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SULFUR IN RELATION TO SOIL FERTILITY

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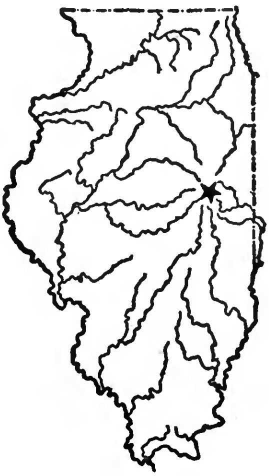

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SULFUR IN RELATION TO SOIL FERTILITY

By ROBERT STEWART, Chief in Soil Fertility

INTRODUCTION

Sulfur is one of the ten essential elements of plant food. It is necessary for the formation of certain essential oils and for many plant proteins in which it is a component part. These facts have been known for a long time. Iron, likewise, is an essential element of plant food, but there are only one or two instances of its having been added to the soil with any economic results.[1] It has been generally assumed by soil investigators that the demands of the plant for iron are so small and the supply in the soil so large that it will never be necessary to add it to the soil.

With sulfur, also, it has been generally assumed, until quite recently, that the supply in the soil was sufficient to meet the *small* requirements of plants for indefinite periods of time. The question of its value as a fertilizer has arisen again within the past few years, however, as a result of several circumstances, one being the attempt on the part of those having sulfur materials for sale to enlarge the agricultural market for their goods. This bulletin brings together in summarized form the available data on the subject, and is published in an attempt to answer the many questions which are coming to the Experiment Station with regard to the use of sulfur in this way.

It is true that compounds of sulfur, and even sulfur itself, have been used on soils for long periods of time. Benjamin Franklin in this country was an early, ardent advocate of the use of land-plaster, or gypsum, the native sulfate of calcium. From his day until the present the question of the use of land-plaster, or gypsum, has periodically arisen. A quarter of a century ago this question occupied the minds of soil men quite prominently. This manifests itself in the field plans of the Pennsylvania and Ohio experiment stations, where provisions were made to test out the effect of gypsum on the production of crops. The results obtained by these experiment stations are considered on pages 101 to 103. They offer the best evidence the world affords today of the lack of value of gypsum in crop production under actual field conditions, in humid regions.

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[1]Cases have been reported from Australia and Hawaii where iron has been used successfully on special soils and for special crops with favorable results.

SULFUR REQUIREMENT OF PLANTS

Until 1911 it had been the custom of analytic chemists, in analyzing plants for sulfur, to burn the plants and determine the sulfur content of the ash, in that way determining their sulfur requirements. In 1911 Hart and Peterson of Wisconsin called attention to the fact that under these conditions a large part of the sulfur escaped in the gases and the reported sulfur content of vegetation was therefore too low. They redetermined the sulfur content of various crops by the improved Osborne method, which consists of careful fusion of the plant material with sodium peroxid, and found that the plant requirements for sulfur were much higher than had been generally assumed. The differences so found may be readily seen by a consideration of the data below.

TABLE 1.—SULFUR CONTENT OF SOME COMMON FARM CROPS

Crop	Large crop yields	Sulfur in plant (After Hart and Peterson)		Sulfur in Ash (After Wolff)	
	per acre	*perct.*	*lbs.*	*perct.*	*lbs.*
Alfalfa hay	8 tons	.287	45.92	.170	27.20
Red clover	4 tons	.164	13.12	.089	7.12
Corn, white	100 bu.	.170	9.52	.004	.22
Corn stover	3 tons	.126	7.56	.113	6.78
Oats	100 bu.	.189	6.05	.002	.06
Oat straw	2½ tons	.195	9.75	.092	4.60
Timothy	3 tons	.190	11.40	.078	4.68
Wheat	50 bu.	.170	5.10	.003	.09
Wheat straw	2½ tons	.119	5.95	.053	2.65

These results were significant. It was found that a hundred-bushel crop of corn, for example, instead of removing only a fraction of a pound of sulfur, actually removes over 9 pounds in the grain alone; while a fifty-bushel crop of wheat, instead of removing less than one-tenth of a pound, actually removes 5.1 pounds. With some plants, such as alfalfa, the sulfur requirements were found to be actually greater than the phosphorus requirements.

SULFUR CONTENT OF THE SOIL

The results reported above directed attention to the sulfur content of the soil, and a number of soils were analyzed for sulfur, especially by investigators in Wisconsin, Iowa, and Kentucky. The amount of sulfur present in the soil was found to be uniformly low, and in most cases less than the amount of phosphorus. The results obtained at the Kentucky station are typical, and are recorded below as pounds in two million pounds of soil (the weight of an acre to a depth of 6⅔ inches):

Source of Soil	*Sulfur*	*Phosphorus*
Wolfe county	440	860
Lincoln county	480	300
Henry county	280	740
Webster county	360	840
Green county	360	600
Groves county	240	860
Fayette county	760	3500
Marion county	460	1240
Jefferson county	380	840
Henderson county	620	1400
Average	438	1118

It is quite clear from these results that the sulfur content of the soil is very limited. Undoubtedly an analysis of the soils of Illinois would show similar results were it worth while to spend the time and money to make the analysis.

Some evidence has also been presented to show that the sulfur content of cropped cultivated soils is less than that of corresponding virgin soils.

These facts have led some investigators to believe that sulfur bears the same relation to soil fertility as phosphorus, and that in a permanent system of soil fertility it is necessary to add sulfur in some form to meet these requirements. This conception has been endorsed with enthusiasm by certain commercial interests, and an active propaganda is now being carried on to promote sales of sulfur-bearing fertilizers. That there is no sufficient basis for this belief is fully borne out by the following data.

EFFECT OF SULFUR ON THE PRODUCTION OF CROPS

A number of pot-culture experiments to determine the effect of sulfur fertilization on the production of crops have been reported by various investigators as meeting with more or less indifferent success. The results obtained by Hart and Tottingham are probably typical. They found that calcium sulfate, or gypsum, alone increased the yield of clover 23 percent. When gypsum was added to a complete fertilizer, the yield of rape was increased 17 percent and the yield of radishes 9 percent. A number of similar pot experiments have been carried on in the greenhouse by investigators elsewhere, with very similar results. The pot cultures so far reported are invalidated, however, as evidence on this question *because no compensation was allowed for the sulfur which may have been added to the soil by rainfall under field conditions.*

During the latter part of the eighteenth and the early part of the nineteenth centuries, gypsum was commonly used in many sections of the country, and articles were written recording the benefit derived by various farmers from its use. These results, however, have no scientific background, and hence have little value as evidence and must be classed only as interesting historical observations. The best and most reliable data the world affords is that furnished by the Ohio and Pennsylvania experiment stations, where gypsum has been used for many years in the regular experimental work and definite records of yields and soil treatment are available.

The data obtained at the Pennsylvania station are wholly negative; no benefit at all is shown from the use of gypsum. Plots 13 and 33 received an application of 320 pounds of land-plaster (gypsum) applied in alternate years. The thirty-five-year average yields on these plots were as follows: corn, 36.1 bushels; oats, 31.3 bushels; wheat, 13.4 bushels; hay, 2,378 pounds; while the average yield of the untreated plots was corn, 37.2 bushels; oats, 31.6 bushels; wheat, 13.4 bushels; and hay, 2,460 pounds. Ground limestone alone gave an average yield of 42 bushels of corn, 34.2 bushels of oats, 15.6 bushels of wheat, and 2,760 pounds of hay.

Altho the results obtained at the Ohio experiment station in experiments with acid phosphate, raw rock phosphate, and gypsum when used to reënforce farm manure, appear to be very favorable to the use of gypsum under certain conditions, it should be realized fully that there are several ways of interpreting the data presented by that station. It seems to the writer that the logical way to determine the effect of farm manure is to compare the average yield of the plots receiving manure alone with the average yield of all check plots in the series. The effect of acid phosphate, raw rock, or gypsum may likewise be ascertained by comparing the yield obtained by manure reënforced with any one of these materials, with the yield obtained by manure alone.

The eighteen-year average yield of crops obtained at Ohio with the various treatments are recorded below:

	Corn, bu.	*Wheat, bu.*	*Hay, lbs.*
Unmanured	31.77	11.76	2,536
Manure, untreated	56.11	21.37	3,668
Manure, rock phosphate	65.07	25.70	4,561
Manure, acid phosphate	65.36	26.81	4,555
Manure, gypsum	61.05	24.30	3,897

The increases due to the treatments were therefore as follows:

	Corn, bu.	*Wheat, bu.*	*Hay, lbs.*
Manure, alone	21.34	9.61	1,132
Raw rock phosphate	8.96	4.33	893
Acid phosphate	9.25	5.44	887
Gypsum	4.94	2.93	229

There are very striking results. The soil is very deficient in nitrogen and phosphorus, and responds markedly to those substances when they are applied in the form of organic manures or inorganic phosphates. Manure, applied at the rate of 8 tons per acre every three years, has produced a markedly increased yield. This amount of manure, however, has not been sufficient to meet the requirements of the plant for food, as is evidenced by the fact that phosphorus, either as acid phosphate or raw rock, when added to the manure has produced still larger yields.

The raw rock phosphate, acid phosphate, and gypsum were applied at the rate of 320 pounds per acre every three years. Gypsum alone has produced an increase of 4.9 bushels of corn, 2.9 bushels of wheat, and 229 pounds of hay. Acid phosphate, which consists of both soluble monocalcium phosphate and gypsum, has produced an increase of 9.3 bushels of corn, 5.4 bushels of wheat, and 887 pounds of hay; while rock phosphate, containing twice as much phosphorus but no gypsum, has produced an increase of 9 bushels of corn, 4.3 bushels of wheat, and 893 pounds of hay. In other words, when manure has been reënforced with the larger amount of phosphorus contained in the raw rock, yields have been produced practically equal to those produced by the combined action of monocalcium phosphate and gypsum in the acid phosphate.

These experimental results obtained at Ohio are not only the best the world affords concerning the use of gypsum but they are in complete harmony with what one would expect as a result of the well-known stimulating action of gypsum. When sufficient phosphorus has not been applied, either in the farm manure or in the applied phosphate, then the application of gypsum has enabled the plant to better draw on the inadequate supply of phosphorus already in the soil, owing to the stimulation of bacterial life, as shown by Greaves, and the more abundant development of root hairs (a well-known effect of calcium compounds), as recently shown anew by Hart and Tottingham. When sufficient phosphorus has been applied in the form of raw rock, however, the needs of the plant have been met without the aid of the stimulating action of gypsum. It is quite evident that the apparently beneficial action of gypsum is due to the stimulating effect described and not to the addition of calcium or sulfur as plant foods.

An abundance of data is also available from the investigations of the Illinois Experiment Station regarding the effect of applications of sulfur, on the production of common farm crops. Potassium sulfate is regularly used in the experimental work. The yield of crops from some of the Davenport plots of the Urbana North Farm are recorded in Table 2.

TABLE 2.—EFFECT OF SULFUR ON THE YIELD OF CROPS ON BROWN SILT LOAM: ILLINOIS EXPERIMENTS (Yields expressed in bushels or (tons) per acre)

Treatment	Corn 19 crops	Oats 17 crops	Wheat 7 crops	Clover 8 crops	Soybeans 4 crops	Alfalfa 6 crops
Grain System of Farming						
RLP	75.4	64.2	42.5	2.16	22.6	(3.56)
RLPS	75.6	64.4	41.7	1.64	24.2	(3.59)
Live-Stock System of Farming						
MLP	72.6	63.5	40.1	(3.62)	(1.92)	(3.58)
MLPS	71.6	62.9	39.4	(3.57)	(2.09)	(3.63)

R=residues; M=manure; L=limestone; P=phosphorus; S=sulfur.

These results, extending over a period of years, clearly demonstrate that sulfur is not a factor, on brown silt loam soil at least, in the production of such common farm crops as corn, oats, wheat, clover, and alfalfa hay, under Illinois conditions.

LOSS OF SULFUR IN DRAINAGE WATER

Sulfur occurs in the soil either in a form soluble in water, or in organic combination which is converted slowly into the soluble form, and hence may be readily lost from the soil in the drainage water. The amount so lost annually is variable. As estimated from the Rothamsted data, the loss varies from 20 to 80 pounds per acre, depending upon the treatment which the soil has received. Norton, from the data obtained by measurement of the flow of Richland Creek, Arkansas, and from the composition of the water, has estimated the annual loss at 6 pounds per acre. The estimates of a number of European investigators vary from 8 pounds to as high as 270 pounds per acre per annum, depending again upon the treatment of the soil and the conditions of the experiments.

The most satisfactory data on this question are those obtained in the lysimeter experiments by the Cornell experiment station and recently reported by Lyon and Bizzell; part of the results (expressed in pounds per acre) are recorded below:

Tank No.	*Treatment*	*Sulfur in drainage water*	*Added in manure*	*Net annual loss from soil*
3	Manure, rotation of crops	31.8	15.5	16.3
5	Manure, rotation of crops including clover	31.5	15.5	16.0
7	Lime, manure, rotation of crops	43.9	15.5	28.4
9	Lime, manure, rotation of crops including clover	41.0	15.5	25.5

Farm manure at the rate of twenty tons per acre was applied to these tanks. The amount of sulfur applied in the manure was estimated to be 62 pounds per acre, which is equivalent to an annual application of 15½ pounds.[1] Other data show quite clearly that the loss of sulfur in the drainage is dependent on the soil treatment and particularly on the amount of sulfur applied in the fertilizer. Caustic lime, as shown by the data here presented, has a marked effect on loss of sulfur in the drainage water. Allowing for the sulfur added in the manure, the net annual loss of sulfur, where a rotation of crops was practiced and manure used, varied from 16 to 28.4 pounds per year. This loss occurred after the requirements of the plants had been completely met and must therefore represent an annual excess of unusable material. In a permanent system of soil fertility, must this loss be met each year by the addition of some form of sulfur materials? Why add more soluble sulfur, which only increases the amount lost in the drainage, since there is already an excess of available sulfur in the soil which the plant refuses to utilize? These two questions are perfectly justified at this point and warrant careful and serious consideration.

Nitrogen, likewise, is lost in appreciable quantities from the soil in the drainage water, especially from bare soil or a soil growing a cultivated crop only part of the time. But nitrogen is used by the growing plant, and when the soil is kept in a continuous crop the loss in the drainage water may be largely, if not entirely, prevented. This is clearly shown by the work of Babcock at the Geneva experiment station, who studied the loss of nitrogen in the drainage water from three tanks—one bare but undisturbed, one cultivated, and one in a continuous grass. He obtained the following results, expressed in pounds per acre:

Lysimeter No.		1	2	3
Treatment		*In sod*	*Bare, undisturbed*	*Cultivated, not cropped*
Loss of nitrogen	1884	.19	69.5	132.0
	1885	1.02	218.7	218.0
	1886	.08	357.7	234.0

The nitrogen, so essential as a plant food, was practically entirely removed from the drainage water, owing to the demands of the plant. Therefore, in a native condition, the loss of nitrogen from the soil is reduced materially, since a crop is constantly present, and such loss as does take place usually more than compensated for by the fixation of atmospheric nitrogen by various agencies.

The work of Lyon and Bizzel at Cornell, on the other hand, shows quite conclusively that the loss of sulfur in the drainage water is not so reduced by cropping, and hence the sulfur in the drainage

[1]While phosphorus is required by the growing animal for bone production and is absorbed from the feed it consumes, sulfur is not so required. Sulfur occurs in large amounts in hay, straw, stover, etc., and consequently finds its way into the manure. Farm manure, therefore, contains slightly more sulfur than phosphorus.

water must represent an excess of *unusable* material. Their results show clearly that the loss of sulfur in the drainage water is five or six times as great as is the amount removed by the crop. Moreover, if sulfur is lost from the soil in such large quantities as some investigators believe, and there is no compensation as in the case of nitrogen, cultivated soil should very soon be actually devoid of sulfur. The soils of Kentucky, for example, having an average sulfur content of 438 pounds should be completely deprived of sulfur in ten or fifteen years *unless sulfur is constantly being added in appreciable quantities from some natural source.*

SULFUR CONTENT OF RAINFALL

The atmosphere contains a variable quantity of sulfur as sulfur dioxid. The quantity is quite appreciable near smelters or near large cities, and cases have frequently been reported of damage being done to vegetation and household fabrics by the production of sulfuric acid by the oxidation of the sulfur dioxid of the air. Undoubtedly the amount of sulfur dioxid in the atmosphere is less in the open country than near large cities, but wherever coal or wood is burned or organic matter decomposes, the sulfur in a large measure escapes into the air and the supply of sulfur in the air is thus constantly being replenished.

The sulfur dioxid of the air is absorbed by the moisture in the air and added to the soil in the rainfall (some is also added to the soil by direct absorption from the air). The amount of sulfur so added has been found to be very appreciable and to fully compensate for that removed by crops and lost in the drainage waters. Some very significant data on this phase of the question have been obtained at the University of Illinois during the past seven years and are reported in Tables 3 and 4.

TABLE 3.—SULFUR ADDED TO THE SOIL BY RAINFALL: ILLINOIS EXPERIMENTS
(Amounts expressed in pounds per acre)

Month	1913	1914	1915	1916	1917	1918	1919	Aver.
Jan.	4.3	2.9	5.8	7.5	3.7	3.5	4.2	4.6
Feb.	2.7	6.9	3.4	2.7	3.3	6.0	5.1	4.3
Mar.	4.5	4.0	4.0	4.7	5.1	3.7	([1])	4.3
Apr.	4.1	4.2	3.0	4.6	5.0	6.0	3.2	4.3
May	1.6	2.2	5.1	8.6	5.6	4.8	5.8	4.8
June	2.6	2.7	3.3	5.2	4.6	4.3	4.5	3.9
July	2.0	2.0	4.4	1.9	3.1	2.2	1.8	2.5
Aug.	2.0	5.7	4.1	2.0	4.3	4.7	4.7	3.9
Sept.	3.3	3.0	3.0	2.3	2.5	3.4	3.0	2.9
Oct.	5.1	3.0	1.6	5.0	4.9	5.8	2.9	4.0
Nov.	4.4	2.4	2.5	3.1	3.9	2.4	3.0	3.1
Dec.	3.4	1.6	5.4	3.3	1.7	.7	1.6	2.5
Total	40.0	40.5	45.5	51.0	47.7	47.6	39.8[1]	45.1
Aver.	3.3	3.4	3.8	4.3	4.0	4.0	3.6	3.8

[1]No record of March rainfall

In 1912 a rain gage was established on the roof of the Agricultural Building; the rain water was collected and measured, and monthly samples were analyzed for various forms of nitrogen and sulfur. The results shown in Table 3 were obtained.

It may be noted that from 40 to 51 pounds of sulfur was brought down annually in the rain water. The amount added to the soil monthly varies from year to year. As an average of the seven years' work, 45.1 pounds of sulfur has been added annually, or 3.8 pounds monthly. This is a large amount as compared with the requirement of crops, as shown on page 100. (In considering the variation from month to month it should be borne in mind that the amount of sulfur collected depends directly upon the amount of precipitation and will vary accordingly.) During the period of five months from May to September, 18.0 pounds was added.

In 1915 the Hopkins soil bins were constructed in order to study certain special problems in soil fertility. These bins are located on the University North Farm at Urbana, under actual field conditions. A rain gage was established in connection with the bins and the rainfall collected, measured, and analyzed. The three years' results available from this rain gage are presented in Table 4.

TABLE 4.—SULFUR ADDED TO SOIL BY RAINFALL: ILLINOIS EXPERIMENTS
(Amounts expressed in pounds per acre)

Month	1917	1918	1919	Aver.
Jan.	1.0	2.3	4.1	2.5
Feb.	.6	4.2	5.9	3.6
Mar.	2.9	3.9	5.4	4.1
Apr.	3.3	7.5	2.9	4.6
May	4.6	4.7	4.6	4.6
June	3.2	3.6	3.7	3.5
July	2.5	2.0	2.8	2.4
Aug.	3.7	2.8	2.2	2.9
Sept.	2.6	4.5	1.8	3.0
Oct.	3.9	4.8	3.8	4.2
Nov.	2.8	3.4	2.9	3.0
Dec.	.5	5.8	.9	2.4
Total	31.5	49.4	41.0	40.8
Aver.	2.6	4.1	3.4	3.4

Again there is a variation from month to month in the amount of sulfur added to the soil in the rainfall. As an average of the three years covered by these data, 40.8 pounds was found to have been added annually, or 3.4 pounds monthly. During the growing period for corn (from May to September) 16.4 pounds was added to the soil.

From the data presented, it is quite evident that the sulfur supply of the soil is automatically replenished from the atmosphere and that the relation of sulfur to soil fertility is not in any sense similar to that of phosphorus. For example, to produce a hundred-bushel crop of corn 17 pounds of phosphorus and 9 pounds of sulfur are required for the grain alone. The phosphorus must come either from the soil or from applied materials, for there is no other possible source. On the other hand, the results obtained at the Hopkins' soil bins indicate that under actual field conditions an average of 16.4 pounds of sulfur is added to the soil during the growing season for corn (from May to September), and that this sulfur is added in monthly installments of 3.4 pounds. Very fortunate would we be could our phosphorus and limestone problems be so easily solved!

CONCLUSIONS

The only conclusion that can be drawn from the available data on this subject is that, under humid conditions, sulfur need not be added to the soil as a plant food. This does not in any sense detract from the possibility of its use in other ways. It may, for example, have a very important use as a germicide or as a fungicide in plant production problem. Mixed with rock phosphate in the compost heap, as advocated by Lipman, it may have some value as a market-garden proposition, but this is simply a method for producing acid phosphate on the farm and should not be confused at all with the use of sulfur as a plant food. Likewise, the question of making available the phosphorus in raw rock in the soil by using it in connection with gypsum. may have some merit owing to the stimulating action of gypsum on the bacterial activity in the soil and the increased root production of the plant; but this again is an entirely separate problem from the use of gypsum *as a source of the plant food, sulfur.*

We must conclude that the sulfur problem, in relation to soil fertility, is not in any sense similar to the phosphorus problem. It has rather a relation similar to carbon, for both sulfur and carbon are supplied to the plant from the atmosphere, in amounts sufficient for its requirements, and this supply is constantly being replenished by natural processes.