LYSIMETER EXPERIMENTS WITH SULPHATE OF AMMONIA AND NITRATE OF SODA[1]

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INTRODUCTION

An advantage sometimes attributed to sulphate of ammonia as a nitrogenous fertilizer when compared with nitrate of soda is that it does not occasion so large a loss of nitrogen in drainage water as does the nitrate. It was decided to submit this to trial in the lysimeter tanks at this experiment station. As the drainage from these tanks consists of the percolation of natural rainfall, a test covering a period of 10 or more years should demonstrate what could be expected from a given soil under a rainfall of 30 to 35 inches.

PREVIOUS INVESTIGATIONS

There have been a number of investigations of this subject, but few of them have extended over any considerable period of years. Some of the experiments have been conducted with soils on which plants were grown; others have been carried on with moist and bare soils which were allowed to stand for longer or shorter periods in a percolation apparatus of some kind and then leached. The literature bearing on this subject was reviewed by Bizzell [2] in 1926. Since then some further work has been reported. In general the results indicate that more nitrogen is found in the drainage water from soil treated with nitrate of soda than from similar soil which received an equivalent quantity of nitrogen in the form of sulphate of ammonia. At least such findings are reported by Collison and Walker (*4*), Hall (*7, p. 235–236*), Morgan, Street, and Jacobson (*9*), Collison (*3, p. 815*), Geilmann (*6*), Eckart (*5*), and Tidmore and Williamson (*12, p. 38–41*). The opposite result was obtained by Peck (*10*) and by Geilmann (*5*) when working with clay soils. Geilmann attributes this result to the deflocculating action of the large quantity of nitrate of soda used in the experiment which prevented the soil so treated from draining properly, and in consequence the volume of drainage was small as compared with that of the soil treated with sulphate of ammonia.

Experiments dealing with the effect of these two fertilizers on the removal of calcium in the drainage water have been reported by Hall and Miller (*8*), Morse (*10*), Morgan, Street, and Jacobson (*9*), Eckart (*5*), and Peck (*11*). All of these investigators found more calcium in the drainage water from the soil to which sulphate of ammonia was applied than from soil treated with nitrate of soda, when both were used in amounts containing equivalent quantities of nitrogen.

[1] Received for publication Jan. 26, 1933; issued August 1933.
[2] Reference is made by number (italic) to Literature Cited, p. 63.

EXPERIMENTAL PROCEDURE

Six tanks, each having a capacity of 3½ tons of soil, a depth of 4 feet, and an area somewhat more than 4 by 4 feet, were used for the experiment. The tanks were filled with Dunkirk sandy gravelly loam, the surface soil and subsoil being placed in the order of their occurrence in the field. As its name connotes this soil is a sandy one, only weakly buffered, well aerated, and readily permeable to water. It is a type of soil that is frequently used for market gardening as it responds readily to commercial fertilizers. The tanks were filled with soil in 1921, and the following year the cropping system was begun.

At the beginning of the experiment three nitrogen carriers were used. These included dried blood in addition to sulphate of ammonia and nitrate of soda. After 1925 the use of dried blood was discontinued. Of the two tanks to which it had been applied (nos. 1 and 22), one afterwards received sulphate of ammonia and the other nitrate of soda. It was thought that by giving each a different treatment they could be continued in the experiment without favoring one or the other of the two nitrogen carriers remaining in the test. Moreover, by retaining these tanks in the experiment each treatment could be made in triplicate.

In order to insure a removal of nitrogen in measurable quantities, the applications of nitrogenous fertilizers were large, and to avoid injury to the growing plants the applications were made twice during the season. For this reason it was desirable to have two crops each year, and this could best be accomplished by using market-garden crops. One application was accordingly made in the spring and the other before the second crop was planted in July.

At the outset of the experiment the fertilizers applied each year contained 82.35 pounds of nitrogen per acre. Later the nitrogen was increased to 164.7 pounds per acre each year. This increase in nitrogen was found to be necessary in order to insure an excess over the quantities used by the crops. Somewhat later the quantity of muriate of potash was also increased to insure an excess of potassium, and the quantity of superphosphate was slightly reduced. Whereas the muriate of potash was applied at the rate of 100 pounds per acre at the beginning it was increased to 200 pounds, and the superphosphate, which was used at the rate of 500 pounds, was later decreased to 400 pounds for each crop.

The soil in the tanks was an acid one, and it was considered best to lime it to make it more favorable for nitrification. Accordingly, ground limestone was applied to all tanks at the rate of 4,000 pounds to the acre before the first crop was planted in 1922. The limestone contained 95 percent calcium carbonate and 2 percent magnesium carbonate and was so ground that 94 percent would pass through a $\frac{1}{50}$-inch opening. In the spring of 1926 all the tanks were again limed, this time at the rate of 2,000 pounds to the acre. From that time on only the tanks which received sulphate of ammonia were limed. It was not until 1927 that the tanks treated with ammonium sulphate began to increase in acidity. It then became difficult to prevent the soil in these tanks from becoming strongly acid. In the spring of 1928 another application 2,000 pounds per acre of ground limestone was given to tanks 1, 21, and 24, and in the fall 4,000 pounds

per acre was applied. Again in 1930 an application of 4,000 pounds per acre of ground limestone was made. The total quantity of ground limestone used on the soil that received nitrate of soda was therefore at the rate of 3 tons per acre and on the ammonium sulphate-treated soil 8 tons.

DETERMINATION OF THE SOIL REACTION

Determinations of the hydrogen-ion concentration were made from time to time, this being done more frequently for the sulphate of ammonia soil. The results are shown in table 1.

TABLE 1.—*Hydrogen-ion concentration in soil on different dates, in tanks receiving sulphate of ammonia or nitrate of soda* [1]

Tank no.	Nitrogen carrier	Apr. 21, 1926	Apr. 1, 1927	Nov. 23, 1927	July 12, 1928	Oct. 31, 1928	Apr. 16, 1930	Nov. 25, 1930	May 2, 1931	Nov. 2, 1931
		pH	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*	*pH*
1	Sulphate of ammonia	6.4	7.4	6.6	6.5	6.1	7.3	7.2	7.0	7.0
21	do	6.3	6.6	6.0	6.1	5.8	7.2	7.2	6.9	6.9
24	do	6.3	7.3	5.7	6.2	5.8	6.6	6.9	6.8	6.8
2	Nitrate of soda	6.5	7.9	7.8			8.1		7.7	7.5
22	do	6.4	7.8	7.7			7.8		7.6	7.6
23	do	6.5	7.8	7.7			7.9		7.7	7.6

[1] In the spring of 1928 ground limestone was applied to tanks 1, 21, and 24 at the rate of 2,000 pounds per acre, and the following fall an application was made at the rate of 4,000 pounds per acre. In 1930 another application was made at the rate of 4,000 pounds per acre.

The determinations of April 21, 1926, were made by the colorimetric method, all the others were made with a potentiometer. Samples were taken from the surface 6 inches of soil. From table 1 it will be seen that there was a strong tendency for the soil that received sulphate of ammonia to become acid. Most of the time the hydrogen-ion concentration in this soil was maintained at a pH of 6.0 or above, but it was only by applying enormous quantities of ground limestone that it could be kept near neutrality. As will be shown later, the quantity of nitrogen applied was not greatly in excess of that removed by the crops and drainage. It was, therefore, not much more than good management would require.

THE CROPPING SYSTEM

Four kinds of plants were used for cropping the soil. Two of these were grown one year and the other two the next year. Thus in 1922 spinach was planted in the spring and carrots in the summer. After the carrots were harvested rye was planted and remained on the land until turned under the following spring in preparation for the next planting. In 1923 lettuce was planted in the spring and this was followed by garden beets. Rye followed the beets and was turned under in the spring. This system was continued until May 1, 1931, at which time the drainage water was collected for the last period recorded in this report.

The crops grew normally. In time of drought enough rain water from the cistern was applied to prevent loss of plants and to maintain growth. All tanks received the same amount of rain water. When seed for the second crop was planted, the ground was usually shaded with muslin to diminish evaporation and protect the young plants. In this way a good stand was obtained.

The drainage water for any year consisted of the quantity collected between May 1 of one year and May 1 of the next. This has been done in all the lysimeter experiments at this station because the drainage water collected during the early spring is greatly affected by the soil treatment of the previous summer. There is little percolation in this climate during the fall and winter months but much when the ground thaws in March and April.

Two constituents only were determined in the drainage water. These were nitrates and calcium. For the former the phenoldisulphonic acid method was used, and for the latter the official method of the Association of Official Agricultural Chemists (*1*). Practically all of the nitrogen in the drainage water was in the form of nitrates.

Drainage water was measured in the receiving cans, each of which had a side tube calibrated to show the contents in liters. An aliquot sample was removed whenever there was enough water to warrant it, and the sample was placed in an acid bottle kept slightly acid with H_2SO_4 to prevent settling out of calcium carbonate.

In the crops dry matter, total nitrogen, and calcium were determined. The official methods of the Association of Official Agricultural Chemists (*1*) were used for these determinations.

EXPERIMENTAL RESULTS

DRY MATTER AND NITROGEN IN THE CROPS

The effect of the nitrogenous fertilizers on the yield of dry matter and nitrogen in the 20 crops is shown in table 2.

TABLE 2.—*Dry matter and nitrogen in the 20 crops grown in soil treated with sulphate of ammonia and nitrate of soda, 1922 to 1931*

Tank no.	Nitrogen carrier	Dry matter	Nitrogen	
		Pounds per acre	*Pounds per acre*	*Percent*
1	Sulphate of ammonia	44,359	937	2.11
21	do	45,232	962	2.13
24	do	45,352	981	2.16
2	Nitrate of soda	53,507	1,069	2.00
22	do	52,513	1,048	1.99
23	do	55,728	1,146	2.06

It is quite evident from table 2 that the crop yields were materially larger in the tanks treated with nitrate of soda and that the quantity of nitrogen removed from the soil was almost correspondingly large. The percentage of nitrogen in the dry matter was slightly higher in the crops grown with sulphate of ammonia. In view of the relative quantities of nitrogen removed in drainage water from the tanks treated with the two nitrogen carriers, which will be shown later, this difference in the amount of nitrogen removed in the crops is interesting.

RELATION OF CROP YIELDS TO HYDROGEN-ION CONCENTRATION IN THE SOIL

While the acidity was greater in the soil treated with sulphate of ammonia than in the soil treated with nitrate of soda during a part of the time consumed by the experiment, such was not always the

case. During the first 4 years there was practically no difference in the soil reaction, as is indicated by the pH determinations made on April 21, 1926. The soil in all tanks had the same reaction at the outset and must have maintained that relation up to the spring of 1926. From 1922 to 1925, inclusive, tanks 21 and 24 received sulphate of ammonia and tanks 2 and 23 received nitrate of soda. The yields of dry matter in the eight crops grown in these tanks during this period are given in table 3.

TABLE 3.—*Average annual yield of dry matter from crops in tanks receiving sulphate of ammonia or nitrate of soda, 1922–25 and 1930–31*

[Data expressed as pounds per acre]

1922–25

Tank no.	Yield from tanks receiving sulphate of ammonia	Tank no.	Yield from tanks receiving nitrate of soda
21	4,325	2	4,884
24	4,203	23	5,118
Average	4,264		5,001
Ratio	100		117

1930–31

21 [a]	5,240	[b] 2	6,107
24 [a]	5,173	[b] 23	6,242
Average	5,206		6,174
Ratio	100		119

[a] pH from 6.8 to 7.3.
[b] pH from 7.6 to 8.1.

The data in table 3 show that the larger yields were in the tanks which received nitrate of soda. The larger yields in tanks 2 and 23 could not be said to be due to differences in the hydrogen-ion concentration of the soil.

Several investigators have found that a marked acidity in soil curtails the effectiveness of sulphate of ammonia, and it was therefore thought that a degree of acidity indicated by a pH value of 6.3 to 6.5 might be sufficient to produce an injurious effect on the growth of the plants in tanks 21 and 24. Accordingly, in 1930 and 1931 the reaction of the soil in these tanks was brought to a point represented by a pH value of 6.8 to 7.3, while that in tanks 2 and 23 was 7.6 to 8.1. As the soil in tanks 2 and 24 had now approached neutrality the reaction should not interfere with the availability of the nitrogen in sulphate of ammonia. The yields of dry matter in the crops grown in tanks 21, 24, 2, and 23 are given in table 3.

The yields of dry matter recorded in table 3 do not indicate that the sulphate of ammonia as compared with nitrate of soda was any more effective when used on a soil with a pH value of 6.8 to 7.3 than when used on a soil with a pH value of 6.3 to 6.5.

NITROGEN IN THE DRAINAGE WATER

All the drainage water that percolated through the soil of these tanks during 9 years was collected, measured, and analyzed for nitrogen and calcium. Nitrogen appeared almost entirely in the form of nitrates. The total quantity of nitrogen from each tank is shown in table 4.

TABLE 4.—*Nitrogen in drainage water from tanks receiving sulphate of ammonia or nitrate of soda, 1922–31*

[Data expressed as pounds per acre]

Tank no.	Nitrogen carrier	Total nitrates	Nitrogen	
			Total	Average annual
1	Sulphate of ammonia	1,236.00	279.34	31.04
21	do	1,204.82	272.29	30.25
24	do	1,034.58	233.82	25.98
Average				29.09
2	Nitrate of soda	1,600.71	361.76	40.19
22	do	1,620.01	366.12	40.68
23	do	1,419.31	320.76	35.64
Average				38.84

The large quantity of nitrogenous fertilizers applied and the sandy nature of the soil combined to cause a large removal of nitrogen in the drainage water. The figures obtained were several times greater than those for nitrogen previously found by the authors in the drainage from a silty clay-loam soil that had received no fertilizer other than a moderate quantity of farm manure.

It is apparent from table 4 that the loss of nitrogen in the drainage was more than 30 percent greater from the tanks treated with nitrate of soda than from those treated with sulphate of ammonia.

It will be recalled that less nitrogen was removed by crops from the soil treated with sulphate of ammonia than from that treated with nitrate of soda. It appears, therefore, that both crops and drainage water from soil receiving nitrate of soda carry off more nitrogen than they do from soil receiving an equivalent quantity of nitrogen in the form of sulphate of ammonia. This is brought out in table 5.

TABLE 5.—*Average quantity of nitrogen removed annually in crops and drainage water from tanks receiving sulphate of ammonia or nitrate of soda, 1922–31*

[Data expressed as pounds per acre]

Tank nos.	Nitrogen carrier	Nitrogen applied—			Nitrogen removed—		
		In fertilizer	In rainfall	Total	In crops	In drainage	Total
1, 21, 24	Sulphate of ammonia	130	6.5	136.5	96.0	29.1	125.1
2, 22, 23	Nitrate of soda	130	6.5	136.5	108.7	38.8	147.5

Table 5 shows that the nitrogen removed in crops and drainage combined was considerably less for the soil treated with sulphate of ammonia than for that treated with nitrate of soda. The quantity of nitrogen applied in fertilizers was somewhat more than the total amount removed from the sulphate of ammonia tanks and less than that removed from the nitrate of soda tanks. In addition to the nitrogen supplied in the fertilizers, the amount brought down by the atmospheric precipitation amounted to 6.5 pounds to the acre.

NITROGEN IN CROPS AND NITRATES IN DRAINAGE WATER IN SUCCESSIVE YEARS

As was to be expected, there were large seasonal variations in crop yields and also in seasonal removal of nitrates from the soil. That there was a fairly uniform relation between these two phenomena is brought out by table 6. Data from tanks 21, 24, 2, and 23 are given because these tanks were treated with the same nitrogen carrier throughout the experiment.

TABLE 6.—*Nitrogen in crops and nitrates in drainage water, during successive years from tanks receiving sulphate of ammonia or nitrate of soda*

[Data expressed as pounds per acre]

Year	Nitrogen in crops		Nitrates in drainage	
	Tanks receiving sulphate of ammonia (nos. 21, 24)	Tanks receiving nitrate of soda (nos. 2, 23)	Tanks receiving sulphate of ammonia (nos. 21, 24)	Tanks receiving nitrate of soda (nos. 2, 23)
1922	52	51	173	220
1923	107	110	33	34
1924	100	118	38	50
1925	90	111	37	43
1926	67	81	300	367
1927	122	159	104	76
1928	76	88	221	319
1929	149	142	44	54
1930	71	92	169	348

The most evident relationship to be seen is that in the years when the crops contained a large number of pounds of nitrogen the quantities in the drainage water were small, and, conversely, when the crops contained little nitrogen the drainage water contained a great deal. This is what might be expected when weather conditions curtail plant growth. Under such circumstances the nitrate nitrogen not absorbed by the plants is carried off in the drainage water.

In every year except one there was more nitrate in the drainage from the nitrate of soda tanks than from those that received sulphate of ammonia. In years when there were small amounts of nitrogen in the crops the removal of nitrogen in the drainage water was such as to entail a considerable monetary loss. This was especially true when the soil was treated with nitrate of soda.

The largest removal of nitrogen in drainage in any one year amounted to 68 pounds to the acre from the sulphate of ammonia tanks and 83 pounds to the acre from the nitrate of soda tanks.

CALCIUM IN CROPS AND IN DRAINAGE WATER

Determinations of calcium were made in the crops and in the drainage water in order to ascertain the relative effects of the two carriers of nitrogen on the removal of this constituent from the soil. Table 7 shows the average amount of calcium removed annually from each tank during the period 1922 to 1931, inclusive. The records for 20 crops and the drainage records for 9 years are included in the table.

TABLE 7.—*Average quantity of calcium removed annually in crops and drainage water from tanks receiving sulphate of ammonia or nitrate of soda, 1922–31*

[Data expressed as pounds per acre]

Tank no.	Nitrogen carrier	Calcium removed	
		In crops	In drainage water
1	Sulphate of ammonia	40.8	357.7
21	do	41.7	385.3
24	do	44.6	359.0
	Average	42.4	367.3
2	Nitrate of soda	31.5	279.2
22	do	34.5	290.7
23	do	34.5	265.8
	Average	33.5	278.6

It is apparent that the crops produced on the soil which was treated with sulphate of ammonia contained more calcium than did those on the soil treated with nitrate of soda, and this despite the fact that larger crops were produced on the latter soil. The drainage water from the ammonium sulphate soil also contained more calcium than that from the nitrate of soda soil. It seems rather curious that with such excessive quantities of soluble calcium in these tanks, as is indicated by the figures for calcium in drainage water, there should have been any greater absorption of calcium by the plants in the sulphate tanks than in the others. It will be remembered, however, that more lime was applied to the sulphate of ammonia tanks than to those that received nitrate of soda. This may account for the larger quantity of calcium in the plants and in the drainage water of the tanks that received sulphate of ammonia. However, from 1922 to 1927, inclusive, both tanks had received the same quantity of lime. A comparison of the calcium removals in the crops and drainage water during these years should therefore indicate what effect, if any, sulphate of ammonia exerted on the removal of calcium. These data are shown in table 8, the figures being given for each year separately.

The same tendency noted in table 7 is apparent in table 8.

In every year except the first the removal of calcium in the crops and drainage water was greater from the tanks that received sulphate of ammonia than from those that received nitrate of soda. Moreover, from 1922 to 1925, inclusive, there was little or no change in soil reaction. The evidence of these years indicates that the addition of sulphate of ammonia is in itself enough to cause a greater removal of calcium, although in later years the application of lime may have contributed to the same end.

TABLE 8.—*Calcium removed in crops and in drainage water, during successive years, from tanks receiving sulphate of ammonia or nitrate of soda*

[Data expressed as pounds per acre]

Year	Calcium removed in—					
	Crops from tanks receiving sulphate of ammonia (nos. 21, 24)	Crops from tanks receiving nitrate of soda (nos. 2, 23)	Drainage from tanks receiving sulphate of ammonia (nos. 21, 24)	Drainage from tanks receiving nitrate of soda (nos. 2, 23)	Crops and drainage from tanks receiving sulphate of ammonia (nos. 21, (24)	Crops and drainage from tanks receiving nitrate of soda (nos. 1, 23)
1922	11.9	11.6	294.5	316.2	306.4	327.8
1923	29.9	23.7	208.5	188.7	238.4	212.4
1924	50.8	61.2	383.9	302.2	434.7	363.4
1925	36.0	30.1	312.7	235.0	348.7	265.1
1926	25.7	24.8	631.4	447.4	657.1	472.2
1927	50.8	36.1	521.7	289.4	572.5	325.5

It would naturally be assumed that the concentration of calcium in the drainage water was greater in the flow from the sulphate of ammonia tanks than from the others. Calculations, when weighted for the drainage measurements and for the calcium found in all of the tanks for the period 1922–31 give the calcium concentration for the water from the sulphate of ammonia tanks at 98.5 parts per million and from the nitrate of soda tanks at 72.5 parts per million.

SUMMARY

Six lysimeter tanks each holding 3½ tons of soil were used in an experiment to ascertain whether as much nitrogen was removed in drainage water from a sandy soil fertilized with large quantities of sulphate of ammonia as from the same soil fertilized with an equivalent quantity of nitrate of soda. The experiment was begun in 1922 and concluded in 1931.

At the beginning of the experiment, the annual application of nitrogen amounted to 82.35 pounds per acre. Later, nitrogen was increased to twice that amount. Ground limestone was applied to all tanks at the rate of 2 tons to the acre at the beginning of the experiment and 1 ton in 1926. After 1926 no lime was given the soil receiving nitrate of soda, but the soil receiving sulphate of ammonia was eventually given 8 tons in an effort to prevent it from becoming too acid.

The hydrogen-ion concentration of the soil did not change materially from the beginning of the experiment in 1922 up to 1926. From that time on there was a constant tendency for the soil treated with sulphate of ammonia to become more acid, and to counteract this tendency 5 tons more of limestone were applied to the soil so treated.

The cropping system consisted of spinach planted in the spring, followed by carrots in the summer. After the carrots were harvested, rye was sown, allowed to grow until spring, and then turned under. This cropping was alternated with lettuce planted in the spring, followed by garden beets in the summer, and rye again grown as a green-manure crop.

Determinations of nitrogen and calcium were made in the drainage water; in the crops dry matter, nitrogen, and calcium were determined.

The average quantity of nitrogen removed annually in drainage water during the entire experimental period was approximately 29 pounds to the acre from the soil that received sulphate of ammonia and nearly 39 pounds from the soil that received nitrate of soda.

In the tanks treated with nitrate of soda crop growth was appreciably greater than in those treated with sulphate of ammonia. The crops in the nitrate of soda tanks removed about 108 pounds of nitrogen to the acre annually, and the crops in the sulphate of ammonia tanks removed 96 pounds. The total average annual removal of nitrogen in crop and drainage combined amounted to between 147 and 148 pounds per acre from the nitrate of soda tanks and 125 pounds from the sulphate of ammonia tanks.

From 1922 to 1925, inclusive, the hydrogen-ion concentration of the soil treated with sulphate of ammonia was approximately the same as that of the soil to which nitrate of soda was applied (pH 6.3 to 6.5). During this period the crop yields in the sulphate of ammonia tanks were smaller than in the nitrate of soda tanks, the ratio being 100 to 117. During 1930–31 the pH readings of the soil in these sulphate of ammonia tanks were 6.6 to 7.3 and those in the soil of the nitrate of soda tanks were 7.5 to 8.1. In these years the crops in the soil receiving sulphate of ammonia still yielded less than those in the soil receiving nitrate of soda, the ratio in this case being 100 to 119. There did not appear to be a relatively better growth produced by the sulphate of ammonia when the soil reaction approached neutrality than when it was more decidedly acid.

In the years in which the crop contained a large amount of nitrogen the quantity in the drainage water was small, and conversely, when the crops contained little nitrogen the quantity in the drainage water was large. The largest removal of nitrogen in drainage in any one year amounted to 68 pounds to the acre from the tanks that received sulphate of ammonia and 83 pounds from those that received nitrate of soda.

Although larger crop yields were produced in the soil that received nitrate of soda, these crops contained less calcium both in percentage and by weight than the crops from soil that received sulphate of ammonia. Moreover, the drainage water from the soil receiving ammonium sulphate contained more calcium than that from soil receiving nitrate of soda. This relationship was recorded both for the period 1922–27, when all the tanks received the same quantities of limestone, and for the period 1922–25, when there was little or no difference in soil reaction in any of the tanks. It may therefore be considered to be associated with the effect of the sulphate of ammonia. The average concentration of calcium in the drainage water from the sulphate of ammonia tanks was 98.5 parts per million, and that from the nitrate of soda tanks was 72.5 parts per million.

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