

## CROP ROTATION AS AFFECTING NITRATE PRODUCTION.

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One of the great outstanding problems of the modern scientific farmer is that of maintaining and improving the soil fertility. It is in connection with this great problem that the science of Soil Bacteriology, the study of the habits and activities of the microbic flora of the soil and their relation to soil fertility and plant growth, has recently developed. Although investigations in this field have just begun, enough has been done to prove that such scientific studies are highly valuable in solving some of the problems relative to the question of soil fertility and plant growth.

As yet few scientific investigations have been reported on the effect of various crops and crop rotations on the nitrate content of the soil. As a result the following studies relative to the nitrate content and nitrifying power of the Rotation Plots of the Purdue Experiment Station Field No. 6 were undertaken.

A brief description of the plots and the experiment being conducted by the Purdue Station will be of value in interpreting the results of these studies.

The soil is a Sioux silt loam, containing some gravel and is underlaid by a gravel subsoil. The top soil is shallow, and just below at varying depths there is a hard layer somewhat similar to a hardpan. This soil dries quickly and packs easily. The organic matter content is fairly high.

The plots were laid out in 1889, as test plots one-tenth acre in size in strips fourteen feet wide separated by strips seven feet wide. In each series there are seven test plots, four treated with manure or fertilizer, and three checks. The purpose of the experiment was to test the relative value of manure and commercial fertilizers applied to different rotations.

At first only one crop of the rotation was grown each year, but in 1911 the plots were divided so that each crop of the rotation is grown every year. As a result some plots are smaller than others.

The accompanying map will give some idea of the relative size and position of the plots.

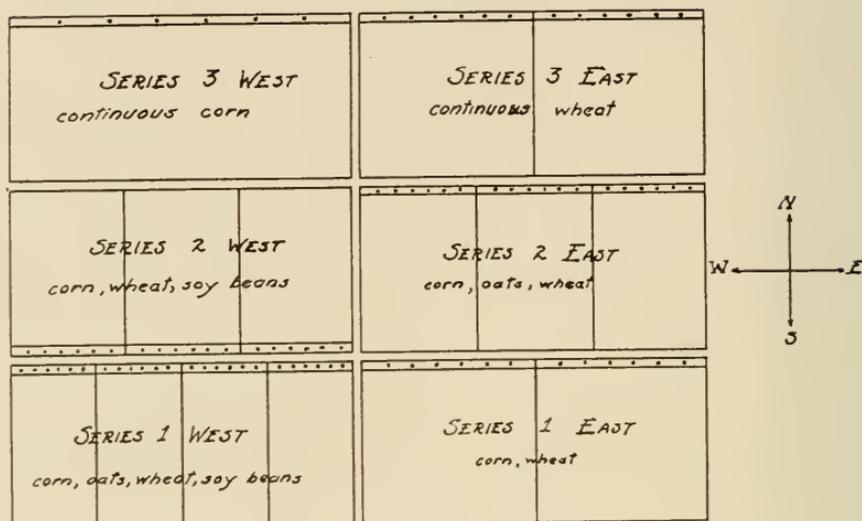
## HISTORY OF LITERATURE.

Until within a generation ago it was not known that nitrification was a bacterial process. The transformation of organic nitrogen was regarded as a purely chemical reaction and was extensively studied from that standpoint.

The work of Kuhlman, Bossingault, Schlosing and Muntz, Warrington and Winogradski and other investigators showed the true nature of nitrification and the organisms responsible were isolated and studied.

PLATE I      MAP OF PLOTS

Shows check plots from which samples were taken  
Dots show location of borings



Later investigations have brought out many of the factors influencing the process in the soil.

In 1893 Deherain,<sup>2</sup> and later in 1901 King and Whitson,<sup>3</sup> compared soil stirred and soil not stirred, and found that nitrates were produced more rapidly in the stirred soils. This they attributed to better aeration.

In experiments conducted in 1907, Voorhees, Lipman and Brown,<sup>6</sup> found decomposition slower under oats and clover than in bare soils.

In later studies King and Whitson,<sup>3</sup> found differences in the nitrates produced under the same crop in different plots and under different crops. Although the differences in some cases were quite considerable, they did not feel justified in drawing any conclusions relative to the effect of certain crops.

Later Deherain,<sup>2</sup> claimed that if soil moisture was not lacking, and if the loss of nitrate nitrogen in the drainage water and the nitrogen in the crop were added, similar nitrification would be found in fallow and in cropped lands. This statement, however, has been severely criticized and with respect to the question of nitrification under legumes, a proposition which has received considerable attention, experiments have shown that sometimes more and sometimes less nitrate nitrogen may be found than under grain crops. Among the more recent experiments are those performed by Brown<sup>1</sup> of Iowa which shows the following:

1. "The rotation of crops brought about a greater nitrifying power in soils than continuous cropping either to corn or to clover.

2. A soil under a three-year rotation of corn, oats and clover possessed a greater nitrifying power than one under a two-year rotation

of corn and oats, or one under a two-year rotation in which clover and cowpeas were used as a green manure.

3. There was an indication that the influence of the crop present on the soil was greater than the influence of the previous cropping on the bacteria in the soil, and this was probably due to the difference not only in the crop but in the treatment of the soil and preparation for the crop."

#### TECHNIC.

The object of this investigation was to determine the effect of different crops and crop rotations on the nitrate content and nitrifying power of the soil.

To accomplish this end samples were taken monthly from each plot over a period from March, 1920, to October, 1920, inclusive, and these samples were analyzed for moisture, nitrates and nitrifying power.

Samples were taken at as near the same date each month as circumstances would permit. In order to eliminate as nearly as possible the factor of denitrification, no samples were taken when the soil was wet enough to "ball up".

Samples were evenly distributed over the plot as shown by dots on the accompanying map, and were taken from about the same places each month. In order to eliminate the factor of fertilizer, the samples were taken from the check plots of each series. (The check plots on the south side of Series V West were used because those on the north side were considerably lower than those of the other series.)

Moisture determinations were made by drying in an oven at 100° C for several hours, duplicate samples of 10 gms. soil each in 30 c.c. tarred crucibles.

The nitrate content was determined by the phenol-di-sulphonic method, as modified by Noyes<sup>5</sup> for soil investigation work.

To determine the nitrifying power of the soil, duplicate samples of 100 gms. each were placed in glass tumblers covered with petri plates, and incubated at room temperature for two weeks. In any instance where the moisture content was noticeably lower than normal, which ran about 20 per cent, distilled water was added to bring it back to normal. At the end of two weeks nitrate determinations were made as in the case of the fresh samples.

In tabulating the data the averages of the duplicates were used, and the nitrate content calculated on the basis of moisture-free soil and in terms of parts per million parts of water-free soil.

#### DISCUSSION OF RESULTS.

Before entering into a discussion of the tables it would be well to note that the factors affecting bacterial activities and hence nitrate formation in the soils as determined by previous investigators are, moisture, temperature, aeration, crop growth, organic matter and plant food content of the soil, presence of toxic substances, cultivation, previous cropping and treatment, and type of soil. Of these many factors, those which may be taken as different in the different plots are aeration, kind of crop grown, cultivation, previous crop and treatment, and

possibly the presence of toxic substances. However, the last named factor is probably of very little importance. The effect of these differences can only be estimated in comparing plots.

The nitrate content of the fresh samples is taken as an indication of the surplus of the amount produced over that used by the crop.

The difference between the incubated and fresh samples is taken as a measure of the additional work done in the laboratory under optimum conditions by those groups of bacteria which change the nitrogen of complex organic nitrogenous compounds first into ammonia, then into nitrites and further to nitrates.

TABLE I.  
Series I East—Rotation Corn, Wheat

Month	Plot 1 Wheat				Plot 2 Corn			
	Moisture %	Nitrates—Parts per million		Moisture %	Nitrates—Parts per million			
		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples		
March..	21.4	28.45	65.04	20.20	16.42	32.85		
April..	21.1	4.04	26.31	21.70	8.16	36.73		
May....	17.23	3.86	19.30	16.48	3.83	19.12		
June....	12.58	1.83	21.96	18.49	35.30	82.35		
July....	16.99	11.56	15.41	15.28	79.32	83.01		
Aug....	14.16	7.45	9.07	15.05	132.62	188.30		
Sept....	11.98	.....	3.62	15.10	26.36	56.52		
Oct....	22.93	.....	4.14	22.48	12.38	24.76		
Total per period		57.19	164.85		194.39	523.64		
Ave. per month		7.15	20.60		24.29	65.45		

DISCUSSION OF TABLE I.

Series I East—Rotation Corn, Wheat.

The average nitrate content of the entire period for the fresh samples for the corn plot is 24.29 parts per million, as compared to 7.15 parts for the wheat plot.

The highest content for fresh samples was reached for corn in August, just after the corn ceased drawing heavily on the nitrates of the soil. The highest content for the wheat plot was in March, before the crop started good growth, but a second high nitrate content was found in July, just after the crop was removed.

The fresh samples for the corn plot showed low from March to June, high from June to September, and low again for September and October. The wheat plot was high in March, low until July, high for July and August, and low again for the remainder of the period.

For the corn plot, the incubated samples show a much higher average for the eight months than do those of the wheat plot,—for corn 65.45 parts, and for wheat 20.60 parts of nitrates per million parts of moisture-free soil.

It will be noticed that the incubated samples for corn showed highest in August, for wheat highest in March. As would be expected, the incubated samples showed highest during the growing season and lowest during the months of less favorable conditions for bacterial action.

During the first part of the season these crops were feeding heavily on the nitrates of the soil, but the corn plot produced a larger surplus over the amount used than did the wheat plot. These differences noted above are in large part due to the corn crop being cultivated and having a larger growing season, thus making a longer period of more favorable conditions for bacterial activities.

TABLE 2  
Series II East—Rotation Corn, Oats, Wheat

Month	Moisture %	Plot 1 Corn		Moisture %	Plot 2 Oats		Moisture %	Plot 3 Wheat	
		Nitrates—Parts per million			Nitrates—Parts per million			Nitrates—Parts per million	
		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples
March.....	22.5	8.24	32.98	22.1	28.74	55.44	21.30	22.35	38.61
April.....	23.8	5.24	29.35	20.45	14.04	40.16	21.00	12.10	40.48
May.....	19.65	3.97	25.84	17.22	5.79	23.16	17.07	9.63	25.04
June.....	18.05	15.61	63.28	11.01	3.59	14.36	12.70	3.66	32.96
July.....	16.05	38.11	64.76	17.21	7.73	23.19	14.18	11.18	24.20
August.....	18.07	58.58	73.52	17.23	7.73	15.46	16.44	7.65	9.52
September.....	13.11	25.91	44.18	19.84	11.95	25.94	16.07	3.81	9.20
October.....	24.52	4.22	10.59	22.85	4.41	12.44	12.95	2.08	8.30
Total for period..		151.84	344.47		83.71	210.15		72.46	188.31
Ave. per month..		18.98	43.05		10.46	26.26		9.05	23.53

#### DISCUSSION OF TABLE 2.

##### Series II East—Rotation Corn, Oats, Wheat.

Table 2 shows that the average for the fresh samples for the eight months were corn, 18.98 parts, oats 10.46 parts, and wheat 9.05 parts of nitrate per million parts of moisture-free soil.

The highest nitrate content of the fresh samples was found in August for the corn plot, in March for the oat plot and in March for the wheat plot. The corresponding low content was found in May for corn, in June for oats, and in June for wheat.

The untreated samples showed an average of 43.05 parts for the corn plot, 26.26 parts for the oats and 23.53 parts for the wheat. The highest content for the corn plot was found in August, with June and July also high; for oats in March with several other months of the growing season high.

The similarity in the nature and feeding habits of the oat and wheat crops can be correlated with the similarity in the results for these crops. The difference between the results of the corn plot and these plots is in all probability due mostly to the difference in lengths of growing season and the cultivation received by the corn crop.

#### DISCUSSION OF TABLE 3.

##### Series III East—Continuous Wheat.

Table 3 shows an average for the eight months for the nitrate content of the fresh samples of 14.66 parts per million for the unlimed continuous wheat plot, and 12.78 parts per million for the limed plot.

TABLE 3  
Series III East—Rotation Continuous Wheat

Month	Moisture %	Plot 1 Unlimed		Moisture %	Plot 2 Limed	
		Nitrates—Parts per million			Nitrates—Parts per million	
		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples
Mar.....	21.5	28.51	40.73	22.4	26.80	43.29
Apr.....	18.35	21.55	50.88	21.0	4.05	36.43
May.....	15.48	7.56	26.46	16.15	11.42	26.66
June.....	10.65	14.30	3.57	9.01	7.03	31.63
July.....	12.23	10.93	21.85	13.17	11.05	33.14
Aug.....	14.50	11.21	17.92	15.88	11.40	15.99
Sept.....	15.28	16.98	22.68	13.03	22.47	33.10
Oct.....	23.16	6.24	20.82	24.37	8.46	19.03
Total per period.....		117.28	204.91		102.28	239.27
Ave. per month.....		14.66	25.61		12.78	29.90

The content of the fresh samples for the unlimed plot was high in March, April, and fairly high in June, July, August and September, while that of the limed plots was high in March and September, and fairly high in June, July, and August.

The incubated samples gave an average of 25.61 parts for the unlimed and 29.90 parts for the limed. Here again the samples taken during the growing season contained the most nitrates.

The addition of lime to the soil brings about conditions more favorable to plant growth and bacterial activities. This in all probability accounts for the higher averages of the treated and untreated samples of the limed plots compared with the unlimed plots. The limed wheat no doubt made greater growth during the months of April, May and June than did the unlimed wheat, and therefore the fresh samples showed a lower average than those of the unlimed wheat.

TABLE 4  
Series I West—Rotation Corn, Oats, Wheat, Soybeans

Month	Moisture %	Plot 1 Oats		Moisture %	Plot 2 Wheat	
		Nitrates—Parts per million			Nitrates—Parts per million	
		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples
Mar.....	21.8	20.44	39.87	22.3	28.80	49.18
Apr.....	20.60	14.10	37.45	22.2	12.32	36.96
May.....	16.55	3.83	21.07	16.12	7.61	28.47
June.....	12.61	1.83	21.96	16.09	3.81	30.47
July.....	14.90	11.28	22.56	13.14	11.05	25.78
Aug.....	18.07	7.81	9.96	17.78	7.78	15.56
Sept.....	11.79	9.05	21.76	12.61	5.48	10.98
Oct.....	22.17	6.16	12.33	22.74	4.14	8.28
Total per period.....		74.50	186.96		80.99	205.68
Ave per month.....		9.31	23.37		10.12	25.71

#### DISCUSSION OF TABLE 4.

Series I West—Rotation Corn, Oats, Wheat and Soybeans.

The average of the nitrate content of the fresh samples for the period was 11.92 parts per million parts of moisture-free soil for the

TABLE 4—Continued

Month	Moisture %	Plot 3 Beans		Moisture %	Plot 4 Corn	
		Nitrates—Parts per million			Nitrates—Parts per million	
		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples
Mar.....	21.1	12.14	32.38	20.8	4.15	20.20
Apr.....	18.6	1.96	19.64	19.75	1.99	23.90
May.....	14.98	3.75	20.67	15.95	3.80	19.01
June.....	14.58	14.90	114.73	14.93	18.80	48.87
July.....	13.36	40.62	40.59	17.5	42.66	54.26
Aug.....	13.41	5.54	5.54	17.18	14.24	27.02
Sept.....	9.78	3.54	10.68	15.95	5.70	17.12
Oct.....	21.33	2.04	4.06	21.39	4.09	10.24
Total per period.....		84.49	248.29		95.43	220.62
Ave. per month.....		10.56	31.03		11.92	27.57

corn plot, 9.31 parts for the oats, 10.12 parts for the wheat, and 10.56 parts for the soybean plot.

The highest content of the fresh samples was found in July for the corn plot, in March with April and July also high for the oat plot, in March with April and July also high for the wheat plot, and in July with March and June high in the case of the soybean plot. During the latter part of the period, when conditions were less favorable for the formation of nitrates, and during the months of heaviest crop growth, the content of the fresh samples ran low for all plots.

Table 4 shows an average nitrate content for the incubated samples of 27.57 parts per million parts of moisture-free soil for the corn plot, 23.37 parts for the oat plot, 25.71 parts for the wheat plot and 31.03 parts for the soybean plot.

The highest content of the incubated samples was found in July for the corn plot, in March for the oat and wheat plots, and in June for the soybean plot.

The results for the corn and soybean plots check very closely with each other in regard to high and low periods and also the averages of the fresh and incubated samples. Both are cultivated crops. Also, as would be expected, the results on the oat and wheat plots check closely.

#### DISCUSSION OF TABLE 5.

##### Series II West—Rotation Corn, Wheat and Soybeans.

Table 5 shows the average nitrate content of the fresh samples for the eight months to be 32.60 parts of nitrate per million parts moisture-free soil for the corn plot, 7.64 parts for wheat and 7.48 parts for the soybean plot.

The corn plot contained the highest amount of nitrates in August, with June and July also high; the wheat plot showed highest in March, with April, May and July also high; the soybean plot contained most nitrates in June and July.

The corn plot showed an average of 59.58 parts in the incubated samples, the wheat plot an average of 20.80 parts, and the soybean plot an average content of 28.12 parts nitrates per million parts moisture-free soil. The highest results for these samples were found in August,

TABLE 5.  
Series 1 West—Rotation Corn, Wheat, Beans.

Month	Moisture %	Plot 1 Corn		Moisture %	Plot 2 Wheat		Moisture %	Plot 3 Beans	
		Nitrates—Parts per million			Nitrates—Parts per million			Nitrates—Parts per million	
		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples		Fresh Samples	Incubated Samples
March	25.5	12.87	37.55	20.4	18.07	42.16	22.5	4.12	37.11
April	27.7	6.63	22.12	21.1	12.14	36.43	22.2	4.11	36.96
May	18.37	5.87	35.18	18.88	9.84	27.55	17.27	1.93	19.30
June	17.41	38.70	88.97	12.38	3.65	18.24	16.13	19.00	53.33
July	18.23	78.27	93.75	17.39	7.74	19.34	15.32	18.85	33.96
August	19.76	99.60	179.28	16.26	5.73	8.74	18.96	5.92	13.80
September	14.58	14.79	7.48	14.30	1.86	5.60	14.11	1.86	22.35
October	22.56	4.13	12.38	23.44	2.09	8.36	21.59	4.08	8.16
Total per period		260.86	476.71		61.12	166.42		59.87	224.97
Ave. per month		32.60	59.58		7.64	20.80		7.48	28.12

June and July for the corn plot, in March, April and May for the wheat plot, and in March, April, June and July for the soybean plot.

The highest results for the corn and soybean plots conform very closely to the period of cultivation, while the highest results for the wheat plot were obtained just before and immediately after the growing season, for the fresh samples, and from March to August for the incubated samples.

TABLE 6.  
Series III West—Continuous Corn.

Month	Moisture %	Plot 1 Corn	
		Nitrates—Parts per million	
		Fresh Samples	Incubated Samples
March	25.4	21.41	34.26
April	27.5	4.43	22.02
May	18.32	29.35	78.27
June	15.88	22.80	60.83
July	18.01	42.93	50.68
August	16.63	14.97	40.22
September	14.17	9.31	18.63
October	22.21	6.17	8.23
Total for period		151.37	313.14
Ave. per month		18.92	39.14

#### DISCUSSION OF TABLE 6.

##### Series III West—Continuous Corn.

The average nitrate content of the fresh samples for the period was 18.92 parts of nitrate per million parts of moisture-free soil. The content was high from March to July, inclusive, with the exception of the month of April, the sample for which was taken just after the plot was plowed, and was lower from August to October. The highest point was reached in July.

The average for the incubated samples was 39.14 parts of nitrate. The months of May, June and July were highest, but the first six months all showed a high content for the incubated samples.

TABLE 7.  
Nitrifying Power—Difference Between Fresh and Incubated Samples.

Series		Nitrates—Parts Per Million								
Number and Rotation	Plot No. and 1920 Crop	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Ave.
I, E.— Corn, Wheat.....	1 Wheat....	36.59	22.27	15.44	20.13	3.85	2.62	3.62	4.14	13.58
	2 Corn.....	16.43	28.57	15.29	47.05	3.69	55.68	30.16	12.48	26.17
II, E.— Corn, Oats, Wheat..	1 Corn.....	24.74	24.11	21.87	47.67	26.65	14.94	18.27	6.27	23.07
	2 Oats.....	26.70	26.12	17.37	10.77	15.46	7.73	13.99	8.30	15.81
	3 Wheat....	16.26	28.38	15.41	29.30	13.02	1.87	5.39	6.22	14.48
III, E.— Cont. Wheat.....	1 Unlimed..	12.22	29.33	18.90	10.73	10.92	6.71	5.70	14.58	10.95
	2 Limed...	16.49	32.39	15.24	24.60	23.09	4.59	10.63	11.57	17.32
I, W.— Corn, Oats, Wheat Beans.....	1 Oats....	19.43	34.59	17.24	20.13	11.28	2.15	12.71	6.17	15.46
	2 Wheat....	20.38	24.64	20.86	26.63	14.73	7.78	5.50	4.14	15.58
	3 Beans....	20.24	17.68	16.92	99.83	— 03	0.	7.14	2.02	20.48
	4 Corn....	16.05	21.91	15.21	30.07	11.60	13.38	11.42	6.13	15.72
II, W.— Corn, Wheat, Beans.	1 Corn.....	24.68	15.49	29.31	50.27	15.48	79.68	7.31	8.25	26.98
	2 Wheat....	24.09	24.29	17.71	14.59	11.63	3.01	3.74	6.27	13.17
	3 Beans....	32.99	32.55	17.37	34.33	15.11	7.88	20.49	77.52	29.81
(Cont. Corn) III, W.....	1 Corn.....	12.85	17.59	48.92	38.03	7.75	25.25	9.32	2.06	20.22
Ave. all Plots..		21.34	25.33	20.21	32.89	12.28	15.47	10.51	11.87	

## DISCUSSION OF TABLE 7.

Nitrifying Power of the Various Plots as Determined by the Differences between the Untreated Incubated and the Fresh Samples.

The averages for the period of the differences between the untreated and fresh samples are 13.58 parts, 14.48 parts, 10.95 parts, 17.32 parts, 15.58 parts and 13.17 parts of nitrates per million parts of moisture-free soil for the plots containing wheat. The lowest average was found for the unlimed continuous wheat plot, and the highest average for the limed continuous wheat plot.

The averages for the period for the corn plots were 26.17 parts, 23.07 parts, 15.72 parts, 26.98 parts and 20.22 parts of nitrate per million parts of moisture-free soil. The lowest difference, 15.72 parts, was for the corn plot in the corn, oats, wheat, soybean rotation, Series I. W., which plot also showed a low average for the fresh samples. This plot contains a large amount of gravel when compared with the other plots.

The averages for the oat plots were 15.81 parts and 15.46 parts of nitrate per million parts of moisture-free soil.

The averages for the soybean plots were 20.48 parts and 29.81 parts per million.

These results in Table 8 show that the nitrifying power of the corn and soybean plots as measured by this test is nearly the same, and is much higher than the nitrifying power of the wheat and oat plots, which plots are about equal in nitrifying power.

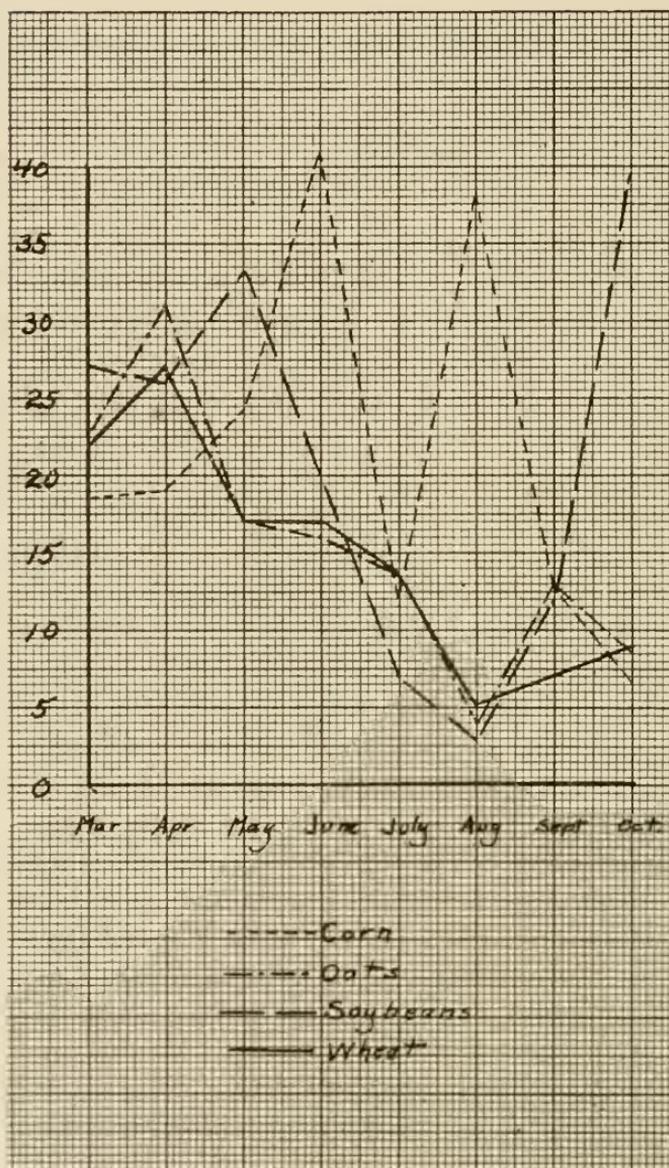


FIGURE I.  
Nitrifying Power of Crops.

#### DISCUSSION OF TABLE 8.

Effect of Different Crops on Nitrifying Power of the Soil Measured by the Averages of all Plots Growing the Same Crop.

In Table 8 the differences between the incubated and fresh samples for all the corn, all the wheat, all the oats and all the soybean plots, are averaged and tabulated.

The curves for these averages are shown in Figure I.

TABLE 8.  
Nitrifying Power—Difference between Fresh and Incubated Samples.

Crop	Average of Nitrates—Parts Per Million								
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Ave. Mo.
Corn.....	18.95	19.53	26.12	42.61	13.03	37.78	12.37	7.04	22.18
Oats.....	23.06	30.35	17.30	15.45	13.37	4.94	13.35	7.23	15.63
Wheat.....	21.00	26.89	17.26	17.42	12.87	4.43	7.56	7.82	14.65
Beans.....	26.61	25.26	32.92	22.36	7.55	3.94	13.81	39.77	21.48
Average.....	22.40	25.51	23.40	24.46	11.70	12.77	11.77	15.46	.....

The highest average difference between the fresh and incubated samples was found in June for the corn plots, in April for the oats and wheat plots, and in May for the soybean plots. The amount of nitrates used by the crops and leached from the soil would affect this curve directly.

#### SUMMARY.

1. The rate of nitrate formation is very greatly increased by cultivation of the soil.
2. The corn and soybean plots, which were cultivated, showed a high nitrifying power as compared to the wheat and oat plots, which were not cultivated during the growing season.
3. The effect of the previous crop and treatment of the soil on nitrate production is not nearly as important as that of the growing crop and the soil treatment.
4. Corn and soybeans are heavy feeders while wheat and oats are less vigorous nitrate feeders.
5. The highest nitrifying power as determined by the methods employed in this work was in July for the corn plot, and in June for the wheat, oat and soybean plots.
6. The addition of lime to acid soils makes conditions for the development of nitrifying bacteria much more favorable.
7. The rate of nitrate production in the plots in the Purdue Experiment Station Field No. 6 is not a limiting factor to plant growth.

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