be more pronounced during the first season. Further evidence of a more abundant supply of available nitrogen in the soil of the limed halves of the plots is the greater proportion of straw to wheat grain on the limed soil as compared with the unlimed.

On limed soil calcium sulphate and magnesium sulphate added to the treatment with nitrogen, phosphorus and potassium increased the yield of rape over that from similarly treated plots which received no sulphates. The addition of sulphates to the unlimed halves of these same plots produced only a slight effect. When potassium sulphate as compared with potassium chloride furnished the potassium, the yield of rape was greater on that part of the plots treated with calcium carbonate. Ammonium sulphate also produced a greater weight of crop than sodium nitrate, the other treatment being the same. A comparison of the unlimed halves of the same plots shows an increased weight of rape when potassium sulphate was used in comparison with potassium chloride, and a decreased yield where ammonium sulphate supplied the nitrogen.

Sulphates when used alone gave lower yields than were secured from the untreated soil. The yield of millet hay on limed plots receiving phosphorus, potassium and nitrogen was decreased by sulphates. Calcium sulphate and magnesium sulphate used with nitrogen, phosphorus and potassium had a favorable effect on the wheat crop, the addition of these sulphates having increased the yield more on the limed soil than on the unlimed.

Acid phosphate used alone, compared with di-calcium phosphate as the phosphorus carrier supplying no sulphur, has given a slight increase of rape, millet and wheat.

TESTS WITH OTHER FORMS OF SULPHUR

EARLY EXPERIMENTAL RESULTS

In the preceding experiments reported, sulphur was applied in the form of sulphates. Numerous investigations have been made within recent years, however, to determine the influence of sulphides, flowers of sulphur and sulphites upon crop production. Happen and Quensell[12] in reporting experiments on transformation of sulphur, sulphides and sulphates, conclude that hydrogen sulphide produced by bacterial action or decomposition of organic compounds in the soil passes first into the form of ferrous sulphide, which is decomposed; the iron is oxidized to an oxide, and the sulphur set free is oxidized to sulphites and then to sulphates. The speed of this transformation was dependent on the form of sulphur used. Oxidation took place more freely in natural than in sterilized soil. This is taken to indicate that bacteria may aid in transforming sulphur compounds in soil, although it is thought that the process is mainly a chemical one, since all known methods of soil sterilization are considered to have an effect on the other soil properties. These authors also found that sulphides and sulphites are transformed so rapidly in soils that the addition of these forms of sulphur does not affect plant growth injuriously.

Bernhard[13] assumed that sulphur acts as a disinfectant, improves the physical condition, hastens the action of commercial fertilizers, makes plant food available in the soil, and aids more in plant nutrition than was formerly supposed.

Demolon[14] found flowers of sulphur to be of decided benefit when applied to the soil for the growing of root crops, such as rutabagas, beets and parsnips. He found that the sulphur was slowly converted into calcium sulphate in the soil, and that the phenomenon is of a biological nature. He claims that the fertilizing action is partly due to its effect on the soil bacteria, and partly to the chemical properties of the sulphuric acid formed which supplies sulphur to the plants and dissolves mineral elements in the soil.

Boullanger[15] conducted a series of experiments to study the effect of sulphur on various crops. The influence of sulphur was noticeable on all crops grown. Another series of experiments with sterilized and unsterilized soil showed that the beneficial action of sulphur was apparent only on the unsterilized soil, while the sterilized soil showed very little effect from the sulphur.

Boullanger and Dugardin[16] attributed the favorable action of sulphur on the soil to the stimulus produced on bacteria which decompose complex nitrogenous matter into the ammoniacal state. More ammoniacal salts are thus presented to the plant and a corresponding larger growth follows.

Vermorel and Danthony[17] concluded that sulphur and pyrites should be applied with organic nitrogen when used as a fertilizer. An increase in yield of 30 to 60 percent was obtained when sulphur and pyrites were used with organic carriers of nitrogen, but no noticeable benefit was derived by applying these fertilizers with nitrate of soda.

Grannetto[18] conducted a series of experiments with sulphur alone and combined with different fertilizing materials on potatoes. The sulphur applied alone at the rate of 400 pounds per acre resulted in a loss, but when applied with other fertilizers a decided gain was obtained.

Preliminary experiments conducted by Heinze[19] indicate that the action of sulphur is similar to that of carbon bisulphide. The action is not supposed to be entirely biological.

Sulphur has been found to have beneficial effects upon the vegetative growth and yield of turnips in some tests by Magnien.[20]

It has been found by Janicand[21] that sulphur used alone at the rate of 2 grams of flowers of sulphur to 1 kilogram of soil appeared to have a somewhat deleterious effect on growth, but when used in combination with either ammonium sulphate or a "complete" fertilizer, a much greater growth was secured than where either of these was used without sulphur.

Reimer[22] states that applications of flowers of sulphur, superphosphate, iron sulphate and gypsum gave marked increases in the yield of alfalfa, and that mono-calcium phosphate, ground phosphate rock and steamed bone meal produced no effect.

The effect of sulphite, thiosulphate and sulphur in pot and water culture were studied by Thalau.[23] He found that ammonium sulphite had about the same fertilizing effect as ammonium sulphate on loam soils, but was less efficient on sandy and peat soils. In water cultures even a very small amount (0.4 percent) of ammonium sulphite was very injurious to plants, while 1 percent of ammonium sulphate had no injurious effects. Sodium thiosulphate had no injurious effect on plants. The results with flowers of sulphur were inconclusive.

The increased lime requirement of the soil after treatment with sulphur has been reported by Lint,[24] who found by laboratory experiments that sulphur mixed with soil at the rate of 1,000 pounds per acre increased the lime requirement and was practically all oxidized within 8 or 9 weeks. Field tests where 300 and 600 pounds of sulphur were used per acre also decidedly increased the soil acidity. Very little change in acidity of the soil was observed after 7 weeks. Experiments with heavy clay loam and sand showed a more rapid oxidation of sulphur in the latter soil.

Shedd[25] concluded that sulphur added to a soil is rapidly oxidized to sulphate. The oxidation proceeds more rapidly in a fertile than in a poor soil. The oxidation of sulphur was found to produce acidity, which, if occuring in sufficient amount and not neutralized by basic calcium compounds, may render conditions unfavorable for plant growth.

TESTS AT THE OHIO EXPERIMENT STATION

Treatment of pots.—In 1914 a series of pot tests was started which included treatment with flowers of sulphur, hydrogen sulphide and blast furnace slag which contains about 2 percent of sulphur chiefly in combination as sulphides. Blast furnace slag was included in the experiment for the reason that beneficial results have been secured where it was applied which cannot be attributed entirely to any basicity developed in the soil from the calcium and magnesium silicates of the slag. It was thought that possibly its sulphur content might have contributed partly to the results secured. Sulphur was applied at the rate of 220 pounds per acre; blast furnace slag, at the rate of 4,400 pounds per acre.

Two liters of saturated solution of hydrogen sulphide was added to the pot receiving this treatment. These tests were conducted in pots 20 inches in diameter and 2 feet in depth, filled with soil and sunk into the ground. In these pots clover was grown under natural conditions. The soil used was a silt loam which was neutral in reaction to litmus, and when placed in the pots had a lime requirement by the Hopkins method of only 120 pounds of calcium carbonate per acre. A few months later the soil treated with sulphur showed a need of 450 pounds of calcium carbonate per acre. Soil receiving sulphur in addition to fertilizer materials had a requirement of 200 pounds of calcium carbonate. The soil in the hydrogen sulphide treated pot had a requirement of 220 pounds. The reaction of the soil treated with hydrogen sulphide was strongly acid to litmus. The soil treated with slag was found to have a strongly alkaline reaction, which was no doubt due to hydrolization of the calcium and magnesium silicates, and which would more than counteract the acidity resulting from oxidation of the small quantity of sulphur in the slag.

Yield of clover.—The treatment and the weight of the crop secured are included in Table XV.

TABLE XV.—Treatment and yield of clover

Pot	Treatment for 20-inch pots	Yield of dry matter
		Grams
1	Check	137
2	Blast furnace slag 100 gm. (4,400 lb. per acre)	181
3	Blast furnace slag 100 gm.; (a) dried blood 3 gm.; muriate of potash 1.5 gm.; calcium phosphate 1.7 gm.	195
6	Sulphur 5 gm. (220 lb. per acre)	163
7	Sulphur 5 gm.+same as 3(a)	141
8	Calcium carbonate 100 gm. (4,400 lb. per acre)	148
9	Calcium carbonate 100 gm.+same as 3(a)	142
10	Hydrogen-sulphide water 2 liters of saturated solution	158

With the untreated soil as a basis, it is seen that the addition of sulphur increased the yield of clover 26 grams. The sulphur treated pot produced 15 grams more dry matter than the one treated with calcium carbonate. The addition of "complete" fertilizer to the pots receiving both sulphur and calcium carbonate decreased the weight of the crop.

Two liters of hydrogen-sulphide water added to the soil in Pot 10 appears to have had a beneficial effect, since this soil produced 21 grams more clover than the untreated soil and 10 grams more than the calcium carbonate treated pot. Blast furnace slag, with and without fertilizer, produced more clover than the calcium carbonate treatment. This cannot be attributed entirely to the bases supplied by the slag, since the basicity of the soil would have been increased much more by the addition of calcium carbonate.

The results indicate that the sulphur content of the slag has been partly responsible for the favorable effect upon the growth of clover in these tests. More than 1 year's work, however, will be necessary before definite conclusions can be drawn.

EFFECT OF SULPHUR ON THE PRODUCTION OF ACIDITY AND THE SOLUBILITY OF PHOSPHORUS

The beneficial effects following the addition of sulphur to soils may result partly from the increased solubility of the soil constituents due to the acidity developed from sulphofication processes. For the purpose of studying the solubility of phosphates in relation to the production of acidity, an experiment was conducted in which sterilized and unsterilized soil (loam and clay) and pure quartz sand were used with different portions of which tri-calcium phosphate, sulphur and calcium carbonate were mixed as indicated in Table XVI.

PLAN OF THE EXPERIMENT

Treatment of soil.—The treatment was as follows where the materials indicated were used with the sand or soil: Sulphur, in the form of flowers of sulphur, 0.25 gram to 500 grams of soil, or at the rate of 500 parts to one million; phosphorus at the rate of 0.06 gram to 500 grams of sand and soil, or 120 parts per million (Phosphorus was supplied by Tennessee rock phosphate which contained 12.38 percent total phosphorus. The rock was ground finer than 100 mesh and added at the rate of 0.5 gram to 500 grams of soil); calcium carbonate at the rate of 0.5 gram to 500 grams of soil.

The several 500-gram portions were weighed into glass jars and sterilized in a hot air oven at a temperature of 150° C. Rock phosphate, sulphur and calcium carbonate were mixed with the soil after sterilization, and the containers properly protected from contamination. Each container received 400 cubic centimeters of distilled water and was allowed to stand for a month. When the excess water had evaporated, 200 cubic centimeters more was added, and the mixtures were allowed to stand for an additional period of a month.

Analytical methods.—The contents of the jars were transferred to graduated flasks and distilled water added so that the volume was 2,000 cubic centimeters. The solutions stood for 12 hours with frequent shaking.

Acidity developed.—For determining the acidity which developed and which was extracted by water, 400 cubic centimeters of the solutions was drawn off and filtered until a perfectly clear filtrate was obtained; 50 cubic centimeter portions were boiled and titrated with N/40 alkali solution, phenolphthalein being used as an indicator.

Hydrochloric-acid solution.—Sufficient standard hydrochloric-acid solution was added to the residual contents of the flask to make a solution which had a strength of 0.2 percent hydrochloric acid when the contents were made up to a volume of 2,000 cubic centimeters. The mixtures were in contact with 0.2 percent acid solution for 12 hours, during which time they were shaken frequently.

Soluble phosphorus.—A 200 cubic centimeter aliquot of the clear filtrate from the 0.2 percent hydrochloric acid extract was transferred to a 500 cubic centimeter Kjeldahl digestion flask and digested with sulphuric and nitric acid as outlined in Bulletin 285 of this Station. A double precipitation of ammonium phosphomolybdate was made and phosphorus determined gravimetrically as magnesium pyrophosphate.

Sulphur in 0.2 percent hydrochloric-acid solution.—Two hundred cubic centimeters of the filtered solution was evaporated to dryness. The residue was taken up with hot water and 3 cubic centimeters of concentrated hydrochloric acid; after filtering sulphates were precipitated as barium sulphate.

RESULTS OF THE EXPERIMENT

The experimental data obtained show that there has been a decidedly increased acidity in the solutions of several of the mixtures, which is greater for the sterilized soils, except where calcium carbonate was added. Calcium carbonate used with floats and sulphur appears to have increased the acidity in the unsterilized soil.

The addition of rock phosphate to the sand did not increase the acidity, but an increase was found in the water extract of the sterilized mixture of soil and rock phosphate. The black clay soil used in this experiment contained 7,000 pounds of calcium carbonate per 2,000,000 of soil, and was alkaline to litmus. The reaction of the water solution of this soil without the addition of phosphate or sulphur was neutral; the solution of unsterilized soil was alkaline, 4 cubic centimeters of N/40 acid being required to neutralize the alkalinity. However, the addition of rock phosphate has caused an apparent acidity in the sterilized soil equivalent to 16 cubic centimeters of N/40 alkali; in the unsterilized soil only 4 cubic centimeters of alkali was required.

The addition of sulphur increased the acidity as indicated by the titration of the water extract of the sterilized soil. In the case of the unsterilized black clay, sulphur did not increase the acidity. It is peculiar that, when calcium carbonate was included in the treatment with rock phosphate and sulphur, the acidity of the unsterilized soil should have been increased over that developed when calcium carbonate was omitted from the treatment.

The percent of sulphur in the form of sulphates was decidedly increased when sulphur was added. More sulphur and phosphorus was extracted by 0.2 percent hydrochloric-acid solution from the sterilized soil than from the unsterilized soil, except when calcium carbonate was used. This difference between the sterilized and unsterilized soil may have been due to changes brought about by sterilization, which would have decreased the absorptive capacity of the soil. This, however, would apply more to the phosphorus than to the sulphur results, since sulphates are not so firmly fixed or absorbed by the soil as are phosphates.

TABLE XVI.—Effect of sulphur on production of acidity and solubility of phosphorus

Soil and treatment	Reaction of water solution to phenolphthalein		N/40 alkali required†		Phosphorus soluble in 0.2 percent hydrochloric acid		Sulphur soluble in 0.2 percent hydrochloric acid	
	Sterilized	Unsterilized	Sterilized	Unsterilized	Sterilized	Unsterilized	Sterilized	Unsterilized
			C. c.	C. c.	Percent	Percent	Percent	Percent
Sand	Neutral	Neutral	....	....	0.0005	0.0006	0.0006	0.0006
Sand—Rock phosphate	Neutral	Neutral	....	....	.0168	.0165	.0012	.0010
Sand—Rock phosphate; sulphur	Acid	Acid	18.0	20.0	.0170	.0170	.0065	.0062
Silt loam	Acid	Acid	12.0	8.0	.0006	.0008	.0037	.0004
Silt loam—Rock phosphate	Acid	Acid	16.0	8.0	.0031	.0017	.0028	.0008
Silt loam—Rock phosphate; sulphur	Acid	Acid	48.0	26.0	.0045	.0019	.0287	.0174
Silt loam—Calcium carbonate	....	Acid	....	6.0	.....	.0005	.....	.0008
Silt loam—Sulphur; calcium carbonate	Acid	Acid	10.0	32.0	.0005	.0014	.0221	.0343
Silt loam—Rock phosphate; sulphur; calcium carbonate	Acid	Acid	10.0	44.0	.0022	.0030	.0220	.0385
Black clay	Neutral	Alkaline	....	*4.0	.0064	.0020	.0039	.0006
Black clay—Rock phosphate	Acid	Acid	16.0	4.0	.0109	.0018	.0161	.0003
Black clay—Rock phosphate; sulphur	Acid	Acid	28.0	4.0	.0114	.0025	.0433	.0380
Black clay—Sulphur; calcium carbonate	.....	Acid	....	4.0	.....	.0012	.....	.0386
Black clay—Rock phosphate; sulphur; calcium carbonate	Neutral	Acid	....	12.0	.0038	.0083	.0380	.0366

*Cubic centimeters of N/40 H_2SO_4.
†Cubic centimeters of N/40 NaOH required to neutralize acidity in 2,000 c. c. solution equal to 500 grams of soil.

The increased acidity after the use of sulphur on soils will require an addition of basic lime materials to counteract it. This would decrease the amount of phosphorus attacked by the acidity developed. The amount of phosphorus soluble in a 0.2 percent hydrochloric-acid solution where rock phosphate, sulphur and calcium carbonate were used together was less in the sterilized soil than when only rock phosphate and sulphur were used. The reverse of this condition was found for the unsterilized soil, larger amounts of phosphorus being extracted from the solution when calcium carbonate was included in the treatment with rock phosphate and sulphur.

SUMMARY

Soils well supplied with organic matter contain more sulphur than soils containing a smaller amount of organic residues. Sulphur is similar to phosphorus in that larger amounts of both these elements are distributed in the surface soil than in the lower strata.

Treatment with fertilizer materials supplying sulphates has increased the sulphur content of the soil over that found in unfertilized soil. Soil treated with acid phosphate and ammonium sulphate contains more sulphur than soil receiving acid phosphate alone.

Cultivation of silt loam soil for 16 years without the addition of fertilizers has decreased the total sulphur supply.

Water extract of soils obtained by leaching 200 grams of soil with 2,000 cubic centimeters of water shows that there is a considerable accumulation of sulphates in silt loam soil deficient in organic matter. Treatment with acid phosphate has not increased the sulphate content over that found in unfertilized soil. Ammonium sulphate used in combination with acid phosphate has decidedly increased the accumulation of sulphates. The soluble sulphur content of plots treated with ammonium sulphate was 126 parts per 2,000,000 of soil. A much less proportion of the total sulphur is found in the water extract of soils containing more organic matter and total sulphur.

The amount of soluble sulphur obtained in the water extract of soils indicates a sufficient supply of available sulphur, assuming that sulphur as sulphates is a satisfactory form of this element.

The 20-year average yields of the Wooster 5-year rotation fertility experiments show that phosphorus carriers (acid phosphate and dissolved bone black) containing sulphates, compared with bone meal and basic slag, produced more corn, oats and wheat. Bone

meal and basic slag increased the yields of clover and timothy. These experiments are conducted on soil deficient in calcium carbonate, which accounts for the better growth of clover on the bone meal and basic slag plots.

Increased yields of crops produced on soil where acid phosphate furnished the phosphorus cannot be attributed entirely to sulphur supplied. The availability of phosphorus in acid phosphate, as compared with bone meal and basic slag, has been a contributing factor.

Acid phosphate, compared with bone meal and basic slag in a 3-year rotation of potatoes, wheat and clover has given larger yields of potatoes and wheat.

In the 5-year rotation experiment conducted for 19 years on Strongsville clay, containing more sulphur than the Wooster silt loam, acid phosphate, compared with bone meal and basic slag, has given larger yields of corn, oats and timothy. The yields obtained show that bone meal and basic slag are more effective than the dissolved bone black used on this soil.

The 3-year rotation fertility plots on Miami clay loam, which have had sulphur supplied by both acid phosphate and potassium sulphate, have produced less tobacco, wheat and clover than plots to which muriate of potash and acid phosphate were added.

The effect of sulphates on soybeans, millet and rape grown on small experimental plots have been as follows:

Under certain conditions of treatment, sulphates have increased the yield of soybean hay and the sulphur content of the crop. The addition of calcium sulphate to fertilizer treatment furnishing nitrogen, phosphorus and potassium decreased the sulphur content of soybeans.

Potassium sulphate and ammonium sulphate, compared with potassium chloride and sodium nitrate, gave an increased yield of beans having a lower percent of sulphur.

Sulphates used with complete fertilizer and calcium carbonate decreased the yields of millet hay and millet seed. Sulphates considerably increased the accumulation of sulphur in millet hay and in soybean hay and decreased the content in the seed. No inorganic sulphur was found in soybeans and millet seed.

Calcium sulphate in addition to complete fertilizer has increased the yield of rape. The proteid nitrogen and organic sulphur content of rape grown on soil treated with sulphates in addition to dicalcium phosphaté, potassium chloride and sodium nitrate has been increased.

The increased amount of sulphur assimilated by the rape crop, from soil treated with sulphur in addition to phosphorus, potassium and nitrogen, is mostly combined as organic sulphur.

The nonproteid nitrogen found in the rape plant grown under the conditions of this experiment is in excess of the proteid nitrogen.

On limed soil calcium and magnesium sulphate, in addition to phosphorus, potassium and nitrogen, increased the yield over that from similarly treated plots receiving no sulphates. Potassium and ammonium sulphate on limed soil also produced more rape than plots where potassium chloride and sodium nitrate furnished the potassium and nitrogen.

Magnesium sulphate, where used with complete fertilizer and calcium carbonate, produced more soybeans and millet seed than calcium sulphate.

The use of sulphur and hydrogen sulphide in pot tests increased the acidity of the soil. Pots so treated gave a greater weight of clover than the untreated or limed pots.

Experimental data obtained by extracting mixtures of soil, sulphur and rock phosphate with 0.2 percent hydrochloric acid indicate that oxidation of sulphur has increased the solubility of the insoluble phosphorus.

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