THE EFFECT OF SULPHUR
ON SOIL REACTION AND PLANT GROWTH

by

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Thesis submitted to the Faculty of the Graduate School of the University of Maryland in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

1926

ACKNOWLEDGMENT

The writer wishes to acknowledge the unfailing help and kindness of Dr. A. G. McCall throughout the entire course of the experimental work and the preparation of the manuscript. He has supplied inspiration, careful guidance and helpful criticism. The cheerful and capable assistance of Mr. J. M. Snyder in the field experimental work has been deeply appreciated.

This experimental work was made possible through a fellowship of the Texas Gulf Sulphur Company, to whom the writer wishes to acknowledge his indebtedness.

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SUMMARY AND DISCUSSION.

The sulphur content of soils is usually lower than their content of any other essential plant constituent. Analyses of eight Maryland soils, reported in Table 1, show an average sulphur content in 2,000,000 pounds of surface soil of 382 pounds. Two of the soils have but 160 pounds of sulphur per 2,000,000 pounds, while the highest in sulphur (a heavily fertilized garden soil) has 828 pounds per 2,000,000 pounds of soil.

Powers (58) gives analyses for 67 Oregon surface soils in which the average sulphur content per 2,000,000 pounds is 488 pounds. The four Pacific Northwest soils analyzed in this laboratory have an average sulphur content per 2,000,000 pounds of 138 pounds. The highest in sulphur of these four soils, a Sagemoor fine sandy loam from Washington, has 296 pounds, and the lowest in sulphur, a Columbia fine sandy loam from Oregon, has only 54 pounds per 2,000,000 pounds of surface soil.

Although these figures giving sulphur content of soils are very low, yet it is unsafe to judge the fertility or lack of fertility of a soil by its total content of a fertility element. Because sulphur is known to enter into the constitution of the protein molecule it has been assumed that sulphur applied to certain soils stimulates crop yields directly by supplying sulphate sulphur for plant metabolism, yet there are certain baffling facts to explain in this connection. Thus two soils with equal amounts of total sulphur may give entirely different crop response to sulphur applications.

It has yet to be demonstrated that there are soils deficient in available sulphur. Displacement of the soil solution with distilled water seems to be the most efficient method of obtaining the soil solution for study of the availability of fertility constituents as they exist in the soil. Experiments at the Maryland Station with soil solutions obtained by the water displacement method show that sulphur and calcium are highly available in all the soils studied. The soils which have a low content of total sulphur generally have a relatively high content of water-soluble sulphur.

The soil which under test at this laboratory gave the least amount of water-soluble sulphur of any of the soils studied, is a Maryland soil, Porter's silt loam, which showed no increase in yield when sulphur was applied to it with field corn as the crop. However, it cannot be said that this soil was very deficient in soluble sulphur, vide Table (26). It is low in total sulphur, having but 160 pounds sulphur to 2,000,000 pounds of surface soil, but it is one of the most fertile soils in the State of Maryland.

A summary of the effect of crop yields of sulphur applied to Maryland soils is given on Page 4. The crop grown and the soil type are considered as well as the effect of sulphur alone and with different fertilizer mixtures.

In no case was sulphur applied at a heavier rate than 300 pounds per acre and only twice at that rate. One hundred pounds and fifty pounds per acre were applied. It is believed that heavier applications than this are not justified in field practice.

It will be noted that in less than one-third of the trials sulphur with acid phosphate mixtures has given increased yields. Of these six cases where sulphur with acid phosphate mixtures has increased the yield two have been on the over-limed Norfolk loam soil the crops being soybeans and Winter wheat. In both cases the sulphur and acid phosphate were on the soil at least five months previous to active crop growth. Buckwheat and sweet potatoes have been increased in yield although they were grown on quite strongly acid soils. Tobacco was increased in yield also on a strongly acid soil. The increased yield of tomatoes on the Keyport silt loam soil in 1924 must be attributed to the lateness of planting and the effect of acidity resulting from the oxidation of sulphur in forcing earlier maturity on the sulphur-treated plots.

If unusual conditions are not considered the three crops buckwheat, tobacco and sweet potatoes have given increased yields when sulphur has been added to acid phosphate-containing fertilizer mixtures. Buckwheat is well-known as an acid-tolerant plant. Tobacco and sweet potatoes are both heavy potash-feeders. Sulphur oxidation produces acidity, and it has been shown that potash is more soluble on sulphured than on unsulphured soils.

Influence of Sulphur on Crop Yields.

Crop	Soil	Sulphur alone	Sulphur with raw rock phosphate mixture	Sulphur with acid phosphate mixture
Alfalfa (Common)	Norfolk loam (1924)	Decrease	--------	--------
Buckwheat (Japanese)	Congaree silt loam (1925)	Increase	Increase	Increase
Corn				
(Boone County White)	Norfolk loam (1924)	Increase	--------	Decrease
(Reed's Yellow Dent)	Penn silt loam (1925)	Increase	--------	--------
(" " ")	Porter's silt loam (1925)	No effect	--------	--------
Cotton				
(King's Early)	Sassafras loam (1925)	Increase	Decrease	Decrease
(" ")	Keyport silt loam (1925)	Increase	Decrease	Decrease
Lettuce				
(Iceberg)	Congaree silt loam (1925)	Decrease	Increase	Decrease
Peas				
(Nott's Excelsior)	Sassafras sandy loam (1925)	Increase	--------	Decrease
(" ")	Keyport silt loam (1925)	Decrease	Increase	Decrease
Potatoes (Sweet)				
(Jersey Bigstem)	Sassafras loam (1925)	No effect	Increase	Increase
Potatoes (White)				
(Irish Cobbler)	Keyport silt loam (1925)	Decrease	Decrease	Decrease
Soybeans				
(Hollybrook)	Leonardtown silt loam (1924)	No effect	Increase	Decrease
(Wilson)	" " " (1924)	Decrease	Increase	Decrease
(")	Sassafras silt loam (1924)	Increase	Increase	Decrease
(Mammoth Yellow)	Norfolk loam (1925)	Increase	Increase	Increase
Sweet Clover (Hubam)	Norfolk loam (1925)	Increase	--------	--------
Tobacco				
(Maryland Mammoth)	Leonardtown silt loam (1925)	--------	Increase	Decrease
(" ")	Sassafras loam (1925)	--------	Increase	Increase
Tomatoes				
(Greater Baltimore)	Keyport silt loam (1924)	Increase	Decrease	Increase
	(1925)	Decrease	Increase	Decrease
(" ")	Sassafras loam (1925)	Decrease	Decrease	Decrease
Wheat (Marquis)	Sassafras silt loam (1924)	Increase	Increase	Decrease
(Currell's Prolific)	Norfolk loam (1925)	Increase	--------	Increase

Sulphur added to fertilizer mixtures having raw rock phosphate as one component has increased the yield above that with the fertilizer mixture alone in twelve out of seventeen cases. Those cases in which an increase was not observed were with Irish potatoes, tomatoes and cotton on Keyport silt loam and tomatoes and cotton on Sassafras loam, all in 1925.

In twelve out of twenty-two cases sulphur used alone has given increased yields with different crops. In three cases out of twenty-two there has been no apparent effect from the sulphur and in seven cases there has been a definite decrease. Alfalfa grown on Norfolk loam soil gave a decreased yield with sulphur. The root nodules appeared unaffected. In the soils of the Pacific Northwest sulphur applied to alfalfa has given notable increases in many instances. Since consistent decrease was obtained with alfalfa on the Maryland Norfolk loam soil, this would indicate that for the Western soils factors other than sulphate sulphur deficiency, or their highly alkaline reaction, are responsible for growth inhibition of alfalfa. As shown in Figure 2, nitrogen is highly available in the Norfolk loam soil, whereas nitrogen as nitrate is very low in the Oregon and Washington soils studied. Sulphate sulphur in water-soluble form is relatively high in all the soils studied. It is accepted by many workers that the chief beneficial action of sulphur on the Western soils is to stimulate the legume nodule organisms, and this seems the most plausible theory.

Sulphur alone has not increased the yield of alfalfa, lettuce, peas on the Keyport silt loam, Irish Cobbler potatoes, Wilson soybeans on the Leonardtown silt loam nor tomatoes, with the exception that the maturity of the late-planted tomatoes in 1924 was hastened. It has increased the yield of buckwheat, field corn, cotton, peas on a Sassafras sandy loam at Riverdale, Maryland, Wilson soybeans on the Sassafras silt loam, Mammoth Yellow soybeans on the Norfolk loam, sweet clover, Marquis wheat on the Sassafras silt loam and Currell's Prolific wheat on the Norfolk loam.

Both in the cropping experiments, and chemical studies of the displaced soil solutions, the behavior of phosphorus is difficult to explain. In fourteen cases out of twenty the addition of elemental sulphur to fertilizer mixtures containing acid phosphate has decreased crop yields.

Within the last few years there has been much work done dealing with the hydrogen ion concentration of culture solutions. Hoagland (27), Shive (33) Olsen (54) among a score of workers have shown that crop plants growing in acid or alkaline culture solutions have the ability to draw the reaction of these solutions towards neutrality.

Soluble phosphate salts are very efficient inorganic buffer salts. Unpublished data from this laboratory show that the ability of wheat plants to draw the solution in sand cultures towards neutrality is governed by the amount of phosphates present in solution; the more phosphate ions present the less the power of the plant to draw the solution to neutrality.

Sulphur oxidation generates acidity. This acidity in a cropped soil will be controlled to a great extent by the growing plants, since it has been shown that they tend to neutralize acid solutions. However, if any quantity of acid phosphate is present, the soluble phosphates will counteract the neutralizing effect of the growing crop and the resulting high hydrogen ion concentration will damage the plants to such an extent as to lower yields. McCall and Haag (45) in 1921 found that only slight increases in soluble phosphates in culture solutions increase the hydrogen ion concentration. Addoms (1) in 1923 found that large increases in hydrogen ion concentration bring about coagulation and flocculation of the protoplasm of the root hairs of seedling wheat plants thereby decreasing their permeability and rendering them unable to act as absorption organs.

The agency by which the growing plant brings about neutralization is not yet clear. Possible explanations are the formation of basic salts through reaction of basic ions with the excreted carbon dioxide from the plant roots; the amphoteric nature of plant proteins; the existence of symbiotic mycorrhizae around the roots of most crop plants, which may account for the phenomenon in whole or in part. None of these explanations is sufficient in itself to account for the phenomenon.

When acid phosphate has been in contact with soil for a short time it reverts to a less soluble form of phosphate.

However, the acidity generated by the oxidation of sulphur must be intense immediately surrounding the sulphur particles, and this strong acidity would tend to make the immediately adjacent reverted phosphate more soluble. After reaction between soil and phosphate salts has gone on for a year or more the phosphate will be mostly in insoluble form in an acid soil, for it will have combined with such ampholytes as iron and aluminum. In alkaline soils it will combine with other bases to form more soluble phosphate salts.

With raw rock phosphate mixtures plus sulphur there is a different behavior. In twelve out of seventeen cases sulphur added to raw rock phosphate mixtures has given increased yields. The phosphorus in raw rock phosphate is in insoluble form and can become available to the plant but slowly. Hoagland (28) has pointed out that the phosphate ion can be utilized from any soil by a crop only very slowly. Gericke (25) has shown that excess phosphates in solution cultures depress the growth of young plants.

The effect of soil reaction on the availability of plant nutrient ions cannot be ignored. Both phosphates and sulphates are relatively less available in acid soils than in alkaline soils. Calcium and potassium seem to be relatively more available in acid than in alkaline soils. Nitrates, while affected by reaction, are greatly affected by moisture relations. Under equal conditions of moisture the azotobacter seem to thrive in either moderately acid or alkaline soils.

The effect of sulphur on the soil reaction is to make it more acid. However, solubility relationships help to govern the availability of calcium. Calcium sulphate is but slightly soluble in water. The trend in our investigations has been for calcium to become less available; phosphorus less available; potassium more available and sulphates present in greater quantities after sulphur is applied to a soil. See Figure 2.

Some conclusions may be drawn from this work. It has been shown that the total amount of sulphur present in a soil is no measure of the sulphur present available for plant use. Except with acidophile crops or on strongly alkaline soils sulphur plus acid phosphate in fertilizer mixtures has decreased crop yields.

Sulphur with raw rock phosphate in fertilizer mixtures has in most cases increased crop yields. Sulphur is effective in increasing the amount of available potassium in soils and by this means should encourage the growth of heavy potash-feeding plants.

The effect of sulphur oxidation on soil reaction cannot be overlooked. An acid reaction in the soil solution may not in itself be harmful to the plant, but other factors present in the soil render it in most cases undesirable. The tendency of crop plants to correct acidity immediately adjacent to their roots is an established fact, but where any considerable amount of acidity is present and buffer salts are present, such neutralization may be impossible.

The extremely low amounts of nitrate nitrogen present in the Washington and Oregon soils worked with would suggest that any marked increase in crop yields from these soils must be accompanied with increased available nitrogen for the plant. The fact that legumes are benefited more than other crops by sulphur applications to these soils, makes it reasonable to suppose that sulphur helps the symbiotic nitrogen-fixing organisms in the root nodules of the legumes. Since sulphur added to these soils decreases nitrification, it must be assumed that any favorable results from its application, in respect to nitrogen, must be concerned with the symbiotic forms of nitrogen-fixing organisms.

All literature and experimental data upon which this discussion is based is given in the main body of this paper.

HISTORICAL

The application of sulphur to the soil has been studied from many different angles. There are almost as many interpretations possible of the results obtained as there have been angles of study of the problem. 36

It is evident that sulphur functions very differently in different soils. In arid soils it will behave differently than in humid soils; in rich, well-fertilized soils it will behave differently than in poor soils. So differently does sulphur behave with different soils that there have arisen two view-points:-

1. That sulphur is a direct fertilizer.
2. That sulphur acts chiefly as an indirect fertilizer through its effect on other soil constituents.

The literature reviewed will be grouped under the following headings, -

SULPHUR APPLIED ALONE

Effect on crop yields when applied in elemental form

Sulphate as a direct fertilizer

Oxidation of elemental sulphur to the sulphate form

a) Influence of sulphur oxidation on soil constituents

b) "Inoculated" and uninoculated sulphur

SULPHUR AS A CONSTITUENT OF FERTILIZER MIXTURES

a) Effect on crop yields

b) Composting sulphur with insoluble fertilizer elements

SULPHUR APPLIED ALONE

Effect on Crop Yields when Applied in Elemental Form

The French were the first to give recognition to the favorable effect of sulphur in elemental form upon crop yields. In 1911 Chancrin and Desriot (13) grew potatoes and beets on two different soil types (at Beaune and Gennetines) and found greatly increased yields when they applied elemental sulphur to these soils at the rate of 250 kilograms per hectare, roughly 250 pounds per acre.

In 1912 Boullanger and Dugardin (7) and again in 1913 Boullanger (8) added flowers of sulphur to soil in pot cultures at different rates of application. Onions, spinach, beets, beans, celery, carrots and other vegetables were among the crops whose yield was greatly enhanced by sulphur. When fertilizer treatments were added to the sulphur-treated soils but slight increase in yield was obtained over the sulphur alone. Boullanger says :-

> "Sulphur in light applications favors the work of nitrifying bacteria; it is toxic in heavy applications."

Boullanger further claims that in presence of sulphur plants "find larger quantities of ammonia salts directly assimilable," and this change in the nitrogen feeding of the plant is interpreted in terms of increases in yield analogous to those obtained by using ammonium sulphate. He remarks that the ammonia thus removed from the soil must be replaced by organic ammonia-containing fertilizers if the fertility of the soil is to be maintained. While pointing out that sulphur plus fertilizer treatments gives but slight increases over the sulphur alone, and that sulphur in heavy applications is toxic in its effect, this author does not explain these facts.

In 1921 Nicolas (51), another French worker, in addition to recording the fact that sulphur treatments give increased yields on many French soils, finds that sulphur plays several roles in plant nutrition. He says that it serves directly as a plant nutrient; it acts as a catalytic agent in the assimilation of soil nitrogen by the plant; and

> "It has a catalytic action in aiding the chlorophyll in fixation of atmospheric carbon in the form of starch."

Scores of workers have presented data showing the effect of sulphur and of sulphur-bearing fertilizers upon crop yields in different parts of the United States and with many different crops. The soil type used is evidently of fundamental importance in any consideration of the effect of elemental sulphur upon crop yields. The rate of application must be carefully controlled or the "toxic effect" mentioned by Boullanger will enter in and yields will be depressed. The crop used also is a factor in determining whether or not increased yields will be obtained from sulphur applications.

Sherbakoff (74) in 1914 found increased yield of potatoes with 100 pounds of sulphur per acre but decreased yields with 300 pounds or more; with red clover he obtained decreased yields through the use of sulphur. Reimer (59) in 1914 and Reimer and Tartar (61) in 1919 published results showing tremendous increases of alfalfa yield obtained on Oregon soils through sulphur applications. Shedd (71) in 1914 reported that sulphur fertilizers increased the yield of soybeans and that the best results were obtained with elemental sulphur. He showed turnips to be materially benefited by sulphur fertilizers on the soil used but found that cabbage, red clover and radishes were not benefited.

Duley (17) in 1916 pointed out that the application of flowers of sulphur markedly increased the production of nodules on the roots of red clover and when used alone the sulphur increased slightly the yield of corn and rape and to a greater extent the yield of red clover on the soil type used. He reports soil acidity increased and the nitrate content of the soil varying inversely with the amount of soluble sulphates present.

Ames and Boltz (2) in 1916 showed that with the use of elemental sulphur on certain Ohio soils the yield of clover is increased; where blast furnace slag and dried blood plus sulphur were used, the yield of clover was decreased below that of the no treatment check. They report increased acidity in the sulphur-treated soil.

Stewart (78) in 1920 in a statement of the relation of sulphur to soil fertility from the viewpoint of the University of Illinois findings, points out the exceedingly small quantities in which sulphur is taken up by the plant. He believes that the role of sulphur may be considered as somewhat analogous to that of iron in the plant economy.

Pitz (57) in 1916 reported increased yield of red clover on Miami silt loam soil due to sulphur.

Olson and St. John (53) in 1921 publish evidence showing that on Washington soils the yields of dry matter obtained on the sulphur-treated soils were on the average much larger than were obtained on the untreated soils. These investigators conducted a series of pot experiments extending over four years in the greenhouse, and they say of their results :-

> "Larger wheat and barley crops were obtained on the sulphur-treated soil than were obtained on the unsulphured soil. In three out of four years, oats and peas gave increases in the sulphured soil, while soybeans gave about the same yields in the sulphured and unsulphured soils. The largest yield of alfalfa was obtained on the unsulphured soil."

These workers conducted work with various sulphur carriers and have the following to say of elemental sulphur,-

> "Elemental sulphur applications also have increased the yields of alfalfa but the plant response to sulphur needs has been necessarily slow because the sulphur must first be oxidized to the available form."

In 1922 Lemanitz (40) reported the results of two years pot work with soils from Brazos County, Texas. He concludes that with corn, sorghum, alfalfa and cotton, sulphur is not needed in the soils used. He found that sulphur increases the acidity of some of the soils worked with and that no relation exists between the percentage of nitrogen and that of sulphur in the sorghum grown.

Rudolfs (64) in 1922 gave the results of applying sulphur to pot cultures of a California orange grove soil at rates of 100, 300, 500 and 1000 pounds per acre both with and without other fertility soil constituents. Soybeans were stimulated in growth by the lower applications and decreased in growth with the heavy applications of sulphur. This experimenter's work will be further discussed.

Reynolds and Leidigh (62) in 1922 published the results of adding sulphur at different rates of application to cotton crop. The yields of cotton were increased and larger vegetative growth obtained where sulphur was applied.

Neidig, McDole and Magnusson (48) in 1923 published evidence to show that sulphur applications increased the yield of alfalfa on all the non-irrigated Idaho soils they worked with. More nitrogen and more sulphur are taken up by the plants on the sulphur-treated soils.

Geise (22) in 1923 reported the effect of 300 and 600 pound applications of inoculated sulphur on potatoes, spinach and sweet corn grown in Virginia soils. Yields were depressed in all cases by these heavy applications.

Lipman and McLean (39) in 1924 reported that barley, buckwheat and mustard give decreased yields with light sulphur applications, while soybeans appear unaffected on an acid Sassafras loam soil. On less acid Sassafras loam soils, barley, radishes and soybeans gave increased yields with light sulphur applications.

Neller (49) in 1925 pointed out that sulphur is effective in increasing the yield of alfalfa only on some of the experimental soils worked with in Washington State. Where it is effective there is a marked increase in the nitrogen content of the crop while the potassium, calcium and phosphorus contents are about the same. He recommends the application of elemental sulphur, where needed, at the rate of about 75 pounds per acre.

Bruce (12) in 1925 reported that sulphur applications to alfalfa on Oswego silt loam soil in pot cultures depressed the yield below that of the check in all cases. Both inoculated and uninoculated sulphur were used at the rate of 384 pounds per acre. In general the acidity of the soil was increased by the sulphur applications.

Sulphate Sulphur as a Direct Fertilizer

Wherever commercial fertilizers are widely used sulphur has been applied in great quantities to the soil in the sulphate form. The principal sulphur carriers used have been acid phosphate, sulphate of potash, sulphate of ammonia and gypsum.

As Lint pointed out in 1925 (36) there is in acid phosphate about twice as much sulphate sulphur as there is phosphoric acid. The other fertilizers mentioned also contain high percentages of sulphate sulphur.

Palladin (56) says of sulphur,-

> "Sulphur is a necessary element because it is essential to the formation of proteins, which are so important in plants. It must be supplied as the sulphate of one of the essential metals; all other compounds of sulphur are injurious. It cannot be replaced by any other element."

In recent years the essential nature of sulphur for best plant growth has been sufficiently demonstrated. As Tottingham (80) says, in 1918,-

> "Calcium sulphate has proved an especially efficient source of sulphur...... it appears that calcium sulphate has peculiar efficiency as a molecular complex."

Tottingham studied the growth of red clover with and without sulphates in the nutrient solutions used. He writes further

.... a deficiency of sulphur supply restricted growth by limiting the synthesis of protein."

In Oregon and Washington the application of any form of sulphur-bearing fertilizer results in increased crop yields on many soils. Reimer and Tartar (61), Miller (47) and Powers (58) from Oregon have dealt fully with this question as have Olson and St.John (53), Neller (49) and Erdman (21) in Washington. All of these workers accept the fact of sulphur itself being a limiting element and that, as Powers says

"The increase caused by its application was not to any great extent due to indirect action."

The introduction of better analytical methods during the first decade of the twentieth century brought widespread attention to bear upon the question of sulphur deficiency of soils. Hart and Peterson (26) in Wisconsin and Shedd (71) in Kentucky were among the first to point out the low sulphur reserves in many United States soils.

A great deal of work has been done with the application of gypsum to soils and there is a confused mass of testimony for and against its use. Erdman (20) found gypsum of some value to alfalfa but of little value with other crops in increasing yields of Iowa soils. At Pennsylvania State University Experiment Station no benefit is found from extended gypsum treatments. At Ohio Experiment Station gypsum at 320 pounds per acre every three years increased the yields of nearly every crop studied, but not so much as acid or rock phosphate at the same rate of application. The experiments covered a period of 18 years.

At Illinois Stewart (78) pointed out that sulphates (in the form of potassium sulphate) have not increased crop yields when used with manure, limestone and rock phosphate. The average yields for many years are presented, for six different crops and for the two systems of farming - "Live-stock" and "Grain."

Work has been done to estimate the outgo of sulphur from the soil. The lysimeters at Cornell, and to a limited extent those at Tennessee, are a means of studying this outgo. Data presented by Lyon and Bizzell (41) show that considerably more sulphur is lost from the soil than enters it through rainfall.

McIntire (46) has shown that where enormous applications of burnt lime (CaO 8 to 100 tons per acre) are made to the soil, the amount of sulphates leaching from the lysimeters at that Station is reduced to a minimum. Magnesic limestone causes more loss of sulphates than calcic in these heavy applications, yet with 100 tons of calcium carbonate per acre there is considerable sulphate sulphur lost.

The rainfall at different parts of the country has been collected, analyzed and reported upon by such workers as Hart and Peterson (26), Erdman (20), McIntire, Willis and Holding (46) and others. The opinion is unanimous that the sulphur contained in the rainfall is insufficient to preserve the sulphur balance in the soil unless it is within areas of heavy atmospheric contamination by soft coal smoke.

Oxidation of Elemental Sulphur to the Sulphate Form.

It is generally accepted by plant physiologists that sulphur is utilized by plants only in the sulphate form. In the oxidation from the elemental to the sulphate form in soils sulphur not only undergoes a radical change itself, but it also exerts a great influence upon the soil constituents.. This would be true if the increase of hydrogen ion concentration in the soil were the only thing considered.

If it is all oxidized to the sulphate form a 100 pound per acre application of elemental sulphur is equivalent to a 300 pound application of sulphuric acid to the acre of soil. The reactions involved in this oxidation process, which is undoubtedly biologically controlled, may be summated thus

$$2S + 2H_2O + 3O_2 = 2\ H_2SO_4$$

The effect of 300 pounds of a strong acid like sulphuric acid is considerable when applied to an acre of even a well-buffered soil. Runk (69) has shown that soils differ very greatly in their ability to resist, by buffer action, the increase in hydrogen ion concentration brought about by addition of sulphuric acid.

This difference in "buffering" effect is responsible for the diverse results that have been obtained from elemental sulphur in increasing the hydrogen ion concentration of soils to which it is applied. Soils high in organic matter; soils high in soluble bases such as calcium, potassium and magnesium; and those high in soluble phosphates, are buffered to the extent of their content of these buffering agencies. In consequence they will show less tendency to become acid upon application of sulphur than other soils not possessing like concentrations of such buffering materials.

French workers were the first to study the oxidation of sulphur to sulphates in the soil. DeGrully (18) in 1911, Boullanger (7) in 1912, Demolon (15) in 1913, Brioux and Guerbet (9) in 1913, did pioneer work in this field. Kappen and Quensell (34) in 1915 in Germany found free sulphur rapidly oxidized to sulphates in the soil. They thought the process to be partly biological and partly chemical. In the United States, in 1916, Lipman, McLean and Lint (37) conducted studies in which they found that in 30 weeks, 70 per cent. of the sulphur added, in a compost of 100 grams soil, 15 grams rock phosphate, and 5 grams sulphur, had been oxidized to the sulphate form.

Ames and Richmond (3) in 1916 pointed out that sulphofication (the oxidation process by which sulphur is converted to the sulphate form) depresses nitrification even where large amounts of calcium carbonate were used to counteract the acidity developed. Ockerblad (52) at Vermont in 1917 actually used a 0.1 per cent. solution of sulphuric acid as a means of soil sterilization and stated that a one-day exposure to such solution killed over 90 per cent. of all soil organisms.

Rudolfs (65) in 1922 working with sulphur oxidation in alkali soils found that after 18 weeks all the sulphur in practically all the cultures had been oxidized. Joffe and McLean (30) in 1922 working with sulphur oxidation in eight Oregon soils found that the addition of 250 pounds of sulphur had not materially changed the reaction after the oxidation of most of the sulphur.

Demolon (16) in 1921 in France found that ammonifying bacteria will oxidize sulphur in the soil. He specifies B.fluorescens liquefaciens and B.mycoides. Waksman (82) in 1922 states that there are two types of sulphur oxidizing bacteria - one effective in acid media and one in alkaline media. Thiobacillus thiooxidans is acidophile and Thiobacillus B. is the alkali-tolerant organism.

In 1922 studies at the Oregon Experiment Station (55) showed temperature and moisture to be the important factors regulating the oxidation of sulphur in the soil, and that the application of sulphur makes a soil a more favorable medium in which sulphur-oxidizing organisms may work. Also it is stated that for field conditions the elemental sulphur is as effective as the inoculated sulphur.

Brown (10) in 1923 describes the oxidation of sulphur in different media and states that the nonbiological oxidation of sulphur in a soil must be very limited. Rippel (63) in Germany in 1924 reported studies which show sulphur oxidation in a soil to be almost entirely biological in nature. He says that most aerobic organisms should possess sulphur-oxidizing power under favorable conditions.

Neller (49) in 1925 states that up to 1000 pound applications per acre sulphur is almost entirely oxidized in Washington soils, but with amounts above that the percentage oxidized decreases rapidly. The hydrogen ion concentration of heavily sulphured soils becomes greater.

a) Influence of Sulphur Oxidation on Soil Constituents

As discussed under the heading "Composting Sulphur with insoluble Fertilizer Elements," the effect of the acidity engendered during the oxidation of elemental sulphur to the sulphate form has been studied widely in concentrated mixtures of sulphur and various insoluble fertilizer materials.

The effect of the oxidation of elemental sulphur on soil minerals is not well understood, if it is considered from the standpoint of sulphur applications to the soil. In this case we have an enormously dilute, ill-mixed "compost", but in spite of this dilution it has been well demonstrated that even light applications of sulphur have an appreciable effect on the reaction of lightly buffered soils.

In soils with an excess of base the acidity engendered by oxidation processes is promptly neutralized in the case of light applications of sulphur, but heavier applications will cause the reaction to become more acid even in these highly basic soils. The formation of sulphate salts certainly results. Upon the solubility of the sulphate salt of a given base depends in part the "freeing" action, upon that base, of the sulphur applied to a soil.

Stephenson and Powers in 1924 (77) used both an arid and a humid soil to study the effect of the oxidation of elemental sulphur upon the soil mineral constituents. These investigators found a decided increase in the water-soluble calcium and potassium of the treated soils, and a marked decrease in the amount of water-soluble phosphorus. In both soils it was found that even the lighter applications of sulphur produced an increase in acidity. Flocculation of the soil colloids by the oxidized sulphur was noted.

Erdman (21) in 1925, using Palouse silt loam soil, found the water-soluble calcium and potassium increased by applications of elemental sulphur, heavy or light. He states that analyses for water-soluble phosphorus were made, but that the amounts obtained were so small as to be within the limits of experimental error. The active acidity of the soil studied was apparently not increased by applications of as high as 1000 pounds of elemental sulphur per acre.

In the work of Stephenson and Powers the soils were studied in controlled pot cultures. Samples were taken three, six and nine months after the application of the sulphur, and analyses made on the water extract. In Erdman's work the soil was leached, under both field and greenhouse conditions, and determinations made upon the leachings. Distilled water was used and carefully controlled conditions were maintained in the greenhouse.

Erdman found that 1000 pounds of gypsum per acre applied to the soil increased the amount of water-soluble potassium slightly less than 186 pounds of elemental sulphur. In each case, the equivalent of 558 pounds of sulphate radical was applied to the soil, and apparently the response to the treatments in freeing potassium is almost

NOTE:- Erdman's unpublished data, which are in the hands of the National Research Council, Sulphur Fellowship Committee, show that the amounts of water-soluble phosphorus leached from the sulphur-treated soils are lower than those from the untreated soils.

identical. This would suggest that the soluble salt potassium sulphate is formed and is leached from the soil by the water passing through it.

Ames and Simon (4) in 1924 presented evidence to show that the solubility of soil potassium in water is increased by applications to the soil of calcium sulphate, sodium nitrate, ammonium sulphate and mono-calcium phosphate. Ammonium sulphate had a more pronounced effect than the other salts added to the silt loam, clay loam and clay soils which were used.

What effect has sulphur applied to the soil upon the soil nitrogen ?

Duley (17) in 1916 found that sulphur depressed nitrification and that nitrates in the soil decreased as the soluble sulphates and the acidity of the soil increased. However, he found that nodule formation on the roots of red clover was very markedly increased by sulphur applications.

Ames and Richmond (3) in 1918 reported that nitrification was depressed by the oxidation of sulphur even where large amounts of calcium carbonate were added to the soil studied.

In France Boullanger (8) in 1913 wrote

> "In the presence of sulphur plants find larger quantities of ammonia salts directly assimilable."

However, no direct experimental proof is cited.

Neller (49) in 1925 states that analyses of alfalfa grown on sulphured soils show a higher amount of nitrogen and of sulphur than the alfalfa from unsulphured soils. He writes

> "This again is an indication that the chief beneficial action of sulphur is to cause the nodule bacteria to supply more combined nitrogen to the plant."

Powers (58) in 1923 writes

> "Legumes, particularly alfalfa, red and alsike clover, have given marked response to sulphur fertilizers."

Also

> "H.V.Tartar and H.G.Miller of the Oregon Experiment Station found that sulphur increases protein content of crops."

And

> "Sulphur seems to be related to nitrogen supply."

Neidig, McDole and Magnuson (48) in 1923 state that their investigations prove that sulphur in all forms produced an increase in the total nitrogen removed by alfalfa.

b) "Inoculated" and Uninoculated Sulphur

Joffe (29) in 1922 published a comprehensive treatise on the biochemical oxidation of sulphur. In discussing the oxidation of sulphur by soil organisms he says in part :-

> "If under certain conditions the addition of sulphur to the soil

> is desirable its oxidation is indispensable. If, however, the soil does not contain the proper sulphur-oxidizing organisms the sulphur will not oxidize rapidly enough and the desired effect of the sulphur application may not be accomplished. Evidence is at hand that native sulphur is the primary source of the most powerful sulphur-oxidizing organism <u>Thiobacillus Thiooxidans.</u>"

Joffe presents data showing the oxidation of sulphur in eight Oregon soils. Each soil was treated with sulphur equivalent to 2000 pounds per acre; "inoculated" and uninoculated sulphur being used. The inoculated sulphur presumably was treated with sulphur-oxidizing organisms from special cultures, for a foot-note states

> "The inoculation was made by introducing 10 mgm. of a soil which was especially prepared for inoculation purposes."

After 32 days incubation the reaction of the soils with inoculated and uninoculated sulphur was about the same. The amount of sulphur oxidized with the two treatments did not differ greatly. Later Joffe showed that these Oregon soils did not contain the T.Thiooxidans but did contain the T.Beijerinckii.

Lipman, Blair, Martin and Beckwith (38) in 1921 state that inoculated seems more effective than uninoculated sulphur for rendering inert mineral plant food accessible to growing crops. With potatoes, barley and corn they found the addition of sulphur to rock phosphate increased the yields over the rock phosphate alone.

Martin (43) of New Jersey reported in 1921 better control of potato scab with inoculated than uninoculated sulphur and claimed that smaller amounts of inoculated than uninoculated sulphur could be used to obtain the same results.

Bruce (12) in 1925 reported that the addition of inoculated and uninoculated sulphur to Oswego silt loam soil increased the acidity to about the same extent. This increase in acidity is a rough measure of the oxidation of the applied sulphur.

The Kentucky Experiment Station (35) reported in 1923 that raw rock phosphate and inoculated sulphur mixed compares favorably with acid phosphate as a fertilizer.

The Oregon Experiment Station (55) reported in 1922 no difference between inoculated and uninoculated sulphur under field conditions.

In 1925 Simon and Schollenberger (76) showed that inoculated sulphur was much inferior to more finely ground sulphur. They conclude that the rate of oxidation of sulphur is governed by the fineness of division of the different forms of sulphur used. They found that

> "The most complete oxidation was correlated with the highest hydrogen-ion concentration."

Inoculated sulphur was the most poorly oxidized of any of the four forms of sulphur used.

SULPHUR AS A CONSTITUENT OF FERTILIZER MIXTURES

Boullanger (8) pointed out that when sulphur is applied with fertilizer mixtures there is little if any increase obtained over the sulphur alone.

Duley (17) found that when he added elemental sulphur to lime, nitrogen, potash and phosphorus mixtures he obtained decreased yields. He also found that when he added lime and sulphur to the soil he got yields of red clover lower than from either of these materials by itself.

Shedd (73) in 1917 reported that the addition of 100 and 500 pounds of sulphur per acre to Yellow Pryor tobacco seedlings together with a mixture of 500 pounds KNO_3, 500 pounds $CaHPO_4$, and 200 pounds $CaCO_3$ per acre, gave increases of 10% and 24% respectively. Shedd further found that 100 and 200 pounds per acre of elemental sulphur, plus 500 pounds Ca_3PO_4, 200 pounds KNO_3 and 8000 pounds $CaCO_3$, increases the production of some crops, has no effect on others, and is injurious to some. He studied soybeans, clover, oats, alfalfa and wheat on eight different soil types of Kentucky.

Miller (47) in 1919 used both soil and sand pot cultures to study the effect of sulphur plus sodium nitrate and calcium carbonate upon crop yields. He used three different soils and oats, rape and red clover as crops. He concluded that crop yields are enhanced in the case of legumes by the stimulating effect of sulphates upon symbiotic legume bacteria.

Rudolfs (64) in 1922 added acid phosphate at the rate of 100 pounds per acre to sulphur applied at from 100 to 1000 pounds per acre on both a California soil and a New Jersey soil. Under these conditions he found less increase in hydrogen ion concentration than where sulphur alone is added to the soil, or where sulphur plus 300 pounds of raw rock phosphate is added. This effect of the acid phosphate might be attributed to the buffering effect of soluble phosphates which will be more fully discussed later.

Rudolfs moreover shows in this paper that in the soils used the acidity engendered by the oxidation of the sulphur was not great enough to render soluble any amount of the raw rock phosphate, although it was so great that the growth of soybeans in the soil was seriously retarded.

In the Kentucky Agricultural Experiment Station Report (35) for 1923, it is reported that a mixture of inoculated sulphur and raw rock phosphate compares very favorably with acid phosphate alone. The acidity produced by sulphur treatments is noted as being inimical, in some cases, for the best growth of wheat plants.

Allison (5) in 1922 pointed out the harmful effect of sodium nitrate upon the oxidation of sulphur, and attributes this effect to the presence of the nitrate radical.

Powers (58) in 1923 reported that on a Medford soil sulphur 200 pounds per acre plus raw rock phosphate, 281 pounds per acre, gave a better yield of alfalfa than 412 pounds of superphosphate per acre and a better yield than either the raw rock phosphate alone or sulphur alone.

Bruce (12) in 1925 found that on Oswego silt loam acid phosphate 400 pounds per acre plus sulphur 384 pounds per acre gave an extremely low yield of alfalfa, lower than where manure or complete fertilizer mixtures were applied with sulphur.

Sulphur as a Compost Constituent

Lipman, McLean and Lint (37) in 1916 first conceived the idea of employing compost heaps of sulphur, soil and raw rock phosphate as a means of making available insoluble phosphate. The theory is that the acidity engendered through oxidation of the elemental sulphur by sulphofying organisms is the active agency in rendering the phosphates soluble.

Many other workers have studied the composting of raw rock phosphate and sulphur with soil. Brown and Warner (11) in 1917 confirmed Lipman's findings that soluble phosphates are produced in composts of raw rock phosphate, sulphur and soil. Brown and Warner, however, used manure as one of the compost constituents. Ellett and Harris (19) in 1920 describe composts of raw rock phosphate, sulphur and soil and also show manure to be beneficial in increasing the soluble phosphate content of the composted mixture.

Rudolfs (67) in 1922 composted raw rock phosphate, sulphur and iron pyrites and found the latter of no effect in rendering phosphates available. In an earlier paper Rudolfs (68) found that too much aeration is bad for sulphofication in the composts. Also, he states that calcareous soils are about as good as acid soils as constituents of the compost.

Joffe (31) in 1922 showed that the moisture content of floats-sulphur composts should be 50 per cent at the start and raised to 60 per cent when a reaction of pH 2.8 is reached in the compost, at which reaction the insoluble phosphate starts to become soluble.

McCall and Smith (44) 1920, composted greensand marl (containing about 4 per cent of potassium) manure and sulphur, and found after the lapse of several months that as high as 41 per cent of the original potassium of the greensand had been rendered soluble.

Rudolfs (66) in 1922 and Joffe (32) in 1923 used greensand marl and raw rock phosphate as components of some sulphur composts, thus trying to derive benefit from the effect of sulphur oxidation on both insoluble phosphate and potassium compounds.

EXPERIMENTAL WORK

Cropping Experiments

Fertilizers and soil amendments are applied to the soil in order to increase the yield and better the quality of the crops grown. Greenhouse and field experiments have been conducted at the University of Maryland Agricultural Experiment Station during the past three years to investigate the effect of sulphur on crops grown in Maryland soils.

The soils studied have been analyzed and a report on their fertility constituents is given in TABLE I. Complete analysis was made for calcium, carbon, iron, magnesium, nitrogen, phosphorus, potassium, sulphur and the amount of hygroscopic moisture in the air-dried soils. Two soils from Washington State and two from Oregon which have given increased yields after the application of sulphur have been included in the chemical study, but in our work no cropping data have been obtained on these four soils.

Eight soils from Maryland each representing a different type have been studied, and crop data as well as chemical studies are presented for them.

The results obtained will be shown under the different soil types, and then again under the heading of the crops studied. When it is desired to call attention to the total fertility content of a soil reference will be made to Table I.

Table I.

TOTAL FERTILITY CONSTITUENTS
OF EXPERIMENTAL SOILS USED

No.	Soil from	Soil type	Calcium	Carbon	Iron	Magnesium	Nitrogen	Phosphorus	Potassium	Sulphur	Hygroscopic moisture
			% Ca	% C	% Fe	% Mg	% N	% P	% K	% S	%
						Pacific Northwest Soils					
1.	Adams Branch Wash.	Ritzville v.f.s.l.	0.556	0.58	0.50	0.420	0.0994	0.0670	1.290	0.0041	1.62
2.	Prosser Wash.	Sagemoor f.s.l.	1.251	0.38	0.56	0.598	0.0580	0.0770	1.526	0.0148	1.38
3.	Grant's Pass Oregon	Columbia f.s.l.	0.862	1.40	0.87	0.476	0.2017	0.0660	0.373	0.0027	1.73
4.	Klamath Falls Oregon	Yakima s.l.	1.195	1.06	0.51	0.664	0.1270	0.0450	0.749	0.0060	1.78
						Maryland Soils					
5.	Cheltenham Pr.Geo's.Co.	Norfolk loam	0.778	0.77	0.34	0.535	0.0860	0.0240	0.855	0.0110	1.21
6.	La Plata Charles Co.	Leonardtown silt l.	0.431	0.58	0.36	0.343	0.0800	0.0244	0.468	0.0143	0.61
7.	Middletown Fred'k Co.	Porter's silt l.	0.695	0.74	1.16	0.363	0.0844	0.0551	0.984	0.0080	1.91
8.	College Park Pr.Geo's.Co.	Keyport silt l.	0.578	1.59	0.53	0.205	0.1391	0.0677	0.690	0.0320	1.21
9.	College Park Pr.Geo's.Co.	Sassafras loam	0.267	1.06	0.33	0.190	0.0964	0.0564	0.791	0.0101	2.14
10.	Back Bay Balto. Co.	Sassafras silt l.	0.256	0.98	0.37	0.175	0.0910	0.0419	0.927	0.0414	0.76
11.	Taneytown Carroll Co.	Penn silt l.	0.417	0.60	1.36	0.428	0.0660	0.0232	0.920	0.0081	1.52
12.	College Park	Congaree silt l.	0.236	1.13	0.46	0.190	0.0987	0.0288	1.383	0.0280	0.96

v.f.s.l. - very fine sandy loam
f.s.l. - fine sandy loam
s.l. - sandy loam
silt l. - silt loam

As stated, both greenhouse and field studies have been made on several of the soils studied. Nearly all the greenhouse work has been done with 20 pounds of soil in 10" by 10" clay pots. The field studies have been made on plots varying in size from 1/20th to 1/200th of an acre. In all cases the yields have been reduced to the acre basis in order to avoid confusion.

Leonardtown Silt Loam from La Plata, Charles County, Maryland

A series of pot cultures was conducted in the greenhouse in the Winter of 1923-24 to study the effect of sulphur on this soil. Twenty pounds of soil was used to the pot and Hollybrook soybeans were grown. Cultures were in quadruplicate and average yields are shown in the tables.

In Table 2 are given the reaction values of this soil as affected by the different treatments, after 2 months, and again after 7 months, which was sometime after the crop had been removed. In Table 2 also are given the yields obtained with elemental and inoculated sulphur, and the yields obtained with sulphur plus fertilizers in mixtures in which the components were varied.

The soil used in these cultures showed a lime requirement of 500 pounds of $CaCO_3$ per acre by the Truog method, and the untreated soil, when taken from the field had a reaction of pH 6.90. Clay pots ten inches in diameter and ten inches deep were used and 20 pounds of air-dried soil was placed in each pot. Calcium carbonate at the rate of 500 pounds per acre was applied

Table 2.

Yields of Hollybrook Soybeans
and Reaction Values of Leonardtown Silt Loam
Pot Cultures in Greenhouse, Winter of 1923-24.

No. Treatment per acre (On basis of 1 acre surface soil = 2,200,000 lbs.) (Cultures in quadruplicate)	Reaction at end of 2 mos. pH	Reaction at end of 7 mos. pH	Yield per acre oven-dry tops Lbs.
1. Nothing	6.73	7.10	1500
2. 100 lbs. elemental sulphur	6.05	6.35	1611
300 " " "	5.10	5.43	1642
3. 100 lbs. inoculated sulphur	5.12	6.80	1594
300 " " "	4.35	5.65	1514
4. 400 lbs. 0-10-4 - Raw rock phosphate and KCl	7.63	7.23	2049
Same plus 100 lbs. elemental sulphur	6.58	6.90	2212
" " 300 " " "	5.38	5.30	1754
" " 100 " inoculated sulphur	6.96	7.73	2501
" " 300 " " "	5.54	5.13	2045
5. 400 lbs. 0-10-4 - Acid phosphate and KCl	7.81	7.13	2827
Same plus 100 lbs. elemental sulphur	5.95	6.65	2089
" " 300 " " "	6.22	5.15	2411
" " 100 " inoculated sulphur	6.99	6.25	2631
" " 300 " " "	5.00	5.50	2447
6. 200 lbs. 0-10-4 - Raw rock phosphate and KCl			
plus 100 lbs. inoculated sulphur	5.93	6.73	2060
" 300 " " "	4.70	5.13	2304
7. 200 lbs. 0-10-4 Acid phosphate and KCl			
plus 100 lbs. inoculated sulphur	5.86	5.92	1609
" 300 " " "	4.92	4.48	1415

to the pots and mixed with the surface three inches of soil on December 1, 1923. The soybean seedlings were sprouted on cheesecloth and transferred to the pots on December 18, 1923, when the seedlings were ten days old.

In this and in all subsequent greenhouse and field work where raw rock phosphate was used, it was one-half by weight of the acid phosphate used. Thus, since the raw rock phosphate was 32% total phosphorus and the acid 16% total phosphorus, one-half as much by weight of raw rock gave the same amount of total phosphorus as the full amount of acid phosphate.

The sulphur and fertilizer treatments were mixed with the surface three inches of the soil on the day that the plants were transferred to the pots. On January 3, 1924, an inch of washed glass sand was placed on the surface of each pot in order to insure uniform moisture conditions. Measured amounts of well water were applied to each pot in equal quantity. The soybeans were harvested from all the pots on April 2, 1924, dried in the oven, and the oven-dry weights recorded.

The habit of growth of the soybeans varied in a peculiar way. The sulphur-treated plants showed two characteristic tendencies - in one case the plants were very tall and slender-stemmed, in the other the plants were very dark green in color and dwarfed, with the leaves tightly clustered on short petioles. Tarr and Noble (79) in 1922 mentioned the spindling growth habit as being characteristic of soybeans under strongly acid culture conditions.

In the case of these sulphured pots an acid condition is present, so it is likely that the growth habit may be correlated with the acidity produced by oxidation of the sulphur in the soil.

As shown in Table 2 sulphur when used with acid phosphate has had a depressing effect on yields compared with the acid phosphate alone. This depression of yields is not apparent when sulphur is used with raw rock phosphate. In this table also are reported the reaction values of the differently treated cultures, and it is shown that those cultures receiving acid phosphate and sulphur have as a rule higher concentrations of hydrogen ion after the lapse of 7 months than those cultures receiving raw rock phosphate and sulphur, or sulphur alone.

Elemental sulphur has been more effective in increasing yields than inoculated sulphur. Inoculated sulphur shows greater acidity developed at the end of 2 months, but less acidity after 7 months, than elemental sulphur.

As a rule 100 pounds of sulphur was more effective in increasing yields than 300 pounds per acre. It is interesting to note the apparent correlation between high acidity and low yields.

In 1924 Wilson soybeans were grown at La Plata on the same Leonardtown silt loam studied in the greenhouse. No lime was applied to this soil in the field trials. The yields of Wilson soybeans in bushels of beans and pounds of straw obtained from the 1/20th acre plots used in the field are given in Table 3. The sulphur and fertilizers used were applied on June 27th, the day that

Table 3.

Yields of Wilson Soybeans,
Field Plots on Leonardtown Silt Loam, La Plata, Md. 1924.

No.	Treatment per acre (1/20th acre plots used) (Plots in duplicate.)	Yields per acre Bushels beans	Pounds straw
1.	Nothing	7.83	647
2.	100 lbs. inoculated sulphur	7.72	572
3.	300 lbs. inoculated sulphur	7.27	558
4.	200 lbs. 4-8-4 $NaNO_3$, Rock Phosphate and KCl	9.30	736
	Same as 4 plus 100 lbs. inoculated sulphur	10.44	899
5.	200 lbs. 4-8-4 $NaNO_3$, Acid phosphate and KCl	9.76	899
	Same as 5 plus 100 lbs. inoculated sulphur	9.53	776

the soybeans were planted, and the crop was harvested on October 11th. The season of 1924 in Maryland was very wet during May and June, so wet that planting operations could not be carried out on this field until the end of June.

In all cases where sulphur was applied with fertilizer mixtures the sulphur was weighed out and thoroughly incorporated with the other components of the mixture at the time the fertilizers for the plots were prepared. The sulphur and the fertilizers were broadcasted by hand as evenly as possible over the 1/20th acre plots.

The field trials at La Plata with soybeans bear out in part the observations made with soybeans grown on this soil in pot cultures in the greenhouse. Sulphur alone has given only decreases, while in the greenhouse slight increases were obtained. Sulphur with raw rock phosphate mixtures has increased the yield, while sulphur with acid phosphate mixtures has decreased the yield as compared with the unsulphured fertilizer mixtures.

In 1925 the same plots at La Plata were used to grow Maryland Broadleaf tobacco. The residual effect of the sulphur treatments on soybeans the previous year as well as the fertilizer and sulphur applications of the current year were studied.

The tobacco plants were transplanted from the seed-bed and placed in the plots during the week of June 15th, 1925, the soil having been prepared and the fertilizers drilled in on June 10th. In the Fall of 1924, after the soybeans had been cut, rye was seeded on these plots and plowed under on May 20th. This La Plata soil is very poor, and while it is not a good practice as a rule to turn under green manure before planting tobacco, in this case the added organic matter could not be very harmful to the tobacco. The tobacco plants were cut on September 20, 1925, speared and hung in the curing barn. After curing was complete and the tobacco in condition, the leaves were stripped and made into "hands". At this stage the stripped leaves were weighed.

With tobacco as well as soybeans, there is depression of yield when sulphur is added to fertilizer mixtures containing

Table 4.

Yields of Maryland Broadleaf Tobacco
Field Plots on Leonardtown Silt Loam, La Plata., 1925.

No.	Treatment per Acre in 1925 (1/20th acre plots)	Inoculated sulphur applied in 1924. lbs.	Yield per acre (mean of 2 plots lbs. Stripped leaf
1.	1200 lbs. 4-8-4 - Tankage, Acid Phosphate, K_2SO_4.	None	520
	Same as 1 plus 60 lbs. sulphur	100	480
	" " 1 " 120 " "	60	480
2.	1200 lbs. 4-8-4 - Tankage, Rock phosphate, K_2SO_4	None	340
	Same as 2 plus 60 lbs. sulphur	100	400
	" " 2 " 120 " "	60	480
3.	1200 lbs. 4-8-4 - $NaNO_3$, Acid Phosphate, K_2SO_4	None	420
	Same as 3 plus 120 lbs. sulphur	None	460
4.	1200 lbs. 4-8-4 - $NaNO_3$, Rock Phosphate, K_2SO_4	None	600
	Same as 4 plus 120 lbs. sulphur	None	640
5.	1200 lbs. 4-8-4 - ½ $NaNO_3$ and ½ Tankage as nitrogen source, Acid Phosphate, K_2SO_4	300	460
	Same as 5 plus 60 lbs. sulphur	100	440
	" " 5 " 120 " "	60	380
6.	1200 lbs. 4-8-4 - ½ $NaNO_3$ and ½ Tankage as nitrogen source, Rock Phosphate, K_2SO_4	300	580
	Same as 6 plus 60 lbs. sulphur	100	560
	" " 6 " 120 " "	60	640

acid phosphate. Here also it is to be noted that sulphur plus raw rock phosphate does not depress the yield but increases it over the rock phosphate mixture alone, even though the fertilizer application is a very heavy one.

Reference to Table 4 will show that acid phosphate and sodium nitrate mixtures do not do well with tobacco on this soil, even where no sulphur is added. The addition of sulphur depresses the yield still further. On the other hand, the raw rock phosphate and sodium nitrate mixtures have given good yields both with and without sulphur.

The quality of the tobacco did not seem greatly affected by the sulphur. The color seemed slightly darker in the tobacco from the heavily sulphured plots. The texture of leaf was about the same in the sulphured and unsulphured plots.

Sassafras Silt Loam from Back Bay, Baltimore County, Maryland

A series of pot cultures was conducted in the greenhouse in the Winter of 1923-24 to study the effect of sulphur on this soil. Marquis Wheat - a Spring wheat - was the crop grown. The same procedure was followed in making up these pot cultures as was used with the Leonardtown silt loam pot cultures in which soybeans were grown during the same Winter. The yields given in the tables are the averages of quadruplicate pots.

In Table 5 are given reaction values for the pot cultures receiving different treatments, after two months and after five months from the date of application of fertilizers. In Table 5 also are given yeilds of Marquis wheat, with sulphur by itself and with sulphur plus fertilizers.

The Sassafras silt loam soil used in these cultures showed a lime requirement of 3000 pounds $CaCO_3$ per acre by the Truog method. The untreated field soil had a reaction of pH 5.75. 20 pounds of soil was used in each pot and Calcium carbonate at the rate of 3000 pounds per acre was mixed with the whole 20 pounds of soil at the time of making up the pots on December 18th, 1923. The wheat was sprouted on cheesecloth and transferred to the pots on January 15th, 1924, when the seedlings were 10 days old. The sulphur and fertilizer mixtures were applied to the pots on January 15th prior to the seedlings being placed in the pots. An inch of glass sand was placed over the surface of the soil in the pots on February 6th.

When the fertilizer was applied it was mixed with the surface three inches of the soil in the pots. As in the case of the La Plata soil cultures the plants were watered regularly with well water, the same amount of water being given each pot. The pots were moved about so as to give an equal amount of light and heat to each.

The wheat plants were harvested June 10th and oven-dry weights of grain and straw recorded separately.

In Table 5 are given the reaction values of the Back Bay soil, with different treatments, at the end of 2 months and

Table 5.

Yields of Marquis Wheat
and Reaction Values of Sassafras Silt Loam
Pot Cultures in Greenhouse, Winter of 1923-24.

No.	Treatment per acre	Reaction at end of 2 mos. pH	Reaction at end of 5 mos. pH	Yield per acre Bushels Grain	Yield per acre pounds Straw
1.	Nothing	7.34	7.26	17.3	4128
2.	100 lbs. elemental sulphur	6.83	6.37	14.3	3639
	300 " " "	6.38	6.10	16.3	3969
3.	100 lbs. inoculated sulphur	6.75	6.63	13.1	3618
	300 " " "	6.80	6.30	14.3	3647
4.	400 lbs. 4-8-4 $NaNO_3$, Rock Phosphate and KCl	7.32	6.75	20.6	4240
	Same plus 100 lbs. elemental sulphur	7.13	7.00	19.7	4790
	" " 300 " " "	6.46	6.25	24.2	5156
	" " 100 " inoculated sulphur	6.54	6.58	22.2	4424
	" " 300 " " "	6.86	6.36	22.0	4596
5.	400 lbs. 4-8-4 $NaNO_3$, Acid Phosphate and KCl	7.60	7.20	21.0	4608
	Same plus 100 lbs. elemental sulphur	6.90	6.71	24.4	5025
	" " 300 " " "	7.15	6.58	17.8	4025
	" " 100 " inoculated sulphur	7.19	6.65	15.7	4083
	" " 300 " " "	6.75	6.60	19.5	4432
6.	200 lbs. 4-8-4 $NaNO_3$, Rock Phosphate and KCl, plus 100 lbs. inoculated sulphur	6.92	6.90	22.6	4710
	" 300 " " "	7.00	6.20	19.2	4162
7.	200 lbs. 4-8-4 $NaNO_3$, Acid Phosphate and KCl, plus 100 lbs. inoculated sulphur	6.63	6.90	18.2	4051
	" 300 " " "	6.45	6.38	18.3	4200

at the end of 5 months. 3000 pounds per acre is a heavy application of lime, and due to this heavy application the reaction of the soil is not much altered by sulphur oxidation. It is altered consistently, however, and after five months the acidity is greater in all cases where sulphur has been applied.

Table 5 also shows the yields of wheat from sulphur applications and from fertilizer mixtures plus sulphur applications. It will be noted that sulphur by itself has consistently decreased the yield of grain and straw, and inoculated sulphur slightly more so than elemental sulphur.

Sulphur when applied with mixtures of sodium nitrate, rock phosphate and potassium chloride has increased the yield over the fertilizer mixture alone in all cases but one, where the mixture was applied at 400 pounds per acre. With mixtures of sodium nitrate, acid phosphate and potassium chloride the reverse is true, for the yield has been lowered below that of the fertilizer mixture alone in all cases but one. At fertilizer mixture applications of 200 pounds per acre 4-8-4 the sodium nitrate, rock phosphate and potassium chloride outyielded the sodium nitrate, acid phosphate and potassium chloride mixtures where sulphur was added.

In 1924 Wilson soybeans were grown at Back Bay, Maryland, on the same Sassafras silt loam soil studied in the greenhouse with Marquis wheat as the crop. 3000 pounds of lime per acre as calcium carbonate was applied to this soil in the field.

The lime was applied June 10th. Half of the plot was limed and half left unlimed in each case. Rains prevented planting the soybeans until June 24th, on which date the fertilizer applications were made and the planting done. The beans were planted in rows and cultivation carried on throughout the Summer. The crop was harvested on October 7th, 1924. Results of applications of sulphur by itself are given in Table 6. Results of applications of sulphur incorporated in fertilizer mixtures are also given in this table. Here too are given results of adding sulphur to heavy applications of sludge from the Baltimore Sewage Disposal Plant, both the dried sludge and the liquid form being used.

The sewage sludge, both dried and liquid, was applied a week previous to planting the soybeans and well worked in with a spike-tooth harrow. The sulphur on these plots was applied at the time of planting the beans. The dried sludge contains approximately twice as much fertilizer constituents as the liquid sludge; the liquid sludge is quite strongly alkaline in reaction, the samples tested running pH 8.0 and pH 8.1 respectively.

Analysis of the dried sludge showed

Constituent	Per cent.
Volatile matter	55.00
Nitrogen (as N)	2.30
Phosphorus (as P)	0.26
Potassium (as K)	0.18

Table 6.

Yields of Wilson Soybeans
Field Plots on Sassafras Silt Loam, Back Bay, Md., 1924.

No. Treatment per acre (1/40th acre plots used plots in duplicate)	Yield Per Acre Limed Bus. Beans	Limed Lbs. Straw	Unlimed Bus. Beans	Unlimed Lbs. Straw
1. Nothing	6.11	659	4.25	554
2. 100 lbs. inoculated sulphur	6.62	765	4.26	483
3. 300 lbs. inoculated sulphur	6.15	624	3.30	483
4. 200 lbs. 4-8-4 $NaNO_3$, Rock phosphate and KCl	6.15	653	4.73	511
Same plus 60 lbs. inoculated sulphur	11.82	1018	8.98	879
" " 120 " " "	11.82	993	6.15	709
5. 200 lbs. 4-8-4 $NaNO_3$, Acid Phosphate and KCl	6.62	709	2.84	369
Same plus 60 lbs. inoculated sulphur	10.37	936	8.04	823
" " 100 " " "	9.46	1049	7.09	622
6. 20 tons dried sludge	8.98	907	8.98	907
Same plus 60 lbs. inoculated sulphur	8.51	851	7.09	624
" " 100 " " "	7.56	794	5.20	681
" " 200 " " "	6.62	624	6.14	567
7. 40 tons liquid sludge	6.62	624	7.56	624
Same plus 60 lbs. inoculated sulphur	9.93	907	8.98	876
" " 100 " " "	15.13	1531	9.45	1077
" " 200 " " "	11.82	1077	8.04	851

The liquid sludge possesses quite a high fat content running from 3% to 9%.

Table 6 presents data to show that sulphur by itself does not have a stimulating effect on the yield of soybeans in this soil. The results obtained with sulphur incorporated with fertilizer mixtures are also given and here the addition of sulphur has uniformly increased the yield, more so where rock phosphate was used as the source of phosphoric acid than where acid phosphate was used.

Table 6 shows that while the addition of sulphur to soil receiving dried sludge at 20 tons per acre has had a depressing effect on yields, the yields have been greatly increased with all applications of sulphur to soil receiving liquid sludge at 40 tons per acre. The alkalinity of the liquid sludge probably has a lot to do with these results.

It is regrettable that work at this Back Bay field could not be continued for another year and with other crops, but the labor difficulty and the inaccessibility of the plots were too great obstacles and the project was dropped after 1924.

Norfolk loam, Cheltenham, Md. (Prince George's Co.)

In the Spring of 1924 plot work was started at Cheltenham. The soil in these plots has been over-limed and on that account difficulty is experienced in getting a good yield with some crops.

Boone County White corn was planted June 30th, 1924. Sulphur and fertilizer applications were made the same day before planting. 1/25th acre plots were used. The corn was cut October 18th, 1924, shocked, and husked out and weighed up on October 29th, 1924.

Table 7.

Yields of Boone County White Corn
Field Plots on Norfolk Loam, Cheltenham, Md., 1924

No.	Treatment per acre (9 replications)	Yields per acre Bushels ear corn.
1.	Nothing	41.09
2.	50 lbs. elemental sulphur	45.57
3.	100 lbs elemental sulphur	43.16
4.	200 lbs. 2-12-4, Acid Phosphate, KCl	52.43
	Same as 1 plus 50 lbs. elemental sulphur	37.45
	" " 1 " 100 " " "	36.38
5.	200 lbs. 4-8-4 $NaNO_3$, Acid Phosphate, KCl	51.36
	Same plus 50 lbs. elemental sulphur	33.17
	" " 100 " " "	44.94
6.	200 lbs. Acid Phosphate	47.61
	Same plus 50 lbs. elemental sulphur	42.80
	" " 100 " " "	31.03
7.	Manure 4 tons	46.99
	Same plus 50 lbs. elemental sulphur	52.43
	" " 100 " " "	41.73

Table 7 shows that sulphur alone increased the yield of field corn on this soil. It is also shown that on this soil and with field corn as the crop the depressing effect on yields is again evident of adding sulphur to acid phosphate mixtures.

The next year, 1925, Mammoth Yellow soybeans were planted on the same plots on which the Boone County White corn had been grown the previous year. The object was to study the residual effect of sulphur applications on this soil. Unfortunately due to a mistake at the time of threshing out the beans the whole of the "50 lbs. of sulphur per acre" plots were mixed up and no results were obtained for these plots. However, the 100 lbs. of sulphur per acre plots were threshed out and the results are given in Table 8. It should be noted that no additional treatment on these plots was given in 1925 - it is residual effect only.

Table 8.

Yields of Mammoth Yellow Soybeans
with Sulphur Treatments the Previous Year, in
Field Plots, Norfolk Loam, Cheltenham, Md., 1925

No.	Treatment per acre in 1924 (9 replications)	Yield per acre Bus. beans
1.	Nothing	12.78
2.	100 lbs. elemental sulphur	16.99
3.	200 lbs. 2-12-4 $NaNO_3$, Acid Phosphate, KCl	8.40
	Same plus 100 lbs. elemental sulphur	13.44
4.	200 lbs. 4-8-4 $NaNO_3$, Acid Phosphate, KCl	9.23
	Same plus 100 lbs. elemental sulphur	22.67
5.	200 lbs. Acid Phosphate	11.34
	Same plus 100 lbs. elemental sulphur	19.32
6.	Stable Manure 4 tons	13.01
	Same plus 100 lbs. elemental sulphur	18.68

The residual effect of sulphur on this soil has been to greatly increase the yield of Mammoth Yellow Soybeans in all cases. The depression of yield noticable in all previous cases where sulphur and acid phosphate have been applied together is not only not apparent here, but the yields are enormously increased. It is possible that much of this increase can be attributed to the fact that the crop of the previous year had not utilized the plant nutrients from the soil and these were available for the soybeans to take up. This of course would not be true in the case of the sulphur alone, which had shown an increase over the no treatment check the previous year.

In 1924 a new set of plots was started on this Norfolk loam and Currell's Prolific wheat was grown. The season of 1924 a crop of Wilson soybeans was grown on this soil and these were harvested on October 14th, the soil prepared, and the wheat planted October 28th, 1924. The sulphur and fertilizer treatments were put on the plots the day that planting was done. 1/25th acre plots were used. The wheat was harvested June 22nd. 1925, and yields are given in Table 9.

It will be noted from the results reported in Table 9 that 50 pounds of sulphur per acre has increased the yield over the no sulphur check in all cases except that of the 8 tons of manure. The 100 pounds of sulphur per acre has decreased the yield below the no sulphur check in all cases with Currell's Prolific wheat.

Table 9

Yields of Currell's Prolific Wheat
Field Plots on Norfolk Loam, Cheltenham, Md., 1924-25

No.	Treatment per acre (9 replications)	Yield per acre Bushels
1.	Nothing	8.63
2.	50 lbs. elemental sulphur	12.73
3.	100 lbs. elemental sulphur	7.53
4.	200 lbs. 2-12-4 $(NH_4)_2SO_4$, Acid Phosphate, KCl	6.50
	Same plus 50 lbs. elemental sulphur	8.10
	" " 100 " " "	6.56
5.	200 lbs. 4-8-4 $(NH_4)_2SO_4$, Acid Phosphate, KCl	6.80
	Same plus 50 lbs. elemental sulphur	9.00
	" " 100 " " "	6.97
6.	Stable Manure 8 tons	18.30
	Same plus 50 lbs. elemental sulphur	16.50
	" " 100 " " "	11.16
7.	Stable Manure 8 tons, Acid Phosphate 200 lbs.	18.50
	Same plus 50 lbs. elemental sulphur	21.80
	" " 100 " " "	15.40

In the Winter of 1924-25 greenhouse study was made of this Norfolk loam. A large representative sample was obtained and screened through a ¼-inch screen and thoroughly mixed. 20 pounds each of air-dried soil was then placed in glazed crocks. Two crops were grown - Common alfalfa and Hubam sweet clover. Both inoculated and elemental sulphur were applied to the soil at different rates. Reaction values were determined on the differently treated soil cultures at intervals. In Table 10 are shown the reaction values obtained and in Table 11 the yields of alfalfa and sweet clover are given.

Table 10.

Reaction of Soil with Sulphur Treatments
Norfolk loam in Greenhouse, Winter 1924-25

No.	Treatments per acre (5 replications)	Reaction at start	Reaction at end of 2 months.	Reaction at end of 5 months.
		pH	pH	pH
1.	Nothing	7.0	8.23	7.46
2.	100 lbs. elemental sulphur	7.0	7.95	7.16
	300 " " "	7.0	7.52	6.74
3.	100 lbs. inoculated sulphur	7.0	7.21	7.00
	300 " " "	7.0	6.90	6.65

The hydrogen ion concentration was determined on all cultures, and the mean of five determinations is given here in each case.

Table 11

Yields of Alfalfa and Sweet Clover
with Sulphur Treatments in Pot Cultures in the Greenhouse
Norfolk Loam from Cheltenham, Md., Winter 1924-25

No.	Treatment per acre - on the basis of 1 acre surface soil = 2,200,000 lbs. 5 replications of each treatment	(Mean of five cultures) Yield per acre "Common" Alfalfa lbs. Oven-dry tops	"Hubam" Sweet Clover lbs. Oven-dry tops
1.	Nothing	3969	2716
2.	100 lbs. elemental sulphur	3384	3374
	300 " " "	3769	3398
3.	100 lbs. inoculated sulphur	3865	3248
	300 " " "	3766	3210

The pots were made up, the sulphur applied on December 22nd, 1924, and the seedlings transferred from the sprouting trays to the pots on January 3, 1925. Trouble was had with mice nibbling the little plants but these were disposed of with traps.

Although no lime application has been made to this Cheltenham soil for at least two years previous to making the pot studies, it can be seen from Table 10 that it is the most heavily buffered soil of those studied from Maryland so far. 300 pounds of inoculated sulphur after five months has given the most acid reaction, viz;- 6.65 pH. The yield of sweet clover has been increased by all the sulphur applications and the yield of alfalfa decreased by all. This is an outstanding example of the difference in crop reaction to identical treatment. Here we have the same soil and the same treatment in all respects, yet consistently different results are obtained with two crops, each leguminous.

Keyport Silt Loam, College Park, Prince George's Co., Md.

Plots were started in 1924 on a Keyport silt loam soil at College Park. This is a heavy rather poorly drained soil which has been limed and fertilized heavily in the past and which was used as a garden for many years.

Although the rainy Spring of 1924 prevented an early start, tomatoes and Fall cabbage were planted in 1/200th acre plots and sulphur was applied to these plots both by itself and incorporated with fertilizer mixtures in which the components were varied. The fertilizer was applied July 10th and the tomatoes were placed in the plots July 11th. The tomatoes were harvested as they ripened and the weight of the ripe fruit recorded. The cabbage were harvested November 4th, 1924. Killing frost came October 15th, 1924, on which date there were masses of green tomatoes on the vines.

With tomatoes sulphur alone has increased the yield of ripe fruit at all rates of application as shown in Table 12. With the cabbage sulphur has greatly lowered the yield at all rates of application.

Where sulphur has been incorporated with fertilizer mixtures, as shown in Table 12 there is an increased yield of ripe tomatoes in all cases except with the $NaNO_3$, Raw Rock Phosphate and KCl, where both 50 and 100 lbs. of sulphur per acre have decreased the yield below the no sulphur check. With cabbage, sulphur plus fertilizer mixtures has uniformly decreased the yield below the no sulphur checks except with 50 pounds of sulphur on the $NaNO_3$, Rock Phosphate and KCl plot.

The application of sulphur seemed to hasten the maturity of the tomatoes in this 1924 crop. The roots of the cabbage which received sulphur or sulphur in addition to fertilizer mixtures were dried up, whereas the unsulphured cabbage roots were normal. It seems highly probable that the acidity developed by the oxidation of sulphur hastened the maturity of the tomatoes and caused the peculiar dried-up condition of the cabbage roots.

Table 12.

Yields of Tomatoes and Cabbage
Field Plots on Keyport Silt Loam, College Park, Md., 1924

No.	Treatment per acre (1/200th acre plots)	Yield per acre "Greater Baltimore" Tomatoes lbs. ripe fruit	Yield per acre "Jersey Wakefield" Cabbage lbs.
1.	Nothing	7,874	8,540
2.	50 lbs. elemental sulphur	7,959	4,084
3.	100 lbs. elemental sulphur	11,960	5,332
4.	300 lbs. elemental sulphur	10,130	5,389
5.	800 lbs. 4-8-4 $NaNO_3$, Raw Rock Phosphate, KCl	10,853	9,746
	Same plus 50 lbs. elemental sulphur	9,587	10,214
	" " 100 " " "	7,618	7,788
6.	800 lbs. 4-8-4 $NaNO_3$, Acid Phosphate, KCl	4,937	14,172
	Same plus 50 lbs. elemental sulphur	7,874	7,916
	" " 100 " " "	9,491	6,895
7.	800 lbs. 4-8-4 P.-H. Tankage, Raw Rock Phosphate, KCl	7,023	12,470
	Same plus 50 lbs. elemental sulphur	9,023	11,704
	" " 100 " " "	8,725	7,533
8.	800 lbs. 4-8-4 P.-H. Tankage, Acid Phosphate, KCl	8,608	15,577
	Same plus 50 lbs. elemental sulphur	10,981	12,938
	" " 100 " " "	8,767	12,428

The plots were continued in 1925 on this Keyport silt loam soil at College Park and tomatoes, Irish Cobbler potatoes, garden peas and cotton were the crops grown. Identical fertilizer treatments were applied to the plots as in 1924. No additional sulphur was applied except in the case of the 50 pounds of sulphur plus fertilizer mixture plots, where 50 pounds was again applied, thus bringing up the total sulphur applied on these plots in the two years to 100 pounds.

The garden peas and potatoes were planted on April 25th, 1925. The peas were harvested June 19th and the weights of vines plus pods and of pods alone recorded. These are shown in Table 13. The potatoes were harvested August 1st, 1925, and the yields in bushels per acre of good potatoes and of culls are recorded in Table 14.

These peas were planted too late in the season for best yields. However, the results should be indicative of the value of sulphur as a fertilizer for this crop. In every case except two the no treatment plot has outyielded the fertilized plots. Sulphur has decreased the yield below the no sulphur checks in all cases except one with acid phosphate in the mixture and has increased it in all cases but one with rock phosphate mixtures. The acid phosphate, sodium nitrate and potassium chloride mixture has given the best yield.

Table 13

Yields of Nott's Excelsior Garden Peas
in Field Plots, Keyport Silt Loam, College Park, Md., 1925

No.	Treatment per acre (1/200th acre plots Identical applications in 1924 and 1925 except where noted)	Yield per acre Nott's Excelsior Garden peas. Lbs. Vines	Lbs. Pods
1.	No treatment	1592	757
2.	50 lbs. sulphur (in 1924 only)	1472	538
	100 " " " " "	1328	493
	300 " " " " "	1176	325
3.	800 lbs. 4-8-4 $NaNO_3$, Rock Phosphate and KCl	1635	413
	Same plus 50 lbs. Sulphur (in 1924 and 1925)	1656	473
	" " 100 " " (in 1924 only)	1976	509
4.	800 lbs. 4-8-4 $NaNO_3$, Acid Phosphate and KCl	2696	1005
	Same plus 50 lbs. sulphur (in 1924 and 1925)	2400	605
	" " 100 " " (in 1924 only)	1627	477
5.	800 lbs. 4-8-4 P.-H. Tankage, Rock Phosphate and KCl	1554	709
	Same plus 50 lbs. sulphur (in 1924 and 1925)	1656	773
	" " 100 " " (in 1924 only)	1336	565
6.	800 lbs. 4-8-4 P.-H. Tankage, Acid phosphate and KCl	2208	541
	Same plus 50 lbs. sulphur (in 1924 and 1925)	2032	537
	" " 100 " " (in 1924 only)	1528	725

All the potatoes harvested from these plots were clean and free from scab. The low yields were characteristic of the 1925 early potato crop throughout Maryland, which was an exceedingly poor one. As will be seen in Table 14 sulphur by itself and sulphur with fertilizer mixtures has consistently lowered the yield of potatoes on this soil. The rock phosphate mixtures which received tankage as the source of nitrogen were particularly effective in increasing yields, even more so than the acid phosphate mixtures.

Table 14.

Yields of Irish Cobbler Potatoes,
in Field Plots, Keyport Silt Loam, College Park, Md., 1925.

No.	Treatment per acre (1/200th acre plots) (Identical applications in 1924 and 1925 except where noted)	Yield per acre "Irish Cobbler" potatoes Bus. primes	Bus. dulls
1.	Nothing	95.6	9.3
2.	50 lbs. elemental sulphur (None in 1925)	67.2	8.8
	100 " " " " " "	91.5	5.7
	300 " " " " " "	63.6	8.8
3.	800 lbs. 4-8-4 $NaNO_3$, Rock Phosphate and KCl	81.2	7.8
	Same plus 50 lbs. sulphur in 1924 and 1925	77.0	7.7
	" " 100 " " in 1924 only	81.1	8.0
4.	800 lbs. 4-8-4 $NaNO_3$, Acid Phosphate and KCl	97.7	4.7
	Same plus 50 lbs. sulphur in 1924 and 1925	95.6	5.2
	" " 100 " " in 1924 only	92.5	6.0
5.	800 lbs. 4-8-4 P.-H. Tankage, Rock Phosphate and KCl	110.1	4.7
	Same plus 50 lbs. sulphur in 1924 and 1925	106.5	5.7
	" " 100 " " in 1924 only	98.8	9.6
6.	800 lbs. 4-8-4 P.-H. Tankage, Acid Phosphate and KCl	109.4	7.7
	Same plus 50 lbs. sulphur in 1924 and 1925	100.3	7.2
	" " 100 " " in 1924 only	98.1	7.1

Table 15.

Yields of King's Early Cotton
in Field Plots, Keyport Silt Loam, College Park, Md., 1925

No.	Treatment per acre (1/200th acre plots identical applications in 1924 and 1925 except where noted	Yield per acre lbs. seed cotton
1.	No treatment	118
2.	50 lbs. sulphur (in 1924 only)	403
	100 " " " " "	598
	300 " " " " "	417
3.	800 lbs. 4-8-4 $NaNO_3$, Rock Phosphate, KCl	627
	Same plus 50 lbs. sulphur in 1924 and 1925	404
	" " 100 " " in 1924 only	689
4.	800 lbs. 4-8-4 $NaNO_3$, Acid Phosphate, KCl	545
	Same plus 50 lbs. sulphur in 1924 and 1925	370
	" " 100 " " in 1924 only	233
5.	800 lbs. 4-8-4 P.-H. Tankage, Rock Phosphate, KCl	763
	Same plus 50 lbs. sulphur in 1924 and 1925	401
	" " 100 " " in 1924 only	415
6.	800 lbs. 4-8-4 P.-H. Tankage, Acid Phosphate, KCl	1003
	Same plus 50 lbs. sulphur in 1924 and 1925	690
	" " 100 " " in 1924 only	400

"King's Early" cotton was planted in 1/200th acre plots on this Keyport silt loam soil on May 13th, 1925. It was thought that sulphur might aid in bringing early maturity and help to overcome the handicap of the short season. A killing frost came on October 10th thus giving a growing season of just five months. The cotton was picked from all the bolls that opened so that it could be removed without trouble.

The cotton grew very well but did not ripen well. From appearance of flowers until opening of first bolls was 65 days.

The cotton was about 7/8-inch staple. Here again the depressing effect on yields is evident of sulphur plus acid phosphate.

"Greater Baltimore" tomatoes were grown on this soil again in 1925. They followed cabbage grown in 1924. The results are given in Table 16. They were set in the plots May 14th and harvested as they became ripe.

Table 16.

Yields of "Greater Baltimore" Tomatoes
In Field Plots, Keyport Silt Loam, College Park, Md., 1925

No.	Treatment per acre (1/200th acre plots identical applications in 1924 and 1925 except where noted)	Yield per acre "Greater Baltimore" Tomatoes lbs. ripe fruit
1.	No treatment	8.305
2.	50 lbs. sulphur (in 1924 only)	7,113
	100 " " " " "	8,095
	300 " " " " "	5,637
3.	800 lbs. 4-8-4 $NaNO_3$, Rock Phosphate, KCl	16,898
	Same plus 50 lbs. sulphur (in 1924 and 1925)	19,486
	" " 100 " " (in 1924 only)	20,391
4.	800 lbs. 4-8-4 $NaNO_3$, Acid Phosphate, KCl	13,263
	Same plus 50 lbs. sulphur (in 1924 and 1925)	11,019
	" " 100 " " (in 1924 only)	6,702
5.	800 lbs. 4-8-4 P.-H. Tankage, Rock Phosphate and KCl	18,829
	Same plus 50 lbs. sulphur (in 1924 and 1925)	18,318
	" " 100 " " (in 1924 only)	17,040
6.	800 lbs. 4-8-4 P.-H. Tankage, Acid Phosphate and KCl	20,022
	Same plus 50 lbs. sulphur (in 1924 and 1925)	18,858
	" " 100 " " (in 1924 only)	20,874

With tomatoes in 1925 sulphur by itself has decreased the yield below the no sulphur check. With acid phosphate, sodium nitrate and potassium chloride mixture sulphur has decreased the yield greatly below the no sulphur check, but where rock phosphate is used in this mixture the yields are increased when sulphur is added. With packing house tankage sulphur in acid phosphate mixtures has not had the depressing effect on yields noticeable with acid phosphate in sodium nitrate mixtures. In 1924, with tomatoes grown in this soil, it will be recalled that sulphur plus acid phosphate increased the yield in all mixtures used.

Sassafras Loam, College Park, Prince George's Co., Md.

In 1925 plots were started on a Sassafras loam soil at College Park. This soil is a mellow loam which had laid fallow for twenty years or more, but which has been cropped during the last six years. The last two crops grown have been corn and winter wheat. The soil had an initial reaction of pH 5.8 but no lime was applied.

Four crops were grown on this soil in 1925 in 1/200th acre plots, viz:- "King's Early" cotton, "Greater Baltimore" tomatoes, "Jersey Bigstem" sweet potatoes and "Maryland Broadleaf" tobacco. The cotton was planted May 13th and picked as the bolls opened sufficiently. The tomato plants were set in the plots May 14th and the tomatoes were harvested as they became ripe. Sweet potato plants were set out May 14th and the

Table 17.

Yields of Tomatoes and Sweet Potatoes in Field Plots, Sassafras Loam, College Park, Md., 1925

No.	Treatment per acre (1/200th acre plots)	Yield per acre "Greater Baltimore" tomatoes lbs. ripe fruit	Yield per acre "Jersey Bigstem" sweet potatoes bus."
1.	Nothing	16,743	289.2
2.	100 lbs. sulphur	16,538	297.8
3.	800 lbs. 4-8-4 $NaNO_3$, Acid Phosphate and KCl	23,631	311.6
	Same plus 50 lbs. sulphur	24,040	342.0
4.	800 lbs. 4-8-4 $NaNO_3$, Rock Phosphate and KCl	25,916	343.0
	Same plus 50 lbs. sulphur	18,789	423.3
5.	800 lbs. 4-8-4 P.-H. Tankage, Acid Phosphate and KCl	21,176	284.1
	Same plus 50 lbs. sulphur	19,096	460.1
6.	800 lbs. 4-8-4 P.-H. Tankage, Rock Phosphate and KCl	20,460	380.6
	Same plus 50 lbs. sulphur	19,880	391.6

potatoes dug on October 20th. Tobacco plants were set out June 18th and the plants were cut September 29th and hung to dry. The cured leaves were stripped February 27th, 1926. Applications of fertilizer mixtures and sulphur were made in every case just before the plants were set out and were worked into the surface soil. This Sassafras loam soil was in excellent physical condition. In Table 17 are given the yields obtained with tomatoes and sweet potatoes in 1925. By comparison with Table 16 in which are given yields of "Greater Baltimore" tomatoes in 1925 on the Keyport Silt loam soil at College Park, an estimate of the good condition of the Sassafras soil may be made. Sulphur by itself has not increased the yield of either tomatoes or sweet potatoes. In all cases but one sulphur plus fertilizer mixtures has decreased the yield of tomatoes. With sweet potatoes sulphur plus fertilizer mixtures has increased the yield in all cases, in Plot 5 by 62 per cent. The lowering of yields where sulphur is used with acid phosphate mixtures is certainly not apparent here.

Sodium nitrate was not used in the fertilizer mixtures applied to cotton on this soil. Sulphur by itself seems to have had a slight effect on maturity, but when used with fertilizer mixtures the yield is depressed in all cases.

Table 18.

Yields of Cotton
in Field Plots, Sassafras Loam, College Park, Md., 1925.

No.	Treatment per acre (1/200th acre plots)	Yield per acre "King's Early" cotton lbs. cotton seed
1.	Nothing	147
2.	50 lbs. sulphur	178
	100 " "	157
3.	800 lbs. 4-8-4 P.-H. Tankage, Acid Phosphate & KCl	201
	Same plus 50 lbs. sulphur	108
	" " 100 " "	107
4.	800 lbs. 4-8-4 P-H. Tankage, Rock Phosphate & KCl	172
	Same plus 50 lbs. sulphur	146

Table 19.

Yields of Tobacco
in Field Plots, Sassafras Loam, College Park, Md., 1925

No.	Treatment per acre (1/200th acre plots)	Yield per acre "Maryland Broadleaf" lbs. leaf tobacco.
1.	800 lbs. 4-8-4 $NaNO_3$, Acid Phosphate, K_2SO_4	1220
	Same plus 50 lbs. sulphur	1266
2.	800 lbs. 4-8-4 $NaNO_3$, Rock Phosphate, K_2SO_4	945
	Same plus 50 lbs. sulphur	1014
3.	800 lbs. 4-8-4 ½ nitrogen as $NaNO_3$ and ½ as P.-H. Tankage, Acid Phosphate, K_2SO_4	1157
	Same plus 50 lbs. sulphur	1404
4.	800 lbs. 4-8-4 Tankage, Acid Phosphate, K_2SO_4	1107
	Same plus 50 lbs. sulphur	982
5.	800 lbs. 4-8-4 Tankage, Rock Phosphate, K_2SO_4	1073
	Same plus 50 lbs. sulphur	992

The yields of tobacco on the Sassafras loam were stimulated in all the mixtures in which sodium nitrate was a component, regardless of the source of phosphoric acid. However, where tankage has been used as the only source of nitrogen sulphur has given lowered yields.

There is no noticeable difference in the quality of the tobacco from the sulphured and unsulphured plots.

Congaree Silt Loam, College Park, Prince George's Co., Md.

A large sample of this soil was obtained for greenhouse study. The sample was thoroughly mixed, screened through a 1/4-inch mesh screen and 300 pounds of the screened soil placed in each of twelve beds 20 inches by 24 inches. "Iceberg" head lettuce seedlings were started in trays and transferred to the beds December 15th, 1924, eight seedlings to a bed. Fertilizers and sulphur applications had been put on the beds December 8th, The initial reaction of this soil was pH 5.15. The lettuce was harvested March 24th, 1925. Buckwheat seedlings were placed in the beds March 31, 1925, and the crop was harvested June 20th, 1925.

Reaction values were taken on the soil in these beds and the results are shown in Table 20.

Table 20

Reaction values of
Congaree Silt Loam Soil, in Greenhouse, 1924-25.

No.	Treatment (per acre)	At start pH	After 2 mos. pH	After 3 mos. pH	After 6 mos. pH
1.	Nothing	5.15	5.20	5.20	5.20
	100 lbs. sulphur	5.15	5.10	4.90	5.22
2.	200 lbs. $NaNO_3$	5.18	5.15	5.18	5.20
	200 " " plus 100 lbs. sulphur	5.15	5.02	4.95	5.00
3.	300 lbs. P.H.Tankage (8% N 3% P_2O_5)	5.19	5.20	5.20	5.19
	Same plus 100 lbs. sulphur	5.15	4.97	4.85	5.25
4.	1000 lbs.4-8-4 $NaNO_3$, Acid phosphate and KCl	4.97	5.00	5.12	5.30
	Same plus 100 lbs. sulphur	5.10	4.95	4.85	4.95
5.	1000 lbs. 4-8-4 Tankage, Acid Phosphate and KCl	5.16	5.23	5.28	5.21
	Same plus 100 lbs. sulphur	5.09	4.90	4.70	4.85
6.	1000 lbs. 4-8-4 Tankage, Rock phosphate and KCl	4.97	5.12	5.20	5.40
	Same plus 100 lbs. sulphur	5.15	4.97	4.90	5.20

From Table 20 it will be noted that after six months from the sulphur application the soil reaction has returned to the initial pH 5.2 in all cases but three. One of these cases is sulphur with sodium nitrate and the other two sulphur plus mixtures containing acid phosphate.

In Table 21 are given the lettuce and buckwheat yields obtained.

Table 21.

Yields of Lettuce and Buckwheat
in Greenhouse, on Congaree Silt Loam, Winter of 1924-25

No.	Treatment (per acre) (Beds 20 x 24 inches)	"Iceberg" Lettuce lbs. green weight	"Japanese" Bus. dry grain	buckwheat lbs. green tops
1.	Nothing	5,754	12.8	10,276
	100 lbs. sulphur	1,442	16,8	13,356
2.	200 lbs. $NaNO_3$	1,464	10.4	9,516
	Same plus 100 lbs. sulphur	432	8.8	6,612
3.	300 lbs. P.H.Tankage(8% N, 3% P_2O_5)	16,354	11.6	9,036
	Same plus 100 lbs. sulphur	8,809	18.0	9,996
4.	1000 lbs. 4-8-4 Tankage, Acid Phosphate and KCl	46,149	13.6	11,692
	Same plus 100 lbs. sulphur	19,703	18.8	8,220
5.	1000 lbs. 4-8-4 $NaNO_3$, Acid phosphate and KCl	51,390	8.8	9,628
	Same plus 100 lbs. sulphur	33,960	15.2	7,916
6.	1000 lbs. 4-8-4 Tankage, Rock Phosphate and KCl	11,810	6.8	6,444
	Same plus 100 lbs. sulphur	26,446	16.4	4,784

In all cases but one the yield of lettuce was decreased by adding sulphur while with the rock phosphate mixture, sulphur increased the yield. In all cases but one the yield of buckwheat grain was increased by adding sulphur; sodium nitrate plus sulphur, however, gave a very low yield of both lettuce and buckwheat. The yield of buckwheat tops was lowered in four out of six cases by application of sulphur.

Porter's Silt Loam, Middletown, Frederick Co., Md.

On May 7th, 1925, 60 pounds of sulphur was applied to one acre of this soil on which field corn was grown. The acre of soil on each side of the sulphur-treated acre was left unsulphured and comparative yields are given in Table 22.

Table 22.

Yields of Field Corn
Porter's Silt Loam, 1925

No.	Treatment per acre	Reed's Yellow Dent Corn Bushels per acre
1.	Nothing	70.0
2.	60 pounds sulphur	70.0

This soil is highly fertile and in good physical condition. Sulphur did not increase the yield of field corn. See Table 1 for analytical data on this soil.

While the percentage of total sulphur in this soil and in the Taneytown soil is very low, there is no increase in this case in the yield of field corn when sulphur is applied. This soil is very high in available nitrates. It has never received any commercial fertilizer.

Penn Silt Loam, Taneytown, Carroll Co., Md.

On May 14th, 1925, 60 pounds of sulphur was applied to one acre of this soil on which field corn was grown. The soil on either side of the sulphur-treated acre was left unsulphured and comparative yields are given in Table 23.

Table 23.

Yields of Field Corn
Penn Silt Loam, 1925

No.	Treatment per acre	Reed's Yellow Dent corn Bushels per acre
1.	Nothing	74.5
2.	60 pounds sulphur	80.0

This also is naturally a highly fertile soil and in good physical condition. Sulphur increased the yield of field corn 11%. See Table 1 for analytical data on this soil.

The Taneytown soil has about the same total sulphur content as the Middletown soil, i.e., about 0.0080 per cent of sulphur as S. It has not received commercial fertilizer. As may be seen from the yield, it is an excellent corn soil.

Chemical Study of the Effect of Sulphur on Different Soils

Plant physiologists and bacteriologists recognize the necessity for good "physiological balance" in the culture media they use. The soil solution is the culture medium for crop growth and the best measure of physiological balance in the soil solution is the crop yield obtained.

Equilibrium is the natural condition of matter throughout Nature. LeChatelier's theorem is one of the few natural "laws" which stands as solidly today as when first conceived. Briefly it is

> "Alter any of the factors which govern the equilibrium point and the equilibrium point will change so as to nullify the effect of the alteration of the factors."

Unwise cropping of a soil will cause exhaustion of available fertility elements within it and crop yields will be lowered. The crop is dependent upon the soil solution; it is an index of the alteration of the equilibrium point in the soil solution.

The availability of nutrient materials for plant use is the criterion of a good soil. It is trite to say "Soils differ tremendously". In all soils the factors of chief importance governing the availability of ions which enter into plant metabolism are :-

1. Biological content
2. Colloid content
3. Moisture content
4. Total content of essential fertility elements
5. Excess or deficiency of any ion
6. Reaction

No attempt is made to place these factors in the order of their importance. They are interlocking throughout.

To emphasize these factors governing ionic availability for plant use each will be discussed briefly in the two following paragraphs.

Hoagland writes (28) "The soil is a biologically controlled system", and he points out that NO_3, SO_4 and CO_3 ions are biologically produced in the soil. Soil colloids govern largely the amount of pore space, the movement of soil water, and in general the physical condition of the soil. If there are no insoluble fertility elements present in a soil to become available, it is self-evident that there can be none available unless applied as fertilizer.

The solubility of soil compounds, the behavior of colloids, and crop response vary greatly with the reaction of a soil. The crop must have water, and it is accepted by plant physiologists that nutrient materials must be water-soluble at the time they enter the plant. An excess or deficiency of any ion will necessarily disturb the physiological balance of the soil solution.

An experiment was planned to determine the effect of sulphur upon the availability of essential nutrient ions in nine different soils. While it is recognized that it is a hard task to obtain the true soil solution, it is believed that the best method developed so far was used.

Two soils from Oregon, two from Washington State and five from Maryland were studied. The soils were all air-dried for at least four months before they were used. Before using they were sifted through 20-mesh screen. Thirty-seven hundred grams of each soil was weighed out in duplicate, and placed in one-gallon glass percolators, making 18 percolators in all.

At the bottom of the percolators small porcelain Gooch crucibles were placed and on these crucibles washed gravel was added to a depth of three inches. The sifted, air-dried soil was then placed on top of the gravel.

The percolators were mounted on two frames, the sides were covered with wall-board and insulated to prevent sudden changes in temperature and to keep the percolators in darkness. A cross-section of one of these frames is given in Figure 1.

The glass percolators are 7½ inches across the top and 15 inches deep. The amount of soil used was sufficient to fill the cylinders to within about two inches of the top thus leaving plenty of space for the water to be applied.

The percolators being set up and filled, leaching operations were started January 5th, 1926. Three successive 500 c.c. portions

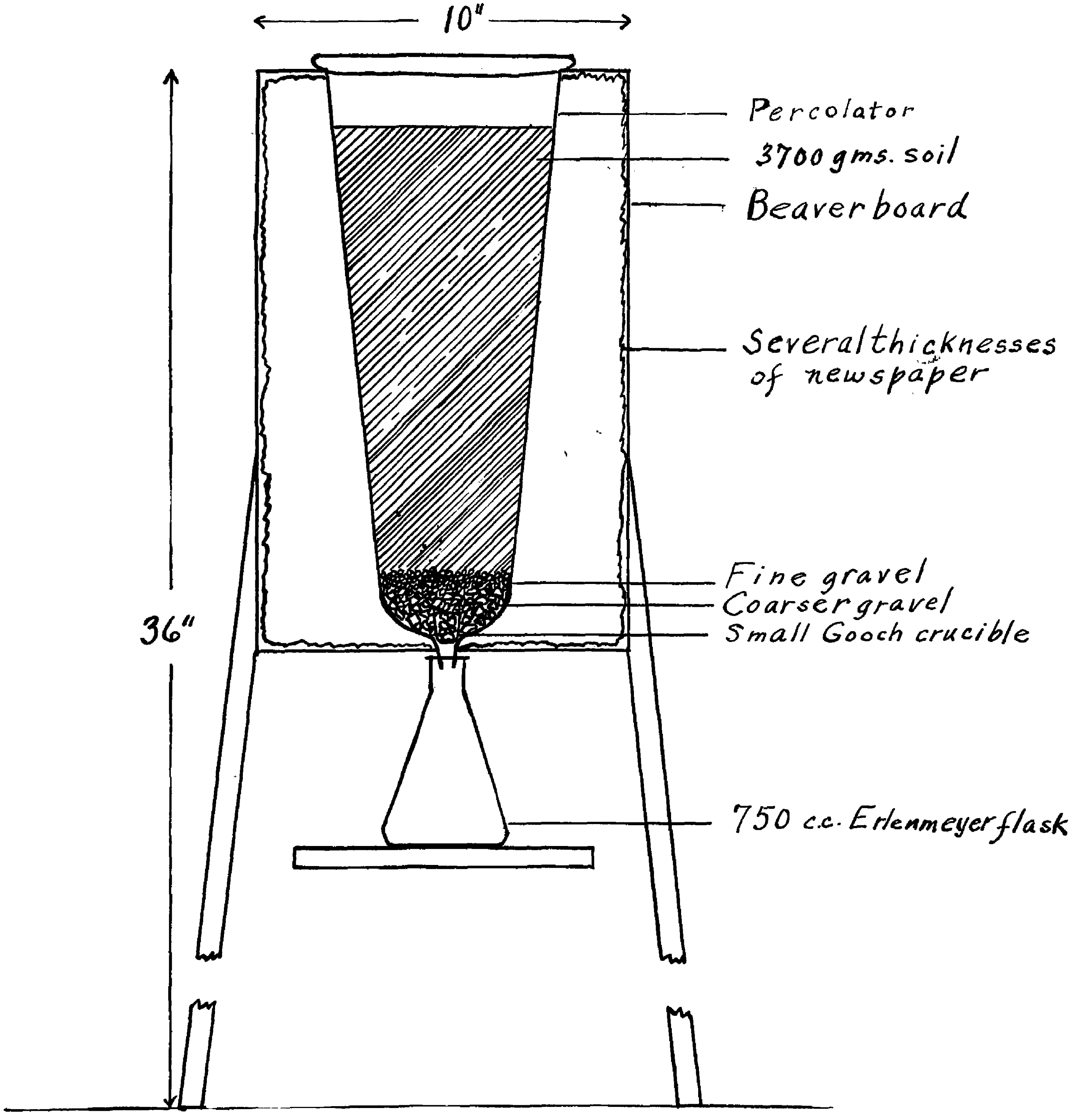

Fig. 1 Cross-section of Stand and Percolator

of distilled water were added to each soil at several hours intervals and the percolate collected. On January 6th and again on January 7th 500 c.c. portions were added and the percolates from each cylinder were collected, placed together, and termed "preliminary leachings".

On January 8th 185 milligrams of elemental sulphur was placed on one of the duplicate percolators containing each type of soil. This amount of sulphur on 3700 grams of soil is equivalent to an application of 100 lbs. per acre. The sulphur was thoroughly mixed with the surface three inches of the soil in the percolators, From this time on there was thus a sulphur-treated and an untreated soil of each type.

After three weeks the percolators were again leached with 500 c.c. of water on each of three successive days, a total of 1500 c.c. distilled water being applied. Separate analysis was made of the percolate from each cylinder.

Exactly the same procedure was followed after six, nine and twelve weeks from the time of application of the sulphur to the soils. Thus, 2500 c.c. distilled water was applied in the preliminary leachings to each percolator and 1500 c.c. distilled water after three, six, nine and twelve weeks, making 8,500 c.c. distilled water in all passing through each 3700 gram portion of soil.

Careful account was kept of the amount of percolate from each cylinder, the hydrogen ion concentration determined and then a few drops of toluol were added to each container to prevent growth of micro-organisms. Analyses were then made for nitrates, sulphates, potassium, calcium and phosphorus.

It is noteworthy that the percolates from the Oregon and Washington soils were much more deeply colored throughout the test than the percolates from the Maryland soils. This color was much less after the 17th leaching than after the first, but it was still noticeable. Gehring and Wehrmann (23) attribute this dark color in soil percolates to potassium salts. In Table (24) are the data on the amounts of percolate collected.

From Table (24) it will be noted that with one exception a greater volume of percolate was collected from the sulphur-treated than from the untreated soils. Stephenson and Powers (77) speak of this "flocculating" effect of sulphur upon the soil colloids.

The importance of any agency which "opens up" heavy soils cannot be denied. Although the Oregon and Washington soils are described as sandy loams, there are really no light soils in this test. The behavior of sulphur-treated soils shows the importance of this physical effect.

The colorimetric standards of Clark and Lubs (14) were used in determining the reaction of the percolates. No trouble was experienced with turbidity. The colorimetric standards were checked electrometrically.

Table 24.

Percolate Collected
from Sulphur-treated and Untreated Soils

Soil	Treatment	c.c. percolate collected:- Prelim-inary leachings	After 3 weeks	After 6 weeks	After 9 weeks	After 12 weeks	Total
1. Ritzville v.f.sa.loam	Nothing	1047	1362	1284	826	690	5,209
	Sulphured	1058	1487	1415	1063	1116	6,139
2. Sagemoor f.sa.loam	Nothing	1466	1496	1423	1109	1288	6,782
	Sulphured	1525	1377	1351	1144	1114	6,511
3. Columbia f.sa.loam	Nothing	1346	1446	1360	703	1300	6,175
	Sulphured	1453	1365	1353	1050	1301	6,522
4. Yakima sandy loam	Nothing	1512	1403	1364	1023	1258	6,560
	Sulphured	1500	1431	1368	1055	1369	6,723
5. Norfolk loam	Nothing	1367	1418	1386	995	1449	6,615
	Sulphured	1379	1493	1323	1555	1508	7,258
6. Leonardtown silt loam	Nothing	1376	1526	1386	1176	1452	6,916
	Sulphured	1361	1462	1483	1421	1548	7,275
7. Porter's silt loam	Nothing	1513	1386	1457	1355	1159	6,870
	Sulphured	1520	1553	1587	1515	1453	7,628
8. Keyport silt loam	Nothing	1192	1456	1245	1228	1280	6,401
	Sulphured	1281	1319	1401	1187	1422	6,610
9. Sassafras loam	Nothing	1498	1253	1194	1061	1003	6,009
	Sulphured	1361	1350	1239	1111	1049	6,110

v.f.sa. - very fine sandy
f.sa. - fine sandy

The reaction values of the percolates from the different soils vary greatly. Except for the Sassafras loam the reaction of the percolate from the preliminary leachings is not so alkaline as that from the leachings after three weeks. In Table (25) it will be noted that sulphur appears to affect the reaction in most cases after six weeks, but that this effect does not last, for in the Washington and Oregon soils after 12 weeks the percolate from the sulphur-treated soil in two cases is more alkaline than that from the untreated soil. Undoubtedly the freeing of bases from the soil colloids is the cause of this anomalous behavior.

The Norfolk loam behaves as the Washington and Oregon soils. This is a heavily over-limed soil, and increases in yield by the application of sulphur were obtained in field tests with wheat, corn, soybeans and sweet clover. A decreased yield, however, was obtained with alfalfa, after treating this soil with sulphur. The Leonardtown silt loam and Porter's silt loam became distinctly more acid in the sulphur-treated percolators. The Keyport silt loam, a heavily limed and fertilized soil, does not appear much affected in reaction by the sulphur, but the Sassafras loam exhibits a peculiar behavior. The reaction of this soil varies but 0.2 pH from its initial reaction of pH. 5.70, in sulphur-treated and untreated percolators.

Sulphate sulphur in the percolates was determined for each set of leachings, by the Schreiner (70) turbidity method. The results are given in Table (26) as milligrams of SO_3.

Table 25.

Reaction of Percolate
from Sulphur-treated and Untreated Soils

Soil	Treatment	pH of Percolate: Preliminary leachings	After 3 weeks	After 6 weeks	After 9 weeks	After 12 weeks
1. Ritzville v.f.sa.loam	Nothing	7.00	8.45	7.45	7.20	8.40
	Sulphured	7.00	8.15	7.42	6.90	7.05
2. Sagemoor f.sa.loam	Nothing	7.15	8.35	8.10	8.20	8.20
	Sulphured	7.15	8.40	7.82	7.35	8.20
3. Columbia f.sa.loam	Nothing	7.00	7.50	7.40	6.85	6.55
	Sulphured	7.05	7.35	7.05	6.65	8.40
4. Yakima sandy loam	Nothing	7.36	7.50	7.25	8.30	8.30
	Sulphured	7.32	7.38	7.24	7.05	8.50
5. Norfolk loam	Nothing	7.00	8.00	8.20	8.30	8.30
	Sulphured	6.90	8.00	8.00	7.40	7.00
6. Leonardtown silt loam	Nothing	6.15	7.40	7.30	6.65	6.10
	Sulphured	6.15	6.40	6.38	5.70	5.55
7. Porter's silt loam	Nothing	6.60	7.05	6.90	6.85	7.00
	Sulphured	6.70	6.50	6.75	6.45	5.65
8. Keyport silt loam	Nothing	6.00	6.58	6.73	6.60	6.00
	Sulphured	6.00	6.25	6.60	6.10	6.30
9. Sassafras loam	Nothing	5.70	5.70	5.65	5.70	5.70
	Sulphured	5.70	5.70	5.70	5.82	5.50

v.f.sa. - very fine sandy
f.sa. - fine sandy

Table 26.

Sulphates in Percolate
from Sulphur-treated and Untreated Soils

Soil	Treatment	Milligrams of SO_3 in percolate: Prelim-inary leachings	After 3 weeks	After 6 weeks	After 9 weeks	After 12 weeks
1. Ritzville v.f.sa.loam	Nothing	106.06	29.69	1.28	3.71	12.42
	Sulphured	80.23	165.06	45.28	47.84	33.92
2. Sagemoor f.sa.loam	Nothing	261.83	15.96	0.99	19.96	28.98
	Sulphured	303.47	82.62	73.49	16.64	38.54
3. Columbia f.sa.loam	Nothing	269.20	32.10	2.72	2.32	7.80
	Sulphured	305.27	111.93	40.18	37.80	117.09
4. Yakima sandy loam	Nothing	348.82	82.49	1.36	9.21	18.87
	Sulphured	339.45	228.96	47.47	31.65	76.66
5. Norfolk loam	Nothing	390.96	497.72	11.09	16.91	19.99
	Sulphured	394.40	515.08	18.52	20.21	37.44
6. Leonardtown silt loam	Nothing	414.45	218.06	7.28	21.17	14.52
	Sulphured	402.85	222.89	15.42	25.58	27.86
7. Porter's silt loam	Nothing	108.93	69.30	5.98	9.81	13.70
	Sulphured	109.44	91.74	10.54	25.75	25.86
8. Keyport silt loam	Nothing	338.53	291.20	14.57	15.96	17.06
	Sulphured	366.37	217.78	25.90	21.37	92.16
9. Sassafras loam	Nothing	188.75	71.55	6.81	11.11	31.47
	Sulphured	187.82	78.31	15.52	11.67	180.54

v.f.sa. - very fine sandy
f.sa. - fine sandy

It will be noted that in almost every case the Maryland soils have given a greater amount of soluble sulphur in the percolates than have the Washington and Oregon soils. However, the second lowest of all the soils in the amount of sulphates in the percolate is the Porter's silt loam from Middletown, Maryland. This soil is low in total sulphur as shown in Table I.

The lowest in total sulphur is an Oregon soil, Columbia fine sandy loam. However, this soil has given quite a large amount of soluble sulphur in the percolate.

In Table (27) is given the ratio of water-soluble to total sulphur for all the soils studied. In the case of the unsulphured checks it will be seen that this ratio varied from 1 to 7.95 with the Columbia fine sandy loam to 1 to 51.30 with the Keyport silt loam.

In ability to oxidize elemental sulphur to the sulphate form the Washington and Oregon soils proved superior to the Maryland soils. The soil with the least total sulphur, Columbia fine sandy loam, oxidized in three months 119 milligrams of the 185 milligrams applied in form of elemental sulphur, or 64.3 per cent. This was the highest percentage oxidized. The lowest percentage oxidized was with the Maryland soil, Leonardtown silt loam, which only oxidized 7.7 milligrams of the 185 milligrams of elemental sulphur applied, or 4.16 per cent.

The soil with the greatest amount of total sulphur, Keyport silt loam, has the lowest ratio of soluble to insoluble

Table 27.

Ratio of Water-soluble
To Total Sulphur and Phosphorus in
Sulphur-treated and Untreated Soils

Soil	Total phosphorus in 3700 g. (as P)	Water-soluble phosphorus in 3700 g. (as P)	Ratio of Water-soluble to Total P 1 to	Total sulphur in 3700 g. (as S)	Water-soluble sulphur in 3700 g. (as S)	Ratio of Water-soluble to Total S 1 to
	mgms.	mgms.		mgms.	mgms.	
1. Ritzville v.f.sa.loam	2,749	18.08	138	1,517	61.26	24.77
Sulphured		18.43	136	1,702	148.93	11.39
2. Sagemoor f.sa.loam	2,849	17.48	163	5,476	131.09	41.75
Sulphured		18.09	157	5,661	205.90	27.45
3. Columbia f.sa.loam	2,442	22.46	109	999	125.66	7.95
Sulphured		23.56	104	1,184	244.51	4.83
4. Yakima sandy loam	1,665	23.39	71	2,220	184.30	12.02
Sulphured		22.50	74	2,405	289.68	8.27
5. Norfolk loam	880	13.35	59	4,070	374.67	10.85
Sulphured		13.29	59	4,255	394.26	10.78
6. Leonardtown silt loam	903	6.31	145	5,291	270.15	19.57
Sulphured		5.26	175	5,476	277.84	19.68
7. Porter's silt loam	2,039	5.22	394	2,960	83.09	35.57
Sulphured		4.82	426	3,145	105.33	30.00
8. Keyport silt loam	2,505	5.37	472	11,840	230.93	51.30
Sulphured		3.53	720	12,025	289.43	41.60
9. Sassafras loam	2,089	2.72	857	3,737	123.87	30.15
Sulphured		1.84	1142	3,922	189.54	20.59

v.f.sa. - very fine sandy
f.sa. - fine sandy

sulphur, i.e., it has relatively the least amount of soluble sulphur. The soil with the least amount of total sulphur, Columbia fine sandy loam, has relatively the greatest amount of soluble sulphur, i.e., it has the highest ratio of soluble to insoluble sulphur.

The ratio of total to water-soluble sulphur in the soils studied varies the least of all the constituents charted in Figure 2. This diagram shows that the ratio of ~~total~~ water-soluble to ~~water-soluble~~ total sulphur is fairly constant when compared with the ratio of ~~total~~ water-soluble to ~~water-soluble~~ total nitrogen, phosphorus or potassium.

Phosphorus in the percolates was determined for each set of leachings by the Deniges coeruleo-molybdate color method described by Atkins (6). The results are given in Table (28) as milligrams of P_2O_5.

The Washington and Oregon soils have given a much greater amount of soluble phosphorus in the percolates than the Maryland soils as a general rule. However, one Maryland soil, the Norfolk loam, which has been described as an "over-limed" soil under the crop experiment section, is also high in soluble phosphates. It is a rule that those soils with the most strongly alkaline reactions have the most soluble phosphates. This observation confirms that of Vanstone (a co-worker of Hissink at Groningen, Holland). Vanstone (8) points out that in acid soils the ratio soluble

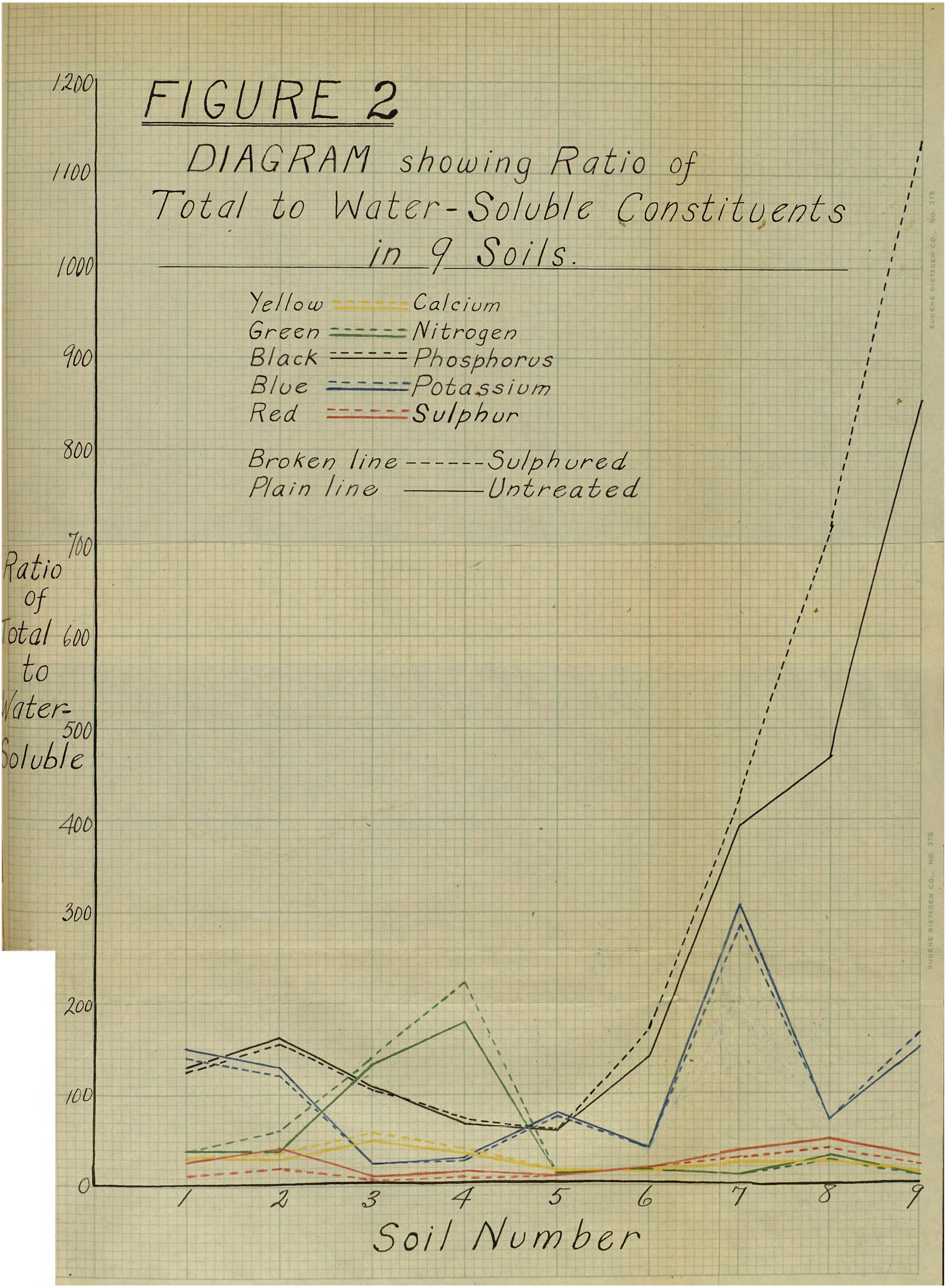

FIGURE 2

DIAGRAM showing Ratio of Total to Water-Soluble Constituents in 9 Soils.

Table 28.

Phosphorus in Percolate
from Sulphur-treated and Untreated Soils

Soil	Treatment	Milligrams of P_2O_5 in percolate				
		Preliminary leachings	After 3 weeks	After 6 weeks	After 9 weeks	After 12 weeks
1. Ritzville v.f.sa.loam	Nothing	21.18	17.20	1.69	0.99	0.36
	Sulphured	21.61	17.90	0.83	0.80	0.74
2. Sagemoor f.sa.loam	Nothing	31.66	6.91	0.35	0.42	0.40
	Sulphured	31.57	8.42	0.44	0.34	0.35
3. Columbia f.sa.loam	Nothing	45.49	7.23	2.64	0.09	0.25
	Sulphured	48.38	4.25	0.58	0.27	0.08
4. Yakima sandy loam	Nothing	43.54	8.34	0.49	0.40	0.39
	Sulphured	45.60	4.06	0.89	0.17	0.42
5. Norfolk loam	Nothing	24.93	5.12	0.11	0.11	0.08
	Sulphured	26.41	3.30	0.11	0.10	0.29
6. Leonardtown silt loam	Nothing	7.99	5.81	0.22	0.25	0.07
	Sulphured	8.16	3.41	0.19	0.09	0.11
7. Porter's silt loam	Nothing	7.24	4.27	0.18	0.12	0.05
	Sulphured	7.04	3.47	0.24	0.10	0.11
8. Keyport silt loam	Nothing	1.52	9.86	0.39	0.35	0.08
	Sulphured	1.66	5.19	0.85	0.25	0.08
9. Sassafras loam	Nothing	1.01	4.33	0.09	0.14	0.05
	Sulphured	0.90	2.32	0.85	0.07	0.05

v.f.sa. - very fine sandy
f.sa. - fine sandy

Potassium in the percolate was determined for each set of leachings by the colorimetric method of Schreiner and Failyer. The results are expressed in Table (29) as milligrams of K_2O. The soils studied very greatly in their content of water-soluble potassium. As a rule the Washington and Oregon soils are higher in their content of water-soluble potassium than the Maryland soils, although the Norfolk loam and the Leonardtown silt loam both are well supplied. It is significant that after repeated leachings the Western soils are still fairly high in soluble potassium in their percolates, while the Maryland soils rapidly fall off.

As shown in Table (29) and in Figure 2 sulphur has increased the solubility of potassium in every one of the soils except the very acid Sassafras loam, in which case there is less soluble potassium in the percolate from the sulphured soil than that from the untreated soil. There is greater increase in solubility of potassium due to sulphur treatment in the Western soils than there is in the Maryland soils as a general rule.

The ratio of water-soluble to total potassium varies from 1 to 26 (Columbia fine sandy loam) to 1 to 305 (Porter's silt loam). Since the Western soils are high in both soluble phosphates and soluble potassium there is here an explanation of their undoubtedly great buffering effect when sulphur is applied, for potassium phosphate salts are quite soluble and act efficiently as buffers.

Table 29.

Potassium in Percolate
from Sulphur-treated and Untreated Soils

Soil	Treatment	Milligrams of K_2O in percolate				
		Prelim-inary leachings	After 3 weeks	After 6 weeks	After 9 weeks	After 12 weeks
1. Ritzville v.f.sa.loam	Nothing	289.89	55.46	15.09	17.84	1.31
	Sulphured	284.78	56.80	26.69	27.64	6.56
2. Sagemoor f.sa.loam	Nothing	392.90	64.48	21.84	34.60	4.02
	Sulphured	414.80	66.23	30.53	38.09	7.42
3. Columbia f.sa.loam	Nothing	533.02	68.11	14.78	11.67	3.90
	Sulphured	575.39	34.12	27.06	20.58	4.55
4. Yakima sandy loam	Nothing	946.51	76.18	25.72	32.94	4.05
	Sulphured	939.00	91.73	54.72	42.20	10.13
5. Norfolk loam	Nothing	390.96	57.14	11.56	16.52	0.98
	Sulphured	394.40	49.12	21.35	18.35	1.91
6. Leonardtown silt loam	Nothing	463.71	30.82	11.66	20.35	0.33
	Sulphured	458.66	30.41	11.42	20.89	0.90
7. Porter's silt loam	Nothing	108.93	15.38	6.78	11.55	0.13
	Sulphured	109.44	20.50	7.49	13.89	0.65
8. Keyport silt loam	Nothing	338.53	75.86	13.34	13.33	0.68
	Sulphured	366.37	39.57	15.56	24.56	2.56
9. Sassafras loam	Nothing	188.75	32.40	3.22	9.67	0.25
	Sulphured	187.82	13.53	5.61	6.36	0.71

v.f.sa. - very fine sandy
f.sa. - fine sandy

Calcium in the percolates was determined by the Schreiner (70) turbidity method. Results are expressed in Table (30) as milligrams of CaO. Three soils give a very large amount of soluble calcium in their percolates, Sagemoor fine sandy loam, Yakima sandy loam and Norfolk loam. The Norfolk loam is especially high in the amount of water-soluble calcium after several leachings, although all of the nine soils have more soluble calcium still coming out at the end of the test than any other constituent.

The lowest in total calcium of the soils studied is the Sassafras loam and the highest in total calcium the Sagemoor fine sandy loam. In only one case has sulphur increased the solubility of calcium when applied to the soil. The Yakima sandy loam shows more calcium in the percolate from the sulphur-treated than from the untreated percolator. In eight out of nine cases the apparent effect of sulphur has been to render the calcium less soluble. This would seem natural, for the salt calcium sulphate is relatively insoluble in water. Why the Yakima soil has shown an increase in soluble calcium with sulphur is not understood.

The ratio of water-soluble to total calcium varies from 1 to 12 (Sassafras loam) to 1 to 48 (Columbia fine sandy loam) in the unsulphured checks and from 1 to 13 to 1 to 56 in the same soils when sulphured. It will thus be seen that the ratio of soluble to total calcium varies but slightly compared with nitrogen, phosphorus or potassium. This is true also with sulphur. See Figure 2.

Table 30.

Calcium in Percolate
from Sulphur-treated and Untreated Soils

Soil	Treatment	Milligrams of CaO in Percolate				
		Prelim-inary leachings	After 3 weeks	After 6 weeks	After 9 weeks	After 12 weeks
1. Ritzville v.f.sa.loam	Nothing	226.78	337.45	122.08	330.40	45.95
	Sulphured	218.56	336.28	109.96	283.39	68.70
2. Sagemoor f.sa.loam	Nothing	771.55	388.56	245.32	554.50	161.00
	Sulphured	748.47	338.69	300.80	457.60	123.76
3. Columbia f.sa.loam	Nothing	307.02	336.87	113.14	104.18	61.88
	Sulphured	322.86	298.89	96.60	210.00	61.92
4, Yakima sandy loam	Nothing	690.64	447.84	80.22	204.60	66.17
	Sulphured	670.50	465.51	120.92	324.94	72.00
5. Norfolk loam	Nothing	845.63	893.59	230.98	520.55	45.21
	Sulphured	793.61	845.58	188.92	566.02	81.30
6. Leonardtown silt loam	Nothing	393.12	388.45	182.12	427.59	30.45
	Sulphured	375.50	363.33	92.54	473.48	36.84
7. Porter's silt loam	Nothing	337.40	635.20	71.24	270.21	52.61
	Sulphured	326.04	621.48	70.20	319.06	36.32
8. Keyport silt loam	Nothing	357.60	477.17	175.12	223.25	51.60
	Sulphured	365.98	490.86	110.06	249.98	28.80
9. Sassafras loam	Nothing	329.56	446.57	118.00	185.09	58.22
	Sulphured	310.85	392.72	105.54	184.61	62.68

v.f.sa. - very fine sandy
f.sa. - fine sandy

Table 31.

Ratio of Water-soluble
to Total Calcium and Potassium in
Sulphur-treated and Untreated Soils.

Soil	Total potassium in 3700 g. (as K)	Water-soluble potassium in 3700 g. (as K)	Ratio of water-soluble to total K 1 to	Total calcium in 3700 g. (as Ca)	Water-soluble calcium in 3700 g. (as Ca)	Ratio of water-soluble to total Ca 1 to
	mgms.	mgms.		mgms.	mgms.	
1. Ritzville v.f.sa.loam	47,730	315.06	151	20,572	758.74	27
Sulphured		334.05	142		726.06	28
2. Sagemoor f.sa.loam	56,462	429.81	131	46,287	1514.34	30
Sulphured		462.37	122		1406.09	33
3. Columbia f.sa.loam	13,801	524.13	26	31,894	659.09	48
Sulphured		549.21	25		572.11	56
4. Yakima sandy loam	27,713	900.88	31	44,215	1063.48	41
Sulphured		944.36	29		1180.86	37
5. Norfolk loam	31,635	396.04	80	28,786	1810.67	16
Sulphured		402.66	78		1767.46	16
6. Leonardtown silt loam	17,316	437.30	39	15,947	1015.11	15
Sulphured		433.49	39		957.96	16
7. Porter's silt loam	36,408	118.50	305	25,715	975.79	26
Sulphured		126.13	287		980.39	26
8. Keyport silt loam	25,530	366.64	69	21,386	917.30	23
Sulphured		372.35	68		889.42	24
9. Sassafras loam	29,267	194.46	150	9,879	812.13	12
Sulphured		177.64	163		754.27	13

v.f.sa. - very fine sandy
f.sa. - fine sandy

Nitrate nitrogen was determined in the percolates by Harper's modification of the phenol-disulphonic acid method. The results are expressed in Table (32) as milligrams NO_3 and in Table (33) as milligrams N.

The Maryland soils are very much higher in nitrate nitrogen than any of the Washington and Oregon soils, although the Western soils towards the end of the test were more efficient in giving out nitrates. The Yakima sandy loam actually did not have a measurable quantity of nitrate nitrogen at the beginning of the test. The Sassafras loam was the highest in nitrate nitrogen of the nine soils; this soil is in a very good state of fertility as evidanced by cropping tests.

The effect of sulphur on the Western soils has been to decrease the amount of nitrates in the percolates very markedly. This would indicate that the apparent effect of sulphur as if it were a "nitrogen fertilizer" as commented on by Power (58) and Neller (49) is not due to its encouragement of nitrification but most probably due to its beneficial effect on the legume nodule bacteria. On the Maryland soils sulphur appears to encourage nitrification slightly.

The ratio of nitrate to total nitrogen varies from 1 to 8.4 (Sassafras loam) to 1 to 181 (Yakima sandy loam) in the untreated soils and from 1 to 8.6 to 1 to 224 in the same soils when sulphured.

Table 32.

Nitrates in Percolate
from Sulphur-treated and Untreated Soils

Soil	Treatment	Milligrams of NO_3 in percolate. Preliminary leachings	After 3 weeks	After 6 weeks	After 9 weeks	After 12 weeks
1. Ritzville v.f.sa.loam	Nothing	102.61	6.26	1.55	0.36	8.62
	Sulphured	103.68	4.16	0.68	0.66	7.43
2. Sagemoor f.sa.loam	Nothing	40.22	2.09	0.91	2.52	32.20
	Sulphured	35.58	2.75	3.38	1.91	2.37
3. Columbia f.sa.loam	Nothing	33.65	9.54	4.51	1.30	21.66
	Sulphured	36.32	8.19	4.17	1.42	18.60
4. Yakima sandy loam	Nothing	Trace	6.73	2.72	3.01	20.96
	Sulphured	Trace	11.44	1.82	2.51	11.91
5. Norfolk loam	Nothing	364.99	5.67	1.33	1.24	0.72
	Sulphured	365.23	8.20	1.26	0.28	4.27
6. Leonardtown silt loam	Nothing	201.11	1.22	2.33	2.55	3.92
	Sulphured	198.14	1.46	1.07	2.84	5.94
7. Porter's silt loam	Nothing	362.44	4.57	1.29	0.30	1.28
	Sulphured	367.84	8.26	1.15	0.36	5.58
8. Keyport silt loam	Nothing	202.64	21.84	1.55	0.94	2.54
	Sulphured	192.15	47.08	5.98	0.45	19.71
9. Sassafras loam	Nothing	498.83	22.54	8.28	0.93	16.15
	Sulphured	478.47	38.80	5.97	0.24	13.37

v.f.sa. - very fine sandy
f.sa. - fine sandy

Table 33.

Ratio of Nitrate Nitrogen
to Total Nitrogen in
Sulphur-treated and Untreated Soils

Soil	Total nitrogen in 3700 g. (as N)	Nitrate Nitrogen in 3700 g. (as N)	Ratio of nitrate nitrogen to total nitrogen
	mgms.	mgms.	
1. Ritzville very fine sandy loam	3,677	92.41	1: 40
Sulphur-treated		90.25	1: 41
2. Sagemoor fine sandy loam	2,146	60.32	1: 36
Sulphur-treated		35.60	1: 60
3. Columbia fine sandy loam	7,463	54.69	1:136
Sulphur-treated		53.17	1:141
4. Yakima sandy loam	4,699	25.87	1:181
Sulphur-treated		21.42	1:224
5. Norfolk loam	3,182	289.44	1: 11
Sulphur-treated		293.53	1: 10.8
6. Leonardtown silt loam	2,960	163.41	1: 18.1
Sulphur-treated		162.11	1: 18.2
7. Porter's silt loam	3,123	286.29	1: 10.9
Sulphur-treated		296.59	1: 10.6
8. Keyport silt loam	5,147	177.64	1: 28.9
Sulphur-treated		205.40	1: 25.0
9. Sassafras loam	3,567	423.17	1: 8.4
Sulphur-treated		415.22	1: 8.6

SUMMARY OF CHEMICAL STUDIES.

From chemical studies of the displaced solution from nine soils the following observations may be made :-

Sulphur

The amount of water-soluble sulphur in a soil is no measure of the amount of total sulphur in that soil, and vice-versa, a soil low in total sulphur may be high in water-soluble sulphur.

Soils low in total sulphur oxidize elemental sulphur readily to the sulphate form.

Phosphorus

The amount of water-soluble phosphorus in a soil is governed by the reaction of the soil and to no great extent by the total amount of phosphorus present. The water-soluble phosphorus, acting as a buffer, undoubtedly helps to govern the reaction of the soil.

A soil high in water-soluble phosphorus is as a rule also high in water-soluble sulphur relative to the total amounts of the two elements which are present.

The occurrence of sulphur oxidation in most soils tends to render phosphorus less soluble rather than more soluble.

Potassium

Alkaline soils as a rule have more soluble potassium than acid soils, due to the greater solubility of the potassium compounds existing there.

The amount of water-soluble potassium depends but slightly upon the total amount of potassium in a soil.

Sulphur in all cases, but that of the most acid soil, released potassium in a water-soluble form.

Calcium

A soil low in total calcium may be high in water-soluble calcium.

Sulphur oxidation in most soils tends to render calcium less soluble.

Calcium, like sulphur, appears to have a relatively constant ratio of total to water-soluble.

Nitrate Nitrogen

In humid climate soils nitrate nitrogen is high compared with soils from semi-arid climates.

Sulphur depresses nitrification on semi-arid soils, and appears to have encouraged nitrification slightly on humid soils except those most acid.

Reaction

The effect of sulphur in increasing the hydrogen ion concentration of a soil solution is modified by bases and buffer substances present. Nevertheless the acidity generated in sulphur oxidation has definite and important effects on the equilibrium of the soil solution.

Colloids

Sulphur flocculates soil colloids - making soils leach more rapidly and fully.

Equilibrium

There is present in soils a balance between water-soluble and insoluble sulphur and calcium. Where the total amount of either of these elements is low the ratio of soluble to total is high.

Reaction is an important factor in the maintenance of equilibrium in the soil solution. The formation of buffer salts, notably phosphates, under alkaline conditions, prevents the reaction from becoming still more alkaline.

Acidity added to a soil flocculates the soil colloids and this permits of the removal of that acidity by leaching.

The biological reaction, nitrification, is very easily disturbed and apparently requires a constant and adequate moisture supply for best efficiency.

The soil is in a state of dynamic equilibrium and its constituents are constantly changing in their relationships to each other.

CONCLUSIONS

1. Sulphur behaves as a soil amendment rather than as a fertilizer. Just as lime helps to restore equilibrium in acid soils by bringing the reaction of the soil solution to neutrality, sulphur helps to restore equilibrium in alkaline soils by bringing the reaction of the soil solution to neutrality.

2. In Maryland soils there are "calciphile" crops, which respond very well to lime applications. There appear to be "sulphophile" crops, such as buckwheat and sweet potatoes, which even on acid soils respond well to sulphur applications.

3. Where crop increases have been obtained from sulphur applications to Maryland soils, these increases may be attributed to the beneficial effect of increased acidity upon the soil solution or the specific crop grown.

4. The crop increases resulting from sulphur applications to Washington and Oregon soils seem to be due to more favorable conditions for nitrogen-fixing organisms.

5. In some soils sulphur applications tend to depress nitrification slightly while in other soils it does not seem to affect it. In some semi-arid soils it has increased the amount of water-soluble phosphorus, but in most cases it has decreased the soluble phosphorus. It has increased soluble potassium and decreased soluble calcium. Its application has of course increased the amount of soluble sulphates.

6. The addition of elemental sulphur to fertilizer mixtures containing acid phosphate has in most cases given lowered yields, while added to raw rock phosphate mixtures it has in most cases increased yields.

7. Crop growth and the lapse of a few months from the time of its application in acid phosphate mixtures lessens the depressing effect of sulphur on yields.

8. Maryland soils are not nearly so strongly buffered as the Oregon and Washington soils studied. In the latter soils the strong buffering effect is probably due to both soluble bases in excess and to soluble phosphates.

9. Applications of sulphur greater than 100 pounds per acre should not be made on Maryland soils. In light applications and for specific crops it is believed that increased yields may be obtained in many cases through the use of elemental sulphur. Mixed with raw rock phosphate it has in most cases made that material more effective as a fertilizer.

Appendix -A-

METHODS

In the analyses for total constituents of the experimental soils reported in Table I, the official methods of the Association of Official Agricultural Chemists were followed except with sulphur and carbon. These official methods are given in "Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists" 2d Edition, 1924.

The sulphur was determined by fusion with magnesium nitrate and precipitation as sulphate sulphur with $BaCl_2$. Total carbon was determined by fusion of the soils with Na_2O_2, treatment of the fused mass with HCl and reading the volume of evolved CO_2 gas in a Parr total carbon apparatus, and then reducing to standard conditions.

The determination of the hydrogen ion concentration throughout all the experimental work was made by the colorimetric method. The standards of Clark and Lubs were used. The colorimetric standards were checked electrometrically.

Two methods of obtaining the soil solution for analysis were used. In one case samples of soil were taken from the pot cultures in the greenhouse with a large cork-borer and 1:5 extractions were made with distilled water, shaking 100 times and centrifuging the extract until clear. In the other case the soil solution was obtained by the water displacement method outlined by Parker in Soil Science XII, No.3, pp.209-232, 1921.

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