THE SIGNIFICANCE OF THE SULFUR IN SULFATE OF AMMONIA APPLIED TO CERTAIN SOILS

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The superiority of sulfate of ammonia to nitrate of soda, nitrate of lime, and other nitrogenous fertilizers for the production of barley, in certain soil types in California, which we have demonstrated (1) led us to inquire into the more direct nature of its cause. While we had shown the high coefficient of nitrifiability which characterizes sulfate of ammonia in those soils to be the cause of its superiority over other nitrifiable materials, it did not appear entirely clear why nitrate of soda and particularly nitrate of calcium should not be equally good with moisture conditions being maintained at the optimum. After studying the situation, it occurred to us that the sulfur of the ammonium sulfate might be the cause of its superiority over the nitrate fertilizers. This seemed particularly reasonable since the soils under study are markedly deficient in organic matter and hence do not support a vigorous sulfofying flora. We, therefore, inaugurated an experiment to determine the rôle of sulfur, in barley growth on one type of the soils in question, when used in conjunction with nitrogenous fertilizers. It was argued that if sulfur in one or more forms, when combined with nitrates, induced similar yields to those obtained with sulfate of ammonia, the sulfur must be the cause of the superiority of the ammonium salt over the nitrates in the cases in question.

DESCRIPTION OF THE EXPERIMENT

The soil employed was the Oakley blow sand, which we have already described in detail elsewhere (2). It was placed in glazed earthenware jars such as those commonly used in greenhouse work. Every test was made in triplicate jars, except in some cases in which the lack of sufficient soil rendered it necessary to employ only duplicate jars. Two parallel series were run. In the first, the various nitrogenous fertilizers were used as in the experiments above cited. In the second, the same nitrogenous fertilizers were used in the same way, but sulfur in various forms was added to each. The amount of nitrogen employed was equivalent in all cases to that added on the basis of a field application of dried blood at the rate of 1000 pounds per acre. Similarly, sulfur was used in the same quantity for all cultures to which it was applied, regardless of the form used and was equivalent to the amount of sulfur contained in the sulfate of ammonia application alone. Nitrogen was

employed in the forms of sulfate of ammonia, nitrate of soda, nitrate of lime, and dried blood. Sulfur was used in the forms of flowers of sulfur, sulfuric acid, and sodium sulfate. The applications of the various materials were made in accordance with the usual procedure which is based on the properties of every one of the substances. The moisture content of the soil was maintained uniformly in all the jars and at as near the optimum point as possible. Twelve barley seeds of the Beldi variety, from selected heads, were planted in every jar as in all other experiments, and the plants were thinned to six after they had attained a height of 3 to 4 inches. At the end of the growing season, determinations were made of the number of heads of grain per jar, the number of tillers, the total height of tillers, and the dry weights of straw, of grain, and of roots. Control jars were used, for growing plants, in which no fertilizer and no sulfur were employed and others in which only sulfur, but no nitrogen was applied. The data gathered are presented in the accompanying tables. It is at once apparent even from a brief study of the data given, that, in the first place, sulfate of ammonia is far superior to the other nitrogenous fertilizers for barley growth under the conditions described above. Secondly, it is clear that sulfur in all forms, when supplementing the nitrate or blood, induces marked increases in barley growth over and above that induced by the nitrogen alone. Thirdly, the sulfur without the nitrogen is practically without effect on barley production on the Oakley blow sand.

Considering the figures more in detail, it is obvious in the first table that marked effects, for the better, result from the application of nitrogen as regards the height of the stalks produced. The number of stalks or of heads produced, however, is only slightly affected, if at all, by all forms of nitrogen except sulfate of ammonia, which stimulates their production very markedly. When however, sulfur is added to the nitrogen, very striking increases in the number of heads and stalks occur in the case of all the jars, without any marked increase in the total height of the stalks. Moreover, the increases noted are, in most cases, sufficient to render the total growth about equivalent in those jars to that obtained in the sulfate of ammonia jars. This is true when any form of sulfur is added to nitrate of soda, but flowers of sulfur are not as good in that direction as sulfuric acid or sodium sulfate. On the other hand, it is true for nitrate of lime only in the cases of flowers of sulfur and sodium sulfate, but not in that of sulfuric acid, which actually depresses growth below that obtained when only nitrate of lime is applied. In the case of dried blood, sodium sulfate was not used and of the other two forms of sulfur, one—sulfuric acid—stimulated the plants in the directions indicated markedly, while the other—flowers of sulfur—was almost without effect.

Coming now to the more accurately measurable criteria for judging of the effects of nitrogen and sulfur on the barley plants, viz., the weights of straw, grain, and roots, the following observations are easily made. The application of sulfate of ammonia to the Oakley sand resulted in the production of about fourteen times as much total dry matter as that produced in the untreated

control jars. The jars treated with nitrate of soda, nitrate of lime, or dried blood, produced only a little more than half as much dry matter as those treated with sulfate of ammonia, the blood being slightly superior to the other two. When any form of sulfur is added to the Oakley sand without nitrogen,

TABLE 1
Number and height of shoots and number of heads

NUMBER	NITROGENOUS FERTILIZER	FORM OF SULFUR	NUMBER OF PLANTS PER POT	NUMBER OF HEADS PER POT	NUMBER OF SHOOTS PER POT	TOTAL HEIGHT OF SHOOTS	AVERAGE HEIGHT OF SHOOTS
						<i>inches</i>	<i>inches</i>
1	(NH ₄) ₂ SO ₄		6	14	15	475.5	31.7
2	(NH ₄) ₂ SO ₄		6	12	12	384.5	32.0
3	(NH ₄) ₂ SO ₄		6	12	12	404.0	33.7
4	NaNO ₃		6	6	6	218.5	36.4
5	NaNO ₃		6	8	8	253.0	31.6
6	NaNO ₃		6	6	6	215.5	35.9
7	Ca(NO ₃) ₂		6	6	6	207.0	34.5
8	Ca(NO ₃) ₂		6	7	8	246.0	30.8
9							
10	Blood		6	8	9	254.5	28.3
11	Blood		6	7	8	247.0	30.9
12		Na ₂ SO ₄	6	6	6	106.0	17.7
13		Na ₂ SO ₄	6	6	6	92.0	15.3
14		H ₂ SO ₄	6	6	6	104.0	17.3
15		H ₂ SO ₄	6	6	6	100.0	16.6
16		Sulfur	6	6	6	99.0	16.5
17		Sulfur	6	6	6	124.0	20.7
18	NaNO ₃	Na ₂ SO ₄	6	12	13	414.0	31.8
19	NaNO ₃	Na ₂ SO ₄	6	10	10	312.5	31.2
20	NaNO ₃	H ₂ SO ₄	6	12	12	403.0	33.6
21	NaNO ₃	H ₂ SO ₄	6	10	13	434.5	33.4
22	NaNO ₃	Sulfur	6	10	11	315.0	28.6
23	NaNO ₃	Sulfur	6	9	9	305.0	33.9
24	Ca(NO ₃) ₂	Na ₂ SO ₄	6	14	15	412.0	27.5
25	Ca(NO ₃) ₂	Na ₂ SO ₄	6	10	10	323.0	32.3
26	Ca(NO ₃) ₂	H ₂ SO ₄	6	6	6	182.0	30.3
27	Ca(NO ₃) ₂	H ₂ SO ₄	6	6	6	203.0	37.1
28	Ca(NO ₃) ₂	Sulfur	6	12	12	388.5	32.3
29	Ca(NO ₃) ₂	Sulfur					
30	Blood	H ₂ SO ₄	6	11	11	327.0	29.7
31	Blood	H ₂ SO ₄	6	12	12	382.0	31.8
32	Blood	Sulfur	6	9	9	276.0	30.7
33	Blood	Sulfur	6	7	9	286.0	31.8
34	Control		6	6	6	95.0	15.9
35	Control		6	6	6	110.0	18.3

it is without effect as regards the dry matter produced, just as it was described above to be, in so far as the numbers of heads and stalks are concerned. When, however, sulfur in any form is added, as described above, to the nitrates or to dried blood, it induces marked increases in the production of dry matter over

that produced by the nitrogen alone and, in most cases, the quantity of such increase is great enough to bring the total yield up to that of the sulfate of ammonia jars or nearly so. As was true in the case of the number of heads and stalks produced, flowers of sulfur appears to be less efficient than the other

TABLE 2
Yields of straw, grain and roots obtained in experiment

NUM- BER	NITROGENOUS FERTILIZER	FORM OF SULFUR	WEIGHT OF STRAW	AVER- AGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVER- AGE WEIGHT OF GRAIN	WEIGHT OF ROOTS	AVER- AGE WEIGHT OF ROOTS	TOTAL DRY WEIGHT	AVER- AGE TOTAL DRY WEIGHT
			<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>	<i>grams</i>
1	(NH ₄) ₂ SO ₄		23.94	23.38	16.06	15.69	5.27	6.84	45.27	45.90
2	(NH ₄) ₂ SO ₄		23.17		14.83		7.20		45.20	
3	(NH ₄) ₂ SO ₄		23.02		16.18		8.04		47.24	
4	NaNO ₃		11.65	11.99	8.15	8.95	5.60	4.91	25.40	25.85
5	NaNO ₃		14.05		10.95		4.95		29.95	
6	NaNO ₃		10.26		7.74		4.20		22.20	
7	Ca(NO ₃) ₂		11.18	13.09	6.82	8.91	5.40	6.60	23.40	28.60
8	Ca(NO ₃) ₂		15.00		11.00		7.80		33.80	
9	Lost									
10	Blood		14.46	13.97	11.03	11.28	5.06	5.08	30.55	30.33
11	Blood		13.47		11.53		5.10		30.10	
12		Na ₂ SO ₄	1.24	1.35	1.46	1.40	0.40	0.40	3.10	3.15
13		Na ₂ SO ₄	1.46		1.34		0.40	0.40	3.20	
14		H ₂ SO ₄	0.94	1.52	1.46	1.18	0.22	0.37	2.62	3.07
15		H ₂ SO ₄	2.10		0.90		0.52		3.52	
16		Sulfur	1.54	1.97	1.46	2.53	0.60	1.25	3.60	5.75
17		Sulfur	2.40		3.60		1.90		7.90	
18	NaNO ₃	Na ₂ SO ₄	20.94	20.66	15.06	14.84	8.26	8.73	44.26	44.23
19	NaNO ₃	Na ₂ SO ₄	20.38		14.62		9.20		44.20	
20	NaNO ₃	H ₂ SO ₄	22.00	23.90	16.00	16.40	7.70	6.60	45.70	46.90
21	NaNO ₃	H ₂ SO ₄	25.80		16.79		5.50		48.09	
22	NaNO ₃	Sulfur	18.17	17.32	12.43	12.30	5.00	6.30	35.60	35.92
23	NaNO ₃	Sulfur	16.47		12.17		7.60		36.24	
24	Ca(NO ₃) ₂	Na ₂ SO ₄	23.35	26.61	16.65	15.39	9.50	7.75	49.50	44.75
25	Ca(NO ₃) ₂	Na ₂ SO ₄	29.87		14.13		6.00		40.00	
26	Ca(NO ₃) ₂	H ₂ SO ₄	7.50	9.56	5.60	6.69	2.15	3.38	15.25	19.63
27	Ca(NO ₃) ₂	H ₂ SO ₄	11.62		7.78		4.60		24.00	
28	Ca(NO ₃) ₂	Sulfur	18.80	18.80	14.20	14.20	1.08	10.80	43.80	43.80
29	CaNO ₃	Sulfur	Contaminated by rain							
30	Blood	H ₂ SO ₄	17.55	18.08	13.64	14.22	11.00	9.40	42.19	41.70
31	Blood	H ₂ SO ₄	18.60		14.80		7.80		41.20	
32	Blood	Sulfur	17.62	17.26	13.08	12.09	7.80	9.40	38.50	38.75
33	Blood	Sulfur	16.90		11.10		11.00		39.00	
34	Control		1.54	1.64	1.26	1.26	0.40	0.45	3.20	3.75
35	Control		1.74		1.26		0.50		3.50	

forms in increasing dry-matter production over that of the nitrogen-treated pots alone, but is none the less markedly stimulating in that respect. It seems, moreover, to be slightly more efficient when added to dried blood than when

added to nitrate of soda but the difference is not great. On the other hand, sulfuric acid is more efficient when supplementing nitrate of soda than when supplementing dried blood. As regards total dry-matter production, sulfuric acid acts similarly when added to calcium nitrate as it does with regard to the production of heads and stalks.

Sodium sulfate is equally stimulating when used with nitrate of soda or with nitrate of lime, and sulfuric acid is likewise so for nitrate of soda and for dried blood. Flowers of sulfur show similarity to the other forms of sulfur in maximum stimulation with regard to one case only, viz., when it is added to nitrate of lime. Unfortunately, one of the duplicate jars in this case was lost and the figure obtained is, therefore, not as reliable as it would otherwise have been.

In general, our data seem to show beyond question that, barring certain pronounced side-effects, such as that evidently obtaining in the nitrate of lime-sulfuric acid cultures, equally good results in barley production can be obtained on soils of the type in question with the nitrates and with blood as with sulfate of ammonia, if sulfur is added in proper form and quantity. Just why sulfuric acid, when added to nitrate of lime, should produce an effect so strikingly different from that produced by it when added to nitrate of soda seems at first sight not very clear. A little reflection brings forward the thought, however, that the greater solubility of the sodium sulfate than that of the calcium sulfate, the salts resulting in the two cases, may account for the supply of sufficient available sulfur in one case and not in the other; and hence the difference in effects on the barley plant. This explanation is not entirely satisfying, however, owing to the very marked depression in the growth of the barley plants induced by sulfuric acid when it is added to calcium nitrate. Another factor entering into the problem may be the loss of nitric acid which may be greater in one case than the other when the acid is added to the nitrate.

The fact above noted of the non-effectiveness of all the forms of sulfur when applied to the soil without nitrogen, requires perhaps another word of comment. If, as seems true from our data, sulfur is needed by the barley plant on the soil in question, why should not sulfur exert at least a part of its beneficial effect even when nitrogen is not added with it? The answer may be in the theoretical consideration, which we propose, to the effect that nitrogen, being needed in this case far more than sulfur, the latter is powerless to influence the plant in the building of further protein substances, to the building of which that nitrogen is absolutely essential.

In view of the striking nature of the results above described, the method of improving the Oakley blow sand and similar soils covering large areas in this state is clearly indicated. Nitrogen in some readily available form must be used as fertilizer until such time as it shall be possible to increase the nitrogen and organic matter content of the soil by means like green manuring, and the efficient use of nitrogen-fixing bacteria. The choice of the most profitable form of nitrogen can be determined by reference to the tables

submitted herewith, taken together with the prevailing prices of the materials in question. For the best results with annual crops, to which our remarks particularly apply, sulfur in some form, probably as flowers of sulfur, will have to be employed to supplement the nitrogenous fertilizer unless sulfate of ammonia is used.

No mention is made here of the work of investigators in this country and in Europe which have testified to the value of sulfur as a soil amendment because they have no direct bearing on the subject of this paper.

SUMMARY

1. The superiority of sulfate of ammonia over other readily available nitrogenous fertilizers for barley on the Oakley blow sand as demonstrated in earlier experiments is confirmed in a new series of tests.
2. The cause of such superiority of sulfate of ammonia was sought for and believed to be found in its sulfur content.
3. A statement of the mode of procedure employed in the experiment, and also details of the results obtained and their discussion are submitted above.

REFERENCES

- (1) LIPMAN, C. B., AND GERICKE, W. F. 1916 A vegetation experiment on the availability of nitrogenous fertilizers in an arid soil. *In* Soil Sci, v. 2, no. 6, p. 575-581.
- (2) LIPMAN, C. B., AND GERICKE, W. F. 1917 Experiments on the effects of constituents of solid smelter wastes on barley growth in pot cultures. *In* Univ. Cal. Pub. Agr. Sci., v. 1, no. 13, p. 495-587.