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EFFECT OF MANURE-SULPHUR COMPOSTS UPON THE AVAILABILITY OF THE POTASSIUM OF GREENSAND

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INTRODUCTION

The greensands and the greensand marl deposits of the eastern United States have long been regarded as a possible source of potassium for agricultural purposes. The literature of the last half of the nineteenth century contains many reports of the success that has followed the application of greensand marls to soils in Maryland, New Jersey, and other eastern States. Since many of these marls contain a high percentage of calcium carbonate, it is probable that the good results that followed their use was due in many cases to their lime content rather than to the potassium which they contained.

During the continuance of the war with Germany, the scarcity and the consequent high price of readily soluble potassium salts has served to direct attention in this country to the possibility of utilizing for agricultural purposes the potassium of these greensand deposits and has indicated the desirability of devising some efficient method of treatment that would render the potassium more available. At the suggestion of the fertilizer committee of the National Research Council, the Department of Soil Investigations of this Station has studied the effect of composting greensand with sulphur, manure, and other materials with a view to making available the potassium contained in the greensand. It is the purpose of this paper to report the results of this investigation.

HISTORICAL

As early as 1830 Thomas Gordon called attention to the great benefits that farmers in New Jersey were deriving from the use of marl. In a geological report published in 1868, Cook (6)¹ gives the analyses of a number of samples of marl from New Jersey and states that the use of this material has raised the land from a low state of exhaustion to a high stage of agricultural development. He states that some of these marls are so acid that heavy applications of as much as 50 tons to the acre

¹ Reference is made by number (*italic*) to "Literature cited," p. 255-256.

have been known to destroy all vegetation and advises that the use of such marls should be confined to well-limed land or that they should be composted with lime before being applied. In 1906 Patterson (12) published the results of the examination of 95 samples of Maryland marl. In summing up the results of his experimental work covering a period of 11 years this writer concludes that the shell marls of Maryland have very little commercial value because of the great bulk of worthless material contained in them but that they should have considerable local agricultural value, both as a source of lime and also for the potassium which they contain. He concludes that while much of the potassium in marls will become slowly available to plants through weathering, the change necessary to liberate the potassium could readily be brought about by burning the calcarious marls and slaking the product.

In a popular discussion of the agricultural value of greensand marl Blair (3) concludes that since potassium is of especial value to grass and to potatoes, the striking benefits derived from the use of marl on these crops would lead to the belief that such crops can use the potassium of the marl to a considerable extent.

From pot experiments carried out with crushed quartz and Shive's cultural solution as a basis, True and Geise (13, p. 492) conclude that—greensands and greensand marls from Virginia and New Jersey are able to supply sufficient potassium to satisfy the demands of Turkey Red wheat and red clover during the first two months of their growth.

They secured a greater dry weight of tops from cultures containing greensand marl than from those in which the potassium demand was supplied by potassium chlorid, potassium sulphate, or potassium phosphate. These results are in harmony with those reported by Lipman and Blair (8) who found that soybean plants fertilized with greensand produced as great a yield of hay as those receiving an application of soluble potassium salts, although the former failed to produce seed. These last-mentioned authors hold that their results seem to furnish proof of the ease with which the soybean gets its potash from slowly available sources up to the time the beans are forming and maturing. In the same report these writers describe another experiment in which Canada field peas and soybeans growing in sand cultures were given a general fertilizer treatment to which was added marl containing 6.5 per cent of potash. Two pots in this series received 20 gm. of marl, while two additional pots received in addition to the 20 gm. of marl, 3 gm. of sulphur each, with the thought that the oxidation of the sulphur might result in making more of the potash of the marl available. The Canada field peas were grown as the first crop, followed by the soybeans as a second crop. Both pots receiving the sulphur treatment gave very much decreased yields of field peas, and in one of the duplicates the soybeans that followed the peas failed completely. The other duplicate, however, gave a yield of soybeans slightly in excess of that produced by any of the other treat-

ments, including the pots receiving 2 gm. of potassium chlorid. In their conclusions they suggest—

the possibility of utilizing the potash of greensand marl and the potash of natural soil materials by growing soybeans and possibly certain other crops, which could be returned to the soil and thus furnish available potash for those crops which can not readily utilize potash from these natural sources.

Lipman, McLean, and Lint (10) composted 100-gm. portions of sea sand, sassafras loam, and greenhouse soil with manure, sulphur, and floats. At the end of 30 weeks analyses for water-soluble phosphoric acid showed increases in all the mixtures to which both sulphur and floats had been added. In one case 85 per cent of the total phosphorus in the floats had been made available, the increase in available phosphorus paralleling the oxidation of the sulphur as measured in terms of sulphates. In experiments conducted under field conditions, two of these authors (9) have shown that the sulphur-floats-soil compost may be utilized in making available the phosphorus of floats or raw ground phosphate rock. They suggest that this compost could be employed to advantage as a substitute for acid phosphate. Further studies at the New Jersey Experiment Station by McLean (11) led to the conclusion that the most economical combination for the production of available phosphoric acid is a compost composed of 100 parts soil, 120 parts sulphur, and 400 parts floats.

Brown and Warner (5) found that by composting floats with manure and sulphur it was possible to obtain a remarkable increase in the amount of available phosphoric acid. The increase was greater where the sulphur and floats were intimately mixed with the manure than where the material was arranged in alternate layers.

Experimenting with two Iowa soils, Brown and Gwinn (4) found that while applications of manure alone increased the availability of raw rock phosphate, the increase was much greater when sulphur was used in connection with the manure. They bring out the fact that there is a definite relationship existing between the sulphofying power of the soil and the production of available phosphorus.

Ames and Richmond (2) found that in an acid soil oxidation of sulphur proceeded vigorously, approximately 50 per cent of the sulphur being changed to the form of sulphate. In a basic soil the acidity resulting from sulphofication was partly neutralized, so that the solvent action on the rock phosphate was much less than occurred in the acid medium.

Since the inauguration of our work, Ames and Boltz (1) have published additional data concerning the effect of sulphur on soils and crops. These investigators found that both the nitrification of dried blood and the oxidation of sulphur in soil mixtures resulted in the liberation of potassium. They conclude that the liberation of the potassium was brought about by the salts formed rather than by the direct action of acidity on the insoluble potassium compounds.

PURPOSE AND PLAN OF THE INVESTIGATION

With the foregoing results in mind the present investigation was undertaken for the purpose of determining the effect of different composts upon the availability of the potassium of greensand. The investigation consisted of composting greensand with sulphur, soil, and manure in varying proportions, taking samples from time to time, extracting these samples with distilled water and analyzing the water extracts for the acidity, sulphate, and potassium contained.

Two series of composts were conducted, one series containing a greensand from Sewell, N. J., having a relatively high percentage of potassium, and the other a greensand from Crownsville, Md., having a rather low percentage of potassium. Each compost contained as a basis 1,500 gm. of greensand. The materials added were the same for each series and were as follows:

COMPOST NO.	MATERIALS ADDED TO GREENSAND.
1 and 8.....	Nothing.
2 and 9.....	500 gm. sulphur.
3 and 10.....	500 gm. sulphur; 500 gm. manure.
4 and 11.....	500 gm. sulphur; 250 gm. manure; 250 gm. soil.
5 and 12.....	500 gm. sulphur; 500 gm. soil.
6 and 13.....	500 gm. sulphur; 500 gm. soil; 0.02 per cent aluminum sulphate ($Al_2(SO_4)_3$) 0.18 H_2O ; 0.02 per cent ferrous sulphate ($FeSO_4$) 0.7 H_2O .
7 and 14.....	500 gm. sulphur; 250 gm. soil; 250 gm. manure; 10 gm. calcium carbonate ($CaCO_3$).

Commercial flowers of sulphur, partially rotted yard manure air-dried and ground fine, Collington sandy loam, and precipitated calcium carbonate were used. The aluminum and ferrous sulphates were added to composts 5 and 12 in order to determine whether these salts would exert a stimulating effect upon the rate and amount of sulphofication. McLean (11) found that, under certain conditions, these salts in combination exerted a marked stimulating action on sulphur oxidation processes when present in small amounts. He advocated the use of 0.4 pound per ton, or 0.02 per cent, of each for sulphur-floats composts. It was thought desirable to ascertain whether this effect would be obtained with sulphur-greensand composts.

METHODS OF PROCEDURE

The air-dry materials for each compost were weighed and thoroughly mixed. Similar smaller amounts of the same materials were mixed in the same proportions, from which the moisture-holding capacity of each compost was determined according to the Hilgard method (7, p. 209).

After being mixed, each compost was placed in a glazed pot, and water was added to one-half the determined water-holding capacity. The samples for the first analyses, showing the amounts of water-soluble

acidity, sulphate, and potassium at the start, were then taken, after which each compost was inoculated with the sulphofying organisms, and the aluminum and ferrous sulphates were added in solution to composts 6 and 13.¹

The period of composting was 23 weeks. Once each week the amount of water lost by evaporation was added, and the composts were removed from the pots and mixed, in order to provide thorough aeration.

The composts were kept in the greenhouse throughout the entire period and were covered at all times with a double thickness of white muslin to protect them from direct sunlight. The temperature of the greenhouse ranged from 50° to 100° F.

For the water extraction a 75-gm. sample was weighed from each compost, air dried, and 50 gm. of the air-dry material were shaken every half hour for 8 hours with 500 cc. of distilled water in a 1-liter Pyrex flask. After standing over night, the contents of the flasks were again shaken and filtered rapidly through folded No. 3 Whatman filter papers. The first 100 cc. of filtrate were poured back. The filtrates obtained were absolutely clear and free from sediment.

The acidity was determined by boiling aliquots of the water extract to expel carbon dioxide, cooling, and titrating with *N/10* sodium hydroxid, in terms of which the results are stated. Phenolphthalein was the indicator used. Titration was continued until all soluble iron, aluminum, and silica were precipitated and the clear solution retained the pink color for one minute.

Sulphur was determined by acidifying aliquots of the water extract with 2 cc. of concentrated hydrochloric acid and precipitating at the boiling point with barium chlorid. The results are expressed as sulphur trioxid (SO₃).

The potassium determinations were made gravimetrically by the platinic chlorid method from aliquots of the water extract, first eliminating the soluble organic matter, silicates, iron, aluminum, and phosphorus by evaporation with sulphuric acid, ignition, and subsequent precipitation. The determination for composts 1 and 8 throughout and the first three determinations for the other composts not containing manure were made colorimetrically because of the small amounts of potassium present.

Moisture determinations were made by heating separate 5-gm. portions of the air-dry compost for 15 hours at 105° C. All results reported in this paper are calculated to the moisture-free basis. No duplicate determinations were made, the idea being that one series of compost treatments would act as a control for the other in regard to the general trend of the reaction and that any serious error in analysis would

¹ Cultures containing sulphofying organisms were supplied by Dr. J. G. Lipman and Prof. A. W. Blair, of the New Jersey Experiment Station.

readily be shown and offset by the frequency with which the analyses were made.

The greensands, soil, and manure used were analyzed at the beginning of the investigation. The results are given in Table I. The potassium determinations were made by the official fusion method.

TABLE I.—Composition of materials used (dry basis)

Materials.	Moisture at 105° C.	Insoluble residue.	Ferric oxid (Fe ₂ O ₃), aluminum oxid (Al ₂ O ₃), phosphorus pentoxid (P ₂ O ₅).	Calcium oxid (CaO).	Magnesium oxid (MgO).	Potassium (K).
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
New Jersey greensand.....	5.46	53.12	31.66	0.16	1.05	5.88
Maryland greensand.....	1.57	87.83	8.38	.13	.25	1.42
Collington sandy loam.....	1.20	89.54	7.54	.18	.22	.83
Manure ^a	6.30	.....	.....	.....	.....	.49

^a Loss on ignition, 69.67 per cent.

Determinations made by the Veitch method showed that the New Jersey greensand required 4,200 pounds of calcium carbonate per 2,000,000 pounds, the Maryland greensand 3,400 pounds, and the Collington sandy loam 1,400 pounds.

The texture of the greensands and soil is shown in Table II, which gives the mechanical analyses of the materials used in the composts.

TABLE II.—Mechanical analyses of greensands and soil

Constants.	New Jersey greensand.	Maryland greensand.	Collington sandy loam.
	Per cent.	Per cent.	Per cent.
Fine gravel.....	4.94	1.49	0.53
Coarse sand.....	30.26	1.77	10.14
Fine sand.....	45.22	9.15	26.27
Very fine sand.....	15.14	83.65	43.93
Silt and clay.....	4.11	3.86	18.72

PRESENTATION AND DISCUSSION OF RESULTS

ACIDITY

In Table III is shown the acidity of the water extract from each compost as determined at the end of each 1-week period for the first 9 weeks and thereafter at the end of each 3 weeks for a total period of 23 weeks. The results are expressed in terms of *N/10* sodium hydroxid required to neutralize the acidity in the water extract from 10-gm. of compost on the dry basis.

Attention is called to the fact that, although both greensands showed a high lime requirement when tested by the Veitch method, neither of them gave evidence of more than a trace of acidity in the water extract. The addition of sulphur to the greensand in the proportion of 3 parts greensand to 1 part sulphur caused a gradual accumulation of water-soluble acidity, because of the slow oxidation of the sulphur. Composts 3 and 10, in which both sulphur and manure were mixed with the greensand, show a slight and gradual accumulation of water-soluble acidity up to the end of the fifth week, after which there is a very rapid rise for three weeks. For the remainder of the period the acidity fluctuates at a high and practically constant level. When one-half of the manure is replaced by an equal quantity of soil, as in composts 4 and 11, the acidity is greatly reduced, the maximum for the Maryland greensand being reached at the end of the 12-week period and for the New Jersey greensand after 15 weeks. When the manure was entirely replaced by soil, the acidity increased gradually throughout the entire period, as shown by composts 5 and 12; but the amount developed was only about one-third as much as when equal weights of soil and manure were used. This indicates rather strongly that in composts made up with a greensand deficient in calcium carbonate the rate of development and the amount of acidity depend very largely on the amount of organic matter present. A further comparison of composts 5 and 12 with 2 and 9 seems to substantiate this conclusion, in that the soil used contained a small amount of organic matter.

The acidity titrated did not, of course, at any time consist entirely of free sulphuric acid. As sulphofication progressed and the amounts of free sulphuric acid and sulphates increased, an increasing amount of acid silicates was obtained in the water extract and was precipitated upon titration with the alkali. Careful inspection of several titrations, made after the maximum acidity had been attained, seemed to indicate that from 45 to 55 per cent of the acidity titrated was due to free sulphuric acid, the remainder of the acidity being due to acid silicates and other acid salts.

Under the conditions of our experiment the addition of ferrous sulphate and aluminum sulphate when used at the rate recommended by McLean (11) for sulphur-floats composts has had no appreciable effect, as may be seen by a comparison of composts 6 and 13 with 5 and 12. The addition of 10 gm. of calcium carbonate to the sulphur-manure-soil compost had a marked stimulating effect, beginning about the third week in the New Jersey greensand compost and two weeks later in the Maryland greensand compost. In the former the stimulating action persisted up to the end of the experiment, while in the latter the effect of the calcium carbonate had entirely disappeared at the end of 12 weeks. A cause for this difference is found when the lime requirement of the New Jersey greensand is

compared with that of the Maryland greensand. As was previously mentioned, the lime requirement of the New Jersey material is 4,200 pounds of calcium carbonate, while for the Maryland greensand the requirement is only 3,400 pounds. The results recorded in Table III would appear to justify the conclusion that an initial acidity corresponding to a lime requirement of 3,400 pounds of calcium carbonate exerts a slightly depressing effect upon sulphofication, and that an acidity corresponding to a lime requirement of 4,200 pounds of calcium carbonate is less favorable. Ames and Boltz (*x*) found that calcium carbonate when added in excess of the lime requirements exercised a depressing effect upon the oxidation of sulphur in their soil-sulphur compost. When they reduced the application to half, the oxidation of sulphur increased but was less than when no carbonates were added.

SOLUBLE SULPHATES

A comparison of the results recorded in Table IV with those given in Table III shows that the accumulation of water-soluble sulphates parallels very closely the development of acidity.

It will be observed that the sulphur trioxid determinations fluctuate somewhat after having attained a maximum at the end of about 12 weeks. These fluctuations are probably due to variations in the moisture content and the temperature of the composts, since such variations are known to have an effect upon colloidal silicates, which in turn might exercise, through adsorption, an appreciable effect upon the soluble sulphur trioxid obtained in the water extraction. A calculation shows that at the end of our 23-week period, approximately 15 per cent of the total sulphur used in composts 3 and 10 had been oxidized, while for the composts in which one-half of the manure had been replaced by soil about 11 per cent of the total sulphur had been oxidized. These figures show that the amount of sulphur used was in excess of the amount necessary to secure the most economical results.

SOLUBLE POTASSIUM

The amount of water-soluble potassium in each compost at stated intervals is given in Table V.

A comparison of these figures with those given in Tables III and IV brings out the fact that with the increase in acidity and the accumulation of sulphur trioxid there is a corresponding increase in the amount of potassium in the water extract. The potassium, however, continues to increase for some weeks after the acidity and sulphur trioxid have reached a maximum. It seems necessary for a certain degree of acidity to be developed before any appreciable amount of potassium is made water soluble, the larger amounts of acidity and soluble sulphate breaking down the greensand more rapidly.

TABLE IV.—Accumulation of water-soluble sulphate

Basis.	Com- post No.	Materials added to 1,500 gm. greensand.	Milligrams water-soluble sulphur trioxid (SO ₃) in 10 gm. of compost (dry basis) after—																						
			0 weeks.	1 week.	2 weeks.	3 weeks.	4 weeks.	5 weeks.	6 weeks.	7 weeks.	8 weeks.	9 weeks.	12 weeks.	15 weeks.	17 weeks.	20 weeks.	23 weeks.								
New Jersey greensand.	1	None.....	0.68	0.93	1.36	1.79	1.88	1.69	1.87	1.94	1.51	1.73	1.91	1.61	1.73	1.76									
	2	Sulphur 500 gm.....	1.07	1.57	8.45	11.94	13.59	14.62	15.82	17.63	18.91	22.99	25.33	26.93	27.47	31.92									
	3	Sulphur 500 gm.; manure 500 gm.....	4.68	22.70	68.59	93.85	133.60	206.60	298.98	606.99	714.69	968.59	638.38	740.72	811.80	812.09									
	4	Sulphur 500 gm.; manure 250 gm.; soil 250 gm.	2.57	7.72	17.75	64.44	100.41	156.44	187.27	213.53	224.87	382.81	408.39	473.47	475.67	485.74									
	5	Sulphur 500 gm.; soil 500 gm.....	1.07	1.49	2.98	14.38	18.01	21.32	24.88	28.04	32.10	42.28	61.76	89.13	116.35	161.87									
	6	Sulphur 500 gm.; soil 500 gm.; 0.02 per cent Al ₂ (SO ₄) ₃ 0.18 H ₂ O; 0.02 per cent FeSO ₄ 0.7 H ₂ O.	1.07	2.41	2.56	13.06	19.00	24.46	30.32	34.90	40.02	42.70	56.24	81.63	114.93	130.62	152.77								
	7	Sulphur 500 gm.; soil 250 gm.; ma- nure 250 gm.; CaCO ₃ 10 gm.	3.50	23.25	47.61	59.66	213.11	320.30	313.29	399.21	317.44	330.69	492.98	543.58	549.24	546.50	535.55								
Maryland greensand....	8	None.....	.42	.91	1.69	1.47	1.65	1.79	1.82	2.43	2.00	2.56	2.46	2.14	2.31	2.14									
	9	Sulphur 500 gm.....	.98	1.57	2.28	7.88	13.40	15.01	16.55	17.43	21.41	25.64	27.57	26.31	30.66	30.66									
	10	Sulphur 500 gm.; manure 500 gm.....	4.84	26.16	34.30	46.64	84.90	136.33	211.75	266.28	609.83	723.14	632.02	673.54	668.98	672.47									
	11	Sulphur 500 gm.; manure 250 gm.; soil 250 gm.	2.53	14.39	21.90	42.52	66.87	107.93	158.88	186.82	212.05	329.96	522.00	544.68	558.13	542.11	568.02								
	12	Sulphur 500 gm.; soil 500 gm.....	.87	1.81	4.91	11.35	16.54	19.63	23.95	27.71	31.89	35.34	47.69	71.78	107.82	143.76	178.12								
	13	Sulphur 500 gm.; soil 500 gm.; 0.02 per cent Al ₂ (SO ₄) ₃ 0.18 H ₂ O; 0.02 per cent FeSO ₄ 0.7 H ₂ O.	.80	2.09	3.10	8.47	14.62	17.52	22.45	25.14	29.24	32.30	44.18	72.85	109.26	125.09	158.08								
	14	Sulphur 500 gm.; soil 250 gm.; ma- nure 250 gm.; CaCO ₃ 10 gm.	4.21	26.92	51.58	55.80	85.87	107.19	153.91	291.09	478.97	506.35	816.51	544.41	551.75	558.37	577.65								

TABLE V.—Accumulation of water-soluble potassium

Basis.	Com- post No.	Material added to 1,500 gm. green- sand.	Milligrams water-soluble potassium in 10 gm. of compost (dry basis) after—														
			0 weeks.	1 week.	2 weeks.	3 weeks.	4 weeks.	5 weeks.	6 weeks.	7 weeks.	8 weeks.	9 weeks.	12 weeks. ^a	15 weeks.	17 weeks.	20 weeks.	23 weeks.
New Jersey greensand.	1	None.....	0.19	0.30	0.22	0.24	0.18	0.41	0.45	0.16	0.41	0.31	.....	0.42	0.41	0.49	0.45
	2	Sulphur 500 gm.....	.24	.29	.45	.87	.98	1.15	1.12	1.12	1.48	1.20	.....	1.26	1.30	1.17	1.43
	3	Sulphur 500 gm.; manure 500 gm.....	2.99	5.75	7.43	9.87	8.56	11.57	11.68	11.88	14.27	17.64	.....	48.04	48.46	62.56	64.11
	4	Sulphur 500 gm.; manure 250 gm.; soil 250 gm.....	1.47	2.70	3.50	5.55	4.68	5.85	5.99	6.10	8.93	8.18	.....	25.91	31.25	30.10	32.77
	5	Sulphur 500 gm.; soil 500 gm.....	.32	.48	.48	.72	1.10	.87	.91	.96	1.07	1.02	.....	1.30	2.08	3.18	3.36
	6	Sulphur 500 gm.; soil 500 gm.; 0.02 per cent $Al_2(SO_4)_3$ 0.18 H_2O.....	.34	.44	.44	.75	1.05	.87	.97	1.17	1.16	1.27	.....	1.34	2.25	3.10	3.36
	7	Sulphur 500 gm.; soil 250 gm.; ma- nure 250 gm.; $CaCO_3$ 10 gm.....	1.78	3.08	5.41	5.85	5.13	10.03	9.42	9.53	11.08	10.36	.....	29.89	31.94	39.39	33.74
Maryland greensand....	8	None.....	.16	.21	.29	.27	.41	.48	.46	.52	.50	.....	.41	.46	.48	.48	
	9	Sulphur 500 gm.....	.26	.24	.50	.32	.08	.72	.96	.99	.92	.96	.....	.84	1.28	1.02	1.08
	10	Sulphur 500 gm.; manure 500 gm.....	3.09	7.18	8.57	8.35	7.96	10.70	10.95	11.39	15.31	16.53	.....	33.62	30.65	39.23	37.11
	11	Sulphur 500 gm.; manure 250 gm.; soil 250 gm.....	2.54	3.48	4.15	5.35	4.37	5.80	6.04	6.21	9.25	8.36	.....	23.74	28.02	26.75	28.16
	12	Sulphur 500 gm.; soil 500 gm.....	.30	.30	.64	.65	1.03	.85	1.02	1.03	.88	1.10	.....	.96	1.58	1.17	1.21
	13	Sulphur 500 gm.; soil 500 gm.; 0.02 per cent $Al_2(SO_4)_3$ 0.18 H_2O.....	.28	.30	.50	.76	.84	.76	.84	.91	1.06	.99	.....	.93	1.26	.95	.82
	14	Sulphur 500 gm.; soil 250 gm.; ma- nure 250 gm.; $CaCO_3$ 10 gm.....	2.30	4.22	6.27	5.86	4.77	6.90	5.71	6.35	11.97	10.22	.....	23.46	25.26	25.33	26.53

^a No analyses made.

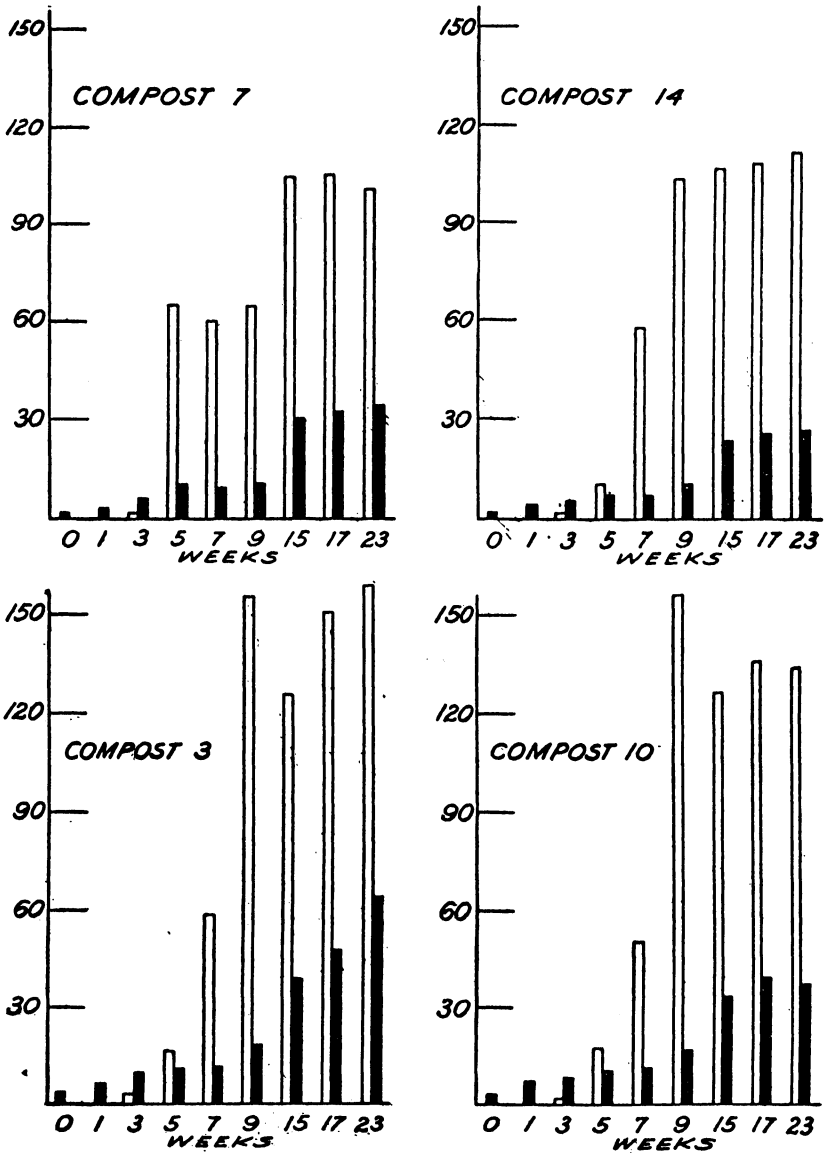


FIG. 1.—Diagrams showing relation of the water-soluble acidity to the water-soluble potassium at different time periods for different greensand composts. The open columns indicate the number of cubic centimeters of $N/10$ sodium hydroxid required to neutralize 10 gm. of compost on moisture-free basis, and the solid columns indicate the number of milligrams of water-soluble potassium obtained from 10 gm. of compost on moisture-free basis.

The diagrams of figure 1 give a graphic representation of the relation of the water-soluble acidity to the water-soluble potassium at different time periods for the greensand-sulphur-manure composts and for the greensand-sulphur-soil-manure composts to which were added 10 gm. of calcium carbonate.

A comparison of compost 3 with compost 7 and compost 10 with compost 14 brings out the fact that the replacement of one-half of the manure by soil has reduced the acidity and at the same time decreased the amount of potassium in the water extract. No. 7 and 14 show also the stimulation in acidity during the early weeks due to the addition of calcium carbonate.

The degree of acidity and the amount of sulphates and of potassium in the water extracts at the beginning of the period and at the end of 23 weeks for all the composts are shown in Table VI, which is a summary of Tables III, IV, and V.

TABLE VI.—Water-soluble acidity, sulphate, and potassium in water extract from 10 gm. of moisture-free compost at beginning and after 23 weeks of composting

Basis.	Compost No.	Acidity (cc. N/10 sodium hydroxid required).		Sulfate (sulphur trioxid).		Potassium.		
		After 0 weeks.	After 23 weeks.	After 0 weeks.	After 23 weeks.	After 0 weeks.	After 23 weeks.	
New Jersey greensand	1	0.05	0.075	Mgm.	Mgm.	Mgm.	Mgm.	
	2	.05	4.50	0.68	1.76	0.19	0.45	
	3	.05	159.20	1.07	31.92	.24	1.43	
	4	.05	96.60	4.68	812.09	2.99	64.11	
	5	.05	35.45	2.57	485.74	1.47	32.77	
	6	.05	33.35	1.07	161.87	.32	3.36	
	7	Alkaline	101.35	3.50	535.55	1.78	33.74	
	8	.05	.05	.42	2.14	.16	.48	
	9	.05	5.15	.98	30.66	.26	1.08	
	Maryland greensand	10	.05	134.15	4.84	672.47	3.09	37.11
		11	.05	116.85	2.53	568.02	2.54	28.16
		12	.05	41.00	.87	178.12	.30	1.21
		13	.05	36.20	.80	158.08	.28	.82
		14	Alkaline	112.15	4.21	577.65	2.30	26.53

Attention is called to the fact that the potassium liberated from the New Jersey greensand is much greater than that recovered from the Maryland greensand. This is to be expected, since the former had an initial potassium content of 5.88 per cent, while the latter contained only 1.42 per cent of potassium, as shown in Table I. It will be seen that the largest amount of potassium was extracted from compost 3, containing the New Jersey greensand, and the second largest amount from compost 10, which is the corresponding mixture made with Maryland greensand. The fact that both of these composts have twice the amount of manure contained in No. 4, 7, 11, and 14 would indicate that

comparatively large amounts of organic matter favor sulphofication and the liberation of potassium under the conditions of this experiment. These results are not in accord with those reported by McLean (11), who, working with sulphur-floats-soil composts, came to the conclusion that a compost is more efficient in the producing of available phosphorus in the absence of large amounts of organic material.

In Table VII the total potassium present in each compost, the water-soluble potassium at the start, and the maximum water-soluble potassium present at any one time during the period of 23 weeks are computed on the basis of the initial weights of the composts.

TABLE VII.—Total potassium made water-soluble (dry basis)

Compost No.	Material added to 1,500 gm. greensand.	Total number grams potassium in compost.	Water-soluble potassium at start (percentage of total).	Maximum water-soluble potassium present.	
				Gm.	Percentage of total.
1	None.....	83.38	0.037	0.070	0.084
2	Sulphur 500 gm.....	83.38	.055	.275	.330
3	Sulphur 500 gm.; manure 500 gm.....	85.68	.832	15.28	17.83
4	Sulphur 500 gm.; manure 250 gm.; soil 250 gm.....	86.58	.408	7.87	9.10
5	Sulphur 500 gm.; soil 500 gm.....	87.48	.088	.812	.928
6	Sulphur 500 gm.; soil 500 gm.; 0.02 per cent $Al_2(SO_4)_3$ 0.18 H_2O ; 0.02 per cent $FeSO_4$ 0.7 H_2O	87.48	.094	.812	.928
7	Sulphur 500 gm.; soil 250 gm.; manure 250 gm.; $CaCO_3$ 10 gm.....	86.58	.494	9.46	10.93
8	None.....	20.97	.112	.070	.333
9	Sulphur 500 gm.....	20.97	.243	.251	1.20
10	Sulphur 500 gm.; manure 500 gm.....	23.27	3.22	9.62	41.34
11	Sulphur 500 gm.; manure 250 gm.; soil 250 gm.....	24.17	2.57	6.88	28.50
12	Sulphur 500 gm.; soil 500 gm.....	25.07	.295	.389	1.55
13	Sulphur 500 gm.; soil 500 gm.; 0.02 per cent $Al_2(SO_4)_3$ 0.18 H_2O ; 0.02 per cent $FeSO_4$ 0.7 H_2O	25.07	.275	.310	1.24
14	Sulphur 500 gm.; soil 250 gm.; manure 250 gm.; $CaCO_3$ 10 gm.....	24.17	2.33	6.49	26.85

Reference to the last two columns of Table VII will show that, while the actual amount of soluble potassium which formed in the composts containing the Maryland greensand was much smaller than that which formed in the composts containing the New Jersey greensand, the percentage of the total potassium made water-soluble in the former was much greater than in the latter. One of the causes for this difference is to be found in Table II, which shows the mechanical analyses of the two greensands. The individual particles are much smaller in the Maryland than in the New Jersey greensand, thus exposing a much greater surface to the solvent action of the acids. Also, the glauconite particles of the

former were softer than those of the latter and seemed to be more soluble, as is shown by composts 1 and 8 in Table V. These figures show that although the New Jersey greensand contains more than four times as much potassium as the Maryland greensand, the amount of water-soluble potassium is the same.

In considering Table VII it is pertinent to ask to what extent the manure has contributed to the total amount of potassium recovered in the water extract. To answer this question Table VIII has been prepared upon the assumption that all the potassium in the manure was made soluble and was recovered in the water extract.

TABLE VIII.—*Relation of potassium content of the manure to the water-soluble potassium obtained*

Compost No.	Total soluble potassium obtained from compost.	Total potassium in manure.	Maximum amount of potassium from manure. ^a
	<i>Gm.</i>	<i>Gm.</i>	<i>Per cent.</i>
3	15.28	2.30	15.05
4	7.87	1.15	14.62
7	9.46	1.15	12.16
10	9.62	2.30	23.91
11	6.88	1.15	16.72
14	6.49	1.15	17.72

^a The percentages in this column are based on the assumption that all the potassium in the manure was made water-soluble.

From the last column of Table VIII it will be seen that even on this basis it is possible in only one case to account for more than 17 per cent of the potassium as coming from the manure. It is evident, therefore, that from 80 to 90 per cent of the potassium found in the water extract must have come from the greensand or from the soil and greensand.

Referring again to the manure composts in Table VII, it will be seen that the total amount of potassium recovered by water extracts from these composts varies from 9.1 per cent to as much as 41.3 per cent of the total initial amount present.

It is important to consider the relation between the oxidation of sulphur and the liberation of potassium. This relation is a converging ratio, which was rather wide during the period of greatest oxidation of sulphur and diminished rapidly as the potassium was released. While it was not expected that this ratio would be resolved to a constant figure for all of the composts, because of the different materials used, in each series the composts containing manure do show a rather uniform relation between these processes. On the basis of the initial weights of the composts, Table IX shows the maximum number of grams of sulphur oxidized and of water-soluble potassium obtained, and their ratio, as determined from the water extracts.

TABLE IX.—Relation between number of grams of sulphur oxidized and number of grams of potassium made water-soluble

Compost No.	Sulphur oxidized.	Potassium made water-soluble.	Ratio of grams sulphur oxidized to grams water-soluble potassium.
	<i>Gm.</i>	<i>Gm</i>	
3	77.43	15.28	5.07:1
4	46.05	7.87	5.92:1
7	52.79	9.46	5.58:1
10	70.15	9.62	7.29:1
11	55.51	6.88	8.07:1
14	56.52	6.49	8.70:1

In the New Jersey greensand composts, approximately $5\frac{1}{2}$ gm. of sulphur were oxidized for each gram of potassium made water soluble. For the Maryland greensand composts, the ratio is approximately 8 to 1. The ratio varies with the materials used, the high-potassium greensand having a lower ratio than the low-potassium greensand, and the composts containing 20 per cent manure having a lower ratio than those containing 10 per cent manure. For the composts in which soil was substituted for all the manure the figures are not shown, but the ratio is much wider, the amount of sulphur oxidized not being sufficient to make water soluble any large amount of potassium.

The results of this investigation would indicate that the composting of greensand, or of soil rich in potassium, with sulphur and manure may prove to be a practical and efficient method for obtaining available potassium from comparatively insoluble materials.

SUMMARY

Two greensands, one containing 5.88 per cent of potassium and the other 1.42 per cent, were used in studying the effect of sulphofication upon the solubility of the potassium. The outstanding results of the investigation are summarized in the following paragraphs.

(1) In composts consisting of greensand, manure, and soil in different proportions, an appreciable amount of the potassium of the greensand was made water-soluble through sulphofication.

(2) The composts containing the largest proportion of manure developed the highest degree of acidity, oxidized the greatest amount of sulphur, and produced the largest quantity of water-soluble potassium.

(3) The composts in which soil was substituted for a part of the manure developed less acidity, oxidized less sulphur, and produced a smaller amount of soluble potassium.

(4) When all the manure was replaced by soil, the rate of sulphofication was so slow that at the end of 23 weeks only a very small amount of acidity had developed and very little potassium had been made soluble.

(5) When no organic matter was added, the amounts of acidity and soluble sulphates were no greater than might be accounted for by the natural oxidation of the sulphur.

(6) The addition of small amounts of ferrous and aluminum sulphates failed to stimulate sulphofication.

(7) Calcium carbonate added to the sulphur-manure-soil compost produced a stimulating effect during the early part of the period but failed to increase the acidity, soluble sulphates, or potassium above the maximum reached by the corresponding compost in which no calcium carbonate was used.

(8) More water-soluble potassium was formed in the composts containing the high-potassium greensand, but a larger percentage of the total potassium present was liberated in the composts containing the low-potassium greensand.

(9) In the composts containing manure, the total amounts of potassium recovered in the water extracts varied from 9.1 per cent to a maximum of 41.3 per cent of the total initial amount present.

(10) Our results indicate that the composting of greensand, or of soil rich in potassium, with sulphur and manure may prove to be a practical and efficient method for obtaining available potassium from comparatively insoluble materials.

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