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DIVISION OF CHEMISTRY

NITRIFICATION IN TEXAS SOILS

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NITRIFICATION IN TEXAS SOILS

BY

G. S. Fraps.

While it is well known that the quantity of nitrogen which can be taken up from the soil by crops depends, to a considerable extent, upon other things than the total amount of nitrogen in the soil; yet in Bulletin 151 of this Experiment Station, it is shown that there is a relation between the average nitrogen content of the soil, and the behavior of the soil toward crops in pot experiments. In the bulletin mentioned, it is shown that there is a relation between the number of crops deficient in nitrogen in pot experiments, and the total amount of nitrogen in the soil. The average quantity of the nitrogen withdrawn by the crops in the pot experiments increased regularly with the average quantity of nitrogen in the soil. The average nitrogen content of the crops also increased with the average nitrogen content of the soil. The effect of additions of nitrogen to the soil in the pots decreased as the percentage of nitrogen in the soil increased.

The total nitrogen of the soil is, therefore, on an average, a measure of the fertility of the soil with respect to nitrogen. This fact has not been so well brought out in field experiments, for the reasons that the soils used in the field experiments may have varied in composition in the different parts of the field, the conditions could not be controlled so well in field experiments as in pots, and experiments were not made with a sufficient number of soils in the field to estimate average results.

The production of active nitrogen, or nitrogen which can be taken up by crops, as pointed out in Bulletin 106 of this Experiment Station, depends to a certain extent upon the total nitrogen of the soil, the nature of the soil, the quantity of water contained therein, and the nature of the organic nitrogenous compounds in the soil. The temperature, and other factors are also of significance. It was also shown in Bulletin 106, that the quantity of active nitrogen produced was related to the growth of the crops in pot experiments and to the quantity of nitrogen contained in the crops.

The object of the present study is to ascertain, if possible, the relation of the nitrate production in the soil to various factors which influence soil fertility.

PRELIMINARY WORK.

Previous work on nitrification, such as that described in Bulletin 106, was carried on with 500 grams of the soil in precipitation jars, which were maintained at a constant water content. This method is ordinarily used, although with smaller quantities of soil in beakers. The method was not used in the present work, for the reason that a method was desired which more nearly approached natural conditions, and also that would permit several determinations of nitrates from the same sample. The soils in the jars are looser than those in the field, and therefore contain a larger quantity of air. They were kept at a uniform condition of moisture, which is not the case in the field conditions. The nitrates were permitted to accumulate until the end of the experiment, which is not the case in the field, as portions are washed out by rain or taken up by the plant roots.

For these reasons a method was used in which the soil was placed in percolators and, at intervale, extracted with water. The percolation with water would compact the soil, as is done by rain; it would extract the nitrates, as is done by rain and plant roots; it would leave the soil in a saturated condition, from which it would gradually dry out, as is the case with the natural soil after a heavy rain. Successive extractions could also be made on the same soil. The soil could also be manipulated, if desired. While the soil in the percolator is not claimed to be under the same conditions as the soil in the field, yet it is subject to a nearer approach to field conditions than the soil in precipitating jars or beakers.

The first one or two experiments were made on the soil placed in iron tubes. After that glass percolators were used.

Recovery by Percolation. An experiment was made to ascertain the efficiency of the extraction of nitrate by percolation; iron percolation tubes, and 500 grams of soil were used. Two portions of the soil were used and to one portion, 0.5 mg. of nitrogen as nitrate was added. The percolation was continued either until 200 c.c. came through, or for the period of the day's work. The nitrate was determined by phenol-sulphuric acid.

Table 1.—Nitrate nitrogen removed by successive percolations in milligrams.

Lab. No.	Addition of nitrate nitrogen	Nitrate Nitrogen				
		First	Second	Third	Fourth	Total
970	0.5 mg.	6.80	.75	.20	.08	7.83
970	0.	6.60	.50	.16	.06	7.32
1119	0.5 mg.	1.70	.05	.03	.02	1.83
1119	0.	1.40	.05	.03	.01	1.49
1121	0.5 mg.	2.22	.15	.06	.03	2.46
1121	0.	1.60	.20	.06	.04	1.90
1201	0.5 mg.	21.60	.30	.22	.12	22.24
1201	0.	22.00	.37	.12	.06	22.55
1406	0.5 mg.	4.00	.05	.06	.02	4.13
1406	0.	4.00	.05	.04	.02	4.11
6268	0.5 mg.	1.24	.05	.03	.02	1.34
6268	0.	.60	.05	.02	.01	0.68
	Average.	6.2	.21	.08	.07	

The results of the experiments are given in Table 1. For practical purposes, the nitrate nitrogen is extracted by the first two percolations. It is true that some of the nitrates are extracted by the third and fourth percolations, and these amounts would affect the results to a slight extent. This would be particularly the case with heavy soils through which the water does not pass readily. As the colorimetric method for determining nitrate nitrogen is not a very exact method, the writer believes that the amount of nitrate extracted in the third and fourth percolations is within the limit of error for the total amount of nitrates present in most cases. It was therefore decided to use only two extractions for the work.

Relation of the Percolation Method to the Jar Method. In order to study the relations between the amount of nitrate formed in jars and that produced in the percolators, an experiment was conducted in which one part of the same soils was placed in jars, mixed with water to one-third its capacity, inoculated with water from a fertile soil, and allowed to stand four weeks.

Other portions of the same soils were weighed out, and placed in galvanized iron tubes. They were extracted immediately with water, by percolation, then allowed to stand four weeks, when another percolation was made; subsequently other percolations were made. The results of the experiment are shown in Table 2.

Table 2.—Nitrate produced in percolators and in jars.
(Parts per million.)

Lab. No.	In percolators			Jars.
	0 weeks	4 weeks	Total	
327	4.0	30.7	34.7	4.0
869	9.0	10.4	19.4	11.0
870	23.2	12.2	35.4	33.0
873	41.2	1.0	42.2	37.7
876	4.2	46.6	50.8	5.0
878	3.3	0.8	4.1	2.2
882	9.0	27.6	36.6	9.6
893	5.6	0.8	6.4	3.2
938	34.8	41.0	75.8	66.7
964	26.5	7.7	34.2	23.3
969	34.2	27.1	61.3	40.0
1128	15.6	0.6	16.2	13.6
Average	17.5	17.2	34.7	20.7

The amount of nitric nitrogen in the soil in the jars should be compared with the amount extracted from the percolator at the beginning of the experiment plus that found at the end of the four weeks. The amount of the nitric nitrogen in the jars was in all cases less than the amount extracted from the percolators in the corresponding period of time. In some cases, the difference was very large, while in other cases the difference was small. For example, with soil 327, 4.0 per million of nitric nitrogen were found in the jar, while 34.7 parts per million were extracted from the soil in the percolator. With soil 876, 5.0 parts per million were found in the jar, and 50.8 parts in the percolator. These are very large differences. On the other hand, with soil 870, 33 parts per million were extracted from the soil in the jar, and 35.4 parts from the soil in the percolator. With soil 908, 66.7 parts were extracted from the soil in the jar, and 75.8 from the soil in the percolator.

The conditions for nitrification seem to be better in the percolator than in the jar. What these favorable conditions are, remains for further study to determine. It is possible that nitrates are formed in the jars, and then partly destroyed, or that the presence of the nitrate decreases the activity of the bacteria.

Effect of Water Content. In another experiment, six soils were selected and two percolators weighed out for each. Series A was percolated and then allowed to remain undisturbed for the period of four weeks. Series B received sufficient water at the end of each week to make the moisture content one-third of the saturation capacity of the soil.

Table 3.—Effect of water content. Nitrate nitrogen in parts per million.

Lab. No.	Kept at 1-3 water	0 weeks	4 weeks	8 weeks	12 weeks	16 weeks	20 weeks
110	B	18.6	95.3	36.4	15.0	8.2	5.2
114	B	43.8	27.6	68.8	2.5	1.6	1.1
142	B	0.4	0.5	29.3	60.6	39.6	37.6
324	B	12.8	95.6	26.9	13.2	6.1	4.0
338	B	7.6	90.0	16.5	5.7	4.9	3.1
993	B	45.8	120.5	14.6	3.8	5.4	4.1
	Average	21.5	71.6	32.1	16.8	10.9	9.2
110	A	28.5	114.0	16.2	8.8	6.8	4.3
114	A	50.0	86.4	38.8	2.7	2.0	1.0
142	A	4.0	0.5	10.0	54.0	40.0	25.0
324	A	13.7	37.4	40.6	15.4	5.5	3.9
338	A	7.8	82.9	33.9	16.0	4.9	3.2
933	A	40.9	109.6	27.6	3.0	5.1	4.2
	Average	24.1	71.8	27.8	16.6	10.7	6.9

The results of this work are given in Table 3. There was some variation in the amount of nitrates found. The amount of the evaporation from these soils was comparatively small, and only a small amount of water was needed to retain the moisture content at one-third the saturation capacity.

In another set of soils, one series was kept undisturbed, water, when needed, being added to one-third of its saturation capacity, while the other set, at the end of eight weeks, on October 6, was emptied just before percolation, into porcelain dishes, mixed thoroughly, and then percolated.

Table 4.—Effects of stirring. Nitrate nitrogen in parts per million.

Lab. No.		0 weeks	4 weeks	8 weeks	12 weeks	16 weeks
818	B	38.5	75.4	8.8	2.1	2.0
850	B	1.0	42.3	13.2	2.0	1.7
882	B	16.5	67.3	11.8	1.8	1.6
894	B	66.6	48.4	10.5	1.6	2.6
895	B	0.9	61.9	14.3	1.2	2.4
932	B	15.7	55.2	4.4	6.9	2.3
	Average	23.2	58.4	10.5	2.6	2.1
818	A	35.3	66.9	19.0	1.0	0.0
850	A	0.9	43.2	30.7	6.0	1.7
882	A	17.7	75.4	11.0	2.6	1.9
894	A	70.6	42.6	16.7	0.2	1.8
895	A	0.5	44.7	40.7	2.1	1.3
932	A	16.3	68.9	4.9	6.0	3.7
	Average	23.4	56.9	20.5	2.9	1.7

The results are presented in Table 4. The amount of nitrates formed after the eight weeks was small, and the stirring of the soil appeared to have little effect upon it.

Effect of Lime. The effect of carbonate of lime was tried on some soils which did not nitrify very well, and the results are presented in

Tables 5 and 6. The results are somewhat peculiar. Without lime, soil 855 had not nitrified to any extent at the end of 16 weeks; while with 1 per cent. of carbonate of lime, it produced a decided amount of nitrates at the end of 20 weeks, and with 2 per cent. of carbonate of lime it had produced a decided amount of nitrates at the end of 12 weeks.

Table 5.—Effects of Carbonate of Lime. Nitrate Nitrogen in parts per million of soil.

Carbonate of Lime Added	Date	855			873			1128	
		A 0	B 5.0 gm.	C 10.0 gm.	A 0	B 5.0 gm.	C 10.0 gm.	A 0.0	C 10.0 gm.
0 weeks	Sept. 23, 1913	1.2	1.9	1.9	35.4	36.2	35.0	15.0	17.6
4 weeks	Oct. 21, 1913	0.0	0.4	0.6	0.4	19.6	19.7	0.0	0.8
8 weeks	Nov. 18, 1913	0.0	0.0	0.0	0.2	25.8	14.6	0.0	4.2
12 weeks	Dec. 16, 1913	0.0	0.2	25.0	7.4	0.3	2.9	0.0	76.9
16 weeks	Jan. 13, 1914	0.0	0.8	24.0	22.7	1.4	1.2	0.0	25.5
20 weeks	Feb. 10, 1914	0.0	37.8	2.1	31.2	2.0	1.6	0.0	10.4
24 weeks	Mar. 10, 1914	0.0	20.7	0.4	6.9	0.8	1.4	0.0	3.6
28 weeks	April 7, 1914	0.0	1.0	1.0	4.2	1.2	1.4	0.0	3.6
32 weeks	May 5, 1914	0.0	1.3	1.4	2.9	1.6	1.6	0.0	4.4
36 weeks	June 2, 1914	0.0	1.7	1.8	5.5	2.5	2.4	0.0	5.4
40 weeks	June 30, 1914	0.0	2.0	3.1	2.7	3.4	3.4	0.0	8.8
44 weeks	Feb. 28, 1914	1.6	3.3	3.8	4.6	4.1	5.2	0.0	8.8
48 weeks	Aug. 25, 1914	0.0	2.7	2.4	1.8	2.7	2.3	17.8	4.4
52 weeks	Sept. 22, 1914	0.0	2.4	2.7	1.6	3.2	2.3	39.6	5.6
56 weeks	Oct. 20, 1914	0	1.3	1.4	.6	1.2	1.0	46.4	2.9
60 weeks	Nov. 17, 1914	0	.8	.9	.8	1.0	.8	18.0	2.0

Table 6.—Effect of Lime. Nitrate Nitrogen in parts per million.

Carbonate of Lime Added	Date	2826			3391			4233		
		A 0.0	B 5.0 gm.	C 10.0 gm.	A 0.0	B 5.0 gm.	C 10.0 gm.	A 0.0	B 5.0 gm.	C 10.0 gm.
0 weeks	Sept. 25	4.0	4.8	5.5	2.1	3.2	3.2	0.8	0.8	0.9
4 weeks	Oct. 23	2.3	28.4	24.2	0.0	12.8	11.8	2.9	8.4	13.2
8 weeks	Nov. 20	29.6	15.8	15.6	......	11.5	9.9	18.2	23.8	24.0
12 weeks	Dec. 18	4.0	7.6	8.6	......	4.3	4.2	9.7	16.9	7.2
16 weeks	Jan. 15	2.1	5.4	4.5	......	2.2	2.3	1.4	5.4	3.0
20 weeks	Feb. 12	3.2	5.2	6.2	......	2.2	2.2	1.7	4.1	3.1
24 weeks	Mar. 12	3.0	4.3	4.5	......	1.2	1.0	1.0	2.6	3.0

Soil 873 without lime nitrified at the end of 16 weeks, with 1 per cent. carbonate of lime at the end of two weeks, and with 2 per cent. carbonate of lime it nitrified during the first four weeks. Soil 1128 alone did not nitrify until 48 weeks, while with 2 per cent. carbonate of lime it nitrified decidedly at the end of 12 weeks.

The effect of carbonate of lime on nitrification was studied in other experiments and will be discussed in more detail later on. It is a well known fact that carbonate of lime will increase nitrification in the soil, but the fact has not been established that this nitrification has always been beneficial to the soil, or to the crops growing on it.

METHOD OF WORK ADOPTED.

After the preliminary work referred to in the preceding pages, the following general method was adopted for the nitrification in the percolators:—

Soils for Nitrification. Weigh 500 grams of the soil into a percolator upon a porcelain crucible top. Secure 50 grams moist soil from three inches below the surface from a garden and shake up with 1000 c.c. water. After the soil has settled, add 50 c.c. of the supernatant liquid to each percolator. Empty each percolator in turn into a porcelain dish, mix thoroughly and return to the percolators. Cover the percolators with a closely fitting wrapper of paper, to exclude the light and prevent the growth of algae. The next day make two percolations, and make other percolations at intervals of four weeks.

COLORIMETRIC METHOD FOR DETERMINATION OF NITRATES IN SOILS.

Standard Nitrate. (A) Dissolve 0.722 gm. C. P. potassium nitrate in 1000 c.c. water. (B) Dilute 100 c.c. of solution A to 1 liter; 1 c.c. equals .01 mg. nitrogen.

Phenol Disulphuric Acid. Mix 15 gm. pure crystallized phenol with 100 c.c. conc. sulphuric acid (sp. gr. 1.84) and heat six hours in a boiling water bath, or inside a steam bath. Preserve in a glass stopped bottle.

The phenol used above may be removed from the bottle by melting it by warming.

Standard Colorimetric Solution. Evaporate to dryness in a shallow porcelain evaporating dish on a water bath in a room free from nitric acid the following quantities of the standard solution B: 5 c.c. or 10 c.c., 20 c.c. or 40 c.c. or the quantities experience has shown necessary. Add one cubic centimeter of phenol disulphuric acid while still on the bath, remove and stir well with a short glass rod. After not less than ten minutes dilute with water and make alkaline with ammonia, then dilute to exactly 100 c.c. When 10 c.c. of the potassium nitrate is used, 100 c.c. equals 0.1 mg. N. and the other solutions are proportionately stronger.

Percolating. Begin to percolate at 8 o'clock in the morning. Use (A) the first 200 c.c., (B) the second 200 c.c., or (X) the quantity that percolates to 5 p. m. and (Y) the quantity that percolates during the night and sufficient of the next day to make up 200 c.c. or the amount that percolates to 3 p. m. Make percolate (A) or (X) up to 500 c.c. and take 5 c.c. (equivalent to 5 gm. soil). In other work the volume may be made up to 200 c.c. and 2 c.c. taken. Use 10 c.c. of B or Y (equivalent to 25 gm. soil). One o'clock is the most convenient time to evaporate the percolates. Percolates must be evaporated immediately and rapidly and must not be exposed to nitric acid fumes.

Nitrate Determination. Evaporate the necessary volume of the percolate (10 c.c. or 2 c.c. or 5 c.c. if the solution is very strong), as described above, and treat with phenol-sulphuric acid as directed for the standard colorimetric solution. Wash into a clean 150 c.c. beaker with about 25 c.c. water (the stream must be fine for this amount of water to be sufficient) and make alkaline with ammonia. Put in comparison cylinder and ascertain the approximate amount of standard solution to match, and dilute the unknown to that volume. It sometimes happens that the solution is off color, due to iron, and must be filtered after the ammonia is added. Pour the standard solution into the standard cylinder until the color is plainly deeper than that of the unknown. Place the cylinders side by side on a block of wood near a window, put a piece of white paper under the cylinders, and lift them so that the light will come up under the bottom while making the comparison. Run out the standard into its beaker until the colors match. Read the volume on the standard cylinder, pour about 20 c.c. of the standard back into its cylinder, and match the colors again. Do not read the volume during the process of color matching at any time, and do not make the second reading on the standard cylinder until you are satisfied that the colors are the same. If the readings agree within 5 c.c. or less for volumes over 50 c.c., and 3 c.c. or less for volumes less than 50 c.c., take the average of the two. If the results do not check within the above limits, repeat the matching until they do. The difference in volume of the unknown and the standard must not be greater than 50 per cent. of the solution of greater volume and the latter should always be the unknown solution. After some experience, it is possible to match the solutions at practically equal volumes, and whenever possible this should be done. If the unknown apparently is equal to 100 c.c. of the standard, make up the unknown to exactly 100 c.c., put 50 c.c. of this solution in the cylinder, match with the standard and multiply the standard reading by 2. Never match the unknown against the standard and never match the standard against the unknown without beginning with at least 20 c.c. of the standard solution, more than seems to be necessary to match.

If the unknown is stronger than the strongest standard, make up to 100 c.c., take 20, 25, 33, or 50 c.c., according to strength, match, multiply by 5 for 20 c.c., 3 for 33 c.c., or 2 for 50 c.c.

Reporting Results. The results may be reported on tabulation blanks (form 139) for experiment work. In alkali soils, report on form 109. Use a column for the unknown and one for each standard. Put down the volumes which match. Report the nitrate nitrogen in parts per million; also put down the total volume of the percolate.

Method of Calculation. As 10 c.c. of the percolate is diluted to 100, the number of mg. nitrogen in this 100 c.c. multiplied by 100 is equal to parts per million. If 2 c.c. of the percolate is taken, it is, of course, five times as many parts per million.

If 10 c.c. of standard nitrate is diluted to 100 c.c., 1 c.c. of the resulting liquid contains 0.001 mg. N. Thus 1 c.c. = .10 parts per million of the percolate, on 10 c.c. percolate.

If 20 c.c. is taken, 1 c.c. = .2 parts per million.

If 30 c.c. is taken, 2 c.c. = .3 parts per million and so on.

The percolate solution may be assumed to have a volume of 100 c.c.; if the volume of the standard color made from 10 c.c. is A c.c., then in 10 c.c. percolate there are A times .001 mg. N., and in 1000 c.c. there are A times 0.1 mg. N, which is parts per million.

The calculation is made in a similar way from other strengths of the solution.

Factors for Calculating Nitrates in Percolates. Five c.c. of A or X when made up to 500 c.c.; if made up to 200 c.c., use 2 c.c.; and use 10 c.c. if B or Y are used.

Percolate	Standard solution taken. 5 c.c.	10 c.c.	20 c.c.	30 c.c.	40 c.c.
A or X	0.1	.2	.4	.6	.8
B or Y	.02	.02	.08	.12	.16

Multiply volume of standard required to match the unknown by appropriate factor above.

RATE OF NITRIFICATION.

In order to study the effect of time upon the rate of nitrification, some of the experiments were conducted for long periods of time, in one or two experiments extending for more than three years. In most cases, the maximum nitrification takes place during the first period of four weeks. This may be considered as the normal nitrification.

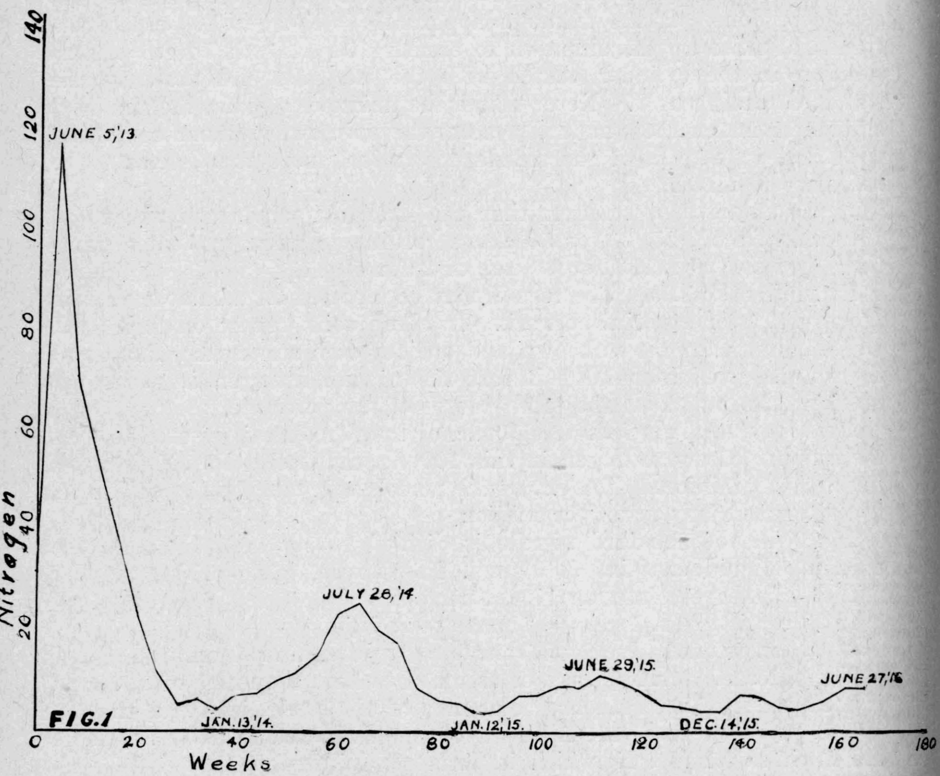

Figure 1—Production of Nitric Nitrogen in soils of Series 6.

With a number of other soils, the maximum nitrification takes place during the second period of four weeks. The proportion of soils in which this occurs is fairly large, being about 40 per cent. of the group in which the maximum nitrification occurs in the first four weeks.

In another series of cases the maximum occurs in both the first and the second four weeks.

With a few soils, the nitrification is delayed to the third period of four weeks or even longer, so that in some cases, as in soil 1128 already referred to, the nitrification may not occur for even a year or more. Table 8 shows the distribution of the nitrification with a number of soils studied in our experiments.

The extent of nitrification decreases with the length of time after the maximum to a degree depending upon the amount of nitrogen originally in the soil, and the maximum amount of nitrate produced.

YEARLY NITRIFICATION.

With some of the series of soils, as already pointed out, the experiment was carried on for several years, partly for the purpose of ascertaining if there was any seasonal variation in the production of nitrate. The soils were not exposed to the regular season temperatures, as they were kept in a room which was heated by steam during the winter. The average results of three of these series is given in Table 7.

Table 7.—Continued nitrification, parts nitrogen per million.

Period.	Set 3		Set 6		Set 8	
	Date	Average nitrate	Date	Average nitrate	Date	Average nitrate
0 weeks.....	May 1, 1913	12.4	May 6, 1913	12.7	May 8, 1913	6.9
4 weeks.....	May 29, 1913	36.3	June 3, 1913	47.1	June 5, 1913	27.0
8 weeks.....	June 26, 1913	16.3	July 1, 1913	27.5	July 3, 1913	12.2
2 weeks.....	July 25, 1913	9.4	July 29, 1913	31.7	July 31, 1913	5.3
6 weeks.....	Aug. 21, 1913	8.7	Aug. 26, 1913	15.5	Aug. 28, 1913	5.1
0 weeks.....	Sept. 18, 1913	4.8	Sept. 23, 1913	9.1	Sept. 25, 1913	3.7
4 weeks.....	Oct. 15, 1913	4.0	Oct. 21, 1913	40.9	Oct. 23, 1913	1.5
8 weeks.....	Nov. 13, 1913	1.3	Nov. 18, 1913	2.3	Nov. 20, 1913	0.9
2 weeks.....	Dec. 11, 1913	1.8	Dec. 16, 1913	2.6	Dec. 18, 1913	1.2
6 weeks.....	Jan. 8, 1914	1.3	Jan. 13, 1914	1.8	Jan. 15, 1914	0.6
0 weeks.....	Feb. 8, 1914	2.0	Feb. 10, 1914	3.1	Feb. 12, 1914	0.9
4 weeks.....	Mar. 5, 1914	1.9	Mar. 10, 1914	3.2	Mar. 12, 1914	0.6
8 weeks.....	April 4, 1914	1.8	May 10, 1914	4.2	April 9, 1914	1.1
2 weeks.....	April 30, 1914	2.4	May 5, 1914	4.8	May 7, 1914	1.9
6 weeks.....	May 28, 1914	3.4	June 2, 1914	6.2	June 4, 1914	2.1
0 weeks.....	June 25, 1914	6.4	June 30, 1914	9.6	July 2, 1914	3.1
4 weeks.....	July 23, 1914	5.3	July 28, 1914	10.4	July 30, 1914	4.0
8 weeks.....	Aug. 20, 1914	6.5	Aug. 25, 1914	8.2	Aug. 27, 1914	3.3
2 weeks.....	Sept. 7, 1914	5.4	Sept. 22, 1914	7.2	Sept. 24, 1914	2.5
6 weeks.....	Oct. 15, 1914	3.5	Oct. 20, 1914	3.6	Oct. 22, 1914	2.1
0 weeks.....	Nov. 12, 1914	2.1	Nov. 17, 1914	2.7	Nov. 19, 1914	1.3
4 weeks.....	Dec. 11, 1914	2.0	Dec. 15, 1914	2.4	Dec. 17, 1914	1.0
8 weeks.....	Jan. 9, 1915	.9	Jan. 12, 1915	1.7	Jan. 14, 1915	0..7
2 weeks.....	Feb. 4, 1915	1.0	Feb. 1, 1915	1.9	Feb. 13, 1915	8.0
6 weeks.....	Mar. 4, 1915	1.7	Mar. 9, 1915	3.0	Mar. 13, 1915	1.1
00 weeks....	April 1, 1915	2.2	April 8, 1915	3.1	April 8, 1915	1.2
04 weeks....	May 1, 1915	2.8	May 6, 1915	3.8	May 6, 1915	2.0
08 weeks....	May 29, 1915	4.1	June 3, 1915	3.6	June 5, 1915	1.5
12 weeks....	June 24, 1915	3.8	June 29, 1915	4.7	July 1, 1915	2.0
16 weeks....	July 22, 1915	3.3	July 27, 1915	4.2	July 29, 1915	1.9
20 weeks....	Aug. 19, 1915	3.3	Aug. 27, 1915	3.5	Aug. 24, 1915	1.6
24 weeks....	Sept. 9, 1915	2.8	Sept. 22, 1915	2.4	Sept. 23, 1915	2.4
28 weeks....	Oct. 14, 1915	2.5	Oct. 19, 1915	2.1	Oct. 21, 1915	1.3
32 weeks....	Nov. 4, 1915	1.9	Nov. 19, 1915	1.8	Nov. 18, 1915	1.0
36 weeks....	Dec. 9, 1915	1.5	Dec. 14, 1915	1.8	Dec. 16, 1915	0.8
40 weeks....	Jan. 1, 1916	1.2	Jan. 11, 1916	3.2	Jan. 13, 1916	1.0
44 weeks....	Feb. 3, 1916	1.2	Feb. 8, 1916	2.9	Feb. 10, 1916	0.7
48 weeks....	Mar. 2, 1916	1.6	Mar. 7, 1916	2.1	Mar. 7, 1916	0.4
52 weeks....	Mar. 30, 1916	1.0	April 4, 1916	1.9	April 6, 1916	0.7
56 weeks....	April 27, 1916	1.2	May 4, 1916	2.6	May 21, 1916	0.9
60 weeks....	May 27, 1916	1.8	June 1, 1916	3.6	June 2, 1916	1.4
64 weeks....	June 22, 1916	2.0	June 27, 1916	3.6	June 29, 1916	0.8
68 weeks....	July 23, 1916	2.2	....	....	July 27, 1916	1.7

The maximum nitrification occurred in the first period of four weeks. It decreased to a minimum with set 3 at the end of 28 weeks, November

13, and at the end of 36 weeks, January 13-15, with sets 3 and 8. It then increased to a second maximum, much smaller than the first, at the end of 64 weeks, July 28-30, with sets 6 and 8, and at the end of 68 weeks, August 20, with set 3. The second minimum was reached on January 9-14, at the end of 88 weeks. The third maximum was reached at the end of 108 weeks, May 29, with set 3; 112 weeks, June 29, with set 6; 124 weeks, September 23, with set 8.

The third maximum was reached in November with set 6, and March with set 3 and 8. There is clearly a seasonal variation in nitrification.

RELATION OF NITRATES PRODUCED TO NITROGEN CONTENT OF SOIL.

Table 8 shows the average quantity of nitric nitrogen produced in the soils, arranged into groups, at the end of several periods of four weeks each. The quantity of nitric nitrogen in the original soil as ascertained by the first percolation is also included, but this does not enter into the discussion. The total nitric nitrogen produced during twelve weeks is given. The tables for 16 to 24 weeks and for 28 and 32 weeks are also given. Carbonate of lime had been added to most of these sets at the end of 12 weeks.

Table 8.—Average production of nitrate nitrogen in soils parts per million.

	Date begun	Number of soils	Per cent nitrogen in soils	0 weeks	4 weeks	8 weeks	12 weeks	Total	16 weeks	20 weeks	24 weeks	Total	28 weeks	32 weeks	Total
Set 21	April 8, 1914	12	.011	6.4	13.4	4.5	1.7	19.6	4.7	3.2	2.0	9.9	1.9	1.0	2.9
Set 22	April 8, 1914	12	.033	19.8	15.6	11.6	9.1	36.3	13.8	8.5	2.9	25.2	2.5	1.3	3.8
Set 23	April 9, 1914	12	.032	8.0	32.1	12.6	4.5	49.2	13.0	8.3	3.6	24.9	2.9	1.2	4.1
Set 24	April 14, 1914	12	.027	7.0	23.4	7.3	3.8	34.5	15.2	6.3	3.1	24.6	2.7	1.1	3.8
Set 25	April 13, 1914	12	.031	.7	12.0	8.7	4.0	24.7	17.1	8.7	4.3	30.1	2.8	1.1	3.9
Set 26	April 14, 1914	12	.030	4.2	11.3	6.7	2.7	20.7	15.2	8.0	2.6	25.8	2.7	1.3	4.0
Set 27	April 15, 1914	12	.030	1.6	7.0	3.3	2.6	12.9	9.4	14.8	3.5	27.7	3.3	....	3.3
Set 28	April 15, 1914	12	.036	.9	9.4	5.6	3.1	18.1	10.0	9.6	2.5	22.1	2.7	1.1	3.8
Set 29	April 16, 1914	12	.034	5.7	8.0	7.2	5.0	20.2	7.3	6.4	2.8	16.5	2.7	1.4	4.1
	Average....	....	.032	6.1	15.4	7.9	4.3	27.1	12.6	8.8	3.2	24.6	2.8	1.2	3.9
Set 8	May 8, 1913	11	.048	7.0	20.7	12.2	5.4	38.3	....	....	....	....	....	....	....
Set 12	May 15, 1913	12	.045	8.3	21.6	12.1	6.9	40.6	4.3	3.3	1.7	9.3	1.5	....	1.5
Set 30	April 16, 1914	12	.052	6.6	38.6	18.7	9.2	66.5	12.2	10.3	4.9	27.4	3.5	2.2	5.7
Set 31	April 19, 1914	12	.053	2.6	25.2	35.4	16.0	76.6	27.9	24.9	7.3	60.1	3.9	2.5	6.4
Set 32	April 20, 1914	12	.048	3.6	24.0	8.9	7.0	39.9	8.8	15.7	5.0	29.5	3.8	2.5	6.3
Set 33	April 20, 1914	12	.047	1.3	11.8	5.8	6.4	24.0	24.2	10.5	5.0	39.7	3.2	2.4	5.6
Set 34	April 21, 1914	12	.045	1.7	14.9	11.7	6.0	32.6	11.7	10.3	5.3	27.3	3.6	2.3	5.9
Set 35	April 22, 1914	12	.047	1.8	21.2	14.4	7.6	43.2	11.3	11.7	5.1	28.1	3.3	2.1	5.4
Set 36	April 22, 1914	12	.048	3.0	15.3	10.3	6.1	31.7	8.6	10.0	4.6	23.2	3.0	2.0	5.0
	Average....	....	.048	4.1	21.5	14.4	7.8	43.7	13.6	12.1	4.9	30.6	3.2	2.3	5.2
Set 37	April 23, 1914	12	.076	19.7	63.2	22.0	21.7	106.9	29.7	10.7	5.9	46.3	5.5	3.4	8.9
Set 38	April 23, 1914	12	.068	18.6	18.6	20.2	9.4	48.2	16.2	17.1	7.5	40.8	5.5	3.4	8.9
Set 39	April 27, 1914	12	.067	24.1	24.1	17.5	9.4	51.0	11.7	7.8	6.6	26.1	3.2	2.3	5.5
Set 40	April 27, 1914	12	.068	23.8	23.8	11.6	8.4	43.8	11.1	6.3	5.4	22.8	3.7	1.9	5.6
	Average....	....	.069	32.4	32.4	17.6	12.2	62.5	17.2	10.5	6.4	34.1	4.5	2.7	7.2
Set 3	May 1, 1913	11	.081	32.8	32.8	14.9	8.1	55.8	....	....	....	....	....	....	....
Set 41	April 28, 1914	12	.088	37.0	37.0	22.9	16.2	76.1	18.8	11.6	8.6	39.0	4.6	3.3	7.9
Set 42	April 28, 1914	12	.090	34.4	34.4	13.4	9.3	57.1	11.7	7.4	6.4	25.5	3.3	2.6	5.9
Set 43	April 29, 1914	12	.110	32.2	32.2	33.3	15.2	80.7	21.9	19.3	....	41.2	....	....	....
	Average....	....	.092	34.1	34.1	21.1	12.2	67.4	17.5	12.8	7.5	35.2	3.9	2.9	6.9
Set 6	May 8, 1913	12	.098	50.6	50.6	27.5	22.4	100.5	....	....	....	....	....	....	....
Set 44	April 29, 1914	12	.111	28.5	28.5	25.6	25.5	79.6	21.7	19.5	....	41.2	....	....	....
Set 45 A	April 30, 1914	6	.170	76.3	76.3	38.2	26.0	140.5	15.3	14.9	10.3	40.5	6.3	5.3	11.6
Set 45 B	April.........	6	.240	77.3	77.3	72.7	42.6	192.6	24.9	23.8	18.2	66.9	10.3	8.3	18.6

On examination of the table, it is immediately seen that the average quantity of nitric nitrogen produced during each period of four weeks increased with the total nitrogen of the soil. The same is also true if the total nitric nitrogen produced is considered. In other words, the nitrification, on an average, is in proportion to the total nitrogen of the soil. This is also shown in Figure 2.

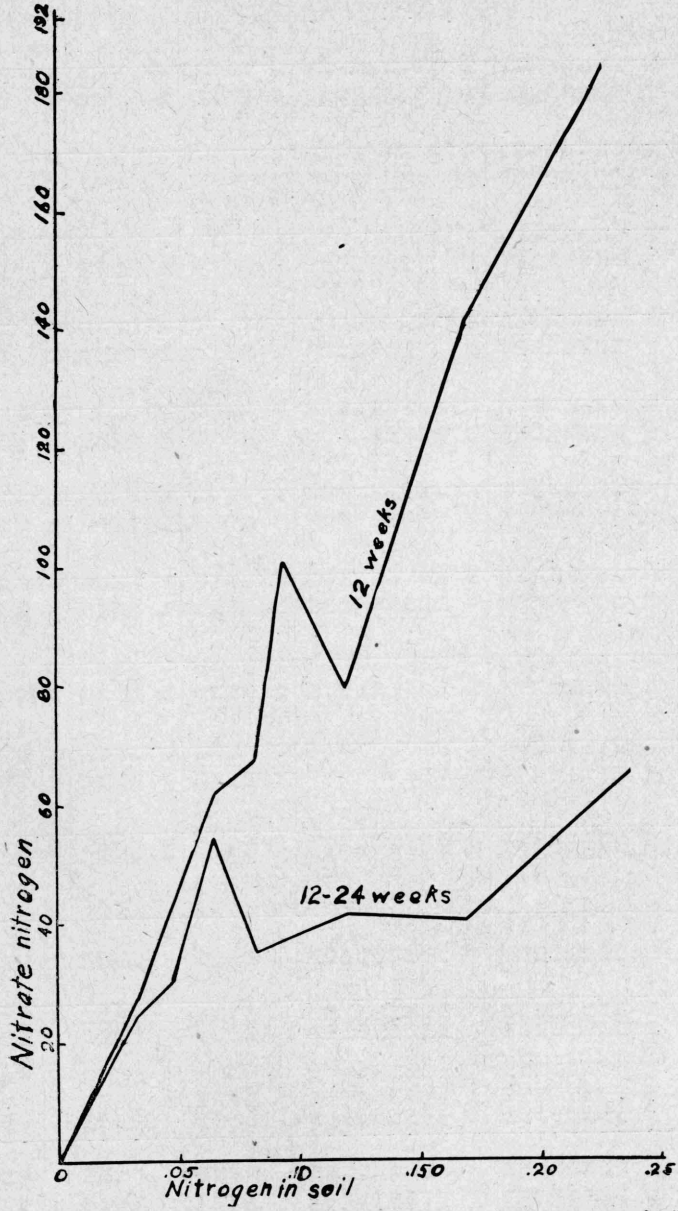

Figure 2—Relation of average nitrate production to nitrogen content of soil.

Table 9.—Percentage of soil nitrogen converted into nitrates during the period of twelve weeks.

	Total nitrogen in soil per cent	0 weeks	4 weeks	8 weeks	12 weeks	Total 12 weeks	16 weeks	20 weeks	24 weeks	Total	28 weeks	32 weeks	Total 8 weeks
Set 21	.011	5.8	12.2	4.1	1.5	17.8	4.3	2.9	1.8	9.0	1.7	0.9	2.6
Set 22, 23, 24, 25, 26, 27, 28, 29	.032	1.8	4.8	2.4	1.3	8.5	3.9	2.7	1.0	7.6	0.8	0.3	1.1
Sets 8, 12, 30, 31, 32, 33, 34, 35, 36	.048	0.8	4.4	3.0	1.6	9.0	2.8	2.5	1.0	6.3	0.6	0.4	1.0
Sets 38, 39, 40	.069	4.6	4.6	2.5	1.7	8.8	2.4	1.5	0.9	4.8	0.6	0.3	0.9
Sets 3, 41, 42, 43	.092	3.6	3.6	2.3	1.3	7.2	1.8	1.2	0.8	3.8	0.3	0.3	0.6
Set 6	.098	5.1	5.1	2.8	2.2	10.1	....	....	....	....	....	....	....
Set 44	.111	2.5	2.5	2.3	2.3	7.1	1.9	1.7	....	3.6	....	....	....
Set 45 A	.170	4.5	4.5	2.2	1.5	8.2	0.9	0.8	0.6	2.3	0.3	0.3	0.6
Set 45 B	.240	3.2	3.2	3.0	1.7	7.9	1.0	0.9	0.7	2.6	0.4	0.3	0.7

This is also shown in a different way in Table 9, in which is given the average total nitrogen for each group and the percentage of it converted into nitric nitrogen.

With the exception of the first group, the percentage of nitric nitrogen produced is very nearly constant, and thus brings out strikingly the fact that the production of nitric nitrogen is, on an average, in proportion to the total nitrogen of the soil. It also shows that from 7.1 to 10.1 per cent. of the total nitrogen was converted into nitrates in 12 weeks.

The soils were in the natural condition during the first twelve weeks, but at the end of this period they received an addition of 5 grams carbonate of lime, equal to .1 per cent. This increased the nitrification decidedly with many of the soils. The nitrification during the second period of 12 weeks is from 2.3 to 9.0 per cent. of the soil nitrogen. During the third period of eight weeks, the nitrification is from 0.6 to 2.6 per cent. of the total nitrogen.

All of the soils used in this work were in the natural condition and had received no additions of lime or fertilizer, the first 12 weeks. Some of them did not nitrify well. The quantity of nitrates produced in these soils is dependent not only upon the quantity of nitrogen contained in them and its form of chemical combination, but also upon the physical condition, and the chemical composition of the soil. In other words, more than one factor takes part in this process. These factors will be discussed later.

The effect of these other factors is visible in wide variations between the individual samples of soil. Some of the soils did not nitrify at all, and thereby lowered the nitrogen production of the group in which they were included. It is only by taking a large number of samples of soil that the average relations here brought out could be clearly shown.

Especial attention will be paid to soils which are particularly high in nitrification, and those which are especially low, to ascertain the reasons for these variations, and particularly their effect upon crop production.

The addition of carbonate of lime, 1 per cent., at the end of 12 weeks, caused a decided increase in nitrification, as may be seen by comparing the nitrate nitrogen produced at the end of 12 and of 16 weeks. As will be seen, this addition to a large extent eliminates differences in nitrification capacity of the soil, and the differences remaining are due to the character of the soil nitrogen.

RELATION OF NITRIFICATION TO COMPOSITION OF SOILS.

A study was made of the relation between nitrate production in soils, and their composition and other properties, in order to trace any relation that might exist. For this purpose, two groups of soils were selected, those containing from .02-.04 per cent. nitrogen and those containing .04-.06 per cent. nitrogen as shown in Table 10. The total amount of nitrate produced during the first 12 weeks was used. With the first group, containing .02-.04 per cent. nitrogen, the nitrates produced during 28 weeks were also included. At the end of 12 weeks the soils in this group were mixed thoroughly with carbonate of lime at the rate of 5 grams lime to 500 grams soil.

Table 10.—Relation of nitrification to composition of soil groups.

	02–04 per cent nitrogen		Nitrification 28 weeks lime	04–06 per cent nitrogen	
	Number averaged	Nitrification		Number averaged	Nitrification 12 weeks
Surface soils	35	25.5	48.9	42	42.3
Subsoils	47	30.9	51.4	45	43.8
Active phosphoric acid per million:					
0–10	24	21.4	52.8	23	49.7
10–20	23	26.3	49.1	17	42.8
20–30	23	25.9	43.1	9	43.0
Over 30	16	28.9	44.1	34	49.0
Active potash, per million:					
0–50	13	32.2	36.9	3	30.0
50–100	16	15.3	40.7	19	35.8
100–150	23	23.8	36.2	23	36.2
Over 150	18	29.3	51.3	34	48.6
Alumina and oxide of iron, per cent:					
0–5	60	26.1	....	41	47.0
5–10	17	26.7	57.3	24	43.5
10–15	4	36.1	72.3	10	64.6
Over 15	1	1.3	44.1	6	29.4
Acid consumed per cent:					
0–2	21	20.1	39.1	12	29.9
3–5	45	23.1	50.5	24	43.9
5–10	2	62.6	105.4	18	31.8
15–20	2	25.8	44.6	7	35.1
Over 20	6	33.1	53.0	20	48.5
Acid soils	16	14.1	46.3	21	33.9

The results of these comparisons are given in Table 10. The surface soils on an average, produced slightly less nitrates than the subsoils. This is possibly due to the fact that more of the easily nitrified material had already been changed in the surface soil, leaving a more resistant residue, since the surface soils were under more favorable conditions for nitrification than the subsoils. The subsoils had not received enough oxygen to oxidize as much material as the surface soils. When both soils are placed under similar conditions, the subsoil nitrifies on an average slightly more than the surface soil. Further differences will be brought out in the discussion of individual soils.

The soils were divided into groups, those containing less than ten parts per million of active phosphoric acid, those containing from ten to twenty, those containing from twenty to thirty, and those containing over thirty, parts per million of active phosphoric acid. No relation could be observed between the quantity of active phosphoric acid present and the amount of nitrate produced.

The soils were divided into three groups based on the active potash present. The first group contains less than 50 parts per million of active potash, the second group from 50 to 100, the third from 100 to 150, and the fourth group over 150 parts per million. No relations were found between the active potash and the amount of nitrate produced.

The soils were divided into groups based upon the amount of alumina and oxide of iron taken together. The first group contained those with less than 5 per cent alumina and iron oxide soluble in hydrochloric acid, the second group those containing 5 to 10 per cent., the third group those containing 10 to 15 per cent., and the fourth group those containing over 15 per cent. No relation could be traced between the nitrates produced, and the amount of iron and alumina present.

The soils were divided into groups based upon the amount of acid consumed in the estimation of active phosphoric acid and potash. In following the method, 200 grams of soil were brought in contact with 2000 c.c. of N/5 nitric acid. At the end of the digestion, the acid was titrated back with N/10 caustic soda, and the amount of nitric acid used expressed in percentage of the amount used. A soil which consumed 10 per cent. of the nitric acid solution would contain 1 per cent. of carbonate of lime or its equivalent in other bases.

The only relation that could be traced between the amount of acid consumed and the amount of nitrates produced in the soil was a slightly lower production with soils having 2 per cent acid consumed or less. Since the acid consumed represents the amount of bases in the soil, this result is not altogether what might be expected. It is possible that the bases in the soil had already caused nitrification to take place in the soils in the fields so that the nitrogen left was not easily oxidized. On the other hand, the soils low in lime might possibly contain more easily oxidized nitrogen. This, however, is purely speculation.

Acid Soils. Sixteen acid soils were found in one group, and twenty-one in the other. With both groups, the nitrification is less than the average for the other soils containing less than 5 per cent. of carbonate of lime. The acid soils thus produce less amounts of nitrate. The acid soils after they had received lime, at the end of twenty-eight weeks nitrified on an average the same as the other soils of the group containing less than 5 per cent. acid consumed.

As a general rule, the acid soils nitrified to a less extent than the non-acid soils. Acidity of the soil thus decreases the amount of nitrates produced in it.

Examination of the nitrification of the individual acid soils shows that they run to extremes. Some do not nitrify at all, or have a low nitrification, while others have a high nitrification. It is the balancing of these extremes which reduces the average difference between acid and non-acid soils.

COMPOSITION OF SOILS WITH LOW AND HIGH NITRIFICATION.

Table 11 contains the chemical composition of soils having low nitrification and Table 12 those having high nitrification.

All soils having a low nitrification in the group containing from .04 to .06 nitrogen, are subsoils; twelve out of sixteen samples are subsoils in the group .02-.04 per cent. nitrogen. More subsoils have a low nitrification than surface soils, but the average of the two groups differs very little. Over 50 per cent. of the soils with low nitrification are acid. The lime content is usually low. The acid consumed is usually low. No other relation can be traced. The samples having a high nitrification in the group containing from .02 to .04 per cent. nitrogen are all subsoils, and eight of the samples containing from .04 to .06 per cent. nitrogen are surface soils, and nine are subsoils. Subsoils thus possess unusually high and unusually low nitrification.

Table 11.—Chemical composition of soils with nitrification below 10.

Lab. No.		Total Phosphoric acid	Nitrogen	Acid soluble potash	Acid soluble lime	Magnesia	Alumina Oxide of iron	Active Phosphoric acid	Active potash	Acid consumed	Acidity	Nitrification
7164	Subsoil to 7163 reddish, mottled with gray.....	.04	.04	.07	.31	.09	2.51	25.0	103.7	2.0	0	5.1
7090	Subsoil to 7089 red sandy..................	.07	.04	.12	.11	.12	7.58	6.9	90.0	....	600	0.0
4596	Subsoil to 4595 red clay....................	.06	.04	.36	.07	.21	13.47	3.8	227.6	3.5	300	0.0
5710	Surface poor prairie bottom subject to overflow.	.08	.07	.21	.22	.09	5.11	10.6	76.2	4.5	0	5.7
4645	Subsoil to 4644 light sandy red..............	.03	.04	.19	.09	.13	10.74	2.5	327.1	2.5	0	1.2
3976	Lufkin clay surface soil.....................	.03	.03	.23	.19	.24	8.71	11.8	19.9	3.6	1000	0
3657	Subsoil Orangeburg fine sandy loam..........	.02	.03	.19	.23	.19	6.82	4.7	86.2	5.0	0	0
3251	Sunsoil to 3250............................	.02	.04	.26	.13	.21	7.45	7.6	88.2	13.7	200	9.1
3346	Subsoil Susquehanna fine sandy loam.........	.06	.04	.94	.11	.16	3.20	93.9	272.9	2.9	0	0
2351	Subsoil to Susquehanna fine sandy loam.......	.02	.04	.35	.33	.23	18.86	3.8	92.2	4.2	200	1.3
2347	Subsoil Susquehanna gravelly loam...........	.04	.03	.17	.10	.23	9.86	5.9	147.7	0	200	8.4
1126	Subsoil Caddo fine sandy loam...............	.02	.03	.19	.07	.03	3.87	1.2	109.0	2.0	68	1.4
875	Subsoil Norfolk fine sandy loam..............	.02	.03	.19	.05	.24	6.76	....	....	....	0	0
322	Surface soil Orangeburg fine sand............	.05	.03	.14	.14	.06	.03	1.8	25.5	15.2	0	3.4
100	Subsoil to 7167............................	.05	.04	.40	.08	.20	10.75	7.5	133.7	3.5	334	0
7168	Surface soil Orangeburg clay................	.04	.00	.06	.67	.10	1.33	91.2	75.0	9.0	0	0
1128	....	.06	.10	1.12	.45	.06	18.07	....	....	....	399	1.7
3316	....	.04	.06	.49	.13	.66	19.58	7.6	154.1	4.9	1800	1.4
164	Subsoil red sandy clay......................	.06	.04	.13	.11	.39	6.22	....	....	....	0	.1
1138	Subsoil Susquehanna fine sandy loam.........	.04	.06	.45	.15	.77	19.16	7.5	150.67	8.2	0	0.4
3417	Subsoil to 3416 red clay....................	.02	.05	.48	.19	.43	4.33	8.2	161.2	6.0	0	1.0
2324	Subsoil Orangeburg clay.....................	....	.04	....	....	....	....	....	....	....	200	1.3
4586	Subsoil to 4585 light brown red clay..........	.03	.04	.29	.07	.10	9.40	2.5	102.5	2.0	600	8.3
3398	Subsoil to 3397 light brown loam.............	.08	.04	.21	.14	.35	4.92	9.4	100.0	5.1	1400	0
855	Subsoil Suehansquna fine sandy loam.........	.04	.05	.20	.40	.32	15.25	5.29	77.6	8.5	120	0.5
3402	Subsoil to 3401 reddish sandy clay...........	.09	.04	.22	.26	.48	6.63	9.10	65.9	7.1	1400	.7
3368	Subsoil to 3367 light red clay...............	.04	.05	.49	.25	.33	19.60	10.0	....	3.9	0	.8
	Average.............................	.05	.04	.31	.19	.25	9.23	14.7	117.7	5.1	32.7	1.9

Table 12.—Chemical composition of soils with nitrification above 60.

	Total Phosphoric acid	Nitrogen	Acid soluble potash	Acid soluble lime	Magnesia	Alumina Oxide of iron	Active Phosphoric acid	Active potash	Acid consumed	Acidity	Nitrification
1136 Subsoil Norfolk fine sandy loam	.02	.03	.43	.92	.12	3.92	.10	.177	4.0	0	67.2
854 Subsoil Lufkin clay	.01	.03	.25	.33	.33	8.27	17.6	1.659	6.1	0	88.0
879 Subsoil Susquehanna sandy loam	.02	.04	.19	.28	.59	10.37	....	....	....	0	83.0
962 Subsoil Laredo silt loam	.13	.04	.25	9.61	.08	6.04	14.3	....	....	0	73.2
880 Subsoil Austin fine sandy loam	.08	.04	.38	14.03	6.56	4.65	....	....	....	0	109.1
884 Wabash clay subsoil	.03	.06	.35	.67	.65	13.82	....	....	....	0	99.2
1211 Surface soil	.01	.06	.10	.40	.30	5.07	....	....	....	0	163.9
877 Laredo silt loam subsoil	.06	.04	.30	4.96	.60	....	....	....	....	0	92.9
826 Wabash fine sandy loam subsoil	.04	.06	.19	.32	.31	5.46	17.7	....	5.9	417	97.3
914 Lufkin fine sandy loam surface soil	.04	.05	.11	.18	.01	1.99	39.0	320.0	2.5	0	63.9
980 Orangeburg fine sandy loam surface soil	.04	.05	.11	.06	.10	3.00	13.3	140.0	3.8	0	64.7
992 Orangeburg fine sandy loam surface soil	.15	.04	1.26	.29	.27	16.09	15	....	7.6	0	65.1
970 Barstow sandy loam	.01	.06	.45	.46	.41	6.60	45.0	408.7	9.6	0	80.7
4231 Upland sample of surface soil	.02	.05	.25	.47	.47	13.23	7.6	77.5	11.1	....	65.3
1972 Surface soil light sandy	.06	.06	.36	6.65	.57	5.38	144.2	160.0	99.5	0	61.2
963 Subsoil Rio Grande silty clay	.17	.05	.70	9.86	1.17	10.47	66.8	295.0	100.0	0	76.8
816 Surface soil Laredo fine sand	.03	.05	.57	.43	.23	7.23	12.7	218.0	21.4	252.0	65.6
388 Surface soil Lufkin clay	.01	.05	.14	.43	.07	3.36	107.7	152.0	100.0	....	114.1
1587 Subsoil San Jacinto clay	.02	.05	.11	.23	.12	.06	11.0	63.0	0.2	34	99.8
1932 Subsoil to 1931	.01	.05	....	.21	.17	1.88	26.3	123.0	4.0	200	61.0
824 Subsoil Wabash clay fine sandy loam	.03	.05	.23	.24	.23	4.66	16.1	137.6	.4	164	83.9
4234 Subsoil red clay	....	.04	....	....	....	....	4.0	82.5	47.5	500	92.6
Average	.05	.05	.34	2.43	0.63	6.58	32.1	112.3	18.6	82	84.9

At least six of these samples with high nitrification are acid. The acid character of the soil, therefore, does not prevent nitrification, for the soil may be acid and yet the nitrification may be higher than the average. However, the soils having a high nitrification generally contain a larger amount of lime than those having a low nitrification.

There are two different explanations of the fact that some subsoils may possess a very low nitrification, and others a very high nitrification. The high nitrification may be due to the fact that the organic matter of these subsoils has been little affected by nitrifying agencies in the past on account of unfavorable conditions for nitrification. The easily nitrified material has not been changed. When placed under conditions favorable to nitrification, this easily nitrified material becomes rapidly oxidized. This may account for the high nitrification on some of the subsoils.

The low nitrification may be due to the presence of substances which interfere with the development of the nitrifying organism, or to a deficiency in substances needed in their growth, or to the presence of substances which promote the growth of bacteria which denitrify the nitrate.

Further work presented in this bulletin throws some light upon this matter.

EFFECT OF ADDITIONS ON SOILS WITH LOW NITRIFICATION.

Table 13 gives the effect of additions on some soils having a low nitrification. The figures given are the totals produced at the end of the period of time stated. Thus soil 100 has produced 20 parts per million of nitrates at the end of 88 weeks. The additions made were di-calcium phosphate or potassium sulphate at the rate of 0.2 gram per 500 grams or a combination of the two.

Table 13.—Effect of additions on total nitrate produced per million.

Soil			Treatment	12 weeks	24 weeks	36 weeks	48 weeks	60 weeks	72 weeks	84 weeks	88 weeks
100	A	O	None	0	.5	.5	.5	1.8	10.4	18.5	20.8
	B	D	Dicalcium phosphate	0	.0	.0	.0	2.6	31.1	52.5	64.5
	C	K	Sulphate of potash	0	.0	.0	.0	.0	.9	1.1	1.2
	DDK		Phosphate and potash	0	.0	.0	.0	2.9	27.5	38.5	45.3
312	A	O	None	93	12.2	13.4	16.0	18.2	21.2	24.3	25.2
	B	D	Dicalcium phosphate	8.8	10.8	11.4	13.9	15.8	18.9	21.2	22.3
	C	K	Sulphate of potash	7.3	9.9	10.3	13.7	16.9	20.1	22.5	23.3
	DDK		Phsophate and Potash	7.4	9.6	11.0	13.3	16.5	20.1	22.4	22.7
1126	A	O	None	.0	.0	.0	.6	10.0	29.8	32.9	32.9
	B	D	Dicalcium phosphate	.0	.0	17.2	39.0	42.8	46.1	50.2	50.6
	C	K	Sulphate of potash	.0	.0	.0	3.2	37.2	45.1	49.2	49.6
	DDK		Phosphate and potash	.0	.2	2.0	32.8	45.4	52.9	55.4	56.4
1201	A	O	None	8.1	10.1	10.1	12.3	14.2	......	......	......
	12	D	Dicalcium phosphate	8.2	9.6	9.8	11.7	13.8	......	......	......
	C	K	Sulphate of potash	6.8	8.0	8.2	9.5	11.3	......	......	......
	DDK		Phosphate and potash	7.7	9.3	9.5	10.3	12.3	......	......	......
2347	A	O	None	.0	.5	3.9	20.4	33.1	......	......	......
	B	D	Dicalcium phosphate	.0	11.6	33.1	38.0	42.6	......	......	......
	C	K	Sulphate of potash	.0	.0	5.6	17.3	22.3	......	......	......
	DDK		Phosphate and potash	.0	2.1	19.9	29.5	34.3	......	......	......
2351	A	O	None	.0	.0	1.4	24.8	33.7	......	......	......
	B	D	Dicalcium phosphate	.0	.0	17.3	26.5	33.1	......	......	......
	C	K	Sulphate of potash	2.0	2.0	2.0	11.4	30.3	......	......	......
	DDK		Phosphate and potash	.0	.0	2.3	22.5	29.2	......	......	......
3251	A	O	None	.0	.0	.0	.0	7.0	24.4	......	......
	B	D	Dicalcium phosphate	.0	.0	.0	7.8	22.2	32.5	......	......
	C	K	Sulphate of potash	.0	.0	.0	5.0	26.0	35.5	......	......
	DDK		Phosphate and potash	.0	.0	.0	5.0	26.9	33.3	......	......
3976	A	O	None	.0	.0	.0	.0	2.0	13.8	......	......
	B	D	Dicalcium phosphate	.0	.0	.0	.0	7.6	28.1	......	......
	C	K	Sulphate of potash	.0	.0	.0	.0	.0	2.4	......	......
	DDK		Phosphate and potash	.0	.0	.0	2.1	15.8	25.9	......	......
4596	A	O	None	.6	5.5	15.7	21.7	29.3	34.3	......	......
	B	D	Dicalcium phosphate	5.8	30.8	35.0	37.8	39.9	43.9	......	......
	C	K	Sulphate of potash	.0	.8	5.8	10.0	22.5	30.0	......	......
	DDK		Phosphate of potash	4.4	29.0	31.6	35.6	38.6	43.8	......	......
4645	A	O	None	.0	.0	.0	.0	18.4	46.7	......	......
	B	D	Dicalcium phosphate	.0	.0	.0	.2	25.9	35.5	......	......
	C	K	Sulphate of potash	.0	.4	.4	.4	2.0	19.1	......	......
	DDK		Phosphate and potash	.0	.0	.0	.0	19.1	33.2	......	......
7090	A	O	None	.0	.0	.0	1.0	8.9	19.3	......	......
	B	D	Dicalcium phosphate	.0	.0	.0	7.6	20.1	26.5	......	......
	C	K	Sulphate of potash	.0	.0	.0	3.6	12.0	19.3	......	......
	DDK		Phosphate and potash	.0	.0	.0	1.0	18.0	28.7	......	......

The addition of di-calcium phosphate increases the nitrification with soil 100 at the end of 72 weeks, with soil 1126 at the end of 48 weeks, with soils 2347 and 2351 at the end of 36 weeks, with soil 3251 at the end of 60 weeks, with soil 3976 at the end of 72 weeks, with soil 4596 at the end of 24 weeks, and with soil 7090 at the end of 60 weeks. The addition of di-calcium phosphate, therefore, increases the production of nitrates, though a considerable period of time elapsed with most of the soils before this increase was apparent.

The sulphate of potash decreased nitrification in soil 100. It increased the nitrification with soil 1126 at the end of 60 weeks although not to the extent of the phosphate. It increased the nitrification with soil 3251 at the end of 60 weeks. It decreased the nitrification with 3976, 2347, and 4685. The potash did not affect the nitrification with soils 312, 1201, 2351, 4596, and 7090.

The combination of phosphate and potash is not as good as the phosphate alone in soil 100. It is somewhat better with soil 1126. It is not as good with soils 2347, 2351, 3976, and 4658, although the difference is usually small.

Table 14.—Effect of carbonate of lime on soils which did not nitrify well. Parts of nitrate nitrogen per million.

Lab. No.	Set No.	Total 12 weeks	16 weeks	20 weeks	24 weeks	28 weeks	Total 28 weeks	Per cent. Nitrogen	Average of group 12 weeks
100	22	.0	24.4	44.4	5.5	3.2	77.5	.04	43.7
100	23	0.7	18.6	46.4	6.2	3.8	75.0	......	......
100	24	4.1	79.0	7.8	3.4	2.6	92.8	......	......
100	25	7.4	84.0	8.4	5.9	2.9	101.2	......	......
100	26	5.4	97.6	10.0	5.1	3.1	115.8	......	......
100	27	1.0	3.4	54.6	4.6	4.0	66.6	......	......
100	28	1.2	17.1	52.4	3.2	3.7	76.4	......	......
100	29	0.0	0.0	0.0	0.0	.1	.1	......	......
164	30	.1	6.4	36.4	8.0	3.7	54.5	.044	43.7
164	31	1.3	38.6	37.1	5.9	3.4	83.2	......	......
164	32	.7	29.6	33.4	6.5	3.6	73.1	......	......
164	33	.5	3.1	33.2	7.4	3.4	47.1	......	......
164	34	.0	3.4	49.0	8.1	3.4	63.9	......	......
164	35	.1	2.7	52.4	6.6	3.6	65.3	......	......
164	36	.1	24.2	38.4	6.6	3.7	72.9	......	......
1126	23	1.4	40.4	11.8	5.2	3.4	60.8	.029	27.1
2347	24	8.4	26.6	9.9	3.6	4.4	44.5	.027	27.1
3251	25	9.1	31.2	8.6	4.2	3.3	47.3	.040	43.7
2351	25	1.3	3.4	28.4	8.0	3.0	42.8	.039	27.1
3976	26	0.0	1.1	33.2	4.1	4.2	42.6	.022	27.1
4596	27	0.0	10.4	12.5	1.2	3.0	27.1	.035	27.1
4645	27	1.2	1.4	38.2	6.5	4.4	50.5	.035	27.1
5711	27	5.7	14.0	......	......	......	14.0	.038	27.1
7090	27	0.0	10.1	11.3	2.6	2.8	26.8	.039	27.1
7164	29	5.1	2.2	3.4	1.6	2.5	9.7	.038	27.1
1138	31	.4	23.6	135.6	15.5	8.4	183.1	.06	62.6
2324	32	1.3	8.6	50.4	3.5	2.8	65.3	.047	43.3
3368	33	.8	38.4	8.6	7.1	2.5	56.6	.055	43.7
3398	33	.0	29.0	6.8	2.2	2.0	40.0	.041	43.7
3402	33	.7	10.3	13.8	3.1	3.7	30.9	.041	43.7
3417	33	1.0	36.4	8.3	5.1	2.7	52.5	.053	43.7
4586	34	8.3	26.2	8.3	4.2	2.7	41.4	.044	43.7

As previously stated, an addition of carbonate of lime at the rate of 5 grams to 500 grams of soil was made in a number of the series at the end of twelve weeks. The results of this addition with respect to the soils which do not nitrify well are given in Table 14. The amounts given are those formed during periods of 4 weeks. It is evident that the addition of carbonate of lime in all cases increases the nitrification to a considerable extent. The effect of the carbonate of lime is much quicker, and more effective than either the phosphate or the potash. It would appear from these results that the conditions in the soil unfavorable to nitrification can be eliminated very rapidly by the use of 1 per cent. carbonate of lime.

Rapid nitrification took place within four to eight weeks after the carbonate of lime was added, and there were only a few soils in which the nitrification was not increased very highly by the carbonate of lime. These soils are 2348, 2711, 7164, and 4596. No. 2711 could be omitted, as it did not allow the water to percolate after the first four weeks of adding the calcium carbonate. Even with these soils, it is not a refusal to nitrify at all, but only a low nitrification compared with other soils in the same group. Table 14 also contains a comparison from Table 8 of the nitrate produced for the group in which these soils belong. It is seen that the addition of calcium carbonate caused the nitrification to be greater than the average of the group, except with soils 4596, 5711, 7164, and 3398, and with two of these, it is practically equal to the average.

NITRIFICATION OF THE ORGANIC MATTER OF THE SOIL.

The following work was designed to test the nitrification of the organic matter of the soil. A quantity of soil 1956 was thoroughly mixed. To 400 gram portions of this soil in twelve percolators, 5 grams of calcium carbonate and 1 gram potassium phosphate finely pulverized were added. The first two portions of the soil received no further addition. To the others 100 grams of the soils to be treated were added in duplicate. The soils were then inoculated with nitrifying organisms from a fertile garden, as in all of these experiments, percolated at once, and again at the end of four periods of four weeks each.

Table 15.—Nitrification of organic matter of soil in parts nitrate nitrogen per million.

	0 weeks	4 weeks	8 weeks	12 weeks	16 weeks	Total 4-8-12-16 weeks	Average	Gain
1956A	11.2	4.8	3.2	3.7	3.4	15.3	15.3	....
B	10.9	5.4	3.0	3.7	3.3	15.4	....	....
4234A	11.2	11.0	6.1	4.4	4.8	56.3	26.8	11.3
B	11.0	11.0	6.4	5.2	4.6	27.2	....	....
4213A	14.3	10.4	2.6	4.1	4.1	21.2	21.4	6.1
B	14.5	10.0	3.9	3.8	3.7	21.5	....	....
4580A	13.6	13.0	6.2	6.1	5.8	31.1	31.3	16.0
B	15.9	13.3	6.2	6.1	5.9	31.5	....	....
4586A	12.6	12.5	3.7	2.7	3.9	22.8	23.2	7.9
B	19.7	9.9	3.9	5.4	4.4	23.6	....	....
4291A	12.3	6.2	2.8	2.6	3.4	15.0	14.4	0
B	13.0	5.8	2.5	2.8	2.7	13.8	....	....
Date percolated	3–22–15	4–19–15	5–17–15	6–14–15	7–12–15			

Table 15 contains an illustration of one of these experiments. The gain of nitrate is the amount secured from 100 grams of soil. The part per million is obtained by multiplying this by five.

Table 16.—Nitrate nitrogen produced from organic matter of soils.

Lab. No.	Set No.	Gain soil	Gain sand	Per million	Nitrification in sets	Set No.	Per cent nitrogen	Nitrifying capacity	Availability of Soil Nitrogen
164	52–55	22.2	28.5	111.0	4.6	31	.04	4	27.7
308	....	29.1	26.7	145.5	114.1	31	.05	79	29.1
3631	....	10.3	10.7	51.5	22.9	34	.06	44	8.2
3634	....	9.0	6.4	45.0	16.2	34	.05	36	8.6
4291	....	2.8	4.9	14.0	23.9	34	.04	170	3.5
4234	56	11.3	....	56.5	92.6	34	.04	146	14.1
4213	....	6.1	....	30.5	25.5	34	.05	83	6.1
4580	....	16.0	....	80.0	33.7	34	.05	42	16.0
4586	....	7.9	....	39.5	8.3	34	.04	21	9.9
7132	57	6.2	....	31.0	13.2	36	.04	42	7.7
7214	....	12.5	....	62.5	47.0	36	.06	76	10.4
7234	....	2.9	....	14.5	11.1	36	.04	76	3.6
7169	....	9.3	....	46.5	28.5	36	.05	61	9.3
7097	....	10.6	....	53.0	41.0	36	.05	75	10.6
1582	58	19.1	....	95.5	22.1	41	.09	23	10.6
1593	....	32.6	....	163.0	108.6	41	.09	66	17.0
1928	....	19.0	....	95.0	48.4	3	.10	50	9.5
1931	....	27.7	....	138.5	103.2	41	.08	74	17.3
3410	....	28.0	....	140.0	67.8	41	.09	48	15.5
112	59	24.4	....	122.0	26.8	22	.04	22	30.5
854	....	7.6	....	38.0	88.0	22	.03	232	12.7
312	....	4.8	....	24.0	16.6	22	.03	67	8.0
819	....	3.7	....	18.5	15.7	22	.02	83	9.2
306	....	12.2	....	61.0	52.6	22	.04	85	15.2
100	60	24.7	....	133.5	2.4	22	.04	2	33.4
4293	....	.0	....	.0	15.6	26	.03	....	.0
3976	....	11.2	....	56.0	.0	26	.03	0	18.8
3412	....	14.6	....	73.0	15.5	26	.02	21	36.5
4587	....	15.6	....	78.0	19.0	26	.03	24	26.0

Table 16 shows the results of several tests of soils. In each set, two samples of soil 1956 were included.

In one experiment, sand was used in place of soil 1956. The results of this test are given in Table 16. The results are somewhat different from that of soil 1956, although the difference is not great.

AVAILABILITY OF ORGANIC MATTER OF SOILS.

The nitrification of the organic matter of soil expressed in parts per million as given in Table 16, divided by the percentage of nitrogen in the soil, may be taken to give the availability of the nitrogen of the organic matter in the soil so far as the production of nitrates is concerned. This is the immediate availability. It has already been pointed out that the organic matter of the soil in many cases is nitrified very rapidly at first, but there is then a very rapid falling off, and the nitrates produced after this are decidedly smaller. This is especially shown in the experiments already mentioned, in which the nitrification was carried on for two or three years. After the easily nitrified nitrogen has been removed, the remaining nitrogen will be oxidized much more slowly. This is a wise provision of nature, because, if the nitrification continued at the same rate, the entire quantity of nitrogen in some soils would be removed in from 48 to 54 weeks in these experiments. The total nitrate nitrogen produced, in parts per million, and the percentages of the soil nitrogen nitrified during several periods of 24 weeks each, is given in Table 17. The quantity fluctuates, and finally becomes about 1 per cent. of the total soil nitrogen.

Table 17.—Percentage of soil nitrogen nitrified.

	Set No. 3 .081% N.			Set No. 6 .098% N.			Set No. 8 .048% N.		
	Date	Average Nitrate	Per Cent Nitrified	Date	Average Nitrate	Per Cent Nitrified	Date	Average Nitrate	Per Cent Nitrified
24 weeks	Sept. 18, 1913	79.5	9.8	Oct. 20, 1913	171.8	8.9	Oct. 23, 1913	54.8	11.4
48 weeks	April 4, 1914	10.1	1.2	May 10, 1914	17.2	1.7	April 9, 1914	5.3	1.1
72 weeks	Sept. 7, 1914	29.4	3.6	Sept. 22, 1914	46.4	4.6	Sept. 24, 1914	16.9	3.5
96 weeks	Mar. 4, 1915	11.2	1.2	Mar. 9, 1915	15.3	1.5	Mar. 3, 1915	14.2	2.9
120 weeks	Aug. 19, 1915	19.5	2.3	Aug. 27, 1915	22.9	2.3	Aug. 24, 1915	10.2	2.1
144 weeks	Feb. 3, 1916	11.1	1.2	Feb. 8, 1916	14.2	1.4	Feb. 9, 1916	7.2	1.5
168 weeks	July 23, 1916	9.8	1.2	June 27, 1916	13.8	1.4	July 27, 1916	5.9	1.2

The availability of the soil nitrogen varies from 3.5 to 37 per cent. Apparently there are some cases where the nitrification is zero, but this is not correct, for the original soil nitrifies in each of these instances. The nitrification of six of these soils is over 25 per cent. See the last column of Table 16.

Table 18.—Composition of soils with high and low availability of nitrogen.

Lab. No.	High availability	Phosphoric acid	Nitrogen	Potash	Lime	Magnesia	Alumina oxide of iron	Active Phosphoric acid	Active potash	Acid consumed	Acidity	Nitrification
164	Subsoil sandy clay	.06	.04	.13	.11	.39	6.22	....	....	....	0	....
308	Surface soil Lufkin clay	.01	.05	0.97	.43	.07	3.36	107.7	15.2	100	....	....
112	Surface soil Susquehanna fine loam	.02	.04	.11	.91	.10	.59	58.3	14.1	17.1	0	....
3412	Subsoil white sand	.02	.02	.11	.11	.06	1.04	12.4	70.6	1.5	0	....
4587	Surface soil poor upland	.03	.03	.09	.12	.06	1.42	12.1	130.4	1.2	0	....
100	Very poor red sand	.05	.04	.40	.08	.20	10.75	7.5	133.7	3.5	354	....
	Low availability											
4291	Good upland fine sandy loam	.07	.042	.38	15.11	.15	6.57	41.9	140.0	100.0	0	23.9
7234	White sand uniform, no hard lumps	....	.044	.04	.14	.07	.53	13.6	66.2	.5	200	22.4
4293	Fine sandy clay	.04	.025	.49	14.88	.37	3.01	53.75	78.7	99.5	0	15.6

The chemical composition of these soils is given in Table 18. The nitrification of three of these soils is below 6. The characteristics of these soils are also given in the table. No general relation can be traced, though two of the soils with high availability of nitrogen are poor or very poor in plant food.

NITRIFYING CAPACITY.

The results of the experiments above described gives the parts per million of nitrate produced from the nitrogen of the soil under favorable conditions for nitrification. In other work presented in this bulletin, the nitrification of the same soils untreated was studied. The organic matter in both cases is the same, but in one case the natural soil was used, while in the other case the soil was added to a good soil, together with carbonate of lime and potassium phosphate, thereby rendering the conditions more favorable for the nitrification of organic matter of the added soil. A comparison between the amount of nitrate produced from the organic matter of the soil and the amount of nitrates produced from the natural soil, throws some light upon the nitrifying power of the original soil. The comparison cannot be made a strict one, for the reason that these two pieces of work were carried out at different times, and it has already been seen that the surrounding temperature may effect the nitrification. Nevertheless, the comparison gives some information of interest, and offers indications which will be followed up. The nitrification in the original soil may be considered as representing the product of the nitrifying capacity of the soil and the availability of the organic matter in the soil to nitrify. In Bulletin 106 (1908) of this Station, we used the term nitrifying capacity to signify the capacity of the soil to serve as a medium for the growth of nitrifying organisms, compared with some other soil of good nitrifying power as a standard. Stevens and Withers used the term in practically the same sense (Centbl. Bakt., 1909). It is essential that the two soils should be provided with nitrifiable matter and placed under conditions favorable for nitrification, the conditions being exactly the same for each soil, and that both soils at the beginning of the experiment should contain the same number of nitrifying organisms of the same activity. We here use the term the "availability of the soil nitrogen" to signify the capacity which the soil organic matter has to be changed into nitrates.

Thus the availability of the soil nitrogen (A) multiplied by the nitrifying capacity of the soil (C), equals the nitrate produced (N).

$$A\ C = N$$

$$C = N/A$$

In this case the term availability is restricted to cover the production of nitrates only. It must not be forgotten that other conditions, such as temperature and soil organisms, influence the total nitrates, but it is assumed that these are equalized as nearly as the experimental conditions allow.

The nitrifying capacity of the soil is thus equal to the nitrates produced in the original soils, divided by the availability of the soil nitrogen. The nitrifying capacity as calculated in this way is given in Table 16. This method of estimating the nitrifying capacity of a soil is different

Table 19.—Composition of soils of high and low nitrification capacity.

Lab. No.	Low capacity	Phosphoric acid	Nitrogen	Potash	Lime	Magnesia	Alumina oxide of iron	Active phosphoric acid	Active potash	Acid consumed	Acidity
164	Subsoil red sandy clay	.06	.044	.134	.11	.39	6.22	.....	.....	.....	0
4586	Subsoil light brown red clay	.025	.044	.29	.07	.10	9.40	2.5	102.5	2.0	600
1582	Surface soil Houston gravelly clay	.....	.093	.....	.....	.....	.....	.....	44.7	35.4	0
122	Surface soil Susquehanna fine sand	.02	.04	.11	.91	.10	.59	58.3	14.1	17.1	0
100	Surface soil very poor Orangeburg clay	.05	.04	.40	.08	.20	10.75	7.5	133.7	3.5	354
3976	Surface soil Lufkin clay	.025	.026	.225	.19	.24	8.71	11.9	89.9	3.0	1000
3412	Subsoil white sand	.024	.024	.11	.11	.06	1.04	12.4	70.6	1.5	0
4587	Surface soil poor upland	.025	.0256	.09	.12	.06	1.42	12.1	130.6	1.2	0
	High capacity										
4291	Surface soil fine sandy loam	.065	.0419	.38	15.11	.15	6.57	41.9	140.0	100.0	0
4234	Subsoil whit sand moderate	.....	.044	.035	.14	.07	.53	13.6	66.2	.5	200
854	Subsoil Lufkin clay	.012	.03	.239	.33	.32	8.29	17.64	165.9	6.12	0

from that previously described, since the organic matter of the soil itself is used for the comparison. The tests should be made at the same time and under the same conditions.

The nitrifying capacity of 29 soils given in Table 16 varies from 2 to 232. There are 8 soils with a nitrifying capacity of less than 25. There are 3 soils with a nitrifying capacity of more than 100. This means that the original soil was a better medium for the growth of the nitrifying organisms than the mixture of the soil with sand and carbonate of lime. The remainder of the soils are intermediate in character.

The low nitrification of some of the soils studied in this bulletin is thus due to the low nitrifying capacity of the soil. This can be remedied, as has been already shown, by the addition of carbonate of lime to the soil. The addition of di-calcium phosphate was also of advantage, and the addition of sulphate of potash was occasionally of advantage, but the addition of carbonate of lime had the greatest and most effective action.

It does not follow from this that the carbonate of lime will necessarily increase the growth of crops on these soils. This matter will be studied in another bulletin. It does not follow that the use of carbonate of lime should be advised on these soils for the purpose of increasing their nitrifying capacity An increase in nitrifying capacity might have an unfavorable effect upon the fertility of the soil, and cause the organic matter to be nitrified, the nitrogen lost, and the fertility of the soil to be rapidly decreased. This is particularly the case with the soils of the Southern States.

NITRIFICATION OF MANURE.

One series of experiments was made in which an addition of 50 milligrams nitrogen in the form of sheep excrement was made to one soil, while another sample of the same soil received no addition. The percolation was carried out as with the other experiments described in this bulletin. An illustration of one of these experiments is given in Table 20, and the results of the series are given in Table 21.

Table 20.—Production of nitrates from manure—parts per million.

	0 weeks	4 weeks	8 weeks	12 weeks	16 weeks	20 weeks	24 weeks	28 weeks	32 weeks	36 weeks	Total
164A (treated)	0	0	0	0	0	1.6	3.6	10.5	14.1	10.3	40.1
B	0	0	0	0	0	0	.4	4.0	12.1	16.8	33.3
308A (treated)	56.8	5.0	9.0	16.0	21.0	14.8	12.3	13.4	9.9	9.0	110.4
B	92.8	15.8	10.2	10.8	16.2	10.3	8.9	8.7	5.0	4.8	90.7
3634A (treated)	.9	.3	9.9	12.9	18.2	11.6	8.2	10.1	5.6	5.8	82.6
B	26.6	6.0	6.9	6.5	9.2	6.1	6.1	4.0	3.8	3.5	22.1
4291A (treated)	0	0	1.8	3.0	6.8	3.4	8.6	6.0	3.7	3.4	36.7
B	4.2	6.8	3.0	0	0	0	0	.2	0	0	10.0
4586A (treated)	1.6	0	0	2.9	11.6	6.0	8.0	5.1	4.0	3.5	41.1
B	12.6	6.0	4.4	3.4	4.0	3.4	3.0	3.0	1.9	2.0	31.1
	0	0	1.0	0.0	6.0	5.7	5.1	5.0	2.4	2.6	27.8
	0	0	.6	2.0	9.0	5.2	3.2	5.6	2.5	1.5	29.6

Table 21.—Nitrate nitrogen produced by manure.

Lab. No.		Length of period	A Manure	B None	Differ- ence	Per cent	Nitrifying capacity
164	Begun March 11, 1915.....	36 weeks	40.1	33.3	6.8	13.6	4
308			110.4	90.7	19.7	39.4	79
3631			82.6	52.1	30.5	61.0	44
3634			36.7	10.0	26.7	53.4	36
4291			41.1	31.1	10.0	20.0	170
4586			27.8	29.6	1.8	0	21
4234	Begun May 10, 1915.......	28 weeks	112.3	101.3	11.0	22.0	146
4213			49.5	24.6	25.1	50.2	83
4580			51.9	52.9	1.0	0	42
4586			27.2	30.1	2.9	0	21
4291			42.9	23.0	19.9	39.8	170
7132	Begun May 5, 1915........	20 weeks	11.6	16.9	5.3	0	42
7214			59.9	33.3	26.6	53.2	76
7234			4.2	8.6	4.4	0	76
7169			47.7	28.7	19.0	38.0	61
7097			43.0	32.7	10.3	20.6	75
4293			9.0	8.9	0.1	0	....
4587	Begun May 10, 1915.......	44 weeks	26.7	18.0	8.7	17.4	24
1593			154.6	110.4	44.2	88.4	66
1928			60.1	30.9	29.2	58.4	50
1931			135.6	96.5	39.1	78.4	74
3410			211.0	85.8	25.2	50.4	48
554	Begun May 14, 1915.......	28 weeks	18.2	50.9	32.7	0	232
312			11.3	13.0	1.7	0	67
819			24.9	17.4	7.5	15.0	85
306			33.2	31.6	1.6	3.2	86
3412			19.0	14.5	4.5	0	21

The addition of manure resulted in an immediate decrease in the nitrates in the percolate. This was shown even in the first percolate, made immediately after the dry soil was mixed with the manure, and before any nitrification took place. For example, with soil 3634, Table 19, the original soil produced 26.6 parts per million nitrates on the first percolation, while the soil to which the manure had been added produced 0.9. The only explanation that can be made is that the organic matter reduces the nitrate. This reduction must have taken place rapidly either in the soil while the percolation is taking place, or in the percolate.

The same is to be observed in the first few weeks of the experiment. Within eight weeks or longer, however, the production of nitrates from the added material is evident. The denitrifying action of the manure complicates the experiments, and renders the results difficult to interpret.

The results of several series of these experiments are given in Table 21. The time of nitrification varies from 20 to 44 weeks with the different sets. The difference between the treated soil, and that untreated, gives the nitric nitrogen produced from the manure. The percentage of nitrogen nitrified, based on the amount of nitrogen in the manure added, is also given. The amounts of nitrates produced vary from zero to 88 per cent. The highest amounts are produced in the experiments which were conducted for 44 weeks, the longest period of time. In this set, there are no negative results, but th nitrification of the manure varies from 17 to 88 per cent.

As previously stated, the results of the experiments are difficult to interpret on account of the denitrification which occurred at first, and the results of which had not been overcome in some of the experiments when they were discontinued. The nitrifying capacity, as worked out in Table 16, is also given in the table for the purpose of comparison. There is no agreement between the nitrifying capacity and the nitrification of the manure. Some of the soils which have a low nitrifying capacity for the soil organic matter, also have a low nitrifying capacity for the manure. But there are also grave irregularities. With the set of soils which was continued 44 weeks, the nitric nitrogen which was produced by the manure is very nearly in the same order as the nitrifying capacity. But in the set which ran 36 weeks, the soil which had the highest nitrification capacity comes third in the amount of nitrates produced from the manure, and the soil which produced the highest amount of nitrates from the manure was the third from the highest in nitrifying capacity. The denitrification caused by the action of the manure had undoubtedly affected the results of the experiments in a material degree. It is evident that manure can affect materially the nitrates of the soil, especially for the first few weeks, but whether this nitrogen is entirely lost is another question. The nitrifying capacity of a soil may depend to some extent on the nature of the organic material used to estimate it.

NITRIFICATION OF SULPHATE OF AMMONIA.

An experiment similar to the one above was conducted, in which sulphate of ammonia, containing 50 milligrams nitrogen, was added to the soil, and the results are given in Table 22. The nitrification varies from zero to 100 per cent. No conclusions are drawn.

Table 22.—Nitrate nitrogen produced by sulphate of ammonia.

	A Ammonia	B None	Difference	Per cent	Set No.	Nitrification
164	4.7	2.2	2.5	0	30	.1
308	88.7	87.3	1.4	2.8	30	114.1
3631	58.5	64.0	5.5	0	34	22.9
3634	60.3	12.4	47.9	97.8	34	16.2
4291	35.4	25.3	9.1	18.2	34	23.9
4586	81.7	31.3	50.4	100.8	34	8.3

NITRIFICATION OF THE SAME SOIL AT DIFFERENT TIMES.

Table 23 contains the results of nitrification on the same soils, used in different series, begun at different times, but, of course, not under the same temperature conditions. There is some variation, as could be expected, and occasionally a wide variation.

These results show that deviations must be expected, and in experimental work, arrangements should be made to eliminate any error that might be due to such variations.

Table 23.—Nitrate nitrogen produced per period in the same soil in different sets. Parts per million.

	Date begun	Period	0 weeks	4 weeks	8 weeks	12 weeks	16 weeks	20 weeks
100	April 8, 1914	22	4.2	0.0	0.0	0.0	24.1	44.4
100	April 9, 1914	23	3.3	0.0	0.0	0.7	18.6	46.4
100	April 13, 1914	24	5.5	0.0	0.0	4.1	79.0	7.8
100	April 13, 1914	25	4.9	0.0	1.1	6.3	84.0	8.4
100	April 14, 1914	26	3.9	0.0	0.0	5.4	97.6	10.0
100	April 15, 1914	27	3.4	0.0	0.0	1.0	3.4	54.6
100	April 15, 1914	28	3.6	0.0	0.0	1.2	17.1	52.4
100	April 16, 1914	29	5.0	0.0	0.0	0.0	0.0	0.0
100	May 4, 1914	47	3.8	0.0	0.0	0.5	86.0	9.0
125	April 8, 1914	22	0.6	1.1	15.0	17.4	20.6	6.2
125	April 9, 1914	23	0.9	0.0	3.2	8.6	28.4	6.0
125	April 13, 1914	24	0.8	8.5	35.1	3.2	10.5	7.0
125	April 13, 1914	25	0.6	9.0	33.0	3.6	8.2	6.3
125	April 14, 1914	26	0.6	12.8	30.5	2.8	13.8	6.3
125	April 15, 1914	27	0.6	1.1	14.6	10.2	23.2	5.9
125	April 15, 1914	28	0.5	4.4	17.7	11.4	19.8	5.4
125	April 16, 1914	29	1.0	7.1	22.9	6.1	16.6	6.4
125	May 4, 1914	47	0.5	16.9	21.6	5.7	12.9	4.6
164	April 16, 1914	30	1.1	0.0	0.0	0.1	6.4	34.6
164	April 20, 1914	31	1.0	0.0	0.4	0.9	38.6	37.1
164	April 20, 1914	32	1.0	0.0	0.0	0.7	29.6	33.4
164	April 20, 1914	33	1.9	0.0	0.0	0.5	3.1	33.2
164	April 21, 1914	34	1.8	0.0	0.0	0.0	3.4	49.0
164	April 22, 1914	35	1.2	0.0	0.0	0.1	2.7	52.4
164	April 22, 1914	36	1.0	0.0	0.0	0.1	24.2	38.4
164	May 4, 1914	46	1.3	0.0	0.0	0.5	63.0	11.0
308	April 16, 1914	30	5.1	73.6	23.2	18.0	18.0	34.6
308	April 20, 1914	31	5.0	88.8	27.4	13.4	20.2	12.2
308	April 20, 1914	32	6.0	67.0	19.4	14.4	8.8	18.8
308	April 20, 1914	33	7.4	81.2	16.2	12.6	13.4	11.9
308	April 21, 1914	34	5.6	81.2	15.2	15.6	15.4	11.3
308	April 22, 1914	35	5.7	72.4	28.6	20.4	17.2	11.6
308	April 22, 1914	36	5.3	68.6	22.2	19.4	15.2	13.1
308	May 4, 1914	46	5.0	66.4	25.0	15.8	10.2	10.2
871	April 23, 1914	37	54.1	18.2	27.6	....	....	....
871	April 23, 1914	38	49.9	14.0	25.2	....	....	....
871	April 27, 1914	39	41.6	18.0	24.0	....	....	....
871	April 27, 1914	40	45.0	12.2	23.2	....	....	....
872	April 27, 1914	37	122.0	117.0	25.6	10.8	12.0	8.7
872	April 23, 1914	38	128.0	75.0	16.8	10.5	9.8	9.1
872	April 27, 1914	39	117.2	77.0	15.4	13.4	9.7	7.3
872	April 27, 1914	40	102.9	90.8	12.0	11.2	14.0	7.0

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SUMMARY AND CONCLUSIONS.

The nitrification was carried on with 500 gram portions of the soil in percolators, and the nitrates were extracted at intervals of four weeks.

The amount of nitrates produced in percolators was more than the amount produced in jars in one set of experiments.

The method of work is described in full.

Usually the maximum nitrification takes place during the first period of four weeks, but in some cases the maximum nitrification is delayed to the second period, or even to the third period, and with some soils, nitrification does not occur for a year or longer.

When the nitrification is carried on for several years, a second maximum occurs during the second summer, and a third maximum during the third summer, but these maximums are much smaller than the first maximum.

The average quantity of nitrates produced increases with the total nitrogen of the soil. The nitrification, on an average, is in proportion to the total nitrogen of the soil.

With the exception of soils containing less than .02 per cent. nitrogen, the percentages of the organic nitrogen converted into the nitrate nitrogen, on an average, are fairly constant. From 7 to 10 per cent. of the total nitrogen is converted into nitrates during the first twelve weeks.

The quantity of nitrates produced in these soils depends on the quantity of organic nitrogen contained in them, the form of chemical combination, the physical condition of the soil, the chemical composition of the soil, and perhaps other factors.

There are wide variations in the amount of nitrates produced by individual soils. Some of the soils did not nitrify, while others had an unusually high nitrification.

The addition of 1 per cent. carbonate of lime caused most of the soils which failed to nitrify without such addition to nitrify within the first period of four weeks.

Acid soils nitrified slightly less, on an average, than non-acid soils with a low lime content. Some acid soils do not nitrify at all, or have a low nitrification, while other acid soils have a high nitrification.

No other relation could be traced between the amount of nitrification and the chemical composition of the soil.

The nitrification in subsoils averages nearly the same as that of surface soils, but the subsoils in some cases have a very low nitrification, while in other cases the nitrification is usually high.

The soils having a low nitrification are mostly subsoils, low in lime, and over half of them are acid.

The samples having a high nitrification are mostly subsoils, and several of them are acid.

The addition of phosphate, or of potash, increases the nitrification in several of the soils, and causes the soils which nitrify very slowly to nitrify in a shorter time. The phosphate is more effective than the potash.

The addition of carbonate of lime increases nitrification.

The nitrification of the organic matter of the soil was studied by comparing the amount of nitrates produced by the soil when added to a soil of good nitrifying power. There is a great difference in the organic matter in different soils, as its availability varies from 3.5 to 37 per cent.

The term nitrifying capacity is used in previous bulletins to signify the capacity of the soil to serve as a medium for the growth of nitrifying organisms. The nitrifying capacity is estimated for the organic matter of the soil by comparing the nitrification in the original soil with the nitrification with the same soil added to a soil with good nitrifying power.

The nitrifying capacity of 29 soils varies from 2 to 232. There are eight soils with a nitrifying capacity of less than 25, and three soils with the nitrifying capacity of more than 100.

The addition of manure to the soil resulted in a decrease in the amount of nitrates in the percolate. Within eight weeks or longer the production of nitrates from the added material is evident. The results of the experiment are difficult to interpret on account of denitrification. There is no agreement between nitrifying capacity of the soil, and the nitrification of the manure

A table is given showing the nitrification of the same soil at different times. There are some variations. As a rule the results are as uniform as could be expected from work of this character.