ciable rate even when the initial concentrations are so low as 0.1 part of nitrite nitrogen per million, and urea in equivalent amount.

(2) That once having added the Griess reagent, and thus converted the nitrous acid into the characteristic dye, urea will not then react with the nitrous acid, even though present in great excess.

(3) That nitrous acid and urea, in very dilute solutions, sometimes fail to react, for no apparent reason.

THE GORDON HALL OF CHEMISTRY
SCHOOL OF MINING, KINGSTON, ONTARIO

THE INFLUENCE OF A PRECEDING CROP ON NITRIFICATION IN SOIL

By T. LYTLETON LYON AND JAMES A. BIZZELL

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While the practices of crop rotations have been fairly well worked out there yet remains much to learn regarding the underlying principles. Most of the effort in experimentation with soils has been to ascertain the effect of certain soil conditions on plant growth or on the solubility of the mineral nutrients in various solvents. The study of the principles of crop rotation will necessitate the investigation of the effect of plant growth on the soil. The fact that a certain plant grows better when preceded by one species of plant than by another is a self-evident indication that plants of different species exert different influences on the soil.

The writers have suggested¹ that certain higher plants have a distinct influence on the process of nitrification in the soil; that this influence varies in intensity with plants of different families, and at different stages in the growth of any one kind of plant. It was found, for instance, that in a soil on which maize was growing the nitrates were sometimes higher at certain periods than in a similar soil on which no plants grew. Timothy (*Phleum pratense*), on the other hand, maintained uniformly a very low nitrate content in the soil throughout the growing period.

The question then arose whether the higher plants exerted any influence on the activities of the nitrifying bacteria after the plants had been removed. To test this it was decided to continue the nitrate determinations a second year in soil that had been planted to several kinds of crops.

Plats that were used for studying the effect of plants on the nitrate content of soils in 1910 were kept bare in 1911 until July 1st. To keep down the weeds the plats were disc harrowed from time to time. Samples of soil were taken from the sections of the plats that were planted and bare in 1910, in order to ascertain the effect of the different crops grown the previous year on the nitrate content of the soil. Soil samples were taken from both the previously planted and unplanted sections of the plats, and the borings were made to a depth of eight inches from the surface, and again from eight to sixteen inches. Table I presents the results, averaged for the entire season, for the four plats planted to the same crop, also the average of the unplanted sections of the same plats during the

growing season of 1910, and consequently shows the nitrate content of the soil in the year during which the test crops were grown:

TABLE I—NITRATES IN PLANTED AND UNPLANTED SECTIONS OF PLATS
AVERAGE FOR THE GROWING SEASON

Plat Nos.	Crop	Nitrates p. p. m. dry soil	On basis of		Nitrogen in crop Lbs. per acre
			Nitrates in bare soil 100		
3612, 13, 22, 23....	{ Maize	167	123		3.5
	{ None	136	100		
3614, 15, 24, 25....	{ Potatoes	104	96		42.7
	{ None.	108	100		
3616, 17, 26, 27....	{ Oats	90	71		28.7
	{ None	126	100		

The nitrates were highest under the maize, next highest under the potatoes and lowest under the oats. Similar results had been obtained in previous years.

The last column of Table I shows the quantity of nitrogen removed per acre by each crop. The maize crop was a very poor one, which accounts for the small quantity of nitrogen contained in that crop. It is doubtless true that the small maize crop is partially responsible for the high nitrate content of the maize soil, but this high nitrate content has been found in maize soil in previous years when the crop was good. Again, the persistently higher nitrate content of the maize soil, as compared with the bare soil, can be explained only on the assumption that nitrification is much more active where the maize is growing, for certainly more nitrates are being removed from the planted soil.

Nitrates are higher in the potato soil than in the oat soil, although the former crop removed fifty per cent. more nitrogen. The nitrate content of a planted soil is not determined by the total quantity of nitrogen removed by the crop, but by a number of factors, of which one appears to be a direct influence which each species of plant exerts on the activity of the nitrifying organisms.

The year following that in which the results given above were obtained these plats were kept free from vegetation until July 1st and nitrates were determined from time to time. Table II contains a statement of the nitrates of the previously planted and bare sections of these plats on each of the dates when the soils were analyzed:

TABLE II—NITRATES IN SOIL PLANTED THE PREVIOUS YEAR
AND SOIL UNPLANTED

Plat Nos.	Crop.	May 1		June 5		June 28	
		First Second		First Second		First Sec'd.	
		8 in.	8 in.	8 in.	8 in.	8 in.	8 in.
3612, 13, 22, 23...	{ Maize	51.5	53.4	77.9	44.6	40.5	34.0
	{ None	48.1	52.3	68.0	44.0	40.3	30.1
3414, 15, 24, 25...	{ Potatoes	31.3	26.0	49.8	26.4	28.6	23.9
	{ None	42.7	43.0	79.7	42.6	35.2	29.4
3616, 17, 26, 27...	{ Oats	22.7	20.7	41.1	33.0	22.1	21.6
	{ None	32.3	39.6	68.4	34.8	33.6	31.9

An examination of this table will show that, except in the case of maize, the nitrates are lower in the soil on which plants grew the previous year than in the soil kept bare at that time. It will also be noticed that the nitrates on this bare soil are in the same order as they were when the plats were planted. That nitrates are highest in the soil previously planted to

¹ Journal of the Franklin Institute, Jan. and Feb., 1911, pp. 1-16, 205-220.

maize, next in that planted to potatoes, and lowest in that planted to oats.

In Table III is given a statement of the nitrates in the planted sections of the plats in terms of the nitrates in the unplanted sections taken as 100. To obtain this the nitrates in both planted ends of the four plats planted to the same crop are averaged and this is divided by the average for the nitrates on the unplanted sections of the corresponding plats. This furnishes the most accurate means of comparison as it removes more effectively than any other method the local variations in the nitrate content of the soil.

TABLE III—RATIO OF NITRATES IN BARE SOIL TO NITRATES IN SOIL OF SAME PLATS PREVIOUSLY PLANTED.

Plat Nos.	Crop.	Surface 8 inches.			Second 8 inches.		
		May	June	June	May	June	June
		1	5	28	1	5	28
3612, 13, 22, 23...	Maize	108	114	100	102	101	112
3614, 15, 24, 25...	Potatoes	73	63	81	60	62	81
3616, 17, 26, 27...	Oats	70	60	66	53	95	68

There is a distinct and characteristic difference in the nitrate content of the soil previously bearing these different plants. While the experiment covers only one season the differences would seem to be too large and well defined to be accidental.

Maize is the only crop following which the nitrates in the planted soil are higher than in the unplanted soil.

These results serve to support the idea already advanced by the writers, that higher plants influence the nitrifying process in soils.

On July 1st the plats used in this experiment were drilled to millet, the entire plat being planted, including the middle section of each plat, which during the preceding year had remained bare. The object in planting the millet was to see how the growth of a crop of these plats would correspond with the nitrate content.

On September 8th careful notes were taken of the growth on each plat and a comparison made not only between different plats but also between the growth of the millet on the previously planted section and the bare section of each plat.

The growth of millet was in each plat markedly better on the sections of the plat that had been in crop the previous year than on the unplanted section. This applied to every crop in the experiment. A comparison of the growth on the planted sections of the plats is given in Table IV, in which the growth of millet on the plats planted to oats is taken as 100 and the growth on the other plats stated on this basis:

TABLE IV—GROWTH OF MILLET ON THE PLATS PLANTED TO DIFFERENT CROPS THE PREVIOUS YEAR

	Soil treat- ment	Plat No.	Growth of mil- let		Growth of mil- let		Average growth of mil- let
			Per cent.	Plat No.	Per cent.	Per cent.	
Maize.....	No lime	3612	37	3622	62	49	
	Lime	3613	47	3623	71	59	
Potatoes....	No lime	3614	60	3624	81	70	
	Lime	3615	65	3625	88	76	
Oats.....	No lime	3616	100	3626	100	100	
	Lime	3617	100	3627	100	100	

It will be seen that the luxuriance of the growth of millet on these plats was inversely proportional to the relative concentration of the nitrates in the soil. For instance, the millet made the best growth on the plats planted to oats and these plats had the lowest nitrate content. The poorest growth of millet was on the maize plats and these had the highest concentration of nitrates.

In Table V the ratio of nitrates to bare soil of the surface eight inches of the several plats on June 28th, which was only a few days before the millet was planted, is compared with the percentage growth of millet on the same plats.

TABLE V—COMPARISON OF NITRATES IN SOIL PLANTED TO CERTAIN CROPS AND THE GROWTH OF MILLET ON THE SAME PLATS

Crop in 1910	Relative nitrate content	Relative growth of millet
Oats.....	59	100
Potatoes.....	67	73
Maize.....	100	54

It would seem from these results that, in this soil, the conditions that favored the growth of millet were unfavorable to the formation of nitrates. That this is not true of other conditions is evident from the fact that the millet grew better on the limed than on the unlimed soil, as shown in Table IV, while the nitrates are also higher in the limed plats, as may be observed in Table VI, which follows:

TABLE VI—NITRATES IN UNPLANTED SECTIONS OF PLATS LIMED AND NOT LIMED.

Plat Nos.	Soil treatment.	Nitrates in soil, p. p. m.			
		May 4	June 5	June 28	Avr.
{ 3612, 22.....	No lime	40.5	61.2	41.8	47.8
{ 3613, 23.....	Lime	54.8	74.9	38.7	56.1
{ 3614, 24.....	No lime	39.9	76.9	34.3	50.3
{ 3615, 25.....	Lime	45.4	82.5	36.0	55.0
{ 3616, 26.....	No lime	28.5	51.7	36.2	38.8
{ 3617, 27.....	Lime	36.2	85.2	40.3	53.9

It is quite evident that although the previous crop influences greatly the nitrate content of this soil, the growth of millet is not increased thereby. Nitrates are not the limiting factor in the growth of millet on this soil.

Lime increases the growth of millet and also the formation of nitrates, but apparently its beneficial action must be due to some cause other than its influence on nitrate formation.

The purpose of this paper is to call attention to the influence of certain kinds of plants on the formation of nitrates in the soil after the crops have been removed. The relation of the nitrate formation to the growth of millet on this soil is a separate problem, probably peculiar to this particular soil, but possibly worth recording in passing. The interesting condition exists that, of the crops used in the experiment, each had a certain and distinct influence on nitrate formation following the removal of the crops, and on the growth of millet also following their removal, but that the effectiveness of the influence is directly opposite. It is not to be expected, however, that this opposite effect would obtain in all soils, since the presence of an abundance of nitrates would, under some circumstances, throw the influence towards a better

growth of the succeeding crop. There is thus presented a problem in crop rotation. If the influence of a certain kind of plant on the formation of nitrates, after its removal, holds for soils, other than the one used in this experiment, something has been learned. That other, and under some conditions, influences more potent than nitrate formation obtain is also indicated by this experiment.

SUMMARY

Plats of land planted to certain crops in 1910 were kept bare of vegetation during the early part of the growing season of 1911. Determinations of nitrates, in the soil of these plats showed a distinct and characteristic relation of the several plants to the nitrate content of the soil in the year following that in which the plants were grown.

Maize was the only crop following which the nitrates in the previously planted soil were higher than in the unplanted soil. Potato soil was the next highest in nitrates, and oat soil contained least nitrates.

Millet planted on these plats July 1st was markedly influenced by previous crops, but the luxuriance of growth was inversely proportional to the nitrate content of the plats.

The beneficial influence of a crop on a succeeding one was not, in this case, to be attributed to the favorable influence exerted on nitrification, but this would doubtless differ with different soils, and if this effect of certain plants on nitrification in the following year should be of general application, the influence of a crop on nitrification may be an important factor in crop rotation.

DEPARTMENT OF SOIL TECHNOLOGY
CORNELL UNIVERSITY
ITHACA, NEW YORK

A COMPARISON OF SOME QUALITATIVE AND QUANTITATIVE METHODS FOR CARBONATES IN SOILS

By E. W. GAITHER

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In connection with certain chemical investigations of soils, which are being conducted in the laboratory of the Chemical Department of this Station, it was found necessary to determine the carbon dioxide existing as carbonates in the soils.

After making a number of determinations by the official method,¹ it was found that there was no correlation between the reaction of the soils with litmus paper or the Veitch qualitative test and the CO₂ obtained by this method.

If it were assumed that the CO₂ was derived from carbonates and it were calculated to CaCO₃, the average amount for acid surface soils would be 3244 pounds CaCO₃ per 2,000,000 pounds of soil and that for acid subsoils would be 1036 pounds per 2,000,000 pounds of soil, which would be a sufficient amount of this material present to render any of these soils alkaline or to indicate that there was a sufficient amount of this compound in all of these soils for all practical purposes. In many cases, where the soil reddened blue litmus, more CO₂ was obtained than from those which turned red litmus blue. These

¹ Bull. 107, Bureau of Chemistry, U. S. D. A.

variations led to the conclusion that this method was unreliable as a measure of soil carbonates.

While considering this point, attention was directed by Mr. J. W. Ames, Chief of the Department, to a method devised by the late F. S. Marr, Carnegie Research Scholar, Rothamsted, England, and published in the *Journal of Agricultural Science*, Vol. III, Part 2, pp. 155-160, for determining CO₂ as carbonates in soils, in which the soil was boiled with very dilute acid under reduced pressure. It is claimed that under these conditions no organic matter is decomposed and that the CO₂ obtained is derived from carbonates only.

Some of Marr's work was repeated and his results were confirmed.

He found that CO₂ was evolved from acid soils even when boiled with distilled water at 100° C. and that the amount was increased upon the addition of a mineral acid, while if boiled at 50° C. under reduced pressure with 2 cc. of conc. HCl per 100 cc. of water, the results were either negative or only a very small amount of CO₂ was evolved. These results were considered to be within the limits of experimental error.

The double titration method of Brown and Escomb with the Amos apparatus² was used by Marr, while a slight modification of the same method and an apparatus designed by the writer³ was used in this work.

In checking Marr's work, four soils were chosen, one acid, the other three giving from slight to strong alkaline reactions to litmus and progressive amounts of CO₂ with weak acid under reduced pressure. Comparative results under different treatments follow.

TABLE I—PER CENT. OF CO₂ BY DIFFERENT METHODS OF TREATMENT

Lab. No.	Per cent. CO ₂ when boiled at 100° C. with distilled water 2 1/2 hours	Per cent. CO ₂ when 50° C. under reduced pressure with distilled water 2 1/2 hours	Per cent. CO ₂ when boiled at 100° C. with 20 cc. of 1-1 HCl and 80 cc. of H ₂ O for 30 mins.	Per cent. CO ₂ when boiled at 50° C. for 30 minutes under reduced pressure with 2 cc. HCl per 100 cc.		Reaction of soil to litmus paper
				CO ₂ when boiled at 50° C. for 30 min.	CO ₂ when boiled at 50° C. for 30 min.	
4715	0.025	0.00	0.190	0.00	0.00	Acid
4722	0.010	0.00	0.205	0.01	0.01	Sl. alk.
4724	0.015	0.00	0.175	0.03	0.03	Alk.
4731	0.265	0.04	4.700	4.62	4.62	St. alk.

ABBREVIATIONS USED IN THE PRECEDING AND FOLLOWING TABLES.

A. = acid, Sl. = slightly, St. = strongly, Alk. = alkaline.
Mi. = Miami, V. = Volusia, D. = Dunkirk, Wab. = Wabash and B. or Blk. = Black. Gr. = Gravel, Sd. = Sand, Si. = Silt, L. = Loam, and C. = Clay. V. O. W. = Virgin open woodland, V. P. = Virgin pasture, M. = Meadow, P. = Pasture. V. F. R. = Virgin fence row, V. M. G. = Virgin "Maple grove," R. = Road side, C = Cultivated.

From these results it is seen that the soil which reddened blue litmus paper gave no CO₂ when boiled under reduced pressure either with distilled water or with dilute HCl, and that none of the other soils gave CO₂ with distilled water under reduced pressure except 4731, which contained a very large amount, of carbonates, while the acid soil gave more CO₂ when

¹ Jour. Agr. Sci., 1905, 1-322.

² THIS JOURNAL, Aug., 1912.

³ The apparatus permits the use of a smaller amount of 4 per cent. NaOH for absorption of CO₂ and makes it convenient to titrate all of the solution rather than an aliquot, thus reducing the analytical error.