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Nitrate Production in Soils as Influenced by Cropping and Soil Treatments

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W. A. ALBRECHT

INTRODUCTION

Though the soil may be judged in terms of its stock of plant nutrient elements, it must be considered also in terms of its microbiological activity by which these are converted into such forms as will serve the plants. Nitrogen is the nutrient element of foremost concern, both in terms of its stock in the soil and of its conversion from the promiscuous, less active, organic matter forms into the water-soluble, nitrate form; consequently, the influence of the long continued soil treatments on the conversion of this element becomes significant. The soil serves effectively as a factory to deliver a liberal supply of nitrate nitrogen to the growing crop regularly, only when soil conditions are favorable for the microorganisms that change it into this form. Considered as a crop produced within the soil, these diminutive performers fit into the categories of soil fertility and duplicate the requirements demanded by good plant growth above the soil. Inasmuch as long time treatments modify microbial activities within the soil, so they will in turn influence the crop yields. Laboratory studies were undertaken to evaluate the nitrate accumulating capacities by the soils which have undergone different long-continued cropping and soil treatments on Sanborn Field* as a measure of the influence by these on the microbial behavior and thus on the soil's capacity to deliver plant nutrients to the growing crop.

PLAN OF THE STUDY

Sanborn Field Plots Used

The treatments given the soils in the field during fifty years divide themselves into those influences arising from (a) the system of cropping, and (b) the soil treatments as fertility additions. Plots were selected for study of the former influence so as to include (a) continuous cropping to wheat, to oats, to corn and to timothy; (b) a rotation extending over three years with corn, wheat, and clover; (c) a rotation extending over four years with corn, oats, wheat, and clover, the last of which was replaced more recently by soybeans;

*Sanborn Field was established in 1888 by J. W. Sanborn. The crop of 1938 was the fiftieth and treatments have been carried out as originated with some modifications.

and (d) a rotation over six years with corn, oats, wheat, clover, timothy, and timothy as the cropping order. For study of the influence by soil treatments as fertility additions, plot selections were made to permit comparisons of manure and no manure, superphosphate and no superphosphate, commercial fertilizer and no fertilizer, ammonium sulfate and sodium nitrate, and limestone and no limestone.

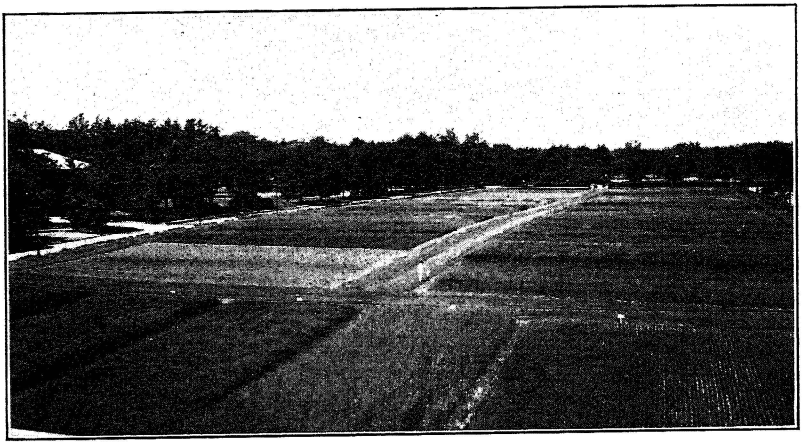

Plate I.—Sanborn Field, where fifty years of different soil treatments and cropping systems reflect their effects on the present soil fertility levels.

Laboratory Procedures

Since such studies involve numerous chemical determinations, only a few plots were studied each year from 1921 to 1937 inclusive. The samples were taken regularly at the same season and the studies carried out from about February 15 to May 15. The soils taken into the laboratory were not dried, but were used at optimum moisture in quantities equivalent to 100 grams dry soil. They were placed in jelly tumblers in sufficient numbers to permit the treatments in duplicate for chemical determinations at fortnightly intervals during ten or twelve weeks. The plots studied each year were chosen to represent comparable cases of field treatments, as manure and no manure, or fertilizer and no fertilizer with a single crop, or for a rotation. Laboratory conditions and methods of determination were standardized as far as possible so that the data of one year might be comparable to those of any other year.

The laboratory treatments consisted of (a) no treatment, (b) addition of one gram of powdered limestone (100-mesh), (c) addition of three grams of dry, finely chopped sweet clover, and (d) addition of these amounts of both the items per one hundred grams of soil. The sweet clover was used from the same supply during most of the tests. This was collected and dried indoors without leaching loss and contained 2.21 per cent of nitrogen on the air-dry basis. The soils in the tumblers were maintained at optimum moisture as far as possible by occasional weighings and moisture additions. They were incubated at room temperature. Though the fertility additions to the soils in the laboratory represent greater concentrations than are used in the field, they were the same throughout and serve, therefore, as comparable cases. For convenience, the laboratory treatments will be designated as (a) no treatment, (b) lime or limestone, (c) organic matter, and (d) lime and organic matter.

Sufficient tumblers of each soil were prepared to provide duplicates of each laboratory treatment for chemical study at the outset and every two weeks thereafter for ten weeks and sometimes for twelve weeks. For each fortnightly determination the soil in the tumbler was divided into two equal parts. One-half was used for determining the ammonia nitrogen. The other served for determination of the nitrate nitrogen. For the former, the moist soil was placed into a Kjeldhal flask; magnesium oxide, some paraffin and water were added; and the ammonia distilled over into the standard acid by means of a flow of air and steam. For the latter, or nitrate nitrogen determination, the soil was dried, the moisture loss determined, and the nitrates measured by the phenoldisulphonic acid method. In the first few studies, the nitrates were determined by extraction, reduction with De Varda's metal and distillation into standard acid. All calculations for both ammonia and nitrate nitrogen were then based on fifty grams of water-free soil.

Since the ammonia accumulation is the precursor of the nitrate production, the latter reflects the former. Consequently, the details regarding the ammonia contents are omitted in this study and attention will be given only to the accumulations of nitrate nitrogen.

Field Treatments of Soils Used

A total of 39 plot studies were made with eight nitrate determinations at each fortnightly period during twelve weeks. With more than two thousand such determinations, complete presentation of the tabulated data scarcely seems feasible. Among these 39 plot studies, only 28 individual plots were involved. Three plots were used three times, four were included twice, and 21 were used only once. The plot numbers, their cropping systems and soil treatments are assembled in Table 1. Plots 6 and 7 listed in the table are omitted in the reported data because of their irregularities in cropping history.

TABLE 1.—PLOTS ON SANBORN FIELD UNDER LONG CONTINUED TREATMENTS USED FOR STUDY OF NITRATE ACCUMULATIONS.

Plot Number	Times Used	Cropping System	Soil Treatment
1	1	Rotation—six year	Manure 6 T. annually Rock Phosphate
2	2	Wheat—continuous	Fertilizers (a)
6	1	Cowpeas—continuous	....
7	1	Cowpeas—continuous	....
9	3	Wheat—continuous	....
10	2	Wheat—continuous	Manure 6 T. annually
12	1	Rotation—six years	Manure 3 T. (b)
13	1	Rotation—six years	....
14	1	Rotation—six years	Manure 3 T. Superphosphate
15	1	Oats—continuous	Manure 6 T.
16	1	Oats—continuous	....
17	2	Corn—continuous	....
18	1	Corn—continuous	Manure 6 T.
19	1	Rotation—six years	Manure 3 T.
20	1	Rotation—six years	Manure 6 T.
21	3	Wheat—continuous	Superphoshpate
22	1	Timothy—continuous	Manure 6 T.
23	3	Timothy—continuous	....
24	1	Wheat—continuous	....
25	1	Rotation—three years	Manure 6 T.
26	1	Rotation—three years	Manure 3 T.
27	1	Rotation—three years	....
29	1	Wheat—continuous	Ammonium sulfate
30	1	Wheat—continuous	Sodium nitrate
34	1	Rotation—four years	Manure 6 T.
35	2	Rotation—four years	....
37	1	Rotation—four years	Fertilizer (c)
38	2	Rotation—four years	Fertilizer

Table 1—Notes

(a) Applications were large enough to replace the fertility equivalent of nitrogen, phosphorus, and potassium of a forty-bushel crop.

(b) The three-ton applications are not made annually, but are the equivalent of three tons annually. The six-ton applications are all made annually.

(c) This is a mixed fertilizer applied with the wheat and the corn.

More complete history of these plots is presented in Missouri Agricultural Experiment Station Bulletin 182.

RESULTS OF THE STUDY

Since the numerous determinations make the presentation of all the data impossible, consideration will be given to the nitrate accumulations according to (a) the influences by the cropping systems, and then (b) the influences by the soil treatments. These accumulations may be shown as related to the time period by means of graphs giving the nitrate nitrogen per fifty grams of soil at intervals of two weeks during ten weeks. They may be presented as nitrate increases in these same amounts of soil during a six-week period represented by the difference between the average of the second and fourth weeks and the average of the eighth and tenth weeks. In addition, the plots may be represented in their nitrate accumulation as measured by the mean of the six determinations for the entire period or ten weeks under observation. As a final figure, the mean of all determinations of all laboratory treatments may be used. Any or all of these measures may be used in presenting the data.

Influence of the Cropping Systems under Constant Soil Treatments

Continuous cropping.—Four continuous crops, namely corn, oats, wheat, and timothy,—all non-legumes,—were represented. Each of these included two plots, one of which was given no soil treatment, and the other given manure at the rate of six tons annually. The two soil treatments are combined for the consideration of the influence by each cropping system. The data are presented together for these four different cropping systems on graphs in Figures 1, 2, 3, and 4. These represent the laboratory treatments of no treatment, limestone, organic matter, and lime and organic matter, respectively.

There was little difference in the nitrate accumulating capacity of the soil according to the crops grown on it, whether corn, oats, wheat, or timothy. In attempting to place these crops in an order of significant effects, they arrange themselves differently as the soils were given the different laboratory treatments. A study of the graphic presentation of the data in the figures for the soils taken from under these crops and given the different laboratory treatments shows the curves so closely intertwined that it is impossible to detect significantly superior influence by any one crop.

When the data are handled in other arrangements as given in Table 2, there are no more significant suggestions of relations to the crops. When the nitrate increase during a six week period is taken as the criterion of differences in nitrate production, no constant place in order can be assigned to each crop. If the mean of

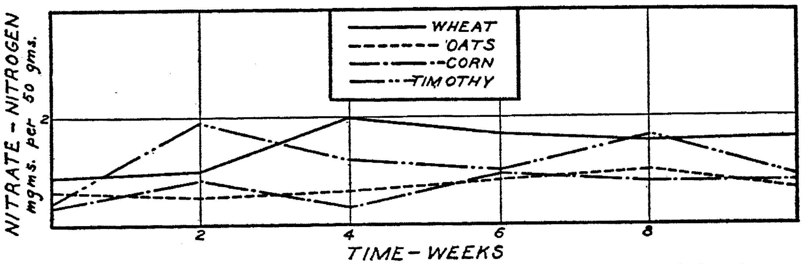

Figure 1.—Nitrate accumulations in soils as influenced by long periods of continuous cropping when given *No Treatment* in the laboratory. (Soils from Sanborn Field)

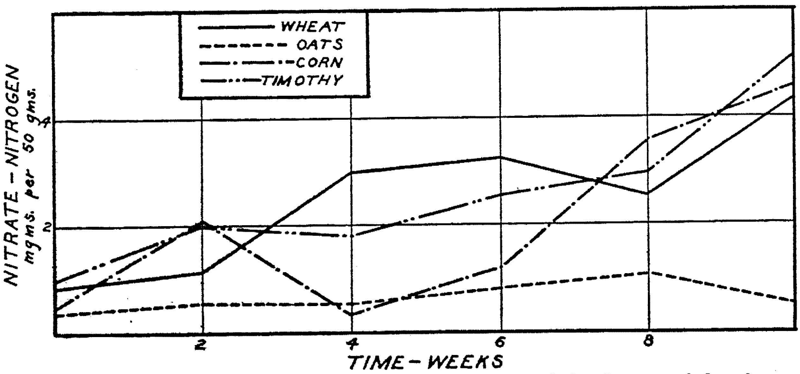

Figure 2.—Nitrate accumulations in soils as influenced by long periods of continuous cropping when given *Lime* in the laboratory. (Soils from Sanborn Field)

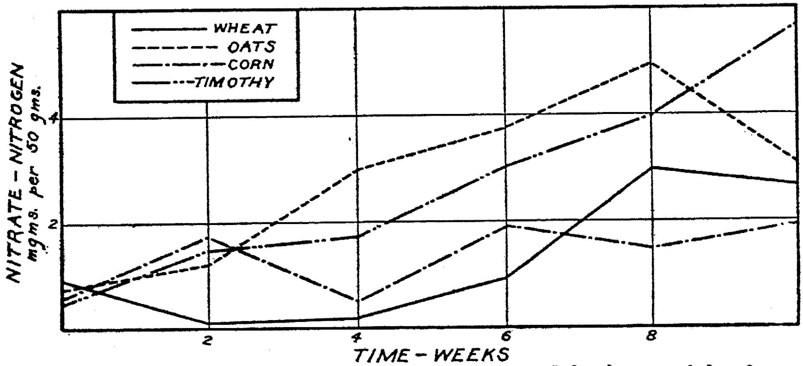

Figure 3.—Nitrate accumulations in soils as influenced by long periods of continuous cropping when given *Organic Matter* in the laboratory. (Soils from Sanborn Field)

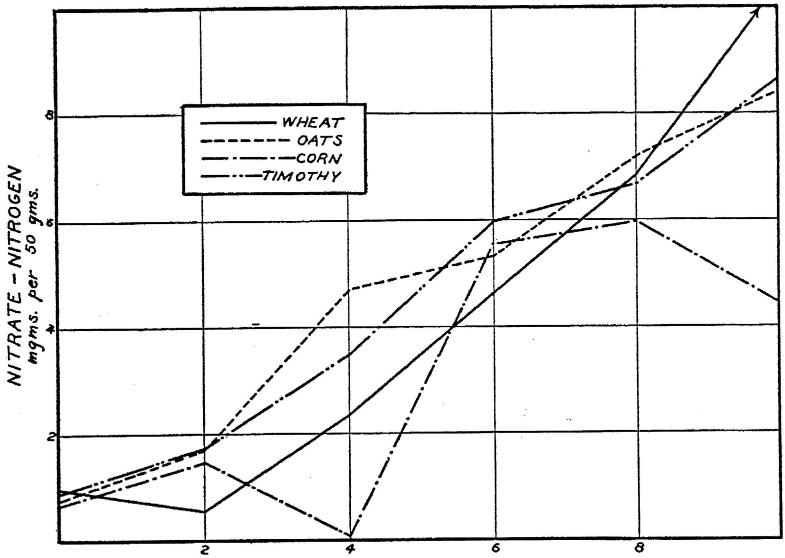

Figure 4.—Nitrate accumulations in soils as influenced by long periods of continuous cropping when given *Lime* and *Organic Matter* in the laboratory. (Soils from Sanborn Field)

TABLE 2.—NITRATE ACCUMULATION AS INFLUENCED BY DIFFERENT CROPS (MGMS. NITRATE NITROGEN PER 50 GMS. SOIL)

Crop	Laboratory Treatments			
	No Treatment	Limestone	Organic Matter	Lime and organic matter
	As increases during six weeks			
Corn	.23	2.74	.62	4.76
Oats	.48	.41	2.57	4.72
Wheat	.13	1.40	2.76	7.11
Timothy	.29	3.85	1.72	5.22
	As mean of six determinations during ten weeks			
Corn	.64	2.08	1.39	3.06
Oats	.77	.66	3.04	4.75
Wheat	1.48	2.56	1.32	4.30
Timothy	1.21	2.62	2.76	4.59
	As mean of all determinations of four treatments during ten weeks			
Corn—1.79	Oats—2.30	Wheat—2.41	Timothy—2.79	

the six determinations made on any one laboratory treatment during the ten weeks is considered as the measure of the nitrate accumulating capacity, then the soil under timothy is consistently high, though oats surpass it slightly in two instances. When a mean of all the laboratory treatments for all determinations extending over ten weeks is taken as a measure of the crop influence on nitrate production, then the crops arrange themselves in the following order: timothy, wheat, oats and corn for lowered nitrate levels in their respective soils. The first three are of almost equal value, save that the oats are the lowest. One cannot say after the soil had been under each of these crops for a long period of time that it has been modified more or less in its capacity to produce nitrates from added materials because one or the other of these particular crops was grown on it. The low level for all of these continuous crops rather than a differentiation amongst them is the significant fact.

Rotations.—The rotations, unlike the continuous crops, differentiate themselves readily for their effects on nitrification according to the graphical data given in Figures 5, 6, 7, and 8. It is evident that the nitrates in the soil from the six-year rotation were not the equal of those in soils from the four-year and three-year rotations. They were higher in the three-year rotation than in the four-

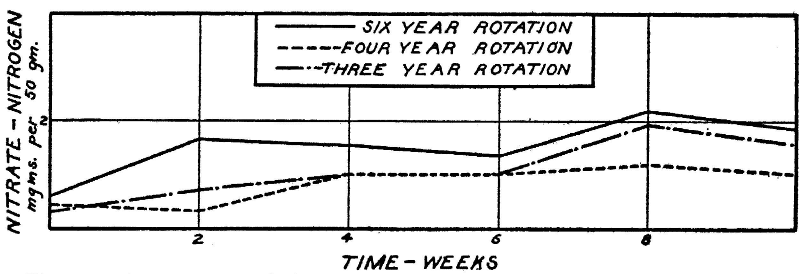

Figure 5.—Nitrate accumulations in soils as influenced by long periods of rotation cropping when given *No Treatment* in the laboratory. (Soils from Sanborn Field)

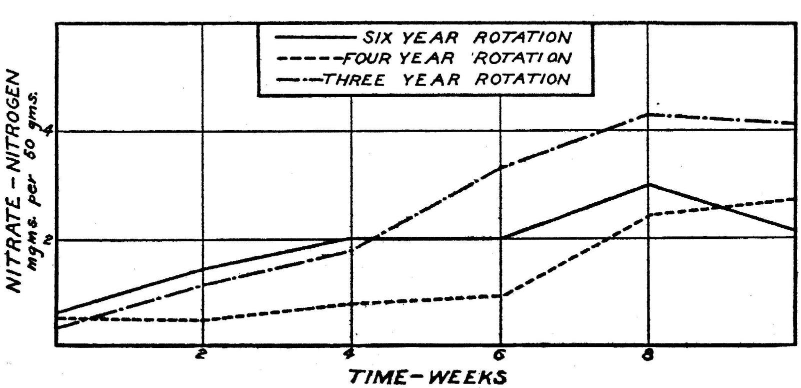

Figure 6.—Nitrate accumulations in soils as influenced by long periods of rotation cropping when given *Lime* in the laboratory. (Soils from Sanborn Field)

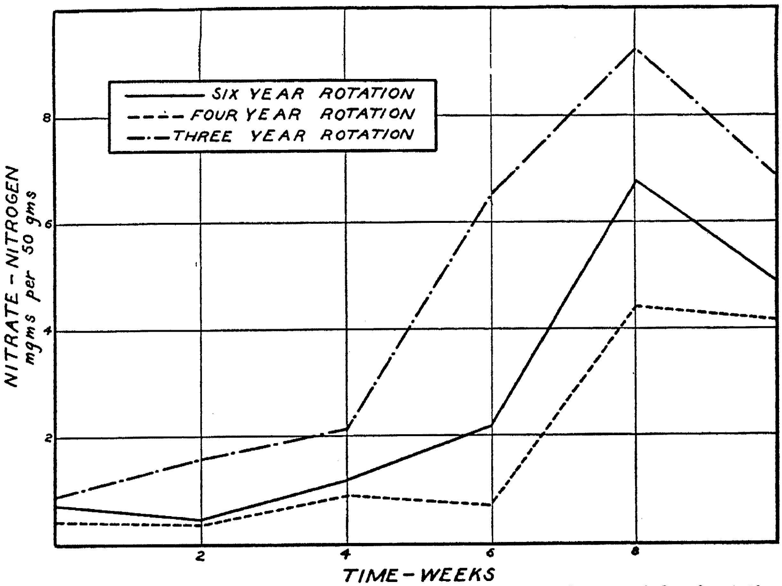

Figure 7.—Nitrate accumulations in soils as influenced by long periods of rotation cropping when given *Organic Matter* in the laboratory. (Soils from Sanborn Field)

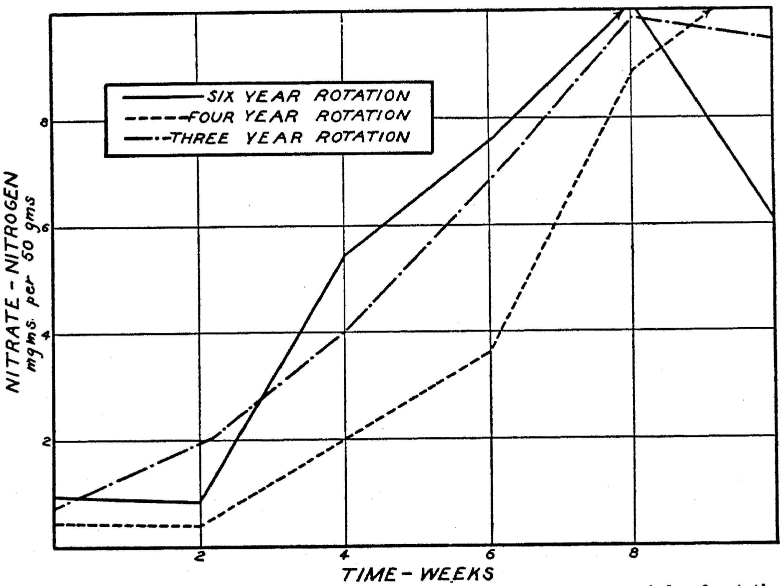

Figure 8.—Nitrate accumulations in soils as influenced by long periods of rotation cropping when given *Lime* and *Organic Matter* in the laboratory. (Soils from Sanborn Field)

year rotation. Irrespective of which set of data as assembled in Table 3 is used in determining the order of influence by these rotations, they fall into the order of largest nitrate accumulation for short, or three-year rotation, and decreasing amounts for the lengthening of the rotation.

TABLE 3.—NITRATE ACCUMULATIONS AS INFLUENCED BY DIFFERENT ROTATIONS (MGMS. NITRATE NITROGEN PER 50 GMS. SOIL)

Rotations	Laboratory Treatments: No Treatment	Limestone	Organic Matter	Lime and organic matter
As increases during six weeks				
Six year rotation	.49	.56	3.69	7.72
Four year rotation	.33	1.01	5.46	5.93
Three year rotation	.86	2.73	6.13	1.75
As mean of six determinations during ten weeks				
Six year rotation	.85	1.30	1.86	4.42
Four year rotation	1.40	1.89	2.73	5.22
Three year rotation	1.11	2.43	4.55	5.48
As mean of all determinations of four treatments during ten weeks				
Six year rotation—2.11.	Four year rotation—2.81.	Three year rotation—3.39.		

The attachment of significance to the data showing an influence by the rotation on nitrate accumulation may seem doubtful when the separate crops in continuation were of less influence. However, the continuous crops were non-legumes while each of the rotations included a legume for one year. The influence by the rotation was greater as the period of the rotation was shorter, or as this one legume recurred oftener in the involved period of the soil's history. Though the clover was not an excellent crop on the unmanured plots in the later period of the cropping history, it was generally of good growth on those given the field treatment of manure. Since the manured and unmanured soils were combined in these data, the greater number of clover occurrences in the cropping history may be a partial reason for the higher nitrate accumulation in the shorter rotation. If these are the facts, then the growing of the clover crop —quite different from the crops of corn, oats, wheat and timothy— is instrumental in giving to the soil on which it grows a higher capacity to transform added materials into nitrate accumulations.

These data suggest then that the non-legume crops can have little influence, per se, on the nitrification activity by the soil, but that a legume crop, possibly through its contribution of organic matter of a narrow carbon-nitrogen ratio, or because of some other conditions, encourages greater nitrate production in the soil.

Influence of Soil Treatments under Constant Conditions of Cropping

Soil treatments in the field, much more than cropping systems, had a significant influence on the soil's activity as a nitrate producer when brought into the laboratory. In case of the field treatments using manure and no manure, both continuous cropping and rotation systems were included. The results from fourteen plot studies were combined under no manure, and from nine plots under manure. Six year rotations and continuous wheat as four plots were combined under the phosphate to be compared with the four corresponding no phosphate treatments. These same four combined with those given mixed fertilizers and with those given nitrogen only, were taken as a group of nine plots as the fertilizer treatment. They were contrasted with the same cropping treatments given no fertilizer. One plot with ammonium sulfate and another with sodium nitrate, both in continuous wheat, and a pair of plots in a four year rotation without and with lime respectively, completed the comparisons of nitrate accumulations as influenced by soil treatments.

Manure.—The data for the accumulation of nitrate during the ten week period as illustrated in Figure 9 show a decided influence by the manure additions. It is evident from these curves that the

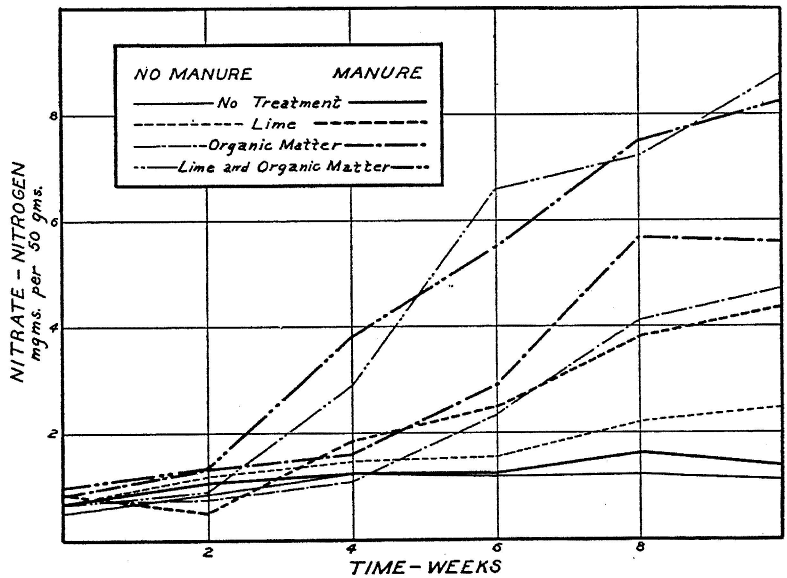

Figure 9.—Nitrate accumulations in soils as influenced by long periods of *Manure* and *No Manure* additions when given different treatments in the laboratory. (Soils from Sanborn Field)

soils which had been receiving manure these many years were consistently higher in nitrate content than those not obtaining it. When their abilities to increase their nitrates in a six week period, or their mean nitrate contents over ten weeks, are calculated as given in Table 4, the significance of the manure as a nitrate increaser is obvious.

TABLE 4.—NITRATE ACCUMULATIONS AS INFLUENCED BY MANURE ADDITIONS OVER LONG PERIODS.

(MGMS. NITRATE NITROGEN PER 50 GMS. SOIL)

Field Treatments	Laboratory Treatments: No Treatment	Limestone	Organic Matter	Lime and organic matter
	As increases during six weeks			
No manure	.21	.85	3.26	5.31
Manure	.47	2.34	4.00	5.69
Increase by manure	.26	1.49	.74	.38
	As mean of six determinations during ten weeks			
No manure	1.02	1.54	2.32	4.49
Manure	1.24	2.33	3.01	4.91
Increase by manure	.22	.79	.69	.42
	As mean of all determinations of four treatments during ten weeks			
No manure—2.34	Manure—2.87		Increase—22 per cent	

It is interesting to note the influence of the lime addition in the laboratory on these soils manured and unmanured for so many years. After lime was on the soil for six weeks in the laboratory, the unmanured had increased its nitrate nitrogen by .85 grams, or an increase of .64 mgms. greater than without added lime. In case of the manured soil given lime similarly, the increase of accumulated nitrate nitrogen was 2.34 mgms. or 1.87 mgms. greater than without lime additions in the laboratory. This indicates that, during the long continued manuring, this soil accumulated a store of nitrogenous organic matter the conversion of which to nitrates did not take place because of the need for liming. Lime addition now hastened the conversion of this residual matter into the soluble form.

The data of Table 4 point further to the significance of the manure. During six weeks in the laboratory the increase was twice as great in the check, manured soil as in the unmanured. This difference amounted to .26 mgms., or the equivalent of ten pounds of available nitrogen per acre. The increases in nitrate nitrogen content for the three different treatments in the laboratory during the six weeks show the manured soil higher by more than this figure. The same holds true for the mean during ten weeks. When all determinations for all treatments are averaged, the manured soil is 22 per cent higher than the unmanured. This points out that the manured soil responds more to lime, and that it converts its organic matter additions more effectively. It indicates too that as the soil is depleted, the restorative treatments are relatively less effective, or, as the fertility level drops, the difficulty in raising it becomes relatively greater.

Superphosphate.—As a means of studying the influence of superphosphate field treatments on the soil's capacity to accumulate nitrates, four plots including the six year rotation and the continuous wheat were studied. The data for the accumulation of nitrate are assembled as graphs in Figure 10. They are assembled as averages for numerical evaluation in Table 5.

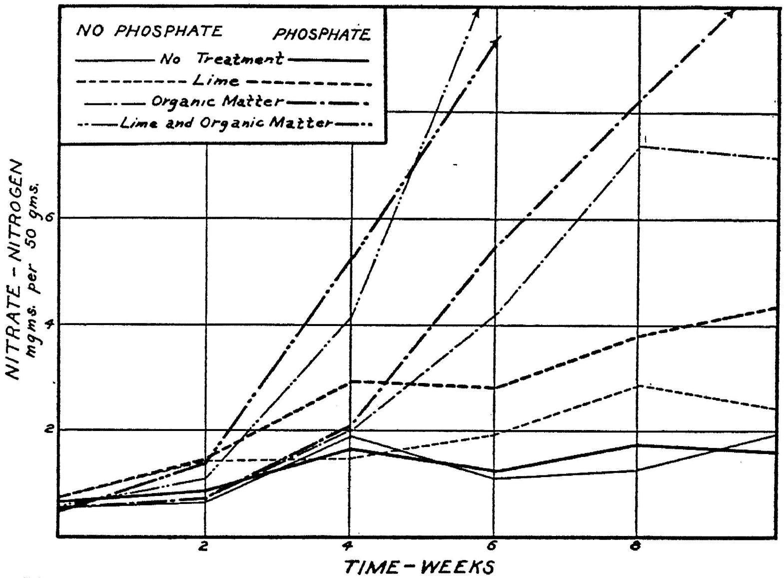

Figure 10.—Nitrate accumulations in soils as influenced by long periods of *Superphosphate* and *No Superphosphate* additions when given different treatments in the laboratory. (Soils from Sanborn Field)

The influence of the phosphate is readily evident. It is interesting to note that the no treatments are not different because one had phosphate. They suggest that, whether given phosphate or not, the nitrate is at a low and relatively constant level. This is different from the effects by manure which contributed to a higher nitrate for the soil given no treatment in the laboratory. When these soils were given limestone only, that which already had re-

TABLE 5.—NITRATE ACCUMULATIONS AS INFLUENCED BY PHOSPHATE ADDITIONS OVER LONG PERIODS.

(MGMS. NITRATE NITROGEN PER 50 GMS. SOIL)

Field Treatments	Laboratory Treatments: No Treatment	Limestone	Organic Matter	Lime and organic matter
As increases during six weeks				
No phosphate	.31	1.27	5.96	9.12
Phosphate	.30	1.92	8.08	9.70
Increase by phosphate	.01	.67	2.12	.58
As mean of six determinations during ten weeks				
No phosphate	1.24	1.78	3.66	6.73
Phosphate	1.25	2.65	4.62	7.06
Increase by phosphate	.01	.87	.96	.33
As mean of all determinations of four treatments during ten weeks				
No phosphate—3.35		Phosphate—3.89		Increase—19 per cent

ceived phosphate in the field was more effective in liberating nitrogen from its reserve than the soil without phosphate. When organic matter was added, the soil with phosphate made more effective use of this nitrogen addition to be converted into nitrates. When both lime and organic matter were added, their behaviors were similar to those for the additions of organic matter only. Hence this suggests that phosphating the soil is similar to a liming treatment. The general superiority of the phosphated soil as a nitrate producer is shown by the mean of all determination in the Table 5 where the difference amounts to 19 per cent.

That phosphate has an effect similar to liming is indicated by the response when organic matter only was added as compared to that when both lime and organic matter were supplied. According to Table 5, under "organic matter," the gain in nitrates in six weeks was 8.08 mgms. on plots receiving phosphate, but only 5.96 by soils with no phosphate. The phosphated soil delivered 2.12 mgms. more. When lime and organic matter were added to the soil with no phosphate, the nitrate increase was 9.12 mgms. or an amount greater by 1.04 mgms. as a consequence of liming. The phosphate treated soil brought with it a capacity to give nitrate increase in 6 weeks from added organic matter that was ⅔ as great as the untreated soil acquired when given both lime and organic matter. This influence on nitrate accumulation by phosphate that tended to duplicate the influence by liming was noticeable regularly in these studies. If the effects by phosphate are similar to those by liming, this suggests that calcium, their common element, which makes up a part of the superphosphate (approaching 25 per cent) may be the responsible item. If these are the facts, we may not have been ascribing the value of superphosphate to the wholly correct item. We may, then also, expect less value from the more concentrated phosphates which carry little or no calcium.

Fertilizers.—When the data for the plots with superphosphate were combined with those from a continuous wheat plot given heavy fertilizer treatment, with the same crop given ammonium sulfate, one given sodium nitrate, and a four year rotation using fertilizers, the results from these nine plots are closely similar to those without these treatments as shown in Figure 11. The curves are so closely

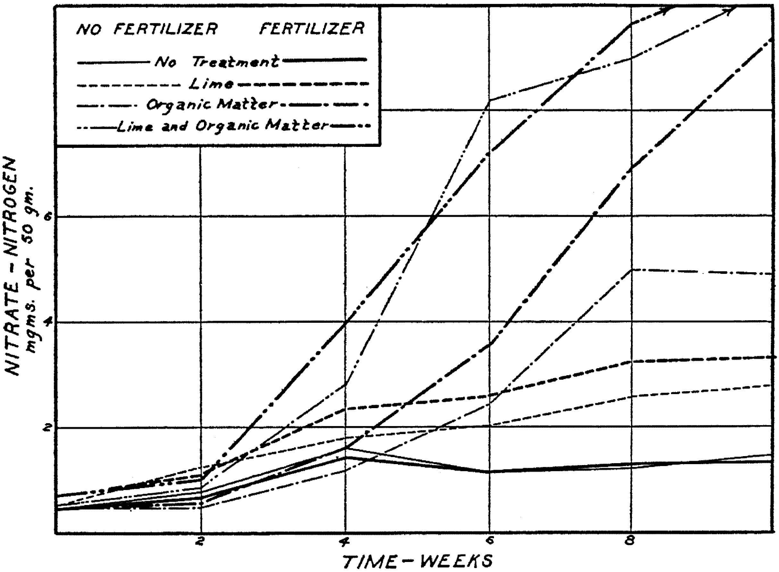

Figure 11.—Nitrate accumulations in soils as influenced by long periods of *Fertilizer* and *No Fertilizer* additions when given different treatments in the laboratory. (Soils from Sanborn Field)

similar in the no treatments for both the no fertilizers and for the fertilizers as to be almost inseparable. The small differences between the two soils are confirmed by the data of Table 6. The values are closely similar except under organic matter. Even these are lesser differences than those shown by the phosphate treatment included herewith and the influence of which is reflected in this larger group.

TABLE 6.—NITRATE ACCUMULATIONS AS INFLUENCED BY FERTILIZER ADDITIONS OVER LONG PERIODS.

(MGMS. NITRATE NITROGEN PER 50 GMS. SOIL)

Field Treatments	Laboratory Treatments: No Treatment	Limestone	Organic Matter	Lime and organic matter
As increases during six weeks				
No fertilizer	.15	1.13	4.02	7.45
Fertilizers	.30	1.48	6.97	7.63
Increase by fertilizer	.15	.35	2.95	.18
As mean of six determinations during ten weeks				
No fertilizer	1.09	1.80	2.40	5.38
Fertilizers	1.09	2.35	3.74	5.56
Increase by fertilizer	.00	.55	1.34	.18
As mean of all determinations of four treatments during ten weeks				
No fertilizer—2.67		Fertilizer—3.18	Increase—19 per cent	

Ammonium sulfate and sodium nitrate.—The data for the nitrate accumulation by the soils under continuous wheat given ammonium sulfate and sodium nitrate treatments are assembled in Figure 12. It is evident that the untreated soils behave similarly, but the effects by lime is the greater on the ammonium sulfate plot. This would be expected from our knowledge of the base depleting activity, or

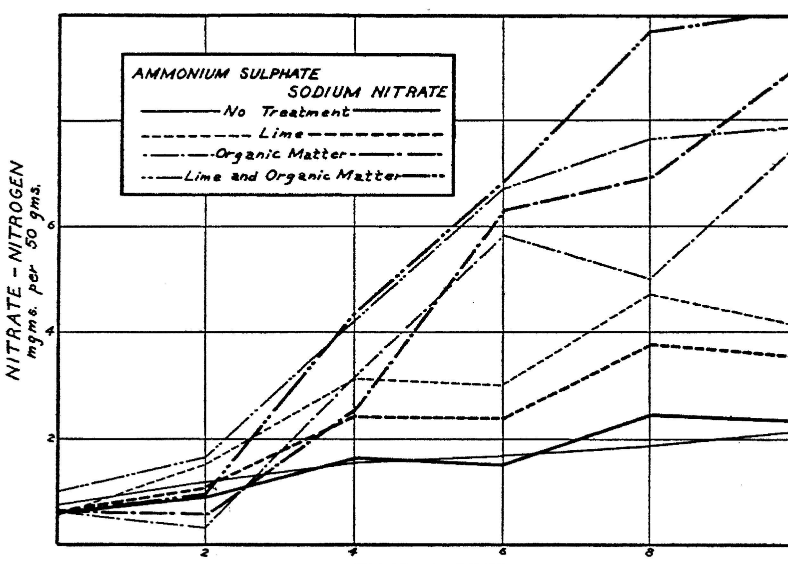

Figure 12.—Nitrate accumulations in soils as influenced by long periods of *Ammonium Sulfate* and *Sodium Nitrate* additions when given different treatments in the laboratory. (Soils from Sanborn Field)

the propensity toward acidity, of a soil treated continuously with ammonium sulfate. Organic matter addition alone was more effective on the soil with sodium nitrate. When both limestone and organic matter were added, the sodium nitrate soil was slightly more effective in producing nitrates.

Limestone.—Only two plots were available that were comparable for measuring the influence of limestone over a long period on the nitrate accumulating activity. The data for these are given in Figure 13. The interesting feature is the pronounced effect by

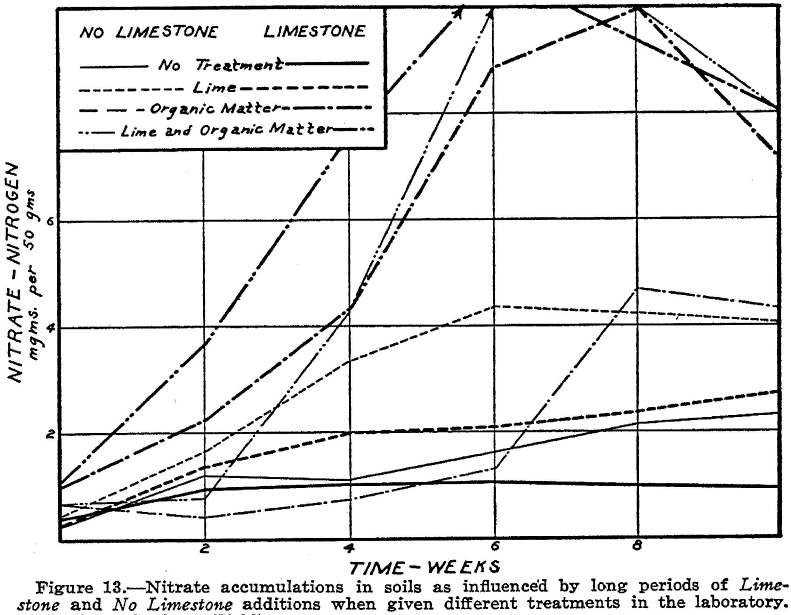

Figure 13.—Nitrate accumulations in soils as influenced by long periods of *Limestone* and *No Limestone* additions when given different treatments in the laboratory. (Soils from Sanborn Field)

laboratory additions of limestone on the unlimed soil, and the much smaller effect by it on the soil from the plot that was limed in the field. Further, the limed soil converted the added organic matter into nitrates at a much higher rate than the unlimed soil. The limed soil was earlier in its effects when both lime and organic matter were added. It gave decided increase at two weeks while the unlimed gave no response until after four weeks. This earlier nitrate production as a result of liming may be a significant item in crop production, and may be an effect not commonly appreciated.

SUMMARY

In order to illustrate more clearly the influence by the continuous cropping history on the soil's capacity to accumulate nitrates at only low figures, as compared to the distinct influence by the rotations and the soil treatments with their higher figures, the average nitrate content during the ten weeks may be taken as a fair criterion for each treatment. Using this figure in terms of pounds per acre, the results of the many foregoing tables are assembled in more generalized form as a summary in Table 7.

If the general mean of all determinations is considered as a basis for comparison, then the soil under timothy had a higher nitrate accumulating capacity than that under wheat, or under oats,—which two were in close agreement,—and these had a higher nitrate producing power than the soil from corn. The nitrate accumulating capacity by the soils in different rotations takes the following order very clearly for decreasing levels; three year, four year, and six year rotations.

As for the influence by soil treatments, the largest nitrate level was supplied by soils with phosphates. These were followed closely by the limed soil. Both of these were higher than any other treatment. If a share of the influence by phosphorus was due to the calcium it carried, then the liming receives double emphasis as an important factor in nitrification. Even if this extra emphasis is not separated out to be given to calcium, joint importance can be given to limestone and phosphate treatments on these older experimental plots. The use of nitrogenous fertilizers, mixed fertilizers, manure, and the three year rotation,—with their additions of nitrogen,—all gave these soils greater capacity to deliver nitrate nitrogen over the time period of the test. This gives emphasis to the need for supplying some nitrogenous materials to these soils if they are to deliver soluble nitrogen at a high rate during the growing season. The need by these soils for mineral fertilizers, particularly limestone and phosphate, if they are to give improved nitrate delivery is the outstanding suggestion from these studies.

TABLE 7.—NITRATE NITROGEN LEVELS IN SOILS UNDER DIFFERENT LABORATORY TREATMENTS AS INFLUENCED BY THE PAST HISTORY OF CROPPING AND SOIL TREATMENTS. (SOILS FROM SANBORN FIELD)

(Pounds Nitrogen per Acre)

Cropping History and Field Treatment		Laboratory Treatments: No Treatment	Limestone	Organic Matter	Lime and Organic Matter	Mean of all Treatment	Increase over lowest item
Continuous Crops	Corn	25	83	55	122	71	..
	Oats	30	26	121	190	92	21
	Wheat	59	102	52	172	96	25
	Timothy	48	104	110	183	111	40
Rotations	Six year	34	52	74	176	84	..
	Four year	56	75	109	208	112	28
	Three year	44	97	182	219	135	51
Soil Treatments	None	40	61	92	179	93	..
	Manure	49	93	120	196	114	21
	Phosphate	50	106	184	282	155	62
	Fertilizers	43	94	149	222	127	34
	Ammonium Sulfate	60	113	150	193	129	36
	Sodium Nitrate	62	87	174	216	134	41
	Lime	36	74	223	267	150	57

CONCLUSIONS

The studies on nitrate accumulating capacities of soils under long continued treatments on Sanborn Field point out that the particular cropping system on the soil was of lesser importance than soil treatments in determining the ability of the soil to accumulate nitrates. Soil from corn continuously had the lowest nitrate producing capacity. Soils from continuous wheat and from oats were of equal capacity, but slightly higher than that from corn. Soil from timothy was above that from these two cereal grains.

Soils from under crop rotations had greater capacities for giving nitrates as the rotations were shorter. Since clover occurred only once in each of three, four, or six year rotations, this suggests that this improved nitrate delivery in the shorter rotation may be due to the more numerous crops of clover to make their greater additions of nitrogenous matter to the soil.

Soil treatments were of significance in giving improved nitrate accumulation. The use of phosphates and limestone was most pronounced in effects on nitrification, even though they added no nitrogen to the soil. Their addition would then hasten depletion of the soil nitrogen through its conversion into the soluble form. The addition of nitrogenous fertilizers, mixed fertilizers, and manure, were all effective in improving nitrate accumulation in the laboratory studies. Soils which had been given these nitrogenous materials as field treatments had a better capacity to deliver soluble nitrogen when under test.

These facts point forcibly to the need for supplying the soil with nitrogen to be nitrified, and then also with the minerals as essentials in the functioning of the microorganisms that convert the nitrogen into the available form. These results emphasize not only the need by the soils for nitrogenous materials to be nitrified, but also suggest the need for more consideration of the importance of the mineral fertilizers as they serve in promoting better microbiological soil condition for the production of soluble nitrogen in the soil. They point out that we need to consider the soil as a supply of plant nutrients, and, in addition, as the factory operated by microbiological activity to convert these into forms and supplies sufficient for the growing plants. Long continued treatments have had their influence on the soil in both these respects.