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T H E S I S.

on

TOXICITY OF "ALKALI" SALTS

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THE SCHOOL OF AGRICULTURE

by

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P R E F A C E

1. The Field Covered

2. The Object.

3. Experimental.

A. The effect on nitrogen-fixation:-
1. by the application of Sodium chloride
2. " " " " " carbonate
3. " " " " " nitrate
4. " " " " " sulfate

B. The effect on Nitrification:-
1. by the application of Sodium chloride
2. " " " " " carbonate
3. " " " " " nitrate
4. " " " " " sulfate

C. The effect on ammonification:-
1. by the application of Sodium chloride
2. " " " " " carbonate
3. " " " " " nitrate
4. " " " " " sulfate

D. The effect on plant growth:-
1.by the application of Sodium chloride.
2. " " " " " carbonate
3. " " " " " nitrate
4. " " " " " sulfate.

E. The effect on the plant growth:-
1. by the application of Salt Combination.
2. " " " " " "
3. " " " " " "
4. " " " " " "
5. " " " " " "

4. Summary

5. Conclusion

6. Literature Cited

7. Acknowledgment.

The detrimental effect of the accumulation in soils of the so called alkali salts on crop growth has long been recognized, and the seriousness of its control appreciated. Considerable work has been done to determine the concentration at which the different salts become toxic to plant growth. The more recent work, notably that of C. B. Lipman, has pointed out the importance of the effect of alkali on bacterial activities. Most of the work up to the present time has been carried on with single alkali salts rather than with combinations of salts as they exist under field conditions. Some of the work has included certain arbitrary combinations. The purpose of the work recorded in the following pages is to perhaps throw more light on this problem under conditions existing in Oregon.

Historical.

As early as 1884 Warrington (7) showed that the presence of .032 percent of sodium bi-carbonate retarded nitrification and that in the presence of .096 percent of this salt, nitrification was very slight. Schlosing (8) added various salts to soils in quantities not exceeding 485 parts per million, but found no apparent effect on nitrification. Dehrain found that sodium chloride became toxic at a concentration of .1 percent and when higher concentrations were used, nitrification ceased. He also found that sodium nitrate may stop nitrification for a time but at higher concentrations stimulates it.

Lipman J.G. (1) showed that sodium chloride was injurious to nitrifying organisms; and that (4) a distinct decrease was produced as the application of sodium chloride was increased. When .1 percent was added, nitrification was greatly diminished.

Both Lipman J. G. and Brown P. E. (2) found that nitrification was accelerated by sodium nitrate. In a later work (10) they found that sodium nitrate increased the accumulation of nitrates in soils but that a certain periodicity in the accumulation existed. This would account for the different results obtained by different investigators. McBeth and Wright (12) found that carbonates, chlorides, and sulfates inhibited nitrification and that the former were more injurious than the latter.

In a recent work, Brown and Hitchcock (18) show that nitrification in a normal soil is stimulated by small amounts of sodium chloride, sodium sulphate, magnesium sulphate and by large amounts of calcium carbonate. Their toxic points for a normal soil under laboratory conditions are sodium chloride .02 percent, sodium sulphate 2 percent, and calcium carbonate between 1½ and 6 percent. Nitrification in an alkali soil was increased by small amounts of sodium bi-carbonate, sodium carbonate and calcium carbonate. Sodium carbonate and sodium bi-carbonate became toxic at .3 percent and calcium carbonate at .6 percent. When crops were grown on the soil, a similar effect was noted on the crop as in the case of nitrification.

Recent investigations by Kelley (19) on nitrification in semi-arid soils show that .05 percent of sodium carbonate is distinctly toxic to the nitrification of 1 percent dried blood; but that concentrations as high as .4 percent had no effect on the nitrification of 1 percent dried blood. When .15 percent of ammonium sulphate was used, .1 percent of sodium carbonate became toxic to nitrification; but this same amount of sodium carbonate stimulated nitrification when .0635 percent of am-

monium sulphate was used. Similar results were obtained when sodium sulphate was used in place of the carbonate.

According to Engberding (3) ammonium sulphate, sodium nitrate, potassium nitrate and caustic lime all increased the bacterial content of soil, but on the other hand decreased the nitrogen fixing power. Lipman C. B. and Sharp (15) found that .5 percent to .6 percent of sodium chloride was toxic to nitrogen fixation, and that 1.25 percent of sodium sulphate and .4 to .5 percent of sodium carbonate was also toxic. Sodium chloride was the only one that acted as a stimulant at any concentration.

Work by Peck (4) showed that sodium nitrate depressed ammonification while the sulphate, phosphate and carbonate of calcium caused an increase. Lipman's J. G. (2) work showed an increase in ammonification due to sodium nitrate, while work done by Lipman C. B. (13) showed that ammonification was inhibited by the chloride, sulphate and carbonate of sodium. Sodium chloride became toxic at a concentration between .1 and .2 percent, sodium sulphate at .4 percent and sodium carbonate at 2 percent. A stimulating effect was noticed in some cases for sodium carbonate but none in the case of the sulphate and chloride. In a later work (14) he found the following toxic points; for sodium chloride less than .1 percent, for sodium sulphate .35 percent and for sodium carbonate .025 percent. All except the carbonate acted as stimulants.

Recently Lipman C. B. (16) has demonstrated that there exists as measured by ammonification a true antagonism between

sodium chloride and sodium sulphate and between sodium sulphate and sodium carbonate. In a previous work (6) he showed that the chlorides of calcium, magnesium, potassium and sodium were toxic in the order names. He also found that no antagonism existed between the calcium ion and the magnesium ion or between the calcium and sodium ion. Marked antagonism existed between calcium and potassium, magnesium and sodium and between potassium and sodium.

Greaves (17) states that at times the stimulating effect or even the toxic influence may be due to the liberation of substances within the molecules of the salt; but he makes no attempt to demonstrate the same. In his work he shows that the toxicity of the chlorides, nitrates, sulphates and carbonates of sodium, potassium calcium, magensium, maganese and iron, determined by ammonification, are controlled by the electro negative ion. As a general rule, to which there are exceptions, chlorides are the most toxic, the nitrates sulphates and carbonates follow in the order named. He also states that the increased osmotic pressure exerted by these salts exerts a great influence in retarding bacterial activities. This tho is not the only factor. The main factor is probably a physiological one, due to the action of the salts upon the living protoplasm of the cells, changing the chemical and physical properties so they cannot function normally. The salts of sodium chloride, calcium chloride, sodium sulphate and calcium nitrate are very toxic to ammonifying organisms and their presence to any extent in the soil will greatly reduce ammonification. The compounds that are the most active

stimulants for higher plants are also the most active for ammonifying organisms.

Harris (20) has carried on quite extensive work to determine the toxicity of alkali salts both alone and in combination to plant growth. In his work he concludes with the following summary: "Land containing more than the following percentages of soluble salts is probably not suited for ordinary crops without reclamation. In loam soils, chlorides .3 percent, nitrates .4 percent, carbonates .5 percent and sulphates 1 percent. In coatse sandy soil, chlorides .2 percent, nitrates .3 percent, carbonates .3 percent and sulphates .6 percent.

Experimental.

The work carried on was divided in three phases, namely:

(a) the determination of the toxic points of sodium chloride, sodium nitrate, sodium carbonate and sodium sulphate on peas and wheat.

(b) The determination of the toxic point for peas and for wheat when a combination of alkali salts where used as found under field conditions by analysis.

(c) The determination of the effect of sodium chloride, sodium nitrate, sodium carbonate and sodium sulphate upon ammonification, nitrification and notrogen fixation.

The soil used was obtained from the Eastern Oregon Branch Experiment Station of Moro, Sherman County, Oregon. This soil is a heavy silt loam soil and is quite extensive in area thru out the Columbia Basin. Under normal condition it is quite productive and when properly handled produces large

crops of small grains. Under dry farming conditions alkali spots are beginning to gradually develop, while under irrigated conditions, due probably to over irrigation alkali soon appears. The following table shows the chemical and mechanical composition.

Table I

Chemical Analysis		Mechanical Analysis	
Silica (SiO_2)	53.04	Fine Gravel	0.65
Potash (K_2O)	1.18	Coarse Sand	1.72
Soda (Na_2O)	2.06	Medium Sand	1.50
Lime (CaO)	7.32	Fine Sand	10.00
Magnesia (MgO)	3.15	Very Fine Sand	11.10
Ferric Oxide (Fe_2O_3)	10.40	Silt	69.60
Alumina (Al_2O_3)	15.92	Clay	11.27
Phos.Pentoxide (P_2O_5)	.28		
Volatile Matter	6.56		
Humus	1.95		

The chemical analyses of the alkali salts of five different soils were obtained. These soils were selected so that in each one, one of the sodium salts predominated. The analysis of each salt is shown in the following table.

Table No. 2

Composition of Alkali Salts

	No.1.	No.2.	No. 3	No.4.	No. 5	No.6
KCl	4.00					6.27
Na_2SO_4		4.67	93.40	58.50		
$NaNO_3$		12.96				87.14
Na_2CO_3		75.95		22,9	2.45	4.03
NaCl	81.15	1.46	6.60	18.6		2.56
Na_2PO_4		4.94				
$CaCl_2$	0.25					
$MgCl_2$	7.71					
$CaSO_4$	6.61				4.05	
$NaHCO_3$	0.28				88.26	
$KHCO_3$					1.76	
$CaCO_3$					3.48	

For the greenhouse tests, 250 grams of soil was placed in tumblers and brought up to optimum moisture content, The different percentages of alkali salts were added and after two weeks the seed was planted. The soils were kept at the optimum moisture content throughout the experiment. Five weeks after germination took place the plants were harvested and the dry weight obtained.

For the work for the bacteriological tests, 100 grams of soil was used. The soil was placed in tumblers and the different salts were added. The soil then was brought to optimum moisture content and an infusion of fresh soil was added to each to insure vigorous bacterial action. The soil was incubated for four weeks at room temperature, the moisture content being kept constant by the addition of sterile distilled water.

Series I

The Effect of NaCl on Nitrogen Fixation, Nitrification and Ammonification.

Each series was run for nitrogen fixation, nitrification and ammonification and differ only from one another in the percentage of the salt used. All work was done in duplicate and the results are expressed in milligrams per million parts of soil. The arrangement and results of Series I are shown in Table III and Figure I.

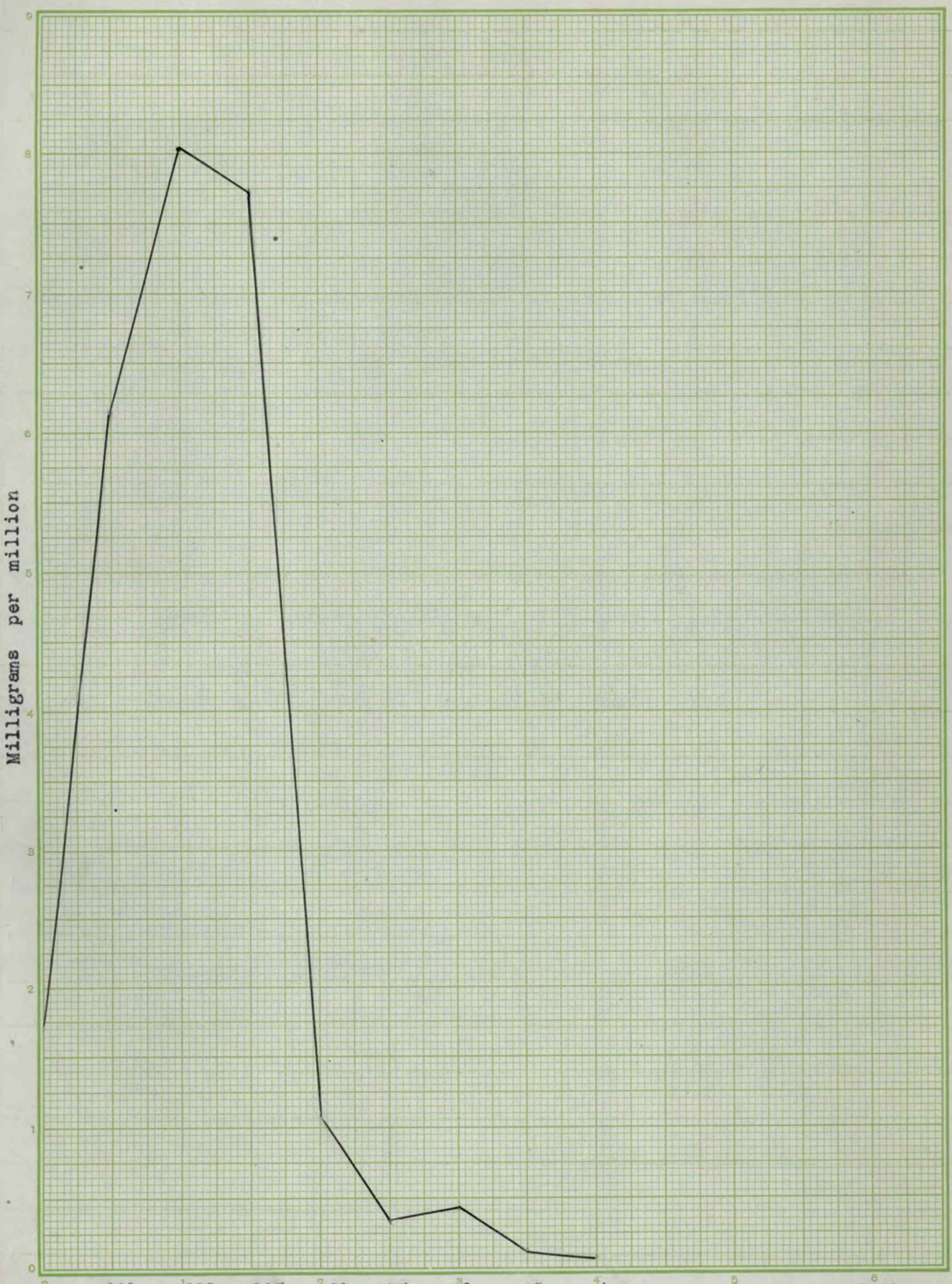
Table III.

Effect of NaCl on Nitrogen Fixation, Nitrification and Ammonification.

No.	NaCl.	Total N mg.p.m.	Average mg. p.m.	NO_3 mg.p.m.	Average mg. p.m.	NH_3 mg. p.m.	Average mg. p.m.
1	none	341		50.8		10.06	
2	none	341	341	89.2	70.0	9.9	9.9
3	.001	1262		57.0		7.0	
4	.001	1195	1228.5	80.9	68.9	6.8	10.2
5	.003	1333		80.0		10.03	
6	.003	1885	1609	60.4	70.2	10.80	10.5
7	.005	1701		63.0		7.5	
8	.005	1388	1544.5	64.0	63.5	6.6	7.0
9	.010	322		69.0		4.8	
10	.010	101	211.5	58.0	63.5	5.09	4.9
11	.050	68		50.0		5.8	
12	.050	71	69.5	37.7	43.8	6.5	6.1
13	.100	76		42.0		5.9	
14	.100	94.4	85.2	34.8	38.4	6.8	6.3
15	.200	35.8		44.0		9.0	
16	.200	7.2	21.5	44.0	44.0	8.4	8.7
17	.400	14.0		30.1		7.4	
18	.400	7.2	10.6	35.0	32.5	7.3	7.3

According to these results NaCl in small amounts acted as a stimulant for nitrogen fixation. The greatest amount of nitrogen was fixed at a concentration of .003 percent. At .01 percent a distinct decrease occurred which continued as the concentration was increased. No marked increase in nitrification was shown in any case and at a concentration as low as .05 percent a decrease occurred as compared with the check.

Nitrogen fixation with NaCl.



Scale
½" per 100 mg.

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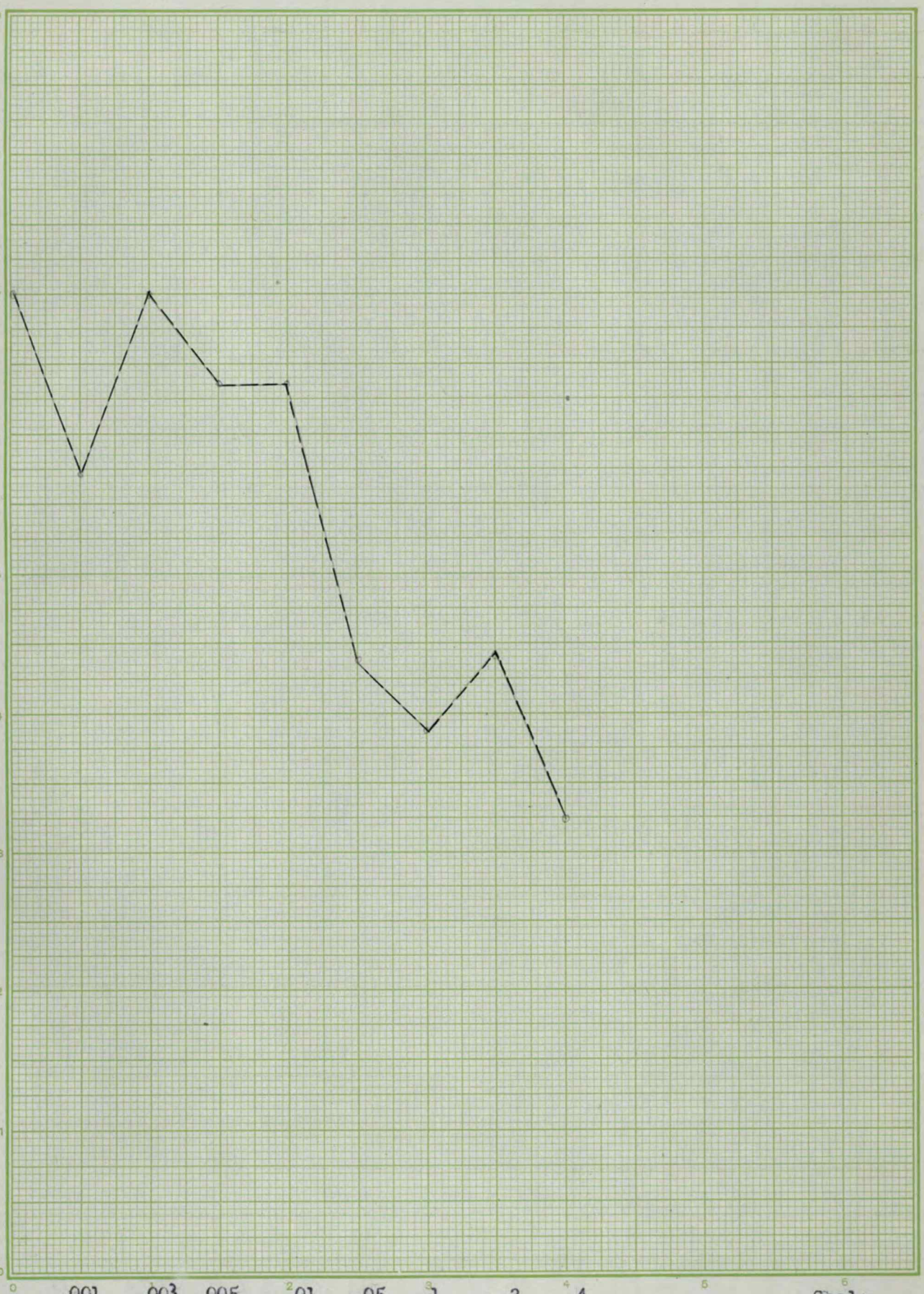
Nitrification with NaCl.



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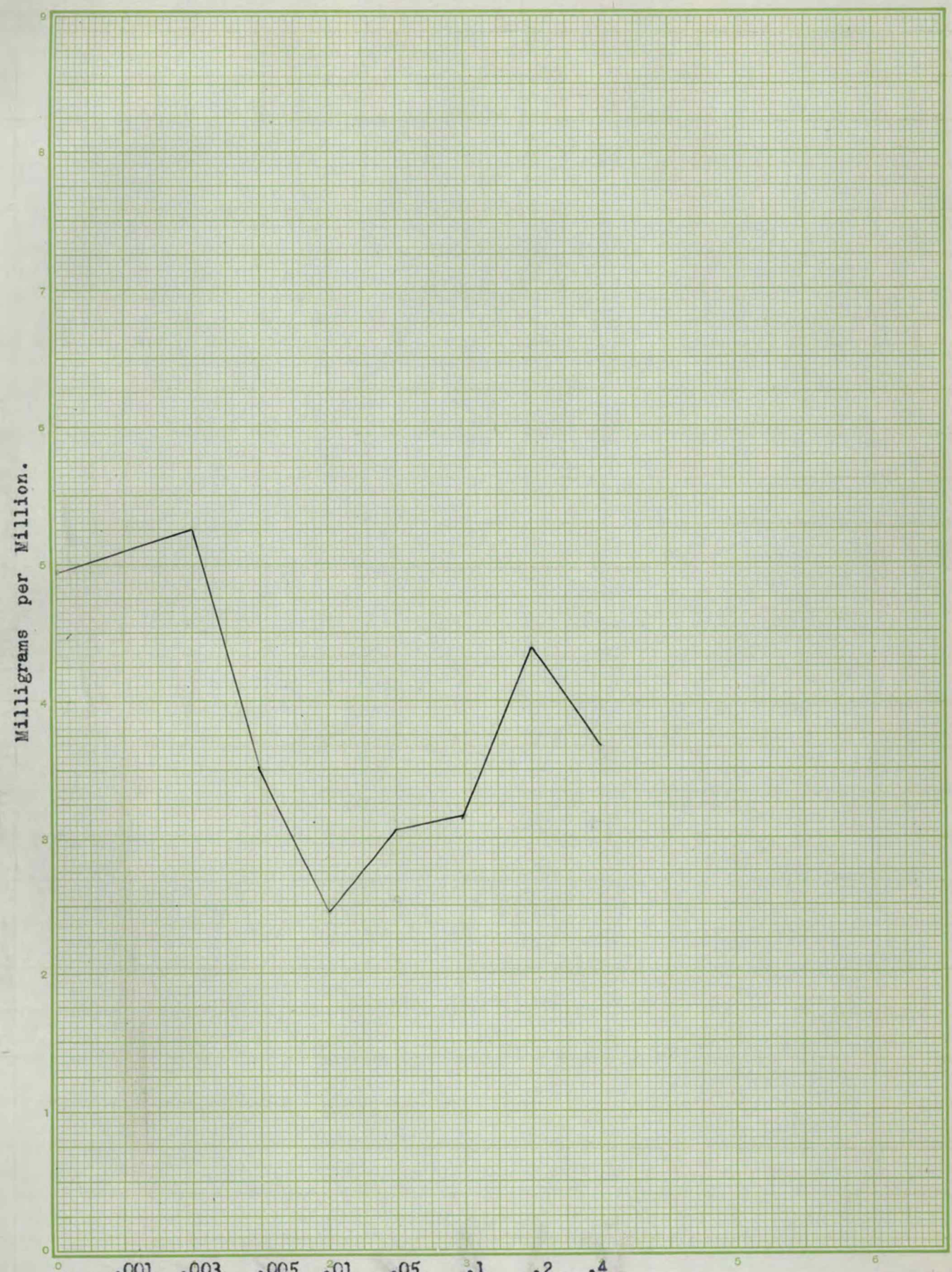
Scale
1" to 10 mg.

Ammonification with NaCl.



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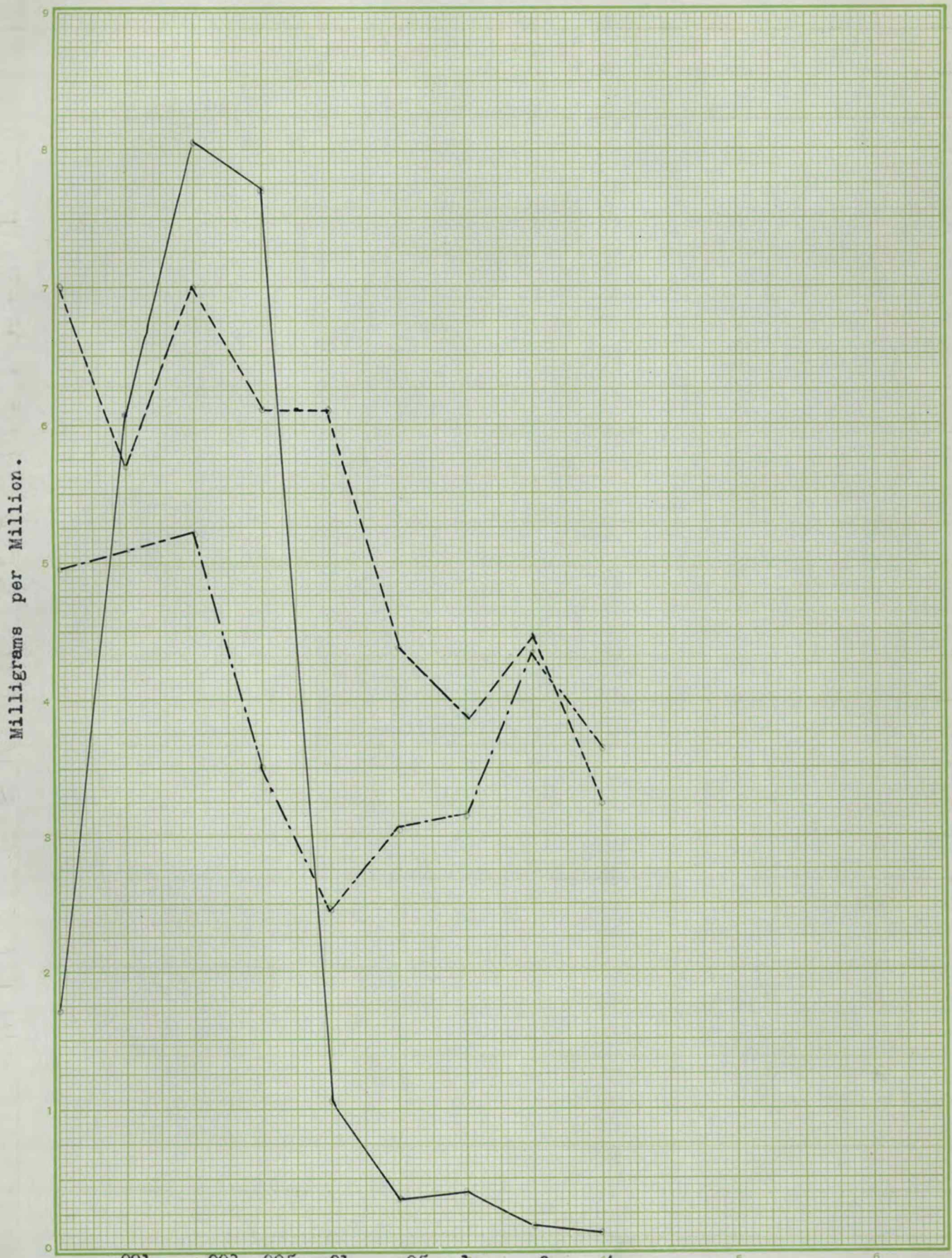
Per cent salt.

Scale
½" to 1 mg.

Total Nitrogen fixation Nitrification and Ammonification with NaCl.



Total N
" NO_3
" NH_3

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Per cent salt.

Scale
N. - ½" to 100 mg
NO_3 1" " 10 "
NH_3 ½" " 1 "

Ammonification was not stimulated to any extent by any of the concentrations. A slight increase was shown at .003 percent while all others were lower than the check.

Series II.

The Effect of Na_2CO_3 on Nitrogen Fixation, Nitrification and Ammonification.

This series was arranged and carried on similar to Series I, the only difference being in concentration of the salt used. The concentrations used were higher than in the case of NaCl.

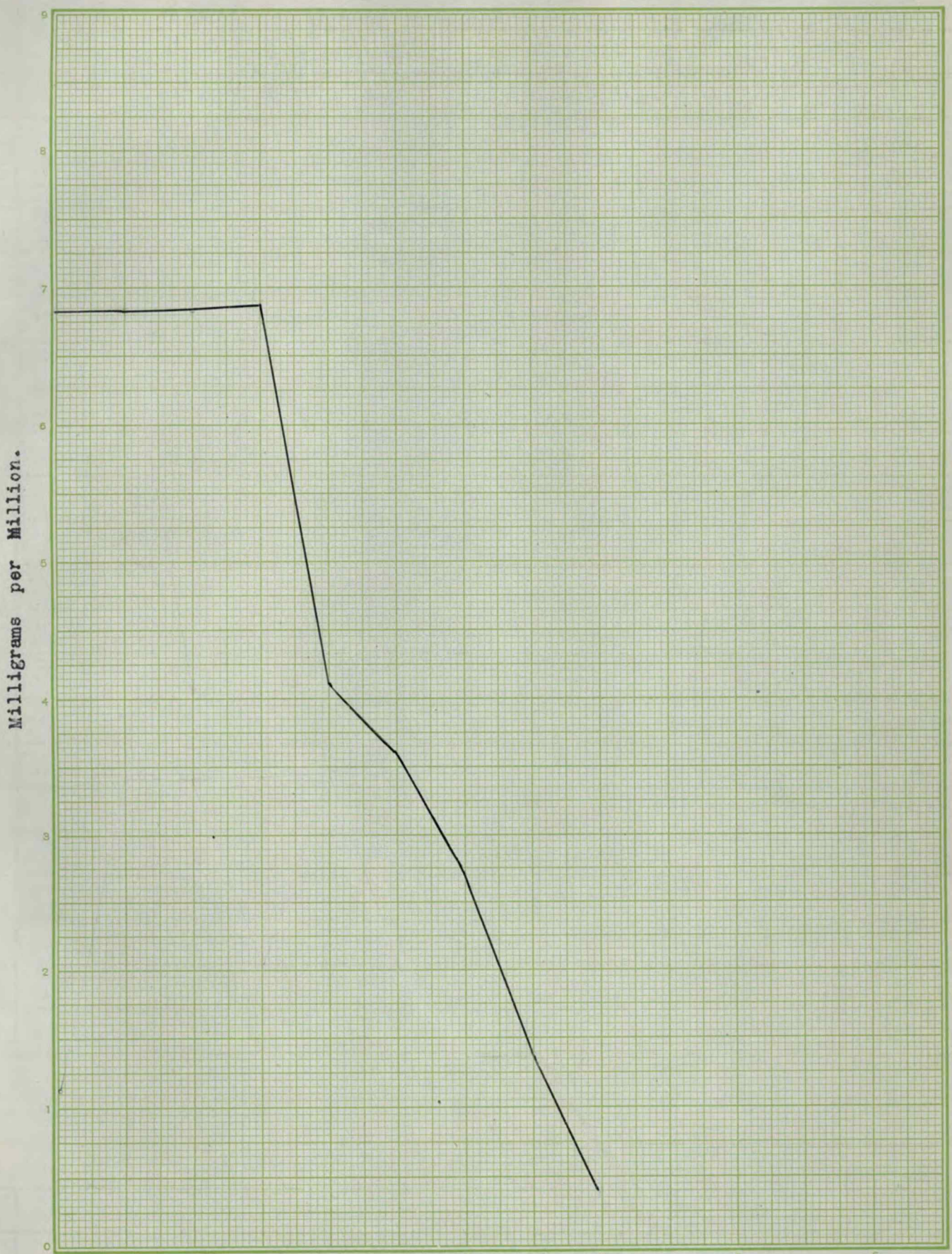
Table IV.

Effect of Na_2CO_3 on Nitrogen Fixation, Nitrification and Ammonification.

No.	Na_2CO_3	Total N mg. p.m.	Average mg. p.m.	NO_3 mg. p.m.	Average mg. p.m.	NH_3 mg. p.m.	Average mg. p.m.
1	none	341		50.8		10.06	
2	none	341	341	89.2	70.0	9.9	9.90
3	.01	341		102.1		17.0	
4	.01	341	341	294.0	198.0	16.6	16.80
5	.03	341		55.0		21.1	
6	.03	341	341	117.4	86.0	7.7	14.40
7	.05	342		89.0		15.9	
8	.05	343	342	106.2	97.5	7.4	11.60
9	.10	205		127.0		13.1	
10	.10	205	205	152.0	139.5	13.1	13.10
11	.20	137		33.4		10.5	
12	.20	138	137.5	174.0	103.7	10.8	10.60
13	.50	138		139.0		11.0	
14	.50	137	137.5	139.0	139.0	13.2	12.10
15	.80	68		68.8		10.5	
16	.80	68	68	67.0	67.9	10.8	10.60
17	1.00	27		57.6		9.7	
18	1.00	14	20.5	57.0	57.3	10.0	9.80

At the concentrations used in this work Na_2CO_3 showed no stimulating effect on nitrogen Fixation. Perhaps if concentrations as low as those used in the NaCl series, had been used, a stimulating effect might have occurred. This of course would then be at a concentration less than .01 percent. Nitrification was increased by concentrations up to .5 percent. Above this it was inhibited when compared with the check. The

Nitrogen fixation with Na_2CO_3



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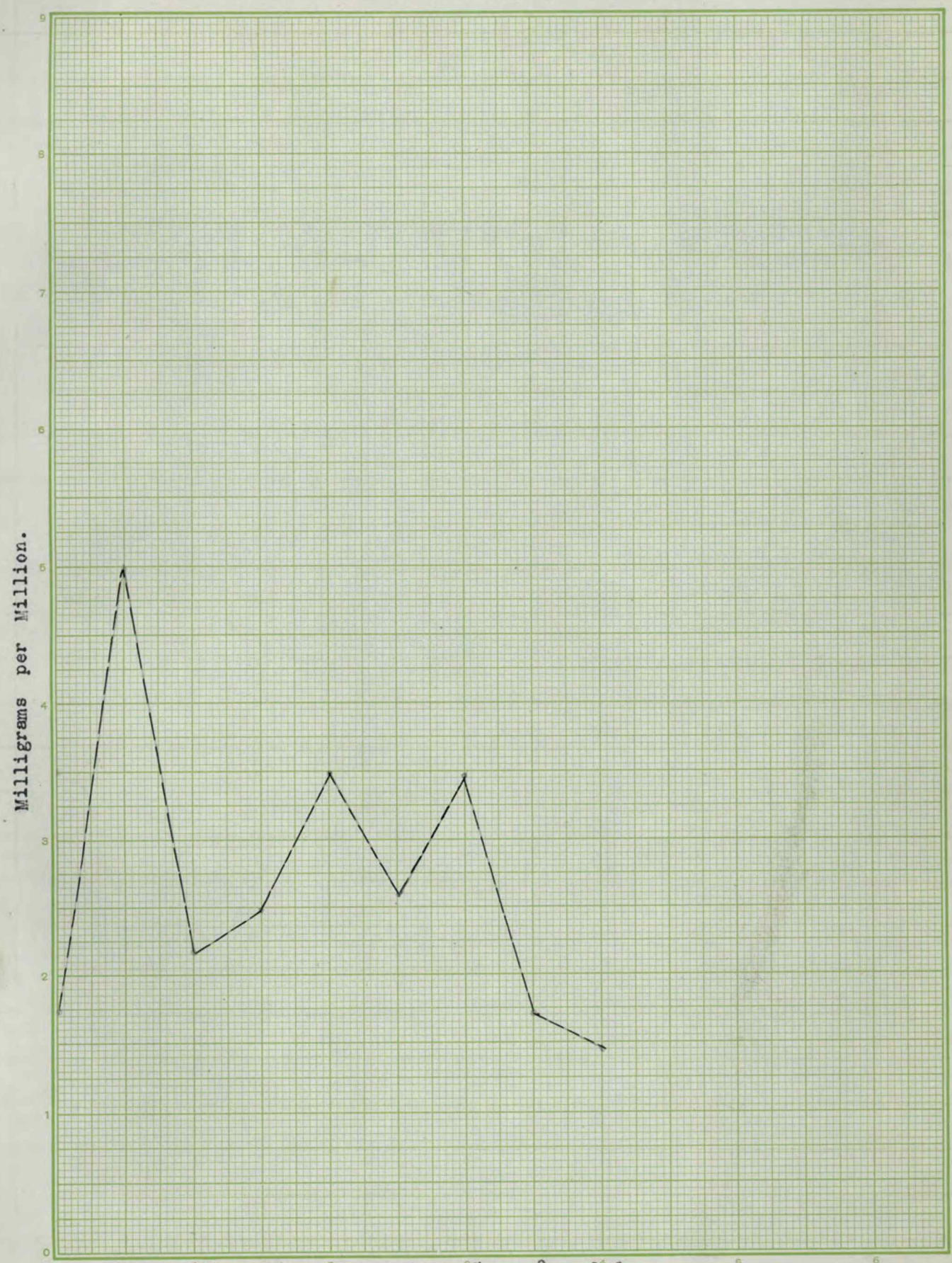
Scale
1" to 100 mg.

Nitrification with Na_2CO_3



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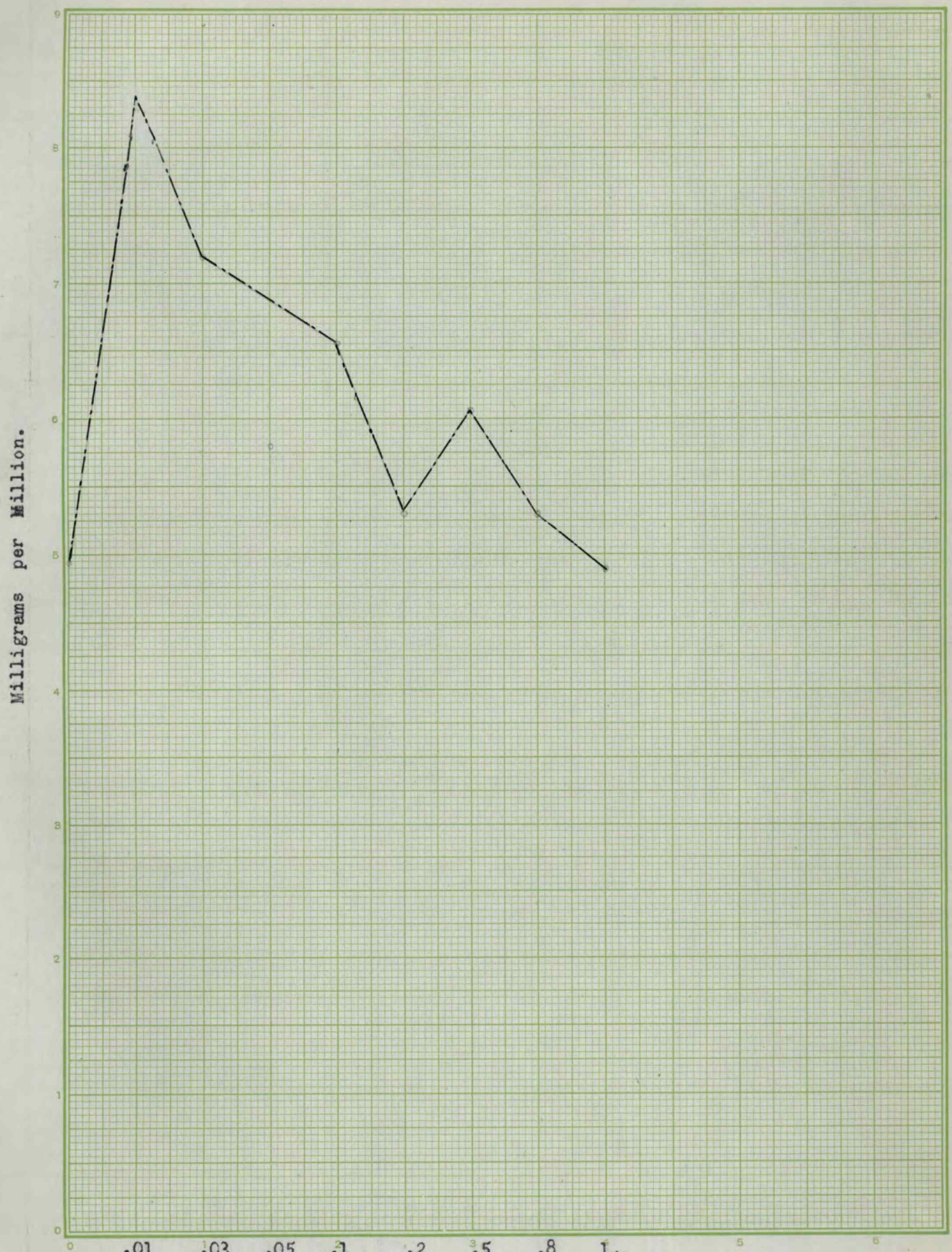
Ammonification with Na_2CO_3



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Per cent salt.

Scale
½" to 1 mg.

Total Nitrogen fixation Nitrification and Ammonification with Na_2CO_3

Total N.
" NO_3
" NH_3

Scale
N. - 2" to 100 mg
NO_3 - $\frac{1}{4}$" " 10 "
NH_3 - $\frac{1}{2}$" " 1 "

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sodium carbonate increased ammonification at concentration up to as high as .8 percent. The greatest stimulation took place at .01 percent and as the concentration was increased there was a gradual decrease in the ammonification.

Series III

The Effect of $NaNO_3$ on Nitrogen Fixation, Nitrification and Ammonification.

This series deals with the effect of sodium nitrate on bacterial activities. The results on the amounts of nitrogen fixed in the case of nitrogen fixation are the amounts above what was added to the soil by the addition of the $NaNO_3$. The same is true for the results given in the case of the nitrates in nitrification.

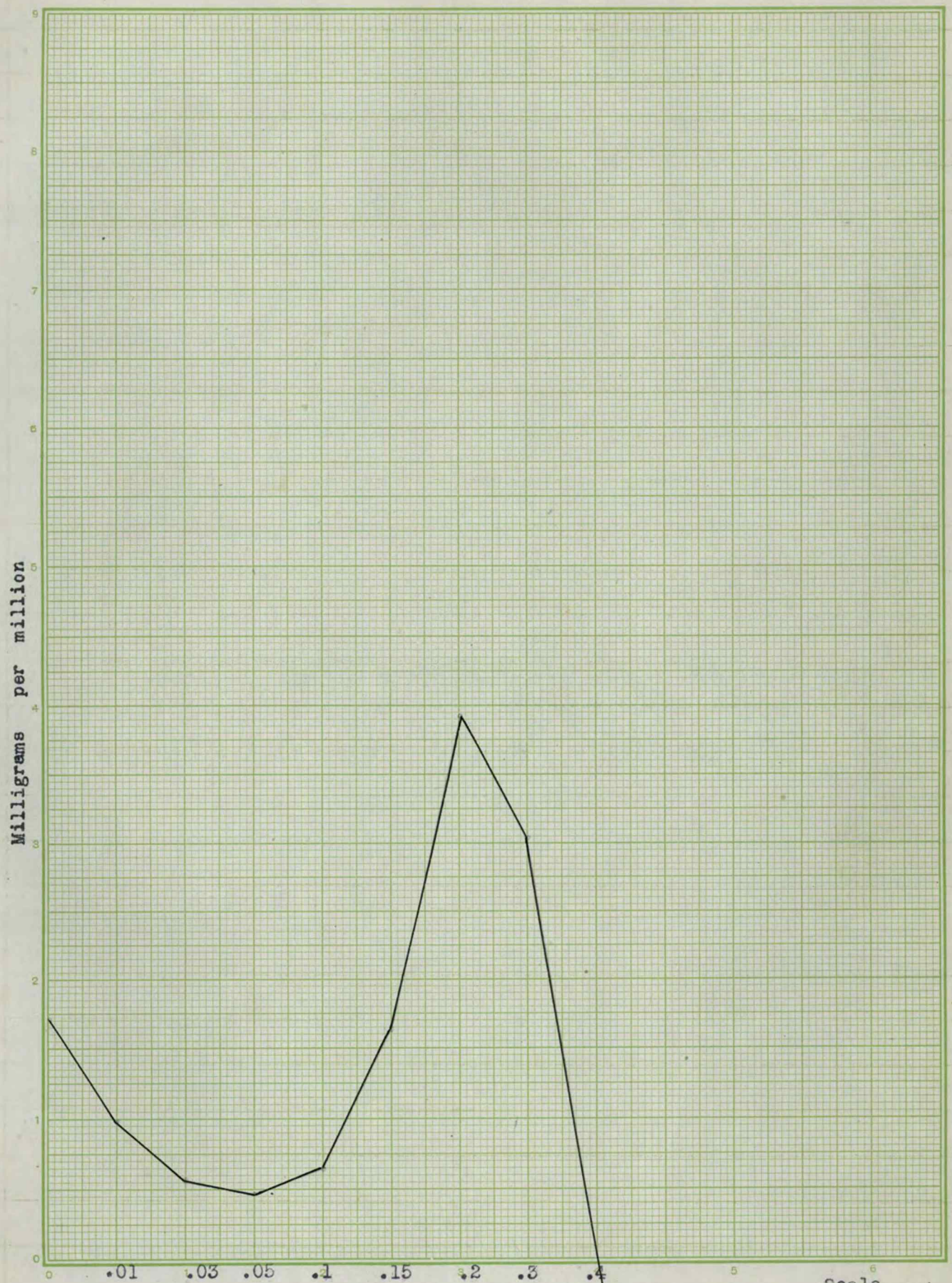
Table V.

Effect of $NaNO_3$ on Nitrogen Fixation, Nitrification and Ammonification .

No.	%$NaNO_3$	Total N mg. p.m.	Average mg. p.m.	NO_3 mg. p.m.	Average mg. p.m.	NH_3 mg. p.m.	Average Mg.p.m.
1	none	341		50.8		10.06	
12	none	341	341	69.2	70	9.9	9.9
13	.01	359		69.0		8.6	
4	.01	72	215.5	69.0	69	8.7	8.7
5	.03	173.2		-23.		42.1	
6	.03	158	165.6	-13	-18	12.6	27.3
7	.05	129		-36		37.1	
8	.05	216	172.5	-32	-34	37.2	37.2
9	.10	288		-64		12.7	
10	.10	302	295	-82	-73	6.62	9.6
11	.15	504		-219		13.0	
12	.15	647	575.5	-223		7.45	10.2
13	.20	1079		-18		10.0	
14	.20	1150	1114.5	-40	-29	10.6	10.3
15	.30	1663		-420		10.1	
16	..30	1052	1357.5	-466	-443	9.5	9.8
17	.40	590		301		7.2	
18	.40	528	559	511	406	7.2	7.2

Small amounts of $NaNO_3$ had no apparent stimulating effect on nitrogen fixation. Up to a concentration of .15 percent, less nitrogen was found than in the checks. As the concentra-

Nitrogen fixation with $NaNO_3$



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Scale ½" to 100 mg.

Per cent salt

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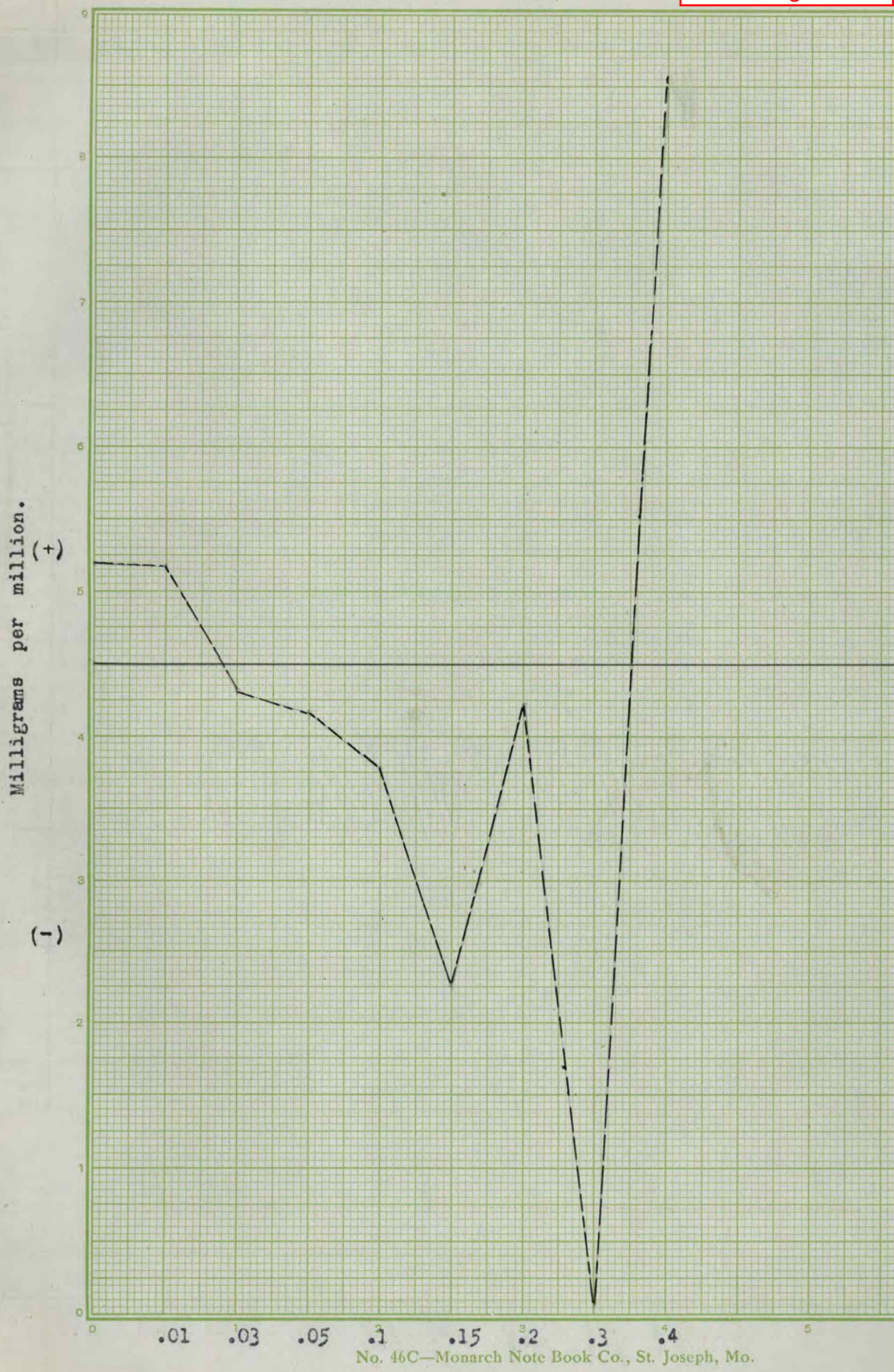
Nitrification with $NaNO_3$



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Ammonification with $NaNO_3$

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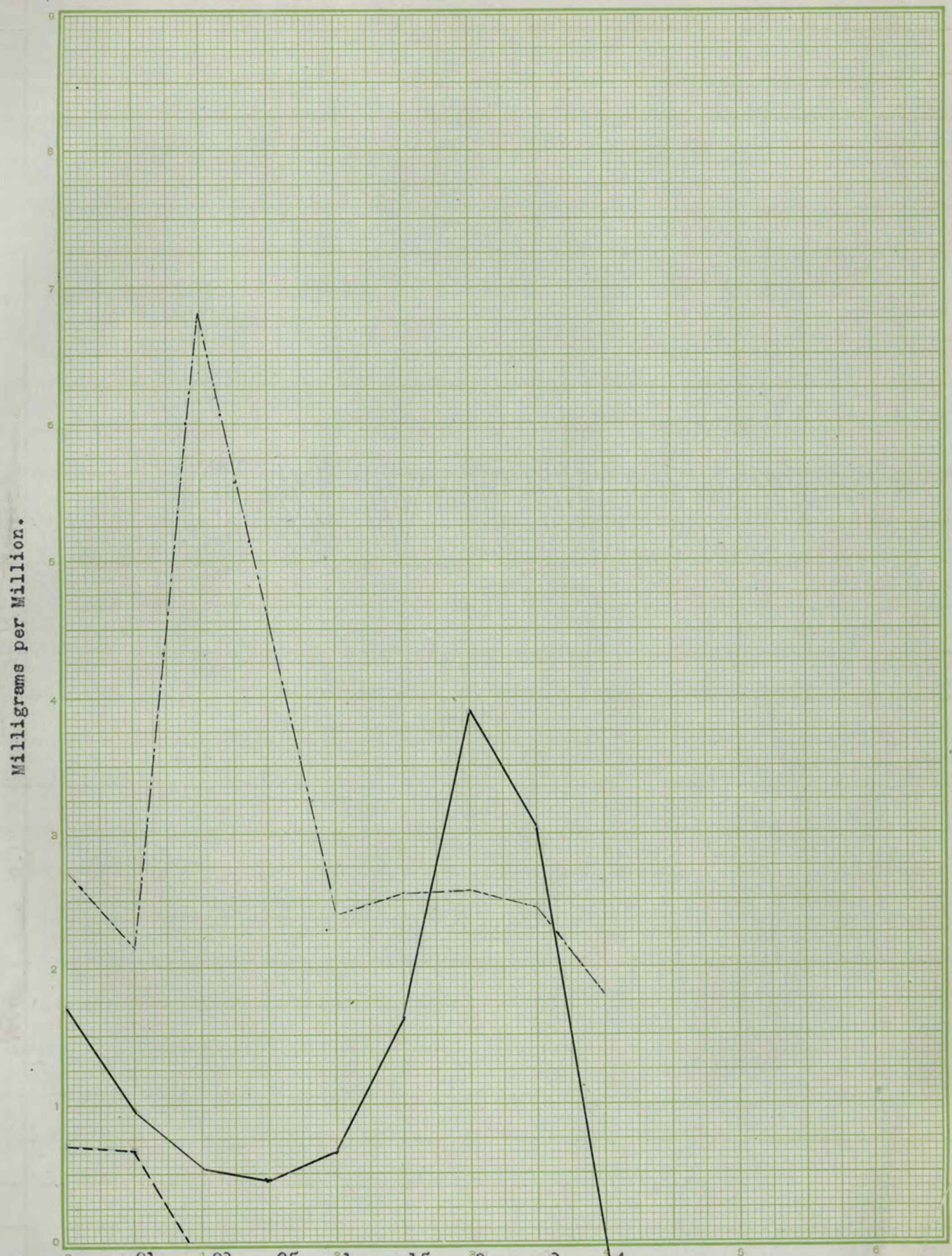
Per cent salt.

Total Nitrogen fixation Nitrification and Ammonification with $NaNO_3$



Total N.
" NO_3
" NH_3

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Scale
N. - ½" to 100 mg.
NO_3 - 1" " 100 "
NH_3 - ¼" " 1 "

tions increased up to .3 percent the amount of nitrogen fixed increased. At percentages higher than this there was a decided decrease. The results of $NaNO_3$ on nitrification are not very consistent. From these results, it appears that nitrification is not only depressed but that there is actually a loss of nitrate below that what was added by the salt. At the highest concentration, .4 percent there was a gain in nitrates. This result corresponds with those of Dehrain (8) who found that nitrates may stop nitrification for a time but later stimulates it.

Ammonification in this series was slightly inhibited by a concentration of .01 percent of $NaNO_3$. The greatest increase was with a concentration of .05 percent. At higher concentration there was a gradual falling off of ammonification and at .3 percent it was inhibited.

Series IV.

The Effect of Na_2SO_4 on Nitrogen Fixation, Nitrification and Ammonification.

In this series the concentration of the salt used is a great deal higher than in the case of any of the other series.

Table VI

Effect of Na_2SO_4 on Nitrogen Fixation, Nitrification and Ammonification.

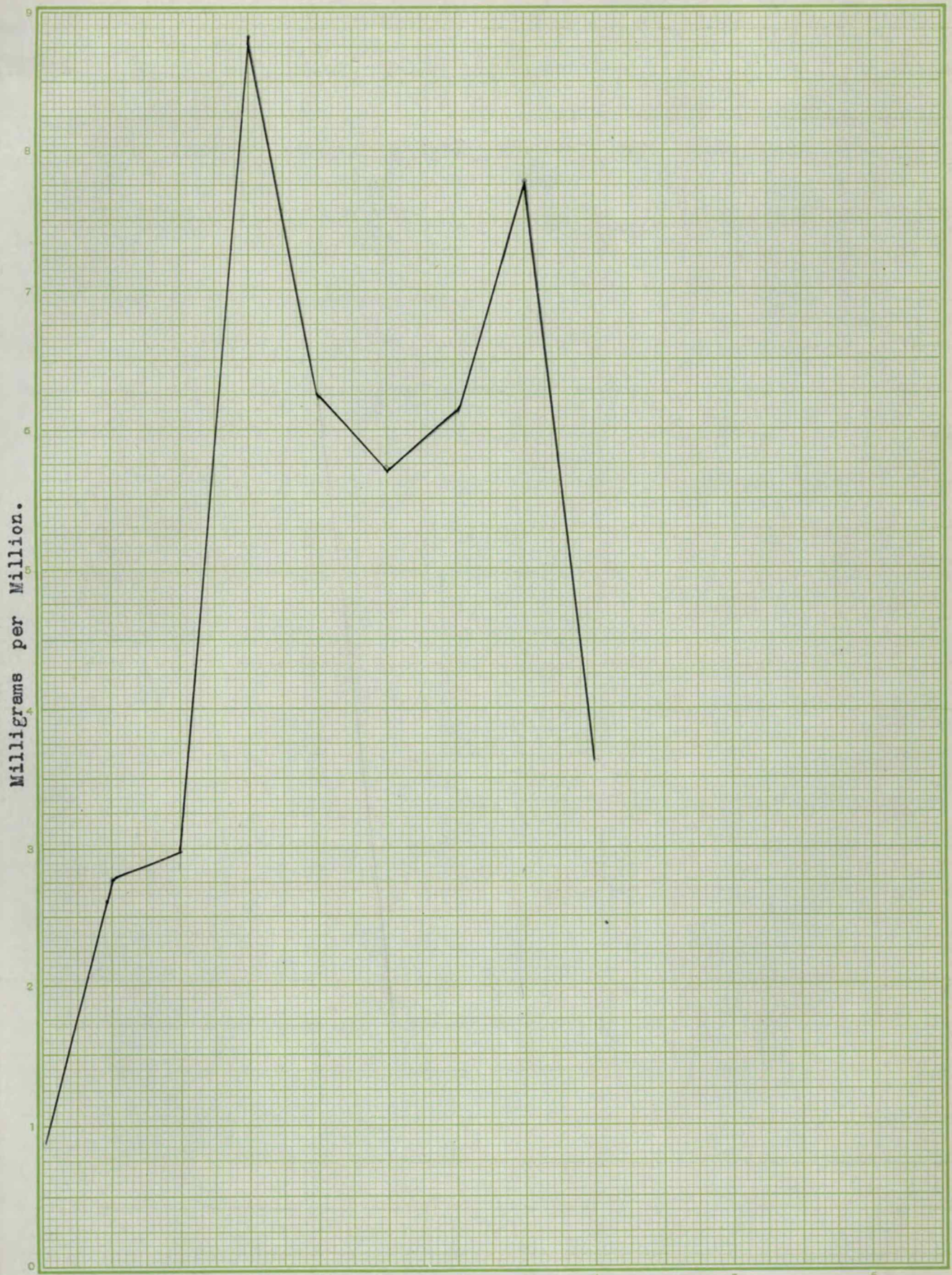
No.	%Na_2SO_4	Total N mg. p.m.	Average mg. p.m.	NO_3 mg. p.m.	Average mg. p.m.	NH_3 mg. p.m.	Average mg. p.m.
1	none	341		50.8		10.06	
2	none	341	341	89.2	70.0	9.9	9.9
3	0.1	1172		115.0		2.05	
4	0.1	1058	1115	119.1	117.0	7.1	4.5
5	0.2	1150		107.0		14.2	
6	0.2	1224	1187	74.0	90.5	10.2	12.2
7	0.4	3230		85.9		17.4	
8	0.4	3826	3528	86.0	86.0	12.2	14.8
9	0.6	1228		71.0		10.7	
10	0.6	3971	2599	74.1	72.0	7.4	9.0
11	1.0	2080		69.0		10.9	
112	1.0	2504	2292	73.0	71.0	13.1	12.0
13	2.0	2519		68.8		12.2	
14	2.0	2373	2446	66.0	67.4	12.1	12.1
15	3.0	3240		60.0		11.3	
16	3.0	2988	3114	57.0	58.5	11.9	16.6
17	4.0	1526		38.0		14.7	
18	4.0	1385	1455	27.6	32.8	19.7	17.2

These results showed rather conclusively that Na_2SO_4 stimulated nitrogen fixation with all the different percentages used. The maximum occurred with a concentration of .4 percent although the amount found at a concentration of 3 percent was almost equal. Nitrification was increased by concentrations as high as .4 percent. Above this concentration there was a gradual falling off. None of the concentrations used inhibited ammonification. The maximum amount took place at the highest concentration. Of all the salts used in this work Na_2SO_4 proved to be the least toxic as measured by all three of the bacterial activities studied.

Crop Experiments.

The crop experiments were carried on in two sets of series, with wheat and with field peas. The one set was carried on to determine the effect of single alkali salts on crop growth, the other when the alkali salts were used in combination as found

Nitrogen fixation with Na_2SO_4



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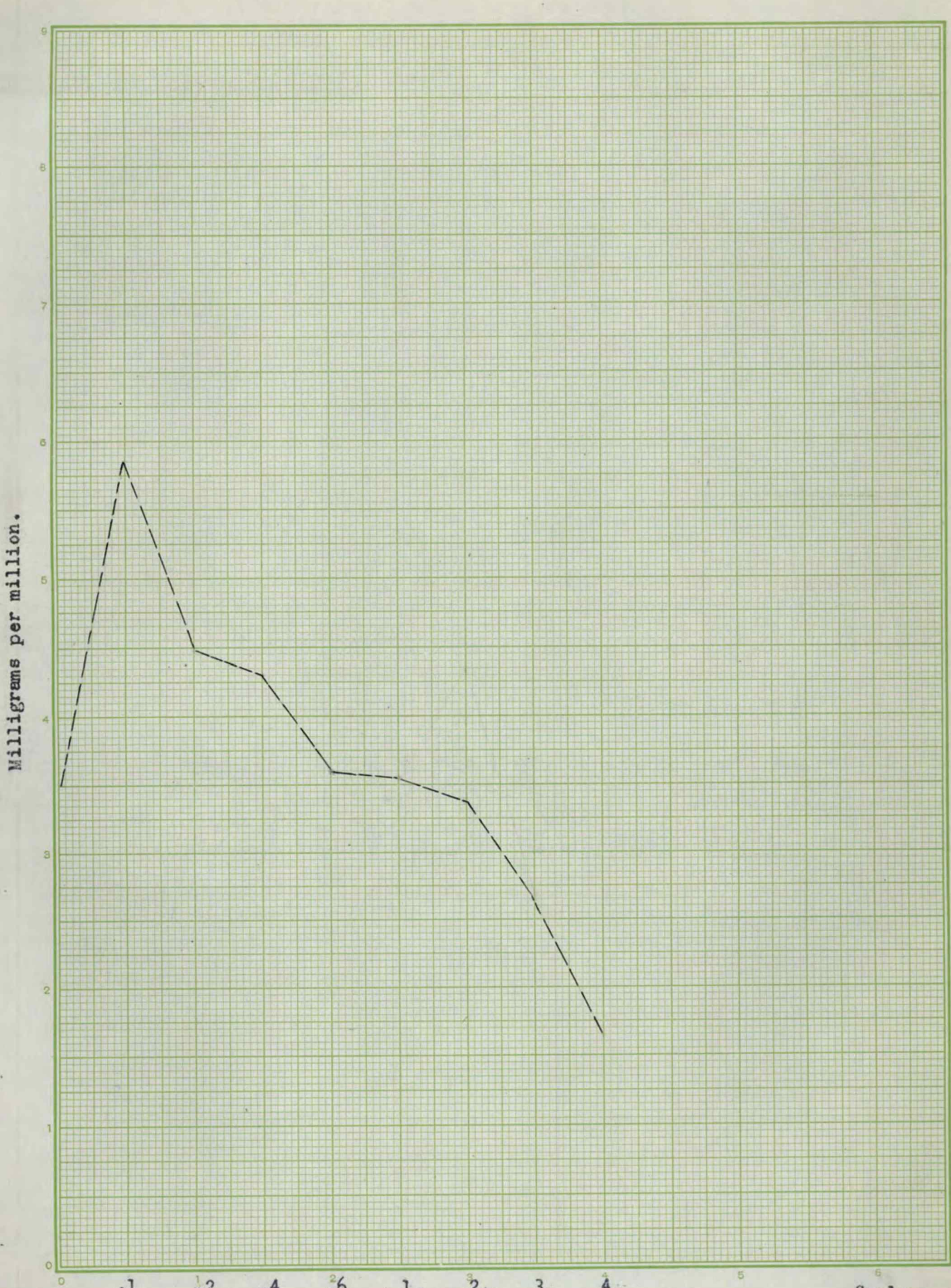
Nitrification with Na_2SO_4



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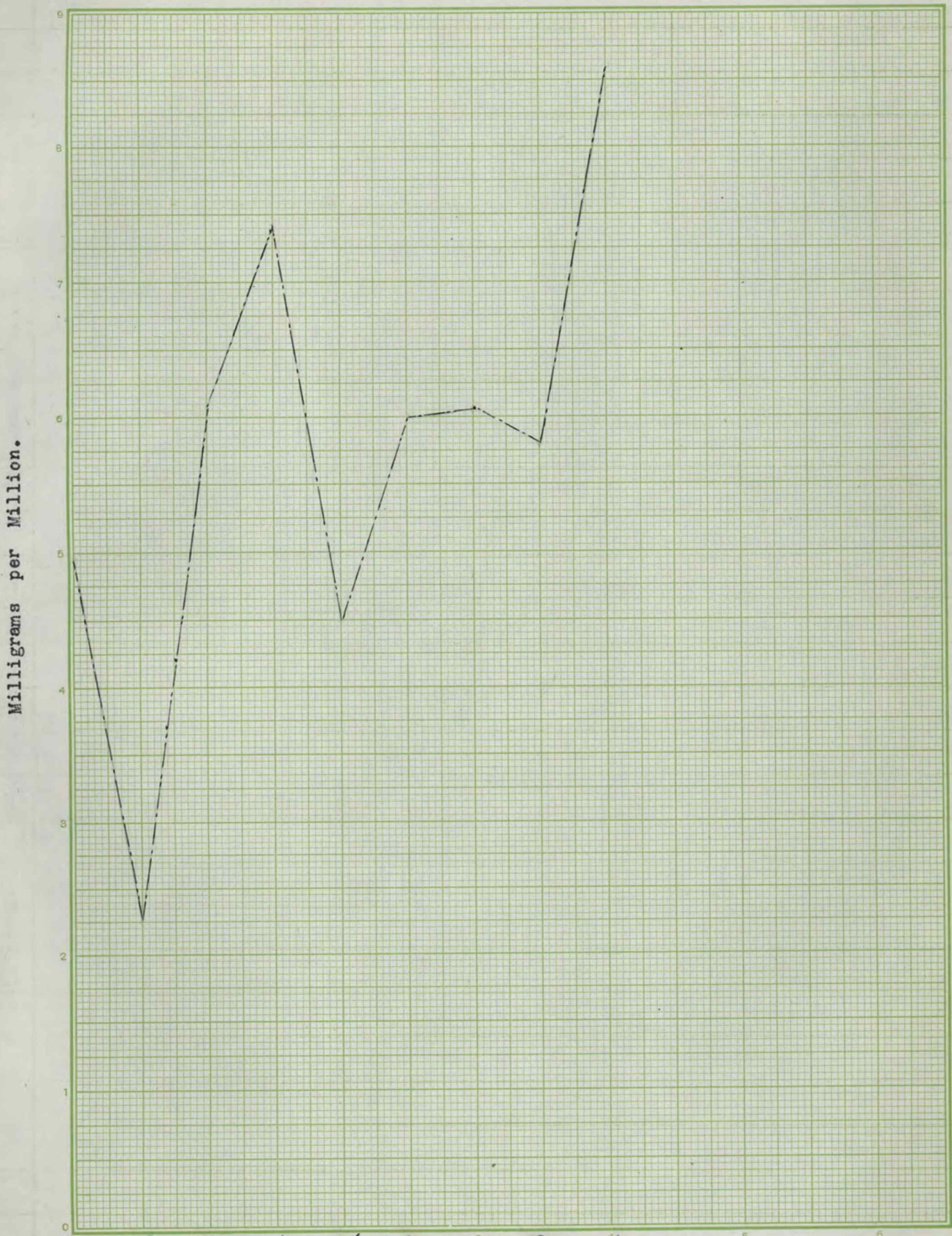
Scale
$\frac{1}{2}$" to 10 mg.

Per cent salt.

Ammonification with Na_2SO_4



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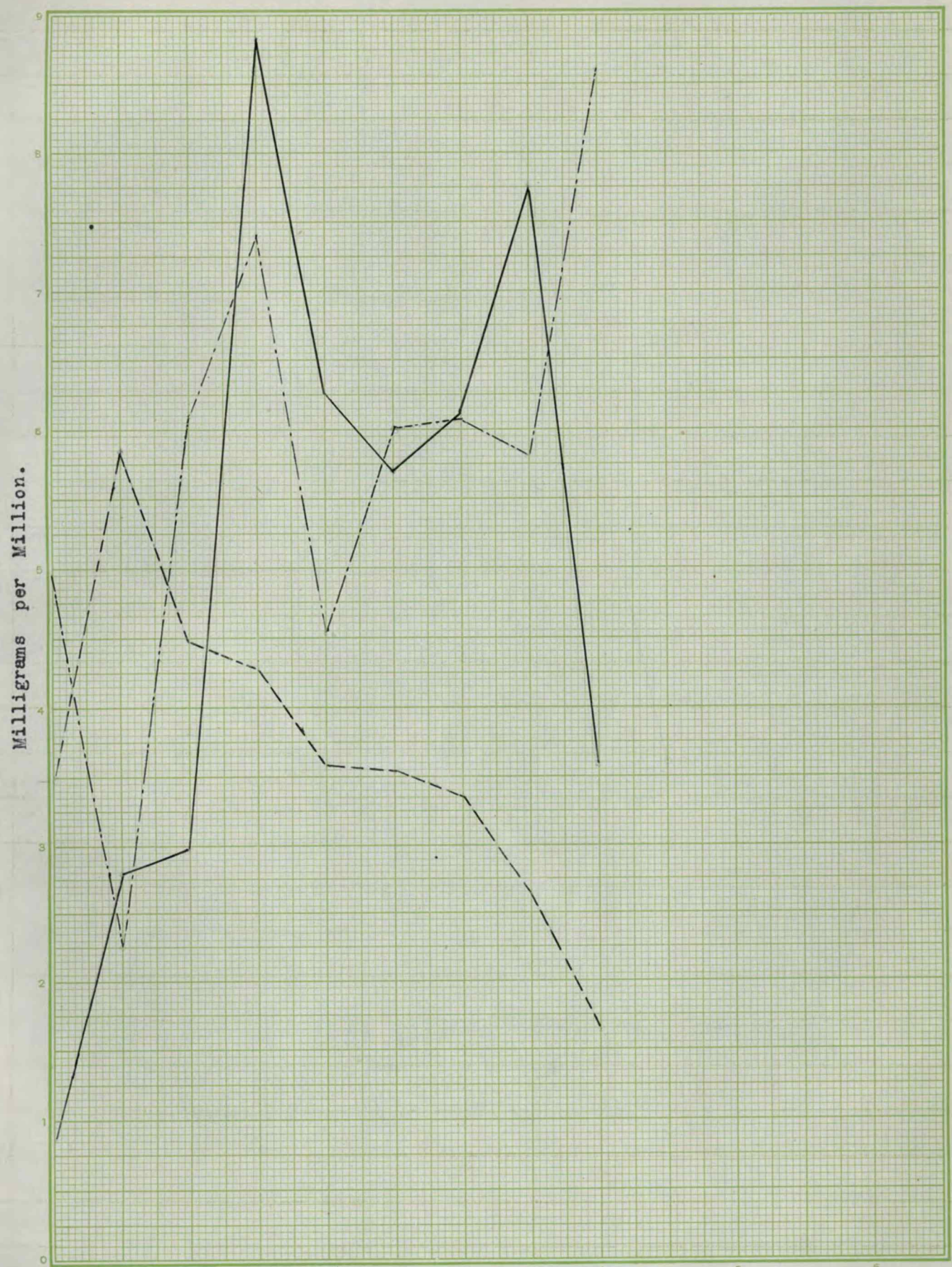
Per cent salt.

Scale
½" to 1 mg.

Total Nitrogen fixation Nitrification and Ammonification with Na_2SO_4.



Total N.
" NO_3
" NH_3

Scale
N. - ¼" to 100 mg.
NO_3 - ½" " 10 "
NH_3 ½" " 1 "

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under field conditions.

Series V.

The Effect of Single Alkali Salts on the Yield of Wheat and of Field Peas.

In this series wheat and peas were grown on soil that contained varying percentages of NaCl, Na_2CO_3, $NaNO_3$ and $NaSO_4$ respectively. Where no yields are recorded, it was impossible to get the seeds to germinate.

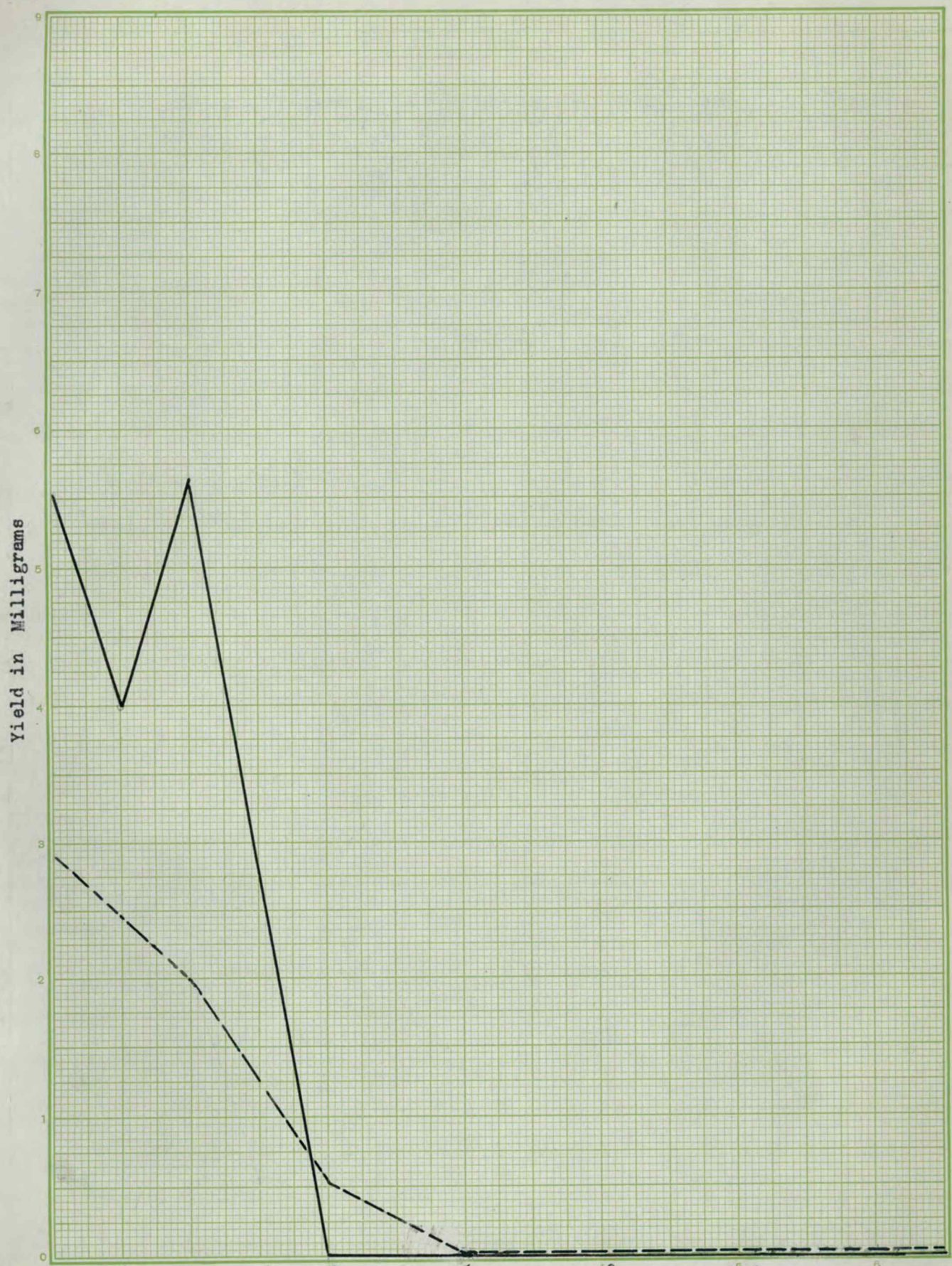
Table V.

Crop Yields of Wheat and of Field Peas on Soil with Different Percentages of NaCl, Na_2CO_3, $NaNO_3$ and Na_2SO_4.

No.	% Salt	NaCl	Na_2CO_3	$NaNO_3$	Na_2SO_4	NaCl	Na_2CO_3	$NaNO_3$	Na_2SO_4
		Yield of Wheat in mg.				Yield of Peas mg.			
1	none	111.0	111	111	111	169	169	169	169
2	none	120.0	120	120	120	201	201	201	201
3	none	115.0	115	115	115	282	282	282	282
4	none	118.0	118	118	118	234	234	234	234
5	.1	98.0	89	118	112	160	172	276	255
6	.2	80.0	130	108	71	226	207 & 275		178
7	.4	22.0	106	75	182	000	202	229	229
8	.6	00.0	137	49	98	000	000	000	164
9	.8	000.0	175	000	116	000	000	000	230
10	1.0	00.0	94	00	62	000	000	000	236
11	2.0	00.0	00	00	50	000	000	000	000

According to these results, field peas are more sensitive to all of the alkali salts used than is wheat. NaCl in small mounts stimulated slightly the growth of peas, but at a concentration between .2 and .4 percent, it was impossible to even get the seed to germinate. No stimulating effect was found on peas when Na_2CO_3 was used, although crop growth took place at a higher concentration than in the case of the chloride. No growth took place at concentration above .4 percent, As with the case of the chloride, $NaNO_3$ produced an increase in yield when low concentrations were used but at percentages above .4 percent no growth occurred. At the different concentration at which growth did take place there was practically

Effect on Wheat and Peas with NaCl.



— Peas
-- Wheat

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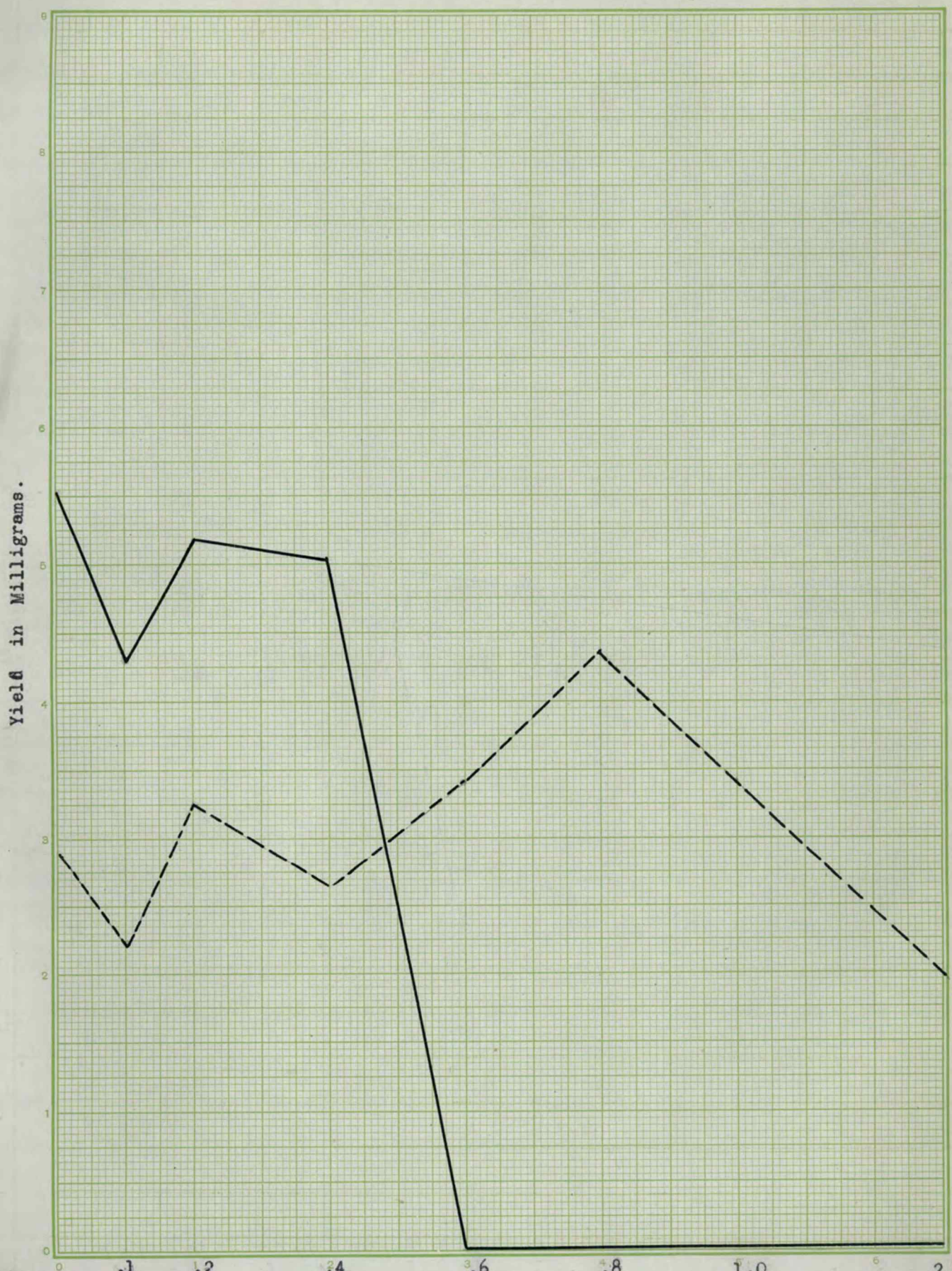
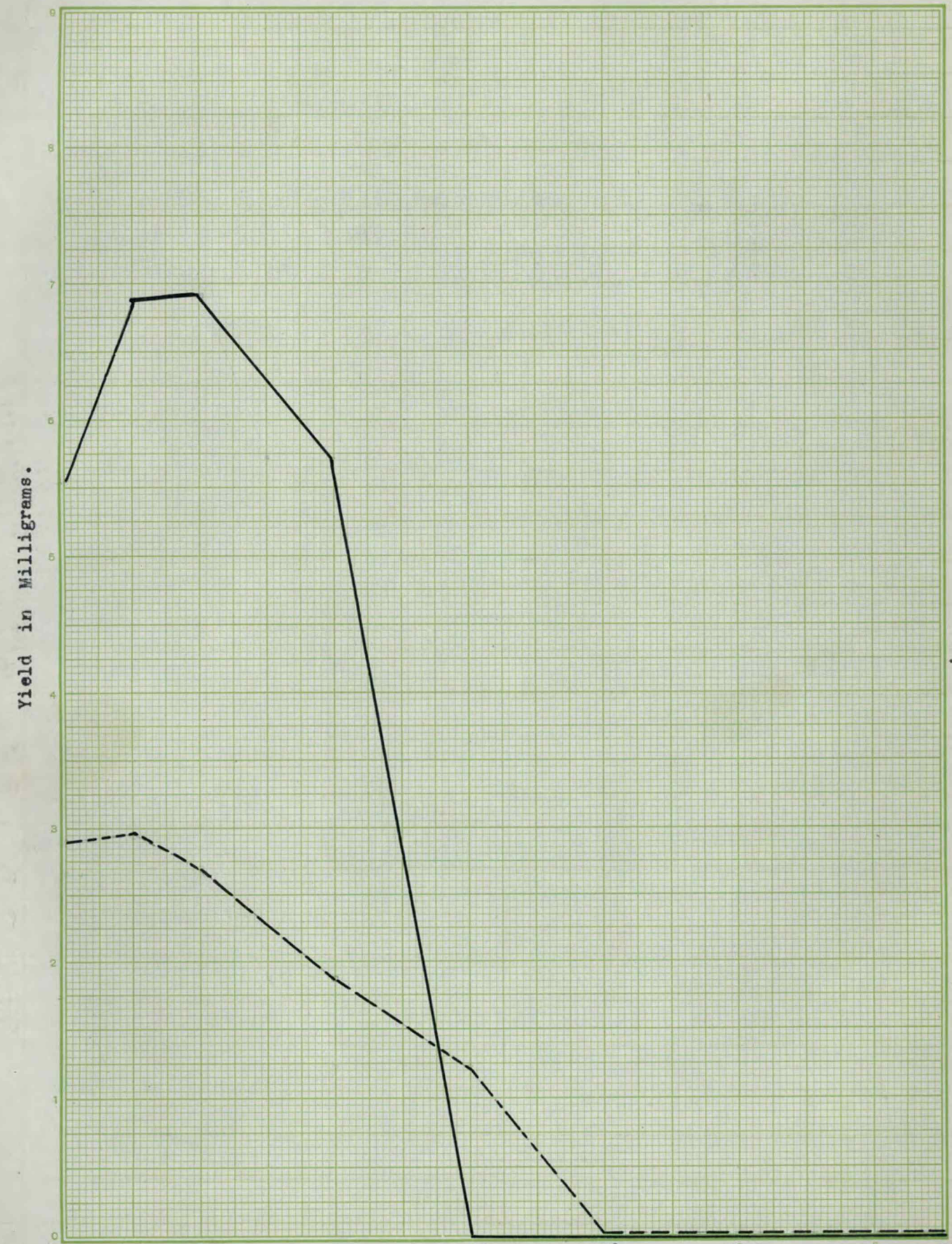
Scale
$\frac{1}{4}$" to 10 mg.

Effect on Wheat and Peas with Na_2CO_3



No. 46C—Monarch Note Book Co., St. Joseph, Mo.

Effect on Wheat and Peas with $NaNO_3$

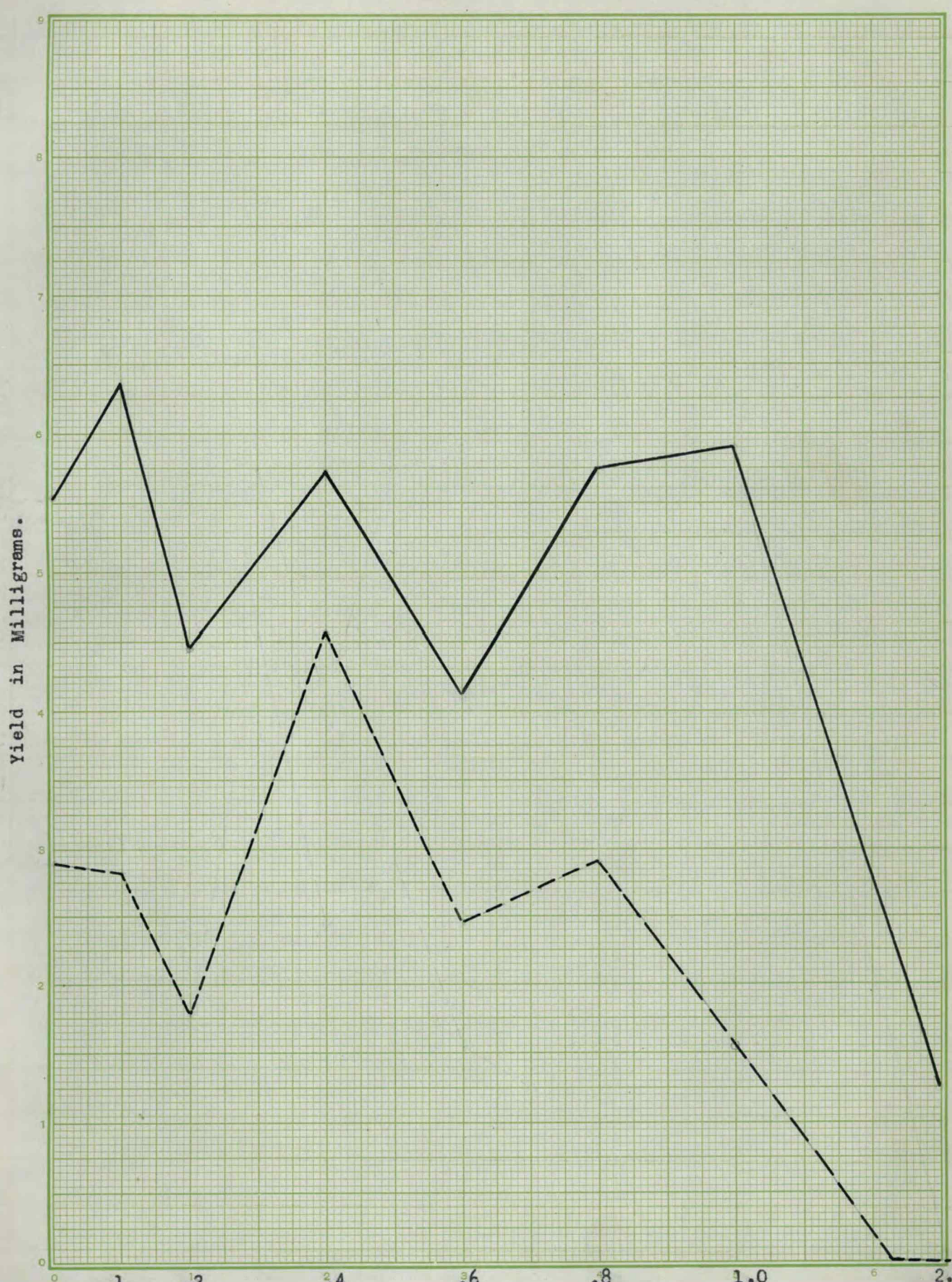


No. 46C—Monarch Note Book Co., St. Joseph, Mo.

Scale

$\frac{1}{4}$" to 10 mg

Effect on Wheat and Peas with Na_2SO_4



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no difference in yield. The least toxic of the four salts was Na_2SO_4. A stimulating effect was shown in all cases and growth took place at a concentration as high as 1 percent. The increase in growth in the case of both the nitrate and the sulphate series undoubtedly is due to the nitrogen and sulphur contained in each respectively.

NaCl had no stimulating effect on the growth of wheat and as the concentrations increased the yield gradually decreased. The growth at .4 percent was very poor and above this no germination took place. The falling off of the yield in the case where Na_2CO_3 was used was not very marked and fairly good growth took place with a concentration of 1 percent. At concentrations above this, the yield decreased very rapidly. No germination took place at 2 percent. $NaNO_3$ ranked next to the chloride in toxicity. Wheat seemed to be more sensitive to this salt than field peas, although germination took place at a concentration as high as .6 percent the yields in most cases were below that of the checks. In the case of Na_2SO_4, the wheat germinated at a concentration of 2 percent but no stimulating effect was marked as was the case with field peas.

Series VI.

The Effect of Crop Yields of Alkali Salts in Combination, NaCl Predominating.

This series and all of the following series contained different percentages of salts as found by analyzing the water soluble salts of an alkali soil. In this series NaCl was present in largest amounts. The complete analysis of the salt is found in the Table below.

Table VI.

Yield of Wheat and of Field Peas on Soil Having Alkali Salts in Combination as Found Under Field Conditions.

No.	Total Salt	%NaCl	%$CaSO_4$	%KCl	%$MgCl_2$	%$CaCl_2$	% $NaHCO_3$	% Germination	Wheat in mg.	Peas in mg.
1	none	none	none	none	none	none	none	100	84,0	250
2	"	"	"	"	"	"	"	100	115.0	206
3	0.1	0.08	0.006	0.004	0.007	0.0002	0.0003	100	163.6	195
4	0.2	0.16	0.012	0.008	0.014	0.0004	0.0006	75	145.6	202
5	0.4	0.32	0.024	0.016	0.028	0.0008	0.0012	25	53.0	86
6	0.6	0.48	0.036	0.024	0.042	0.0012	0.0018		00.0	00
7	0.8	0.64	0.048	0.032	0.056	0.0016	0.0024		00.0	00
8	1.0	0.80	0.060	0.040	0.070	0.0020	0.0030		00.0	00
9	2.0	1.60	0.120	0.08	0.14	0.004	0.006		00.0	00

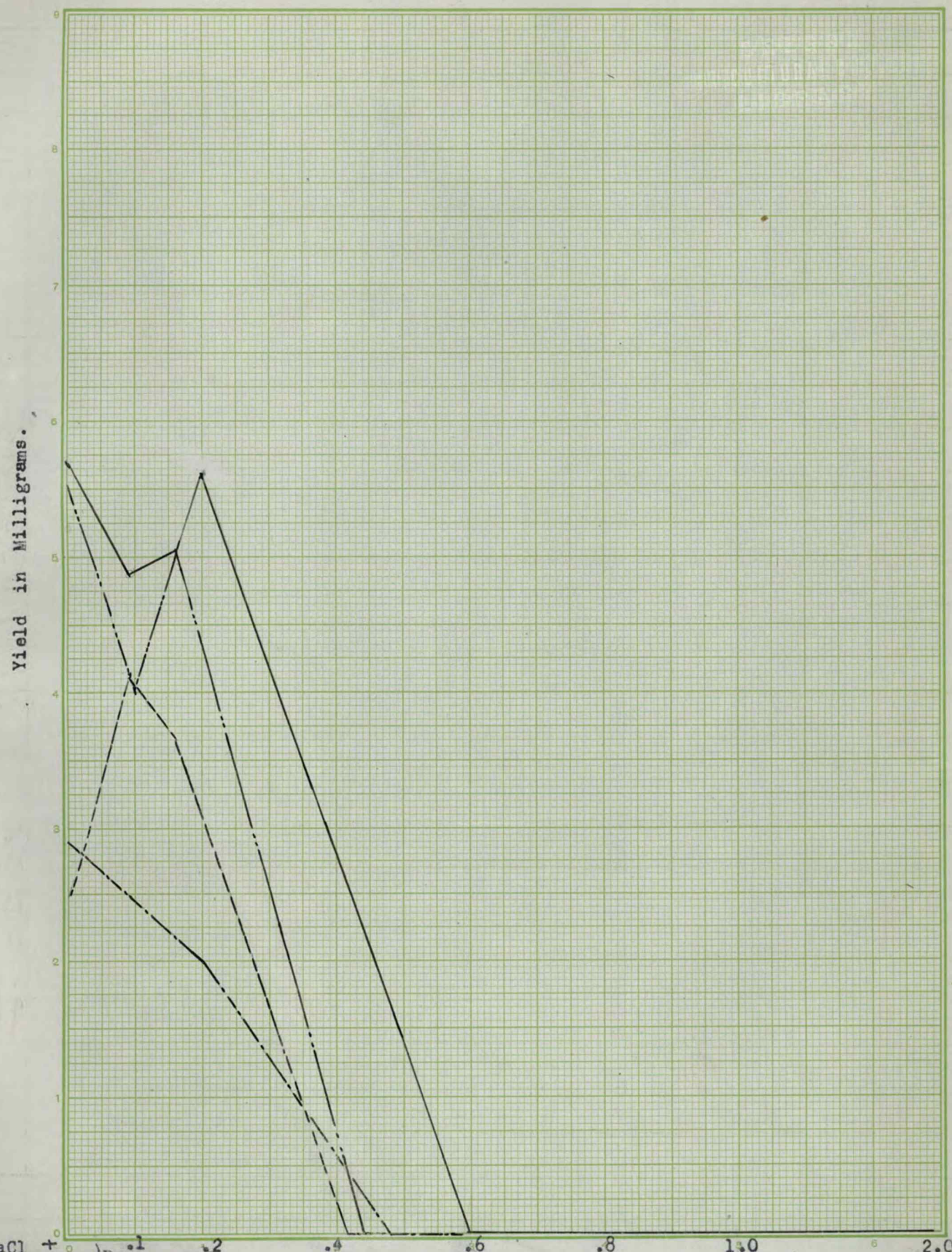
In this series the field peas made a poor growth at a percentage higher than that where NaCl was used alone. This may be due to the fact that a small amount of $CaSO_4$ was present. Wheat on the other hand stopped growth at a lower concentration than in the case where the single salt was used. Both this series and Series I and V indicate that NaCl is the most toxic of all the salts tested.

Series VII.

The Effect on Crop Yields of Alkali Salts in Combination, Na_2CO_3 Predominating.

In this series Na_2CO_3 made up about 75 percent of the salts and there was about 12 percent of $NaNO_3$ with small amounts of the chloride and sulphate present.

Crop NaCl alone
" " in Combination



NaCl + alone) Peas
" + alone) Wheat

Per cent salt.

Scale
¼" to 10 mg.

No. 46C—Monarch Note Book Co., St. Joseph, Mo.

Table VII.

Yield of Wheat and of Field Peas on Soil Having Alkali Salts in Combination as Found Under Field Conditions.

No.	% Total Salt	% Na_2CO_3	% $NaNO_3$	% Na_2PO_4	% Na_2SO_4	% NaCl	% Germination peas	Wheat in mg.	Peas in mg.
1	none	none	none	none	none	none	100	84	250
2	"	"	"	"	"	"	100	115	206
3	0.1	0.075	0.013	0.005	.00467	.0014	100	148	175
4	0.2	0.150	0.026	0.010	.00934	.0029	100	60	162
5	0.4	0.300	0.052	0.02	.00868	.0058	50	75	152
6	0.6	0.450	0.078	0.03	.02802	.0087	50	132	140
7	0.8	0.600	0.104	0.04	.03736	.0116		122	00
8	1.0	0.750	0.130	0.05	.04670	.0146		00	00
9	2.0	1.50	0.260	0.1	.09340	.0292		00	00

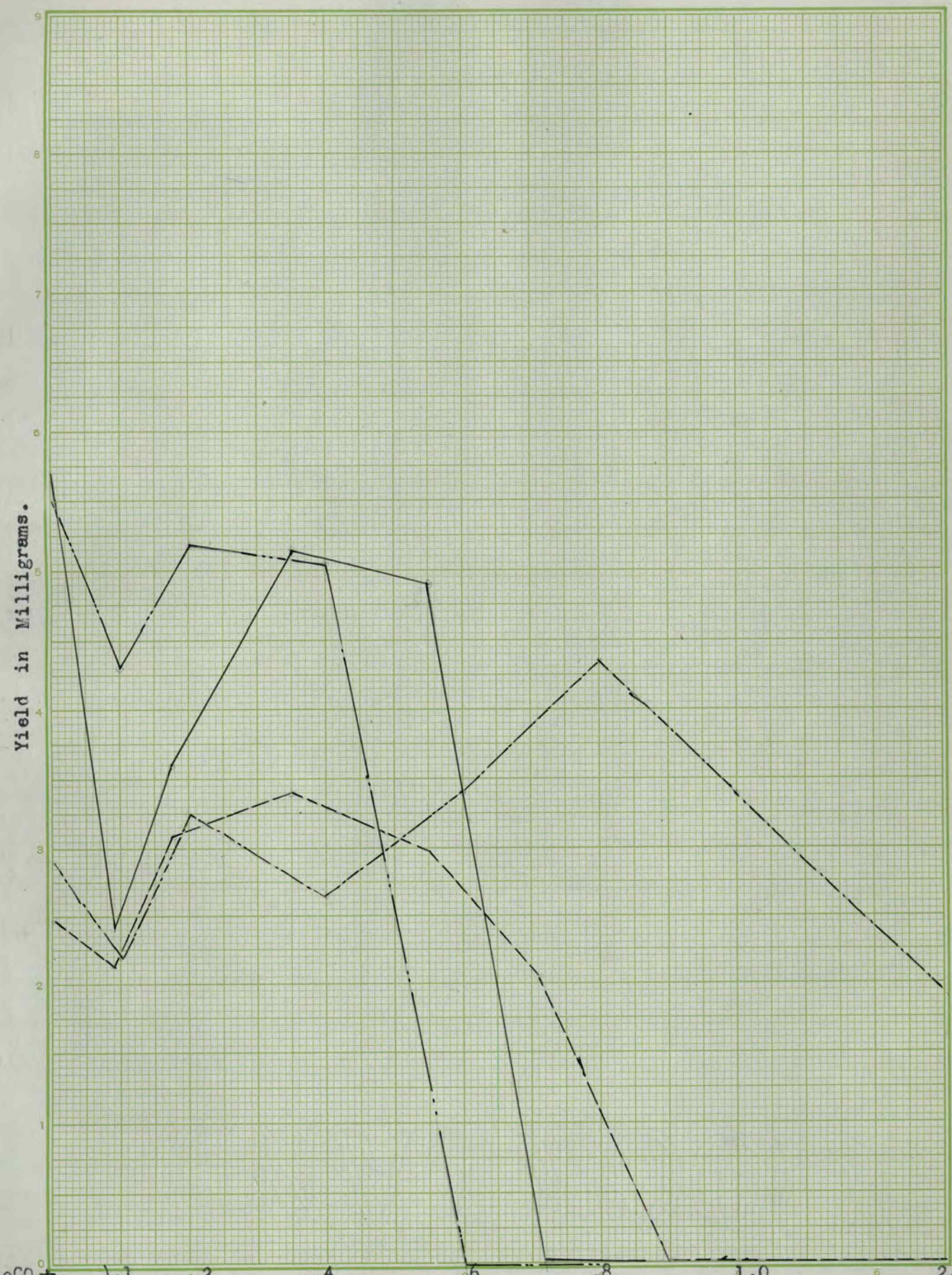
In this series the peas again showed a greater resistance to the carbonate thanwhen the carbonate was used alone. This perhaps is due to the small quantities of $NaNO_3$. Wheat stopped growth at a concentration lower than when Na_2CO_3 was used alone. Both of these results are in accord with the results in Series II and V. When $NaNO_3$ is more favorable to the legume than wheat.

Series VIII.

The Effect on Crop Yields of Alkali Salts in Combination Na_2SO_4 Predominating.

In this series there were two alkali salts present, Na_2SO_4 and NaCl. There was 94 percent of the sulphate and 6 percent of the chloride.

Crop Na_2CO_3 alone
" " in combination



Na_2CO_3 + Alone } Peas
" + Alone } Wheat

Scale ¼" to 10 mg.

No. 46C—Monarch Note Book Co., St. Joseph, Mo.

TABLE VIII.

Yield of Wheat and of Field Peas on Soil Having Alkali Salts in Combination as Found Under Field Conditions.

No.	% Total	%% Na_2SO_4	% NaCl	% Germination-peas	Wheat in mg.	Peas in mg.
1	none	none	none	100	84	250
2	"	"	"	100	115	206
3	0.10	0.093	.006	100	229.6	178
4	0.20	0.186	.013	100	162.4	238
5	0.40	0.373	.026	100	150.0	178
6	0.60	0.560	.039	100	143.0	224
7	0.80	0.747	.052	100	115.0	117
8	1.00	0.934	.066	100	90.0	161
9	2.00	1.868	.132		00.0	00

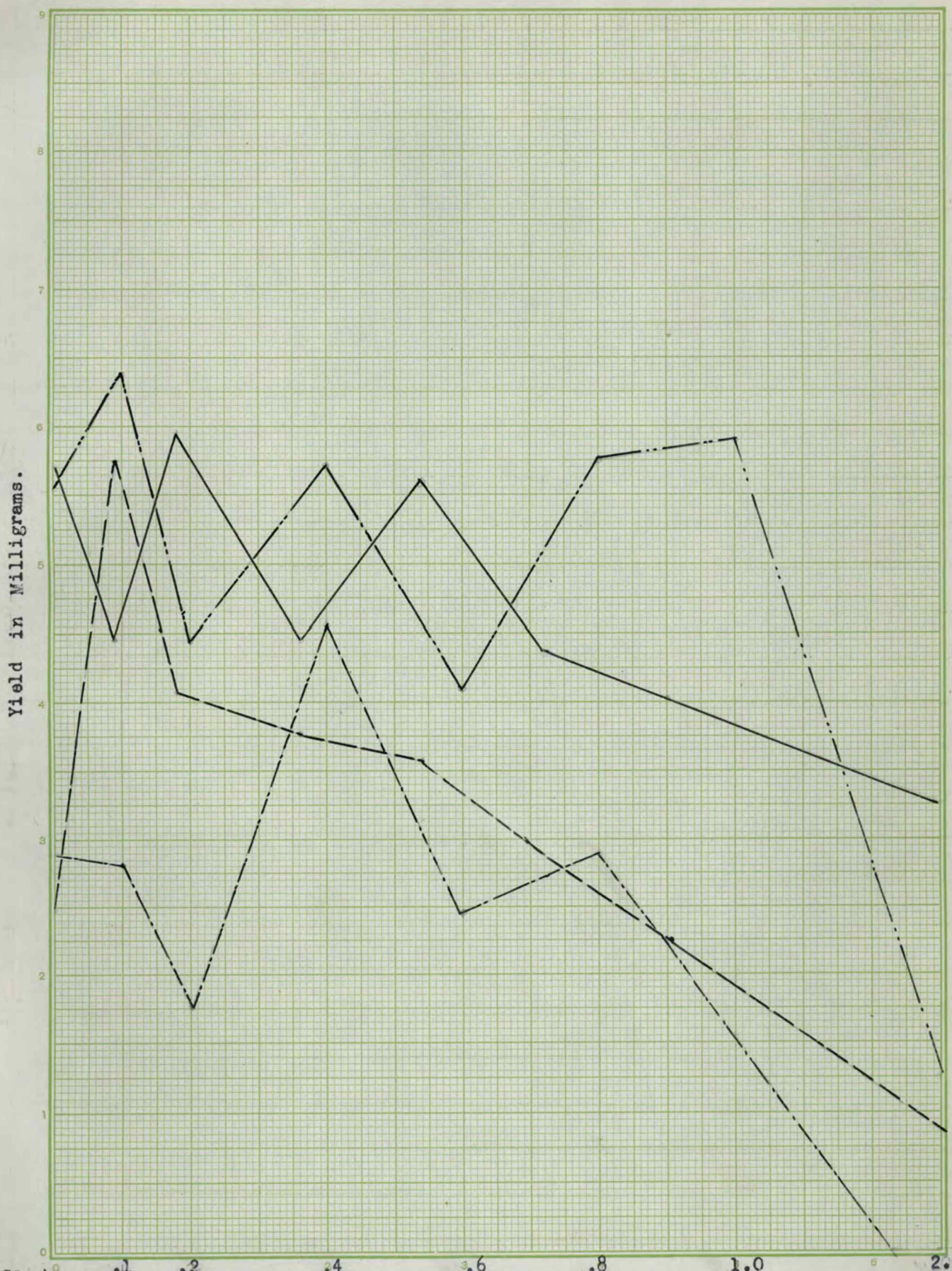
Crop growth took place in a concentration as high as .8 percent of the total salt without any apparent decrease in yield. At 1 percent there was a slight decrease in the case of both the wheat and the field peas and at a higher concentration no growth took place. The toxicity point in this series is lower than where Na_2SO_4 was used alone. This undoubtedly is due to the NaCl present.

Series IX.

The effect on Crop Yields of Alkali Salts in Combination Na_2SO_4 Predominating.

In this series like in Series VIII Na_2SO_4 predominated but it only made up about 58 percent of the total salt. The other 42 percent was made up of the carbonate and chloride of sodium.

Crop Na_2SO_4 alone
" " in combination



— Na_2SO_4 + Peas
---- " alone
– – " + Wheat
-.- " alone

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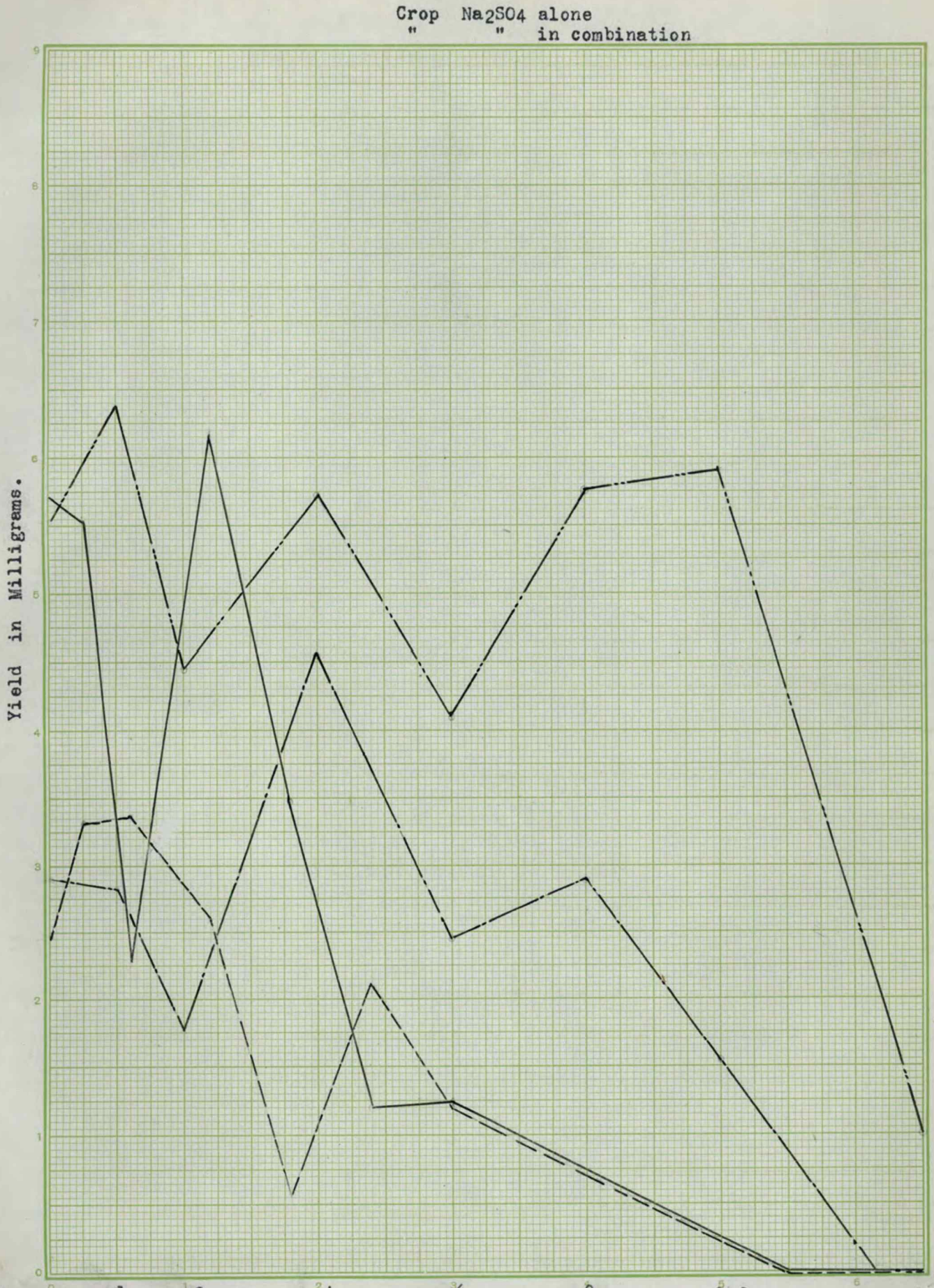
Scale
¼" to 10 mg.



No. 46C—Monarch Note Book Co., St. Joseph, Mo.

Table IX.

Yield of Wheat and of Field Peas on Soil Having Alkali Salts in Combination as Found Under Field Conditions.

No.	% Total Salt	% Na_2SO_4	% Na_2CO_3	% NaCl	% Germination peas	Wheat in mg.	Peas in mg.
1	none	none	none	none	100	84	250
2	"	"	"	"	100	115	206
3	0.1	0.058	.022	.018	100	132.4	221
4	0.2	0.117	.045	.037	50	134.2	90
5	0.4	0.234	.091	.074	100	103.5	247
6	0.6	0.351	.137	.111	75	23.0	139
7	0.8	0.468	.183	.148	25	84.0	48
8	1.0	0.585	.229	.186	25	49.0	50
9	2.0	1.170	.458	.372		00.0	00

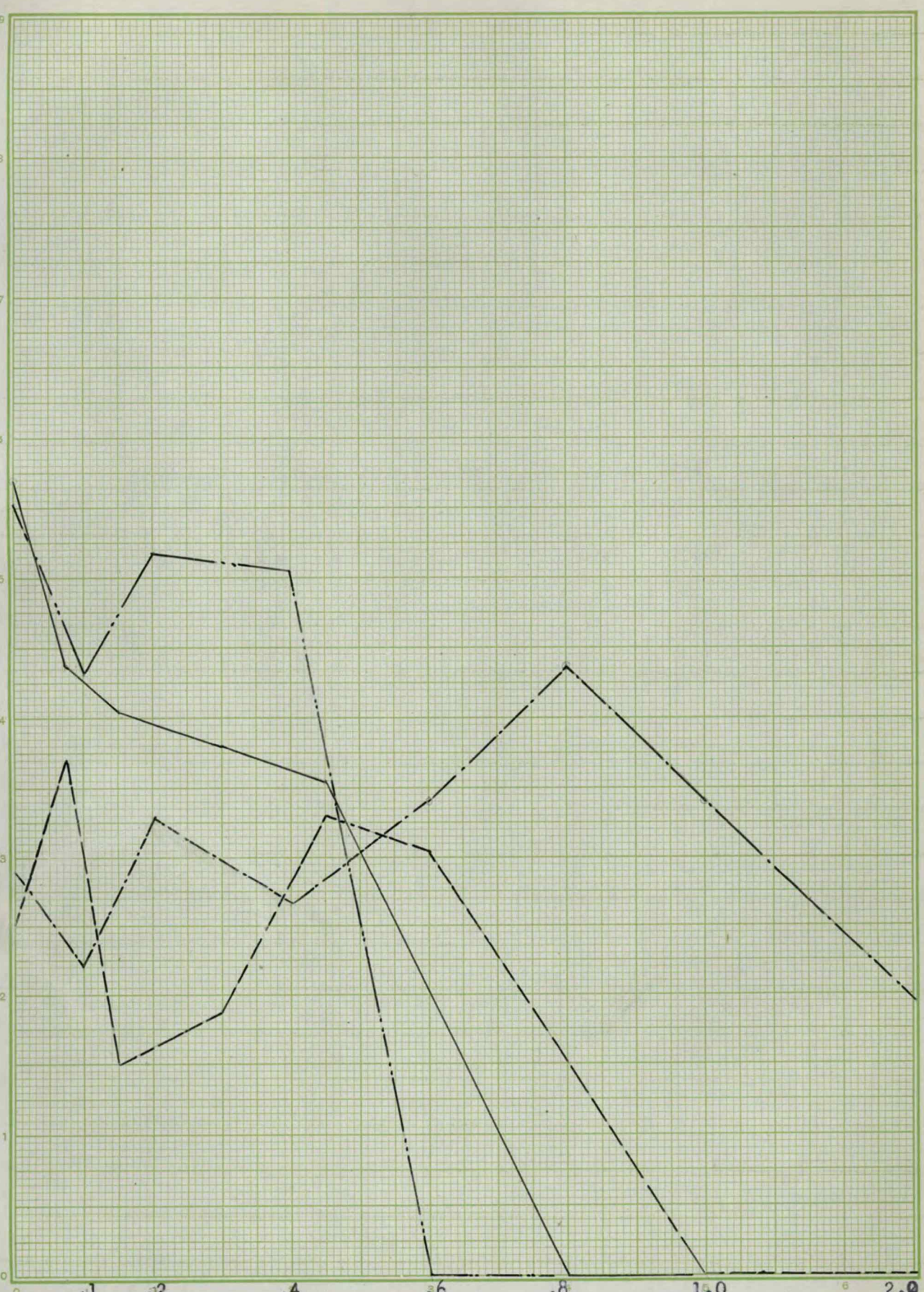
These results show that as in the case of the previous series both peas and wheat germinated at a concentration as high as 1 percent. The germination and yield though at the higher concentrations were considerably less than in Series VIII. This injurious effect is undoubtedly due to the presence of both the chloride and carbonate.

Series X.

The Effect on Crop Yields of Alkali Salts in Combination $NaHCO_3$ Predominating.

The salts used in this series were chiefly the carbonates and bi-carbonates of sodium, potassium and calcium with a small amount of $CaSO_4$. The bi-carbonate of sodium predominated in this combination.

Crop Na_2CO_3 alone
" " in combination



- Na_2CO_3 + Peas
- " alone
- " + Wheat
- " alone

Per cent salt.

Scale
$\frac{1}{4}$" to 10 mg

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Table X.

Yield of Wheat and Field Peas on Soil Having Alkali Salts in Combination as Found Under Field Conditions.

No.	% Total Salt	% $NaHCO_3$	% $KHCO_3$	% $CaCO_3$	% $CaSO_4$	% Germination peas	Wheat in mg.	Peas in mg.
1	none	none	none	none	none	100	84	250
2	"	"	"	"	"	100	115	206
3	0.1	.090	0.002	0.003	0.004	50	85	96
4	0.2	.181	0.004	0.006	0.008	75	124	144
5	0.4	.362	0.008	0.012	0.016	100	136	206
6	0.6	.544	0.012	0.018	0.024	100	119	196
7	0.8	.725	0.016	0.024	0.032		81.2	00
8	1.0	.907	0.021	0.030	0.04		00.0	00
9	2.0	1.814	0.042	0.06	0.08		00.0	00

Peas would not germinate at a concentration of .8 per-cent and wheat made very little growth at this same concentration. These percentages are lower than the toxic points found when Na_2CO_3 was used alone. These results would indicate that the bi-carbonate is more toxic than the carbonate.

Series XI.

The Effect on Crop Yields of Alkali Salts in Combination $NaNO_3$ Predominating.

In this series the salts used were the nitrate, carbonate and chloride of sodium. Sodium nitrate made up 87 percent of the total.

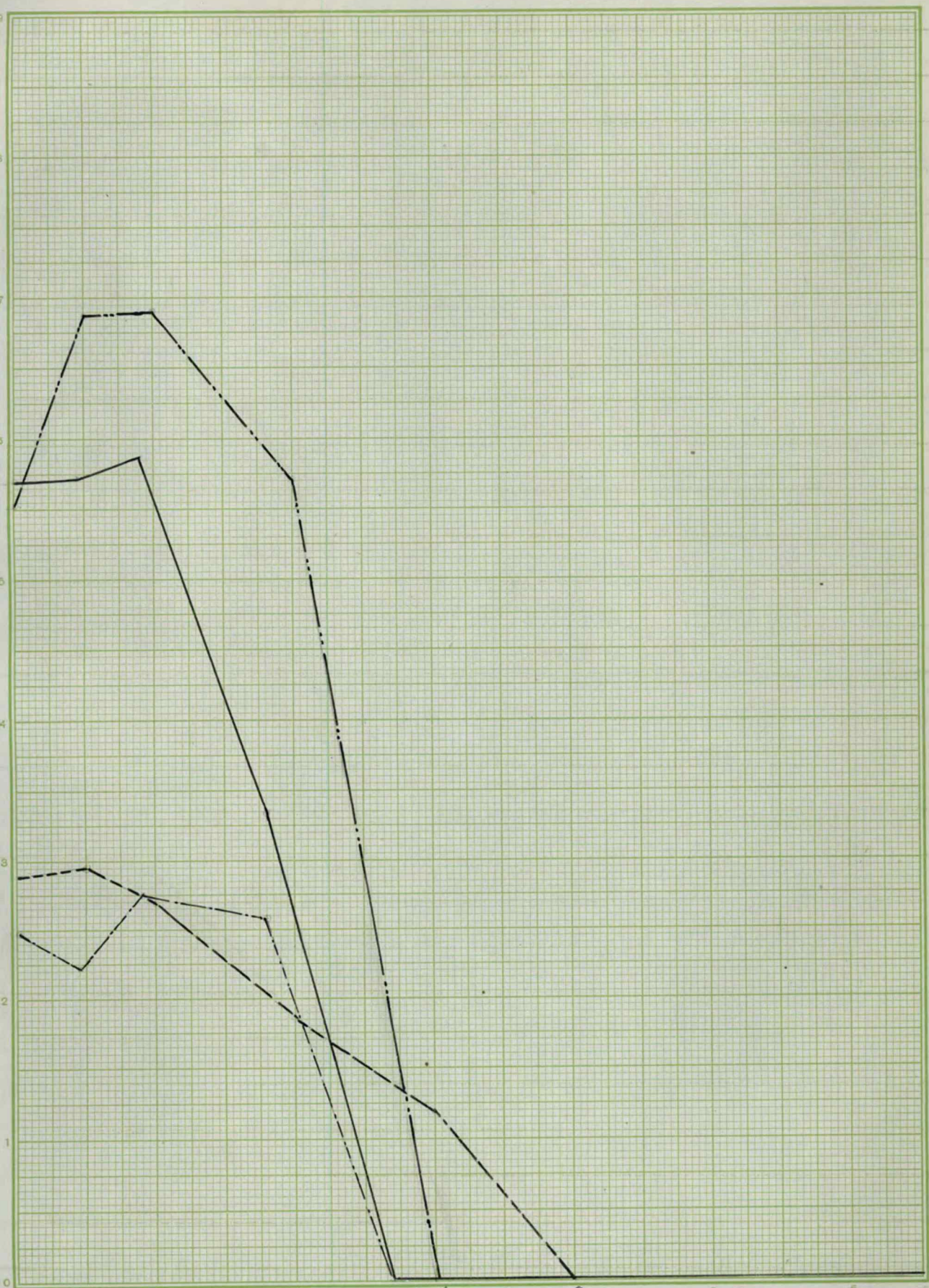
Table XI.

Yield of Wheat and of Field Peas on Soil Having Alkali Salts in Combination as Found Under Field Conditions.

No.	% Total Salts	% $NaNO_3$	% Na_2CO_3	% NaCl	% KCl	%Germination-peas	Wheat in mg.	Peas in mg.
1	none	none	none	none	none	100	84	250
2	"	"	"	"	"	100	115	206
3	0.1	.087	.004	.002	0.006	100	89	229
4	0.2	.174	.008	.005	0.012	100	110	235
5	0.4	.348	.016	.010	0.024	75	103	133
6	0.6	.522	.024	.015	0.036		00	00
7	0.8	.696	.032	.020	0.048		00	00
8	1.0	.870	.040	.025	0.06		00	00
9	2.0	1.740	.000	.051	0.12		00	00

Crop $NaNO_3$ alone

" " In combination.



$NaNO_3$ + Peas

= alone + alone Wheat

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Scale

$\frac{1}{4}$" to 10 mg.

This combination was the most toxic one used and is in accordance with the results found where the individual salts were used. Neither germination or crop growth took place at a concentration above .4 percent.

S U M M A R Y.

The results of this investigation on the effect on crop growth and bacterial activities of alkali salts although carried on under laboratory conditions, can be used to advantage for planning field work on this problem.

1. In order of toxicity the salts rank as follows: NaCl, $NaNO_3$, Na_2CO_3 and Na_2SO_4: The percent of the anion and not the cation is the determining factor.

2. Small amounts of each of the different salts used stimulated both crop growth and bacterial activities. This amount varied with the crop grown and the concentrations at which stimulation took place bore the same relationship to each other as did their toxicity points.

3. NaCl became toxic to both ammonification and nitrification at a concentration of .005 percent and to nitrogen fixation at .01 percent . The toxic point for wheat was .4 percent and for field peas .2 percent.

4. $NaNO_3$ became toxic to ammonification at a concentration of .01 percent and to nitrogen fixation above .4 percent. Small concentrations of $NaNO_3$ proved toxic to nitrification but at a concentration of .4 percent a marked stimulation took place. The toxic points for wheat and for peas were .8 and .6 percent respectively.

5. Na_2CO_3 was toxic to ammonification at a concentration of .02 percent, to nitrification at .8 percent and to nitrogen fixation at .01 percent. For wheat the toxic point was 1.0 percent and for peas .6 percent.

6. Na_2SO_4 proved to be the least toxic of all the salts.

Neither Ammonification or nitrogen fixation was inhibited to any extent at concentrations as high as 4.0 percent. Nitrification though, was stopped at 1.0 percent. Wheat thrived at concentrations up to 2.0 percent and peas up to between 1.0 and 2.0 percent.

7. The toxicity point as found when salts were used in combination as found under field conditions, checked very closely with the points found when the individual salts were present. The toxic point of the combined salts depended upon the percentages of the chlorides, nitrates, carbonates and sulphates present, and the combination in which they exist. $CaSO_4$ when present lowered the toxic point of the chloride, carbonate and nitrate of sodium.

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