

THE EFFECTS OF ALKALI SALTS ON NITRIFICATION

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During the last few years it has been recognized that the effects of certain so-called "alkali" salts on soil bacteria, as well as their action on higher plants, should have an important bearing on the development of methods of reclamation of the alkali soils of the arid regions. It was for the purpose of throwing more light on this problem that the following experiments were carried out.

Many experiments have been conducted to determine the concentration at which various alkali salts become toxic to plants, but it remained for C. B. Lipman (8, 9, 10) to point out the importance of bacteriological studies along such lines. The investigations of this author have indicated that bacterial activities in alkali soils are very different from those in normal soils, and that the amount and character of the salts present determine the kind and extent of bacterial action occurring in such soils.

He studied the influence of sodium chloride, sodium sulfate and sodium carbonate on ammonification, nitrification and nitrogen-fixation. He found that all these processes are inhibited by the presence of certain amounts of these salts but the concentration at which each became toxic varied among the different processes. Thus the ammonifying and nitrifying bacteria were differently affected by the salts. The nitrifying bacteria were affected in a manner similar to that shown with the higher plants, but such was not the case with the ammonifying organisms. The nitrogen-fixing organisms seemed to be more resistant to injury from the salts than either of the other groups studied. The results with nitrification which are of special interest in this work showed that sodium carbonate became toxic at a concentration of 0.025 per cent, sodium sulfate at a concentration of 0.35 per cent and sodium chloride at a concentration of 0.1 per cent.

The toxic effects of salts on nitrification have been considered in few other experiments. Deherain (2, 3) noted an injurious effect of sodium chloride on nitrification and J. G. Lipman (11) found that sodium chloride became toxic at 0.1 per cent but did not entirely stop nitrification. This latter experiment was carried out by the solution method.

Headden (5, 6) and Sackett (12) have assumed the occurrence of a very intense nitrification in certain areas in Colorado to account for the excessive accumulations of nitrates occurring there, but Stewart (13) insists that such accumulations are not due to rapid *present* bacterial action, but to a concentration of the nitrates already present in the soils, the irrigation water merely furnishing a medium by which they are moved from place to place.

Furthermore, he asserts that these accumulations of nitrates always occur with large amounts of other water-soluble salts. The study of the effect of salts on nitrification may throw some light on this controversy.

Recent experiments by Kelley (7) on nitrification in semi-arid soils showed that 0.05 per cent of Na_2CO_3 was distinctly toxic to the nitrification of 1 per cent of dried blood, but as high a concentration as 0.4 per cent had no effect on the nitrification of 0.1 per cent of dried blood. When 0.15 per cent of ammonium sulfate was employed in the tests, 0.1 per cent of Na_2CO_3 became toxic to nitrification, but the same amount was markedly stimulating when 0.0625 per cent of ammonium sulfate was used. Similar results were secured with Na_2SO_4 .

No other investigations of a nature to be of value to the general problem have been carried out so far as the authors are aware.

EXPERIMENTAL

The purpose of the experiments reported in the following pages was to determine the concentration at which various alkali salts become toxic to the nitrifying bacteria. Alkali salts, in the concentration which was found in an alkali soil, according to chemical analysis, were added to a similar normal soil. Thus artificial alkali soils containing single salts and various combinations of the same salts were prepared. Comparative tests were run on a typical alkali soil and it was desired by this plan to ascertain the relative and absolute toxicity to the nitrifying bacteria of various salts in actual concentrations found in the field.

Alkali soil was then treated with sodium carbonate and sodium bicarbonate with and without the amount of gypsum necessary to react with the salt added in order to study nitrification under such conditions.

Samples of alkali soil and of a similar normal soil were secured through the courtesy of the Agricultural Experiment Station of the University of Wyoming, and served as a basis for the work. The tests were therefore carried out with typical alkali soil and a typical normal soil from the same region.

Chemical analyses were made of the soils and the water-soluble calcium, sodium, magnesium, potassium, bicarbonate, carbonate, chloride and sulfate determined.

The results of the analyses were as follows:

	NORMAL SOIL	ALKALI SOIL
	<i>per cent</i>	<i>per cent</i>
Calcium (Ca).....	0.0220	0.0550
Magnesium (Mg).....	0.0064	0.0096
Sodium (Na).....	0.0796	0.2570
Potassium (K).....	0.0218	0.0470
Bicarbonate (HCO_3).....	0.0042	0.1190
Chloride (Cl).....	0.0003	0.0084
Sulfate (SO_4).....	0.0980	0.8330
Nitrogen (Total N).....	0.1170	0.0440

The laboratory tests were carried out in tumblers with both the normal and the alkali soils according to the treatments indicated above. One-hundred-gram quantities of the air-dried, sieved soil were weighed out, salt additions made according to the various series, 100 mgm. of ammonium sulfate added, the moisture content of the soils adjusted to the optimum, 5 cc. of a five-minute infusion of a fresh soil added to each soil to introduce a vigorous nitrifying flora, the tumblers were then covered and incubated for four weeks at room temperature, the moisture content being kept up by additions of sterile water to weight every ten days. The nitrates present were then determined by the aluminum reduction method, modified somewhat from the procedure recommended by Burgess (1).

Series I. The effects of NaCl on nitrification in normal soil

The arrangement of this series and the results are shown in table 1 and figure 1. All the treatments were in duplicate and the untreated normal soil and

TABLE 1
Effects of NaCl on nitrification in normal soil

NUMBER	SOIL	NaCl	N	AVERAGE N
		<i>grams</i>	<i>mgm.</i>	<i>mgm.</i>
1	Normal	None	2.1728	
2	Normal	None	2.2316	2.2022
3	Normal	0.005	3.1164	
4	Normal	0.005	3.2460	3.1812
5	Normal	0.010	2.2316	
6	Normal	0.010	2.5452	2.3884
7	Normal	0.020	2.0328	
8	Normal	0.020	1.7164	1.8746
9	Normal	0.040	0.6608	
10	Normal	0.040	0.9464	0.8536
11	Alkali	None	2.0888	
12	Alkali	None	1.8312	1.9600

untreated alkali soil were used in this and all succeeding series for the sake of comparison.

The addition of 0.005 per cent of NaCl gave a stimulation in nitrate production but the large amounts, at least beyond 0.010 per cent depressed nitrification. This latter amount apparently had no effect.

The alkali soil gave a smaller nitrification than the normal soil and about the same as that receiving 0.020 per cent of NaCl. The toxic point for the NaCl in this test evidently occurred at about 0.02 per cent, which is very much lower than the concentration at which Lipman found toxicity. Differences in the soils tested may account for the variation in the results. It is apparent, however, that small amounts of NaCl stimulate nitrification, while larger amounts bring about a depression.

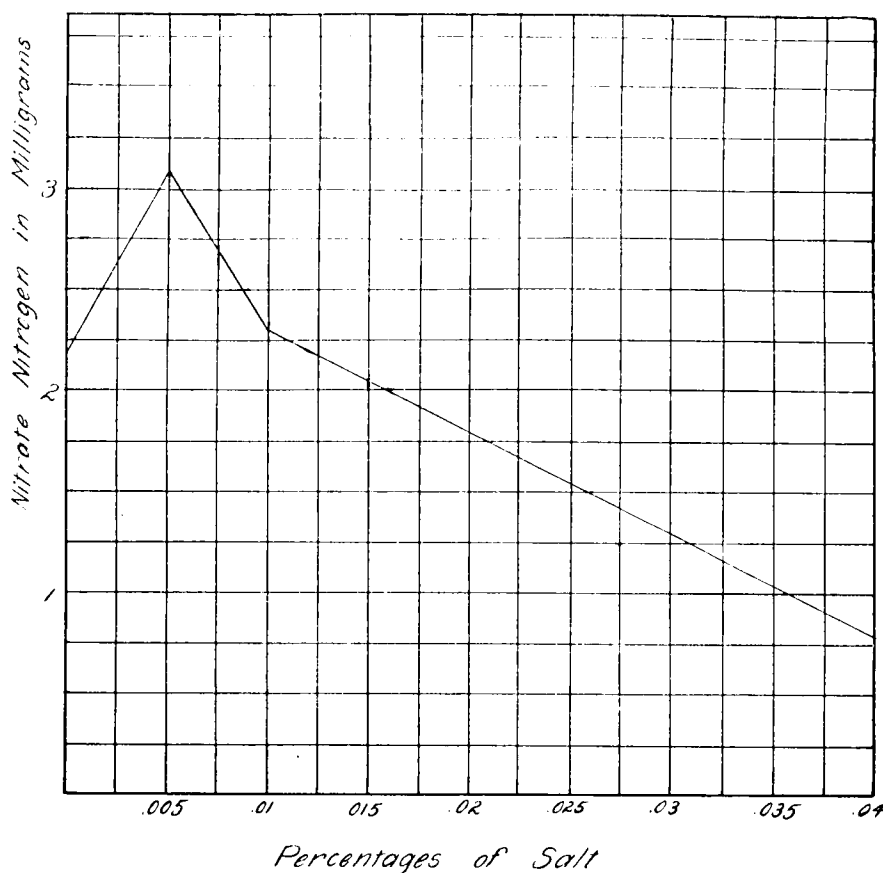


FIG. 1. EFFECTS OF NaCl ON NITRIFICATION IN NORMAL SOIL.

Series II. The effects of Na_2SO_4 on nitrification in normal soil

This series was arranged in a manner similar to the preceding except that the treatments with Na_2SO_4 were much larger than those with NaCl. The data obtained are presented in table 2 and figure 2.

The addition of the Na_2SO_4 up to 2.0720 per cent increased considerably the nitrifying power of the soil. The greatest increase was secured with 0.5180 per cent of the salt, but the differences between the results with this application and with the larger amounts were small until 4.1440 per cent was added, when a distinct depression in nitrification occurred. The concentration at which the sodium sulfate becomes toxic was therefore much higher in this soil than in Lipman's experiments, where the toxic point was found to be 0.35 per cent. The variation in the soil used would again probably explain the difference in the results. It is evident again, however, that sodium

TABLE 2
Effects of Na_2SO_4 on nitrification in normal soil

NUMBER	SOIL	Na_2SO_4	N	AVERAGE N
		grms	mgm.	mgm.
1	Normal	None	3.3150	
2	Normal	None	3.6960	3.5030
3	Normal	0.5180	4.6280	
4	Normal	0.5180	Lost	4.6280
5	Normal	1.0360	4.4570	
6	Normal	1.0360	4.3140	4.3850
7	Normal	2.0720	4.1740	
8	Normal	2.0720	3.8860	4.0290
9	Normal	4.1440	1.6010	
10	Normal	4.1440	1.7750	1.6880
11	Alkali	None	3.1720	
12	Alkali	None	2.9450	3.0580

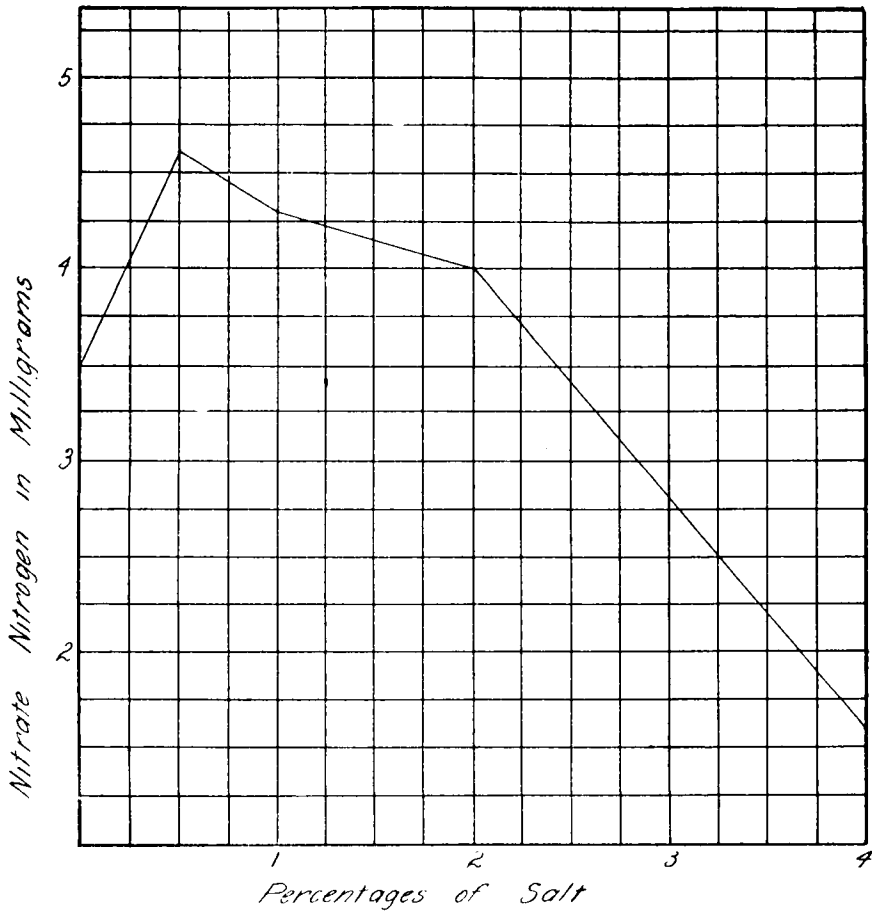


FIG. 2. EFFECTS OF Na_2SO_4 ON NITRIFICATION IN NORMAL SOIL

sulfate stimulates nitrification when added in small amounts, but when the concentration is increased beyond a certain point, which varies in different soils, it becomes distinctly toxic to the nitrifiers.

Series III. The effects of $MgSO_4$ on nitrification in normal soil

The arrangement of this series and the results secured appear in table 3 and figure 3.

TABLE 3
Effects of $MgSO_4$ on nitrification in normal soil

NUMBER	SOIL	$MgSO_4$	N	AVERAGE N
		grams	mgm.	mgm.
1	Normal	None	2.5375	
2	Normal	None	2.4841	2.5108
3	Normal	0.0235	4.0984	
4	Normal	0.0235	4.2998	4.1991
5	Normal	0.0570	3.4020	
6	Normal	0.0570	4.0292	3.7156
7	Normal	0.1140	3.6008	
8	Normal	0.1140	3.6306	3.6162
9	Normal	0.2280	3.1724	
10	Normal	0.2280	3.0604	3.1164
11	Alkali	None	2.0964	
12	Alkali	None	2.0952	2.0976

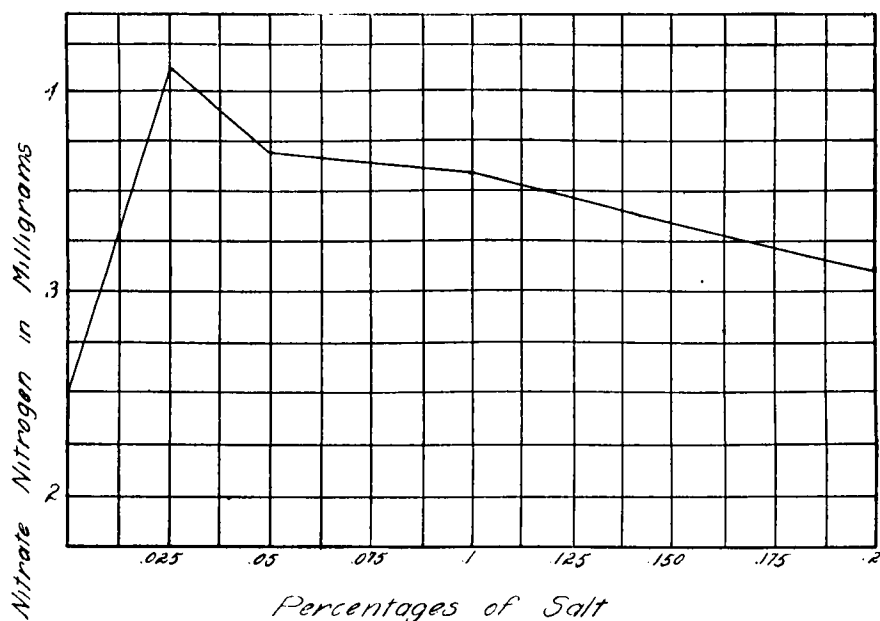


FIG. 3. EFFECTS OF $MgSO_4$ ON NITRIFICATION IN NORMAL SOIL.

The MgSO_4 evidently stimulated nitrification in all the amounts used, that is, up to 0.2280 per cent. The greatest stimulation occurred, however, with the smallest application--0.0235 per cent, and the larger amounts brought about smaller effects. If the application had been increased beyond 0.2280 per cent it seems that a depression in nitrification would have occurred, for the figures gradually decreased with increasing applications. Just where a toxic effect from the MgSO_4 would occur, cannot, of course, be stated from these results, but it is probable that about 0.3 per cent would mark the point at which depression would occur.

Again it is seen that this salt, like the others tested, stimulates nitrification when present in small amounts, but beyond a certain maximum concentration undoubtedly becomes toxic.

Series IV. The effects of CaCO_3 on nitrification in normal soil

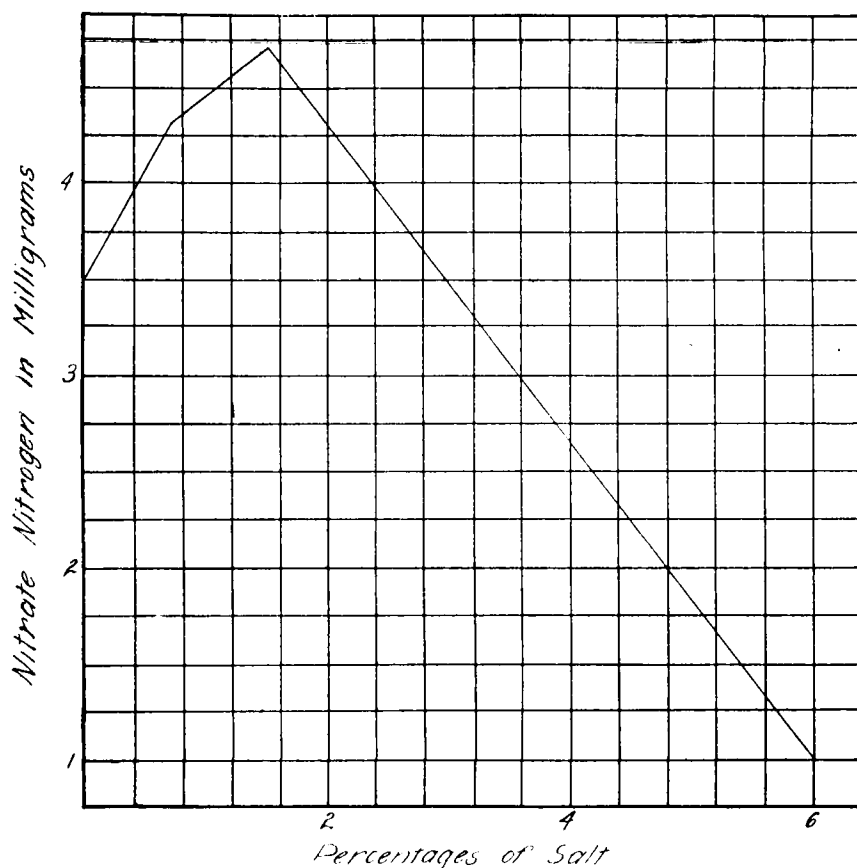
The effects of calcium carbonate upon crops and soils have commonly been found to be beneficial, with but few exceptions. It might be expected, therefore, that the nitrifying bacteria would be stimulated in action by additions of this salt.

Examining the results of this series in table 4 and figure 4, it will be seen that a stimulation in nitrification occurred when calcium carbonate was ap-

TABLE 4
Effects of CaCO_3 on nitrification in normal soil

NUMBER	SOIL	CaCO_3	N	AVERAGE N
		grams	mgm.	mgm.
1	Normal	None	3.5168	
2	Normal	None	3.5364	3.5266
3	Normal	0.189	3.5978	
4	Normal	0.189	3.6700	3.6339
5	Normal	0.378	3.8444	
6	Normal	0.378	3.9452	3.8948
7	Normal	0.756	4.2728	
8	Normal	0.756	4.3736	4.3232
9	Normal	1.512	4.7432	
10	Normal	1.512	4.7824	4.7628
11	Normal	6.048	1.1340	
12	Normal	6.048	1.0612	1.0976

plied up to a treatment of 6 per cent. Somewhere between 1.512 per cent and 6.048 per cent occurred the toxic point for this salt on this particular soil. Unfortunately, the exact point was not ascertained. It is of considerable interest to note, however, the undoubted toxicity to nitrification indicated by the application of 6.048 per cent. Evidently calcium carbonate in small or reasonable amounts is beneficial to nitrification, but when the addition becomes excessive there is a depression in the activities of this group of or-

FIG. 4. EFFECTS OF CaCO_3 ON NITRIFICATION IN NORMAL SOIL.

ganisms. This depression may not occur in other soils, but these results on one particular soil indicate that calcium carbonate may be applied to soils in too large amounts.

Series V. The effects of NaHCO_3 on nitrification in alkali soil

This series deals with the effects of sodium bicarbonate on nitrification in an alkali soil. The treatment of the soil and the results appear in table 5 and figure 5. Examining the table, it is seen that the NaHCO_3 in additions up to and beyond 0.10 per cent stimulated considerably the nitrification process in this soil. Beyond 0.30 per cent, however, a distinct depression occurred which increased with increasing additions.

When calcium sulfate was added with the sodium bicarbonate, all toxic effects of the additions were removed, as is indicated by the results of the last two tests in the table.

TABLE 5
Effects of NaHCO₃ on nitrification in alkali soil

NUMBER	SOIL	NaHCO ₃	N	AVERAGE N
		grams	mgm.	mgm.
1	Alkali	None	4.6172	
2	Alkali	None	4.5416	4.5794
3	Alkali	0.05	4.8740	
4	Alkali	0.05	4.7650	4.8190
5	Alkali	0.10	5.4740	
6	Alkali	0.10	5.3228	5.3984
7	Alkali	0.30	3.8864	
8	Alkali	0.30	4.2148	4.0506
9	Alkali	0.50	3.8360	
10	Alkali	0.50	3.9116	3.8738
11	Alkali	1.00	3.7604	
12	Alkali	1.00	3.1808	3.4706
13*	Alkali	1.00	4.9448	
14*	Alkali	1.00	4.8440	4.8944

* Plus 1.6197 grams CaSO₄.

Sodium bicarbonate appears, from these results, to have a stimulative effect on nitrification when added to soil to 0.10 to 0.30 per cent, but it becomes toxic to the process when applied at the rate of 0.30 per cent and beyond, the toxicity increasing with the addition.

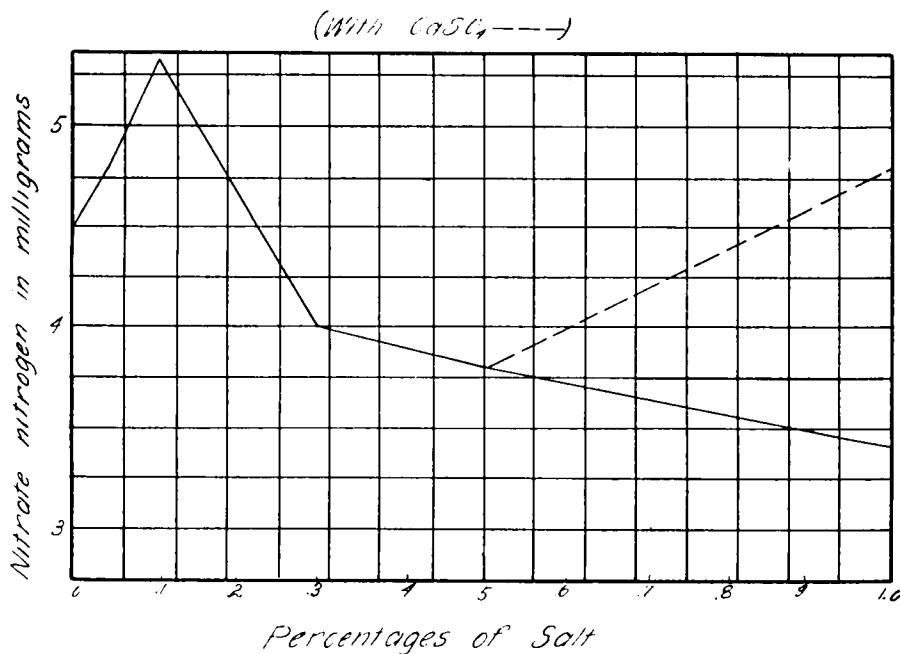


FIG. 5. EFFECTS OF NaHCO₃ ON NITRIFICATION IN ALKALI SOIL.

When calcium sulfate is added with the sodium bicarbonate in the proper amount to react with this latter salt, all toxic effect is removed and there is apparently no influence from the addition, except perhaps a slight increase in the nitrification process.

Series VI. The effects of Na_2CO_3 on nitrification in alkali soil

The arrangement of this series was very similar to the preceding. It is shown in table 6 and figure 6 together with the results.

TABLE 6
Effects of Na_2CO_3 on nitrification in alkali soil

NUMBER	SOIL	Na_2CO_3	N	AVERAGE N
		grams	mgm.	mgm.
1	Alkali	None	2.1476	
2	Alkali	None	1.7948	1.9712
3	Alkali	0.05	3.1528	
4	Alkali	0.05	1.8480	2.5004
5	Alkali	0.10	1.6436	
6	Alkali	0.10	2.5256	2.0846
7	Alkali	0.30	2.2484	
8	Alkali	0.30	1.6184	1.9334
9	Alkali	0.50	1.9936	
10	Alkali	0.50	1.5176	1.7556
11	Alkali	1.00	1.2656	
12	Alkali	1.00	1.7416	1.5036
13*	Alkali	1.00	2.1252	
14*	Alkali	1.00	1.8480	1.9866

* Plus 1.30 grams CaSO_4 .

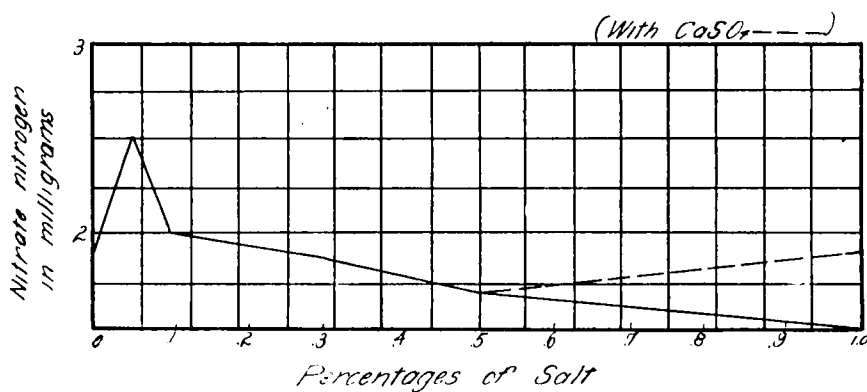


FIG. 6. EFFECTS OF Na_2CO_3 ON NITRIFICATION IN ALKALI SOIL

The application of the sodium carbonate at the rate of 0.05 per cent gave a decided stimulation in nitrification. The 0.10 per cent addition, likewise, gave a stimulation, but it was not large. The larger additions brought about

depressions in the process which became greater as the size of the application increased. When calcium sulfate was added in the proper amount to react with the sodium carbonate there was no effect whatever from the addition. This result is in accord with that of the preceding series with the bicarbonate of sodium and the calcium sulfate.

The concentration at which the sodium carbonate became toxic to the nitrifiers in this soil was much greater than that noted by Lipman. He found toxicity at 0.025 per cent, but stimulation occurred in this work up to 0.10 per cent. His results with Na_2CO_3 , however, were not considered satisfactory, as there was much mold growth on the soils which may have used up the nitrates produced, and losses may have occurred in the several filtrations through bone black which were necessary to the determination. However, the variation from Lipman's results may be due, as was concluded in the preceding series, to differences in the soil used. It is evident, however, that sodium carbonate, like the other salts tested, stimulated nitrification when used in small amounts, but depressed the process considerably when large applications were made. When calcium sulfate is used with the sodium carbonate, there is no effect on the nitrifying bacteria.

Series VII. The effects of CaSO_4 on nitrification in alkali soil

The results in the preceding tables indicated that calcium sulfate applied with sodium carbonate and sodium bicarbonate neutralized the toxic effects

TABLE 7
Effects of CaSO_4 on nitrification in alkali soil

NUMBER	SOIL	CaSO_4	N	AVERAGE N
		<i>grams</i>	<i>mgm.</i>	<i>mgm.</i>
1	Alkali	None	4.1804	
2	Alkali	None	4.3120	4.2462
3	Alkali	0.022	4.4156	
4	Alkali	0.022	4.4436	4.4298
5	Alkali	0.033	4.4436	
6	Alkali	0.033	4.5752	4.4894
7	Alkali	0.044	4.5472	
8	Alkali	0.044	4.6284	4.5878
9	Alkali	0.088	4.4156	
10	Alkali	0.088	4.3120	4.3638
11	Alkali	0.176	4.1664	
12	Alkali	0.176	4.3904	4.2784

of these salts. It seemed advisable, therefore, to ascertain the influence of the CaSO_4 when applied alone to the alkali soil. The treatments used and the results secured appear in table 7 and figure 7.

It is apparent upon an examination of this table that the CaSO_4 had little effect on nitrification. There seemed to be a slight stimulation with the

smaller additions, but the differences were not large. With the larger amounts, no increase was secured. The applications were not increased beyond 0.176 per cent, so it is quite possible that further additions might have brought about an increase in nitrification. However, in the absence of sufficient data, general conclusions cannot be drawn. The differences secured seem too small to conclude a stimulation of the process, but the results may be considered to indicate the possibility of such a stimulation at least.

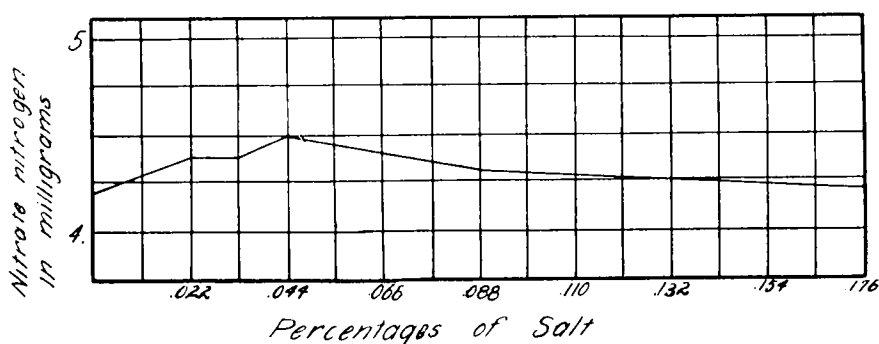


FIG. 7. EFFECTS OF CaSO_4 ON NITRIFICATION IN ALKALI SOIL.

Series VIII. The effects of CaCO_3 on nitrification in alkali soil

When calcium carbonate was applied to the normal soil used in this work, a distinct stimulation of nitrification occurred up to 6.0 per cent. At that point, however, the activities of the nitrifiers were quite considerably depressed. It seemed desirable, therefore, to test the effects of that salt on nitrification in the alkali soil.

This series was arranged in a similar manner to series IV except that the alkali soil was used. The arrangement of the series and the results are given in table 8 and figure 8.

The small amounts of the CaCO_3 did not seem to influence nitrification, but when 0.378 per cent was used an increase in the process was noted. Further gains occurred with the larger applications up through 1.512 per cent. When 6.046 per cent was added, however, a distinct depression in nitrification occurred. Evidently the maximum increase in the process through the use of CaCO_3 on this soil occurred at 1.512 per cent, or between that amount and 6.048 per cent.

The absence of tests using intermediate amounts prevents any definite point being established. It is evident, however, that just as was the case in the tests with the normal soil, CaCO_3 when applied in small amounts to this alkali soil increased nitrification, but when 6.048 per cent was used, a decided depression in the process occurred. Such an amount of CaCO_3 is rarely found in soil and hence, even if an injurious effect were found to be quite general (with many soils), which is extremely unlikely, no danger from a reasonable use of lime on soils need be apprehended.

TABLE 8
Effects of CaCO_3 on nitrification in alkali soil

NUMBER	SOIL	CaCO_3	N	AVERAGE N
		<i>grams</i>	<i>mgm.</i>	<i>mgm.</i>
1	Alkali	None	2.1586	
2	Alkali	None	1.8900	2.0243
3	Alkali	0.189	2.0188	
4	Alkali	0.189	2.0440	2.0314
5	Alkali	0.378	2.1700	
6	Alkali	0.378	2.2960	2.2330
7	Alkali	0.756	2.3960	
8	Alkali	0.756	2.4976	2.4468
9	Alkali	1.512	2.7134	
10	Alkali	1.512	2.9026	2.8080
11	Alkali	6.048	1.0108	
12	Alkali	6.048	0.7840	0.8974

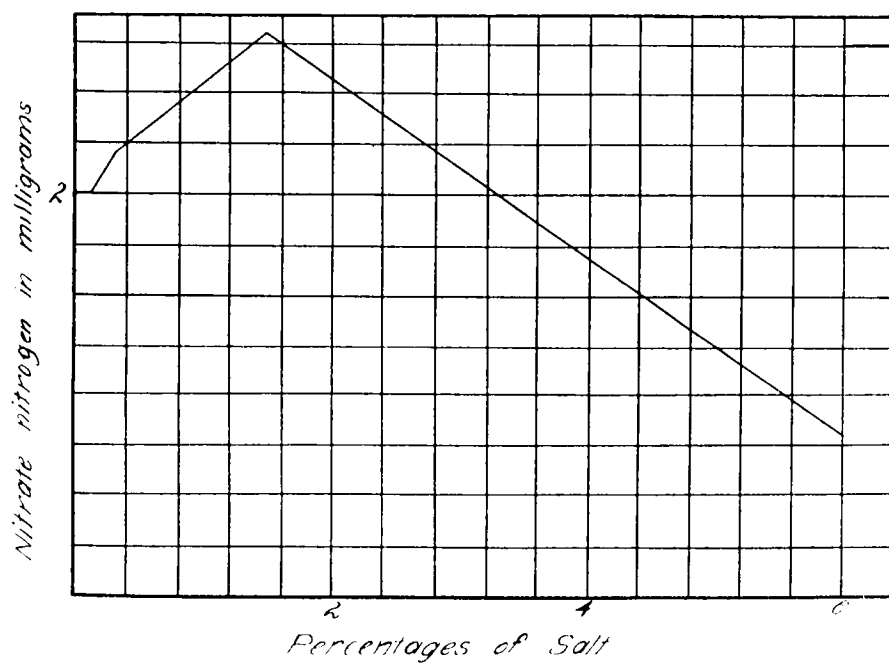


FIG. 8. EFFECTS OF CaCO_3 ON NITRIFICATION IN ALKALI SOIL

Series IX. The effects of NaHCO_3 , Na_2CO_3 and CaSO_4 on nitrification in alkali soil

This series was planned to test the effect of the carbonate and bicarbonate of sodium on nitrification in alkali soil in the presence of calcium carbonate and with and without the addition of sufficient calcium sulfate to react with the carbonate used. The arrangement of the tests and the results secured are given in table 9 and figure 9.

TABLE 9

Effects of NaHCO_3 , Na_2CO_3 , and CaSO_4 on nitrification in the presence of CaCO_3 in alkali soil

NUMBER	ADDITION	N	AVERAGE N
		mgm.	mgm.
1	Nothing.....	2.3296	
2	Nothing.....	2.5312	2.4304
3	0.536 gram CaCO_3	2.9960	
4	0.536 gram CaCO_3	4.1440	3.5700
5	0.536 gram CaCO_3 + 1.00 gram NaHCO_3	2.6852	
6	0.536 gram CaCO_3 + 1.00 gram NaHCO_3	2.5760	2.6306
7	0.536 gram CaCO_3 + 0.044 gram NaHCO_3 + 0.072 gram CaSO_4	2.4640	
8	0.536 gram CaCO_3 + 0.044 gram NaHCO_3 + 0.072 gram CaSO_4	2.9688	2.7164
9	0.536 gram CaCO_3 + 0.044 gram NaHCO_3	Lost	
10	0.536 gram CaCO_3 + 0.044 gram NaHCO_3	3.0016	3.0016
11	0.536 gram CaCO_3 + 0.056 gram Na_2CO_3	2.7104	
12	0.536 gram CaCO_3 + 0.056 gram Na_2CO_3	2.7552	2.7328
13	0.536 gram CaCO_3 + 0.056 gram Na_2CO_3 + 0.072 gram CaSO_4	3.0912	
14	0.536 gram CaCO_3 + 0.056 gram Na_2CO_3 + 0.072 gram CaSO_4	4.2928	3.6920
15	0.536 gram CaCO_3 + 1.00 gram Na_2CO_3	2.8224	
16	0.536 gram CaCO_3 + 1.00 gram Na_2CO_3	Lost	2.8224
17	0.536 gram CaCO_3 + 0.056 gram Na_2CO_3 + 0.044 gram NaHCO_3	2.5760	
18	0.536 gram CaCO_3 + 0.056 gram Na_2CO_3 + 0.044 gram NaHCO_3	3.4272	3.0016

On examining this table it is apparent that calcium carbonate increased the nitrification process to a considerable extent. This is in accord with the tests previously discussed with calcium carbonate. The sodium carbonate and the bicarbonate both depressed considerably the activities of the nitrifiers over calcium carbonate alone, the larger application bringing about a greater depression in the case of the bicarbonate, but practically the same results being secured with both amounts in the case of the carbonate.

Some differences are evident here from the results secured with the use of the two salts without calcium carbonate. In those cases the small amount

of the carbonates increased nitrification slightly, but in the presence of CaCO_3 in this series, a depression occurred. This is an interesting difference and points to the fact that amounts of these salts which alone are non-toxic may become toxic when present with CaCO_3 .

When calcium sulfate was used with the smaller amount of the sodium carbonate, the injurious effect of the carbonate was neutralized and no influence on nitrification is noted. This is in accord with the results secured with the two salts in the absence of CaCO_3 . When the bicarbonate is considered, however, the use of the calcium sulfate with the bicarbonate depressed the process more than was the case with the bicarbonate alone. This is exactly opposite from the results secured in the previous series in the ab-

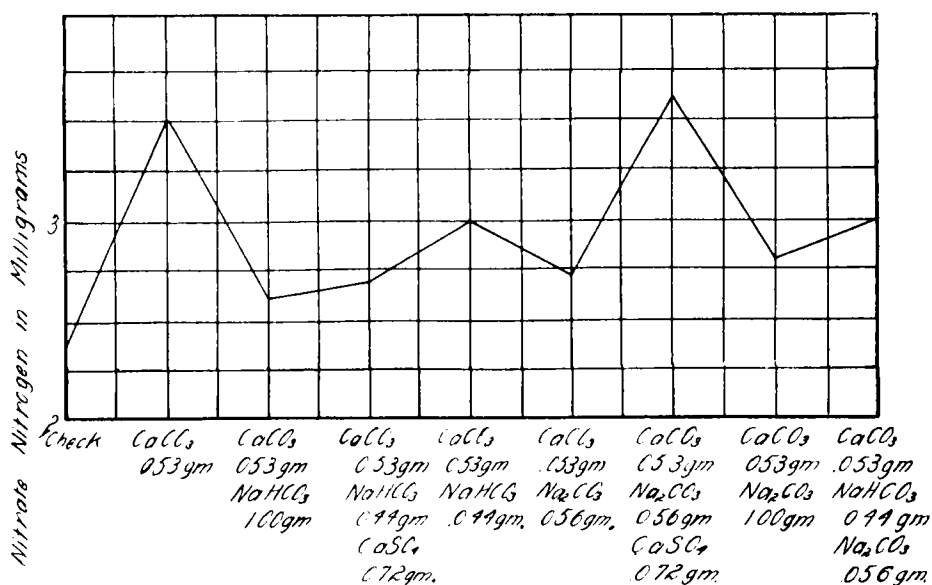


FIG. 9. EFFECTS OF CaCO_3 AND NaHCO_3 , Na_2CO_3 AND CaSO_4 IN THE PRESENCE OF CaCO_3 ON NITRIFICATION IN ALKALI SOIL.

sence of CaCO_3 . Only one determination was made with the use of the bicarbonate alone, and hence that result may not be absolutely accurate, but the differences secured are definite enough so that it must be concluded that in the presence of CaCO_3 calcium sulfate does not neutralize the toxic effect of sodium bicarbonate.

When the bicarbonate and carbonate of sodium were applied together, the depression in nitrification was less than with the sodium carbonate alone and about the same as that from the bicarbonate alone.

These results, as a whole, show distinctly the toxic effects of the carbonate and bicarbonate of sodium on nitrification in this soil in the presence of CaCO_3 . Furthermore, smaller amounts became toxic than in the same soil

in the absence of CaCO_3 . CaSO_4 prevents the toxic action of sodium carbonate, but it does not seem to be similarly efficient with the bicarbonate in the presence of CaCO_3 .

GREENHOUSE EXPERIMENTS

Comparative experiments similar to the above were carried out in the greenhouse, nitrification tests being run on both the normal and alkali soils, after beans had been grown and harvested. In these pot experiments 10 pounds of soil were used and the treatment of the normal soil was calculated to imitate alkali-soil conditions. The amounts of the various alkali salts added singly or in combination to the normal soil were the same as those found

TABLE 10
Effects of NaCl, Na_2SO_4 , MgSO_4 and CaSO_4 on nitrification in normal soil

NUMBER	TREATMENT	FIRST SAMPLING		SECOND SAMPLING		THIRD SAMPLING	
		Average N	Average N for pots	Average N	Average N for pots	Average N	Average N for pots
		mgm.	mgm.	mgm.	mgm.	mgm.	mgm.
1	None.....	6.6570		6.6010		6.9060	
2	None.....	6.2748	6.4659	6.2916	6.4463	6.7088	6.8074
3	0.005 per cent NaCl.....	6.1562		6.5464		7.0280	
4	0.005 per cent NaCl.....	6.0088	6.0825	6.5874	6.5664	7.0168	7.0224
5	0.518 per cent Na_2SO_4	6.5562		6.5996		6.3168	
6	0.518 per cent Na_2SO_4	5.9066	6.2314	6.3476	6.4736	6.4932	6.4050
7	0.023 per cent MgSO_4	7.4466		5.8660		6.8368	
8	0.023 per cent MgSO_4	6.5940	7.0203	6.4381	6.1520	6.9622	6.8995
9	0.189 per cent CaCO_3	6.4932		6.6280		7.7420	
10	0.189 per cent CaCO_3	7.3234	7.1583	6.7340	6.6810	6.6870	7.2145
11	All four salts.....	6.4288		6.4932		6.8152	
12	All four salts.....	6.5940	6.5114	6.1278	6.3105	7.0158	6.9155

by analysis in the alkali soil. The alkali soil received additions of calcium carbonate and of sodium carbonate and bicarbonate with and without additions of calcium sulfate.

All the treatments were in duplicate, and the arrangement of the pots is shown in tables 10 and 11.

The pots were weighed at the time of filling and brought up to the optimum moisture content, which was 20.0 per cent for the normal soil and 20.8 per cent for the alkali soil. The moisture content was kept constant throughout the experiment by adding water to weight. This water was added by means of a tube at the bottom of the pots, in order to prevent puddling. The experiment was started on November 12, 1915, and beans seeded in all the pots in the attempt to ascertain whether the effects of the alkali salts would be the same on the crop grown as on the nitrifying organisms. After the crop was removed, samples were drawn and tested for nitrifying power on February

23, March 10 and March 20 for the normal soils, and on February 6, February 25, March 12 and March 22 for the alkali soils. The procedure in these tests was the same as that already outlined, except that fresh soil was used, no soil infusion was added, and of course, no salts were used, the idea being to determine the nitrifying power of the soils receiving the various salts *after* a crop had been grown and *after* the salts had been present in the soil for a comparatively long period.

The results of the tests of the normal soils are given in table 10 and figures 10 and 11, and of the alkali soils in table 11 and figures 12 and 13.

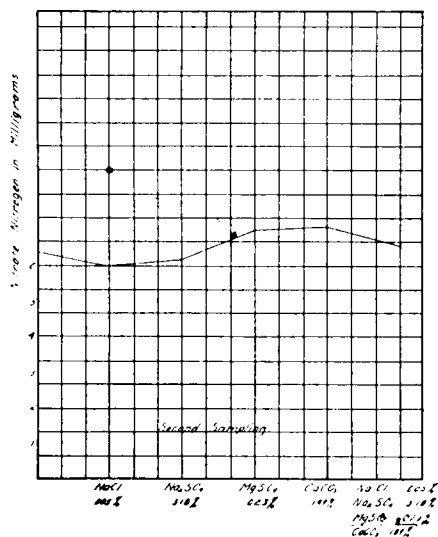


FIG. 10

FIG. 10. EFFECTS OF NaCl, Na₂SO₄, MgSO₄ AND CaCO₃ ON NITRIFICATION IN NORMAL SOIL—SECOND SAMPLING (POT EXPERIMENTS)

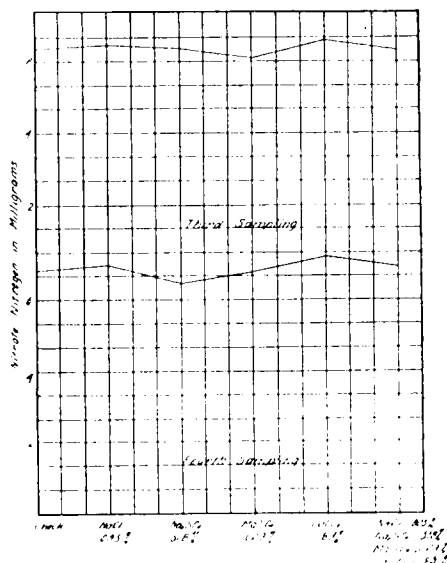


FIG. 11

FIG. 11. EFFECTS OF NaCl, Na₂SO₄, MgSO₄, AND CaCO₃ ON NITRIFICATION IN NORMAL SOIL—THIRD AND FOURTH SAMPLINGS (POT EXPERIMENTS)

Normal soil tests

Considering the results as a whole, it is apparent from table 10 that sodium chloride gave a very slight increase in nitrification. This increase was quite noticeable at the last two samplings. This effect of the use of 0.005 per cent of NaCl checks exactly with the results secured in the laboratory test with the use of NaCl as shown in table 1. Evidently the stimulative effect of the NaCl on nitrification when amounts not exceeding 0.005 per cent were used continues for some time after the application is made, if these results in the pots are considered sufficiently definite to warrant conclusions. At any rate, no toxic effect is seen. Na₂SO₄ gave a slight toxic effect on the nitrifying power of the soil, as shown at the first and last samplings. A very slight increase

TABLE 11

Effects of CaCO₃, NaHCO₃, Na₂CO₃ and CaSO₄ on nitrification in alkali soil

NUMBER	TREATMENT	FIRST SAMPLING		SECOND SAMPLING		THIRD SAMPLING		FOURTH SAMPLING	
		Average N	Average N for pots	Average N	Average N for pots	Average N	Average N for pots	Average N	Average N for pots
		mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.
1	None.....	4.1370		4.6844		4.5150		5.4955	
2	None.....	4.0614	4.0992	4.8454	4.7149	4.7264	4.6207	5.2106	5.3531
3	0.189 per cent CaCO ₃	5.4642		4.9784		4.5262		5.4950	
4	0.189 per cent CaCO ₃	5.6014	5.5328	4.6592	4.8183	4.5703	4.5482	5.4418	5.4684
5	0.378 per cent CaCO ₃	Lost		4.7348		4.7454		5.8422	
6	0.378 per cent CaCO ₃	5.5384	5.5384	5.8954	5.3151	5.1310	4.9382	5.3998	5.6210
7	0.109 per cent NaHCO ₃	4.8174		5.0414		4.9560		5.9528	
8	0.109 per cent NaHCO ₃	4.6601	4.7384	5.2696	5.0435	4.4716	4.7138	4.9518	5.4523
9	0.218 per cent Na ₂ CO ₃	4.9518		4.9261		4.5402		5.9010	
10	0.218 per cent Na ₂ CO ₃	4.8622	4.9070	6.1726	5.5493	4.8342	4.6872	5.7512	5.8261
11*	0.109 per cent NaHCO ₃	4.9644		6.0970		4.8384		5.7512	
12*	0.109 per cent NaHCO ₃	4.7710	4.8677	6.0088	6.0529	4.8230	4.8307	6.2216	5.9864
13†	0.218 per cent Na ₂ CO ₃	Lost		5.6168		4.9560		7.0424	
14†	0.218 per cent Na ₂ CO ₃	5.5916	5.5916	6.5170	6.0669	5.1310	5.0440	6.5324	6.7874

* Plus 0.177 per cent CaSO₄.

† Plus 0.261 per cent CaSO₄.

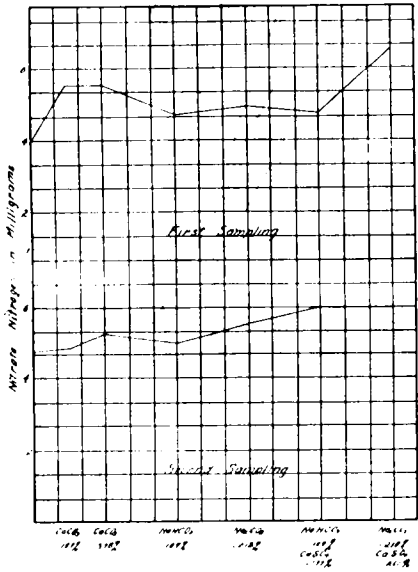


FIG. 12

FIG. 12. EFFECTS OF CaCO₃, NaHCO₃, Na₂CO₃ AND CaSO₄ ON NITRIFICATION IN ALKALI SOIL—FIRST AND SECOND SAMPLINGS (POT EXPERIMENTS)

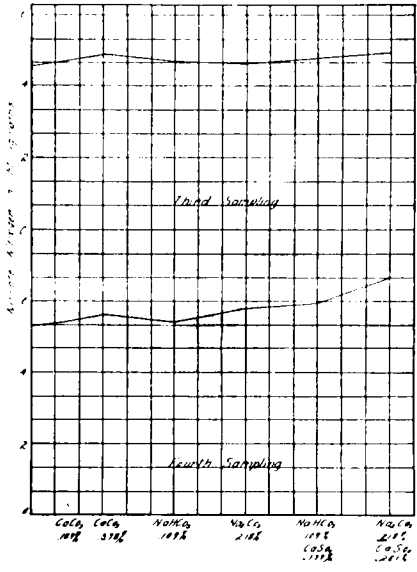


FIG. 13

FIG. 13. EFFECTS OF CaCO₃, NaHCO₃, Na₂CO₃, AND CaSO₄ ON NITRIFICATION IN ALKALI SOIL—THIRD AND FOURTH SAMPLINGS (POT EXPERIMENTS)

occurred at the second sampling, but the difference was too small to be considered significant. The laboratory tests showed a stimulative effect of 0.518 per cent of Na_2SO_4 on nitrification but the effect evidently disappears after the salt has been in the soil for several months and a slight toxic effect is found from this amount of this salt. MgSO_4 gave a beneficial effect on nitrification at all samplings except the second, and this is in accord with the results secured in series III, where 0.022 per cent of MgSO_4 gave a distinct increase in the process. The effect was not so great here and evidently the beneficial influence of the salt gradually decreased as the time since application increased. After a still longer period it is possible that there would have been no effect whatever or the opposite influence from this salt, just as was noted with the Na_2SO_4 .

CaCO_3 in all cases gave a pronounced increase in nitrification and this result checks with that secured in the laboratory test. The effects of this salt evidently persist for a longer period after it is applied to the soil than is the case with the other salts just mentioned. This salt is so essential in soils for the process of nitrification to occur to the best advantage that its effect in increasing the process is easily understandable.

When all four salts were applied together there was no effect on nitrification. The beneficial effect of the calcium carbonate just noted was not apparent in the presence of the other salts. The slight toxic effect from the Na_2SO_4 noted when it was used alone evidently increases in the presence of calcium carbonate and this is offset by the beneficial influence of the CaCO_3 . Harris (4) found this fact to be true in his tests of the alkali salts on crop growth. It also forms a basis for the result secured in series VIII showing the toxic effect of CaCO_3 when applied in larger quantities to the alkali soil.

Alkali soil tests

On examining the results of the nitrification tests in the soils from the alkali pots it is seen that CaCO_3 in both amounts used increased the nitrifying power of the soil. The larger amount gave the larger increase in all cases. The gains were generally quite considerable. Likewise, the NaHCO_3 gave quite considerable increases in the nitrifying power of the soils. These results are in agreement with the laboratory tests in series V which showed decided benefit to nitrification from the use of 0.10 per cent NaHCO_3 . That series showed larger amounts than this to be toxic to the nitrifiers and experiments of others have shown that larger amounts are injurious, hence it is evident that this alkali soil does not contain any considerable amount of NaHCO_3 . With Na_2CO_3 , very similar results were secured as with the bicarbonate. Distinct increases in nitrifying power were noted at every sampling. These results check fairly accurately with those secured in series VI which showed a stimulation in nitrification from the application of 0.10 per cent and a depression at 0.30 per cent. It is quite possible that the turning point occurred in that case at about 0.30 per cent and that 0.20 per

cent would have shown an increase. Larger amounts of this salt, like the bicarbonate, depress nitrification, and hence it would seem that this alkali soil is not extremely high in this salt. When calcium sulfate was used with the sodium salts, in every case, with both salts there was an increased stimulation in nitrification. The calcium sulfate alone in the laboratory tests in series VII showed no effect on nitrification in the alkali soil, so the effect here is evidently due to the combinations with the sodium salts. Series IX showed a slight increase in nitrification when CaSO_4 was applied with Na_2CO_3 in the presence of CaCO_3 , and that result may serve to verify the present. NaHCO_3 in that series did not produce this effect. It is apparent from these results that the nitrification process in this alkali soil was not low as a result of any excess of sodium carbonate or bicarbonate. Calcium carbonate in large amounts likewise did not depress nitrification, so the alkali condition is evidently not due to excess of this salt in the alkali soil. The laboratory tests and the tests in the greenhouse soil several months after treatment were in excellent agreement.

Crop experiment

As has been mentioned, beans were seeded in both the normal and alkali soils in the greenhouse tests. Four separate plantings were made in the

TABLE 12
Crop results of pots containing normal soils

POT NUMBER	TREATMENT	GREEN WEIGHT OF CROP	AVERAGE WEIGHT OF POTS
		<i>grams</i>	<i>grams</i>
1	None.....	33	
2	None.....	39	36.0
3	NaCl —0.005 per cent.....	41	
4	NaCl —0.005 per cent.....	39	40.0
5	Na_2SO_4 —0.518 per cent.....	31	
6	Na_2SO_4 —0.518 per cent.....	31	31.0
7	MgSO_4 —0.023 per cent.....	49	
8	MgSO_4 —0.023 per cent.....	46	47.5
9	CaCO_3 —0.189 per cent.....	42	
10	CaCO_3 —0.189 per cent.....	38	40.0
11	All four salts.....	35	
12	All four salts.....	34	34.5

alkali soil but the seed refused to germinate. Barley was then seeded, but grew only in the pot receiving CaCO_3 , and the per cent of germination was very small. No crop results in the alkali soil were secured, therefore.

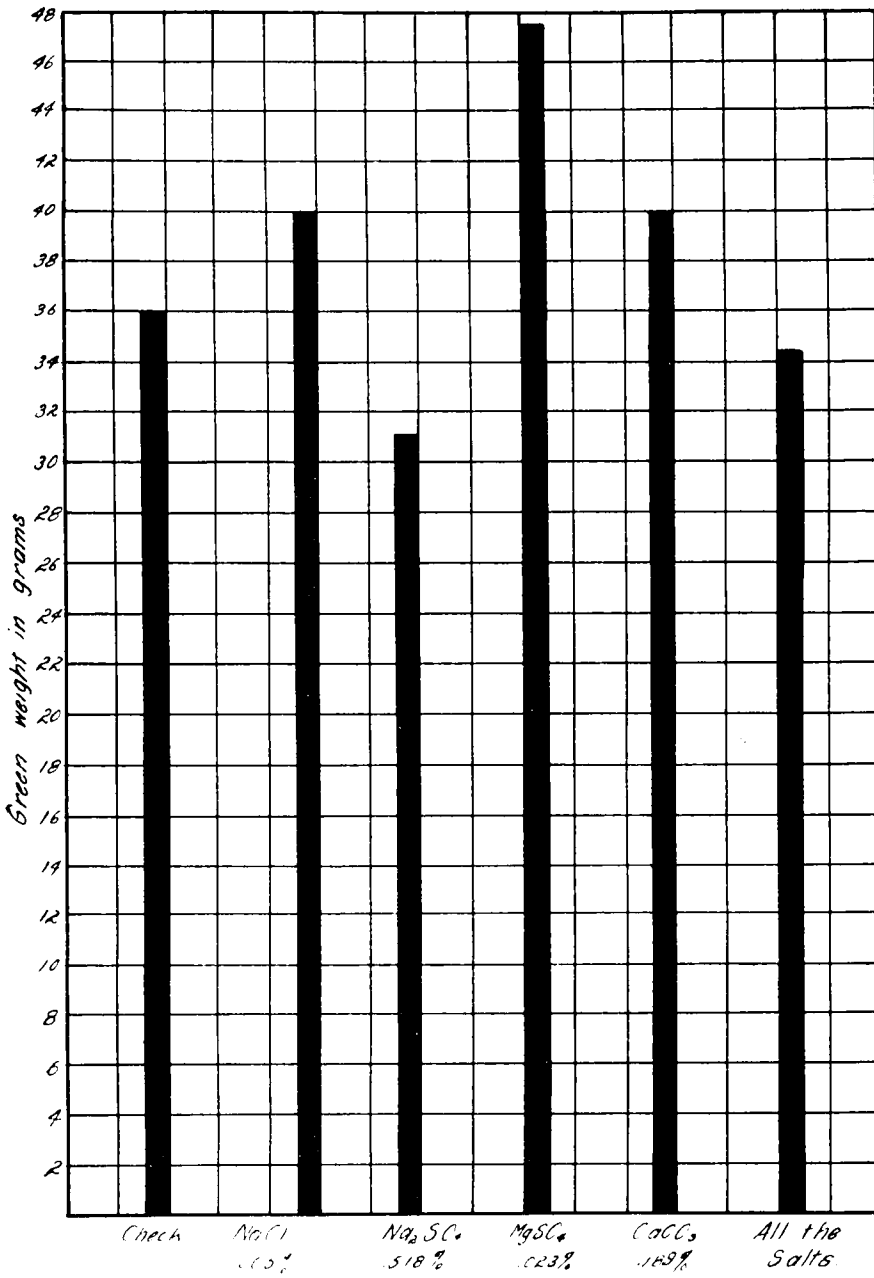


FIG. 14. EFFECTS UPON BEANS GROWN IN NORMAL SOIL WITH THE ADDITION OF VARIOUS ALKALI SALTS

In the normal soil the bean crop was harvested on February 4, and the green weight secured. The results in table 12 and figure 14 show the crop yields. The NaCl gave an increase in the crop, as did the MgSO_4 and CaCO_3 ; the Na_2SO_4 depressed the yield slightly and the combination of all four salts gave no effect on the crop. These results check quite accurately with the results of the nitrification tests in the greenhouse soils and, except for the Na_2SO_4 , with the results in the laboratory. Na_2SO_4 in these latter tests increased nitrification. The amounts of NaCl, MgSO_4 and CaCO_3 used were beneficial, both to crop growth and to nitrification, while the Na_2SO_4 was injurious, except in the laboratory test. All the salts together had no effect. Lipman's (8, 9, 10) conclusion that nitrification tests and crop effects agree, in the case of alkali salt studies is thus confirmed. These crop results agree very well with those of Harris (4) already referred to.

SUMMARY AND CONCLUSIONS

These studies on the effects of alkali salts on nitrification in a normal soil from Wyoming, and on comparative nitrification in normal soil variously treated and in alkali soil, untreated and treated, gave results which, while perhaps not conclusive, are at least indicative of certain relations in the field. These indications may be summarized thus:

1. Nitrification in normal soil is stimulated by small amounts of NaCl, Na_2SO_4 and MgSO_4 , and large amounts of CaCO_3 . These salts become toxic, however, at certain points, which undoubtedly vary in different soils. With this soil in laboratory tests the toxic point was 0.02 per cent NaCl, 2.00 per cent Na_2SO_4 and between 1.5 and 6.00 per cent CaCO_3 . The toxic point for MgSO_4 was not determined.

2. Nitrification in alkali soil was increased by small amounts of NaHCO_3 , Na_2CO_3 and CaCO_3 . Calcium sulfate had no effect. These salts became toxic in this soil at 0.30 per cent for both the sodium carbonate and bicarbonate and at 6.0 per cent for the CaCO_3 . The addition of CaSO_4 with the sodium carbonate and bicarbonate, in the proper amount to react with them, prevented any toxic effect from the largest amount used.

3. The tests in the greenhouse soils checked very closely with the laboratory studies in the case of the alkali soils. In the normal soils the agreement was likewise good, except in the case of Na_2SO_4 . That salt became toxic according to these tests at a concentration of 0.5 per cent. This is a very much lower toxic point than was noted above but nearer that found by others.

4. The effect on the crop grown in normal soil of the alkali salts, with the exception of the Na_2SO_4 , were very similar to the effects on nitrification in both laboratory and greenhouse tests. Increases were secured with NaCl, MgSO_4 and CaCO_3 , but Na_2SO_4 caused a depression in crop and in nitrification in the greenhouse soils. All the salts together had no effect. In general, it seems that nitrification and crops are very similarly affected by alkali salts.

5. Crops refused to grow in the alkali soil, but the injurious factor was evidently not an excess of NaHCO_3 or Na_2CO_3 , as additions of these salts increased nitrification in the soil. The injurious factor was likewise evidently not CaCO_3 , for that compound stimulated nitrification in the alkali soil.

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