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BACTERIAL ACTIVITIES AND CROP PRODUCTION

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Until the present time studies in soil bacteriology have dealt almost exclusively with the occurrence and activities of microorganisms in the soil and no attempt has been made to interpret experimental results from the standpoint of crop production. This is due, of course, to the fact that as a science soil bacteriology is scarcely out of its infancy and the preliminary investigations in any science must of necessity deal mainly with underlying principles and such studies are always apt to be rather fragmentary in character.

A knowledge of the relation of soil bacteria to soil fertility is of importance, however, if the subject is to be of any value in practical agriculture. While, therefore, much work on methods remains to be done, so much knowledge of bacterial action in soils has been accumulated that it seems time now to call attention to the practical phases of the subject; to attempt to correlate the results secured with known facts regarding soil fertility. This need in no way detract from the scientific value of the investigations, but involves merely a broader, more practical interpretation of results.

Many experiments have shown the numbers of bacteria in soils and some of the chemical changes which they bring about. The influence of different soil treatments, both on the numbers of organisms and on the processes which they engender, has also been studied. Only one step further is necessary to show the relation of bacterial numbers and activities to crop production. This step will make soil bacteriology a vital factor which must be considered in ordinary farm practice. It is the step which puts alongside the physical and chemical factors governing soil fertility a third group, the bacteriological, equally important, although largely influenced by the others.

The soil not only furnishes the necessary physical environment for the growth of plants, but it also supplies them with certain chemical compounds which serve as food. This food is not present, however, in a form directly assimilable by plants, but is normally insoluble. Bacteria, of which soils contain vast numbers, are the active agents which bring about the transformation of these insoluble materials into soluble forms. Therefore, it seems probable that a very close relationship exists between such bacterial activities and actual crop production.

Ever since the discovery of the necessity of mineral nutrients in a soluble form for the nourishment of plants attempts have been made to ascertain by chemical means the amount of available plant food in soils with a view of determining their crop-producing power. All these efforts have failed because of the absolute impossibility of imitating bacterial action by means of chemical agents. The importance of bacteriological methods for determining the rate and extent of the production of soluble plant food in a soil, and hence its crop-producing power, is evident therefore.

In most soils nitrogen has been considered the limiting factor of growth and attention has been centered upon investigations dealing with the production of available nitrogen compounds. Nitrates are produced in soils through the action of various groups of bacteria on complex nitrogenous compounds or proteins, normally present. This transformation is accomplished in nature in several stages. One is the production of ammonia and this ammonifying power of a soil, giving as it does an indication of the rate of production of nitrogenous plant food, may be assumed to be closely related to actual crop production. Another stage is the change of ammonia into nitrates, and this nitrifying power of the soil may also be closely allied with its crop producing power. Finally there is the azofying or nitrogen-fixing power of the soil and this may also indicate the amount of crop which may be produced.

THE PURPOSE OF THE EXPERIMENTS

The purpose of the experiments reported in this bulletin was to study certain bacterial activities in field soils in the attempt to secure definite information regarding their relation to the actual crops produced. If special methods of soil treatment exert similar effects on certain bacterial activities and on crops, then it may be assumed that there is a fairly definite relation between the two and the particular bacterial activities in a soil may indicate its crop-producing power. Thus, if the ammonifying power, the nitrifying power, or the azofying power of a soil is enhanced, according to laboratory tests, by some method of soil treatment, and the crop production is also increased, the conclusion that ammonification, nitrification or azofication, and crop production are very closely related would be well warranted. Furthermore, if such results are secured, then it may be assumed that a soil yielding, according to laboratory tests, an ammonifying power, a nitrifying power or an azofying power greater than that of some other soil would be capable of greater crop production, and hence a measure of soil fertility would be secured. The importance of obtaining such a means of determining the crop producing power of soils, can, of course, hardly be estimated.

Experiments covering many years of varying seasons and including tests of all varieties of treatments must, of course, be carried out before any definite conclusions can be reached. The experiments reported in this work indicate that nitrogen transformation in the soil and crop production may be very closely related and they represent, therefore, a preliminary contribution along this line. Some of the results have been reported elsewhere in connection with other studies, but they are assembled here for the purpose of calling especial attention to the relations which they indicate as existing between the bacterial transformations of nitrogen in the soil and the crops produced.

THE FIELD SOILS STUDIED.

Three series of field plots were used, one consisting of 14 one-tenth acre plots located on a uniform soil in the Wisconsin drift soil area and classed by the United States bureau of soils as Carrington loam. The land was somewhat rolling, but not enough to affect seriously its value for experimental purposes. Prior to 1907 it had been under a regular four-year rotation and had been subjected to no special treatment of any kind. In that year the plots were differentiated according to the following plan:

Plot.	Treatment.
601	Continuous corn.
602, 603	2-year rotation, corn and oats.
604, 605, 606	3-year rotation, corn oats and clover.
607, 608	2-year rotation, corn and oats, clover plowed under after the oats.
609, 610	2-year rotation, corn and oats, cowpeas plowed under after the oats.
901, 902	2-year rotation, corn and oats, rye plowed under after the oats.
903	Continuous clover.
904	4-year rotation, corn, corn, oats and clover.

The first tests were carried out in 1911, the fourth year of the special treatment. Plots 601, 602, 604, 607, 609 and 901 were studied during that season, for the reason that they were all in corn, and it was thought that the effects of the previous treatment could be studied more satisfactorily where the influence of the crop growing at the time of the experiment was presumably the same for all the plots. Plots 903 and 904 were also examined bacteriologically in 1911, but the results are not included here, because of the impossibility of comparing the crop yields. The results from the plots in corn were the only ones considered, because of the impossibility of comparing the bacteriological results from plots under clover and under corn, and also because of the impossibility of comparing the crop yields.*

In 1912 the work begun in 1911 was continued, but in some cases the same plots were not used again for only those in corn were chosen. A plot representing each of the same treatments, however, was investigated. Thus during this season plots 601, 603, 605, 608, 610, 902 and 904 were used. Complete data secured in this work is presented, but the discussion will deal mainly with the relation of the results to the crop yields.

Again in 1913 some bacteriological studies of the soils in this series were carried on, the plots under corn being chosen as previously, plots 601, 602, 606, 607, 609, 901 and 904. Only a comparatively small amount of data was secured, however, owing to the pressure of other work, but the ammonification studies were complete and the results secured may be compared with the crop yields.

The second series of plots studied consisted of five one-tenth acre plots located likewise on the Wisconsin drift soil area and on Carrington loam. These plots were subjected to special treatments of manure in the fall of 1910 as follows:

Plot. No.	Treatment.
1004	Check.
1005	8 tons manure per acre.
1006	12 tons manure per acre.
1007	16 tons manure per acre.
1008	20 tons manure per acre.

*The complete results of the bacteriological studies of these soils in 1911 were reported in Research Bulletin No. 6 of this Station under the title "Bacteriological Studies of Field Soils. II. The Effects of Continuous Cropping and Various Rotations," and the crop yields from the same plots have been reported also. A preliminary statement was made in the bulletin referred to regarding the relation between the bacterial activities studied and the actual crops produced. In the present work, therefore, summaries only of the various bacterial studies which were carried out are given, and special emphasis is placed on the comparison of these results with the crops produced.

Prior to this treatment the soils had been under a regular four-year rotation without any special handling. In 1911 the corn crop suffered very severely from a continued drought, the yields on the manured plots being appreciably less than on the unmanured. Evidently the manure exerted quite a little injury because of the dry weather. In 1912, however, when the experiments reported in the following pages were carried out, the season was favorable and the effects of the manure were evidently more nearly normal.*

The third series of plots was composed of three one-twentieth acre plots located also on the same soil area and consisting of soil of the same type.** Special treatment on these soils consisted in the application of lime as follows:

Plot. No.	Treatment.
510	Check.
509	2 tons ground limestone per acre.
508	3 tons ground limestone per acre.

BACTERIOLOGICAL METHODS

When it became evident that the mere counting of soil organisms could hardly be expected to yield a complete story of the processes occurring in the soil, attention was concentrated on the development of methods for measuring the physiological activities of bacteria. A complete discussion of the results secured by Remy's solution method, which was the first suggested, together with minor modifications of it may be found in another publication.[1] Difficulties in the use of the solution method have been pointed out by the writer [2] and investigations on the use of soil as suggested by Stevens and Withers [3] and Lipman and Brown [4] led to the conclusion that for the examination of field soils, soil itself seemed the most rational medium to employ, offering as it does, conditions as

*The complete results secured from the study of these soils in 1912 have been reported in Research Bulletin No. 13 of this Station under the title, "Bacteriological Studies of Field Soils III. The Effects of Barnyard Manure," and in this work summaries only of the bacteriological results will be given and the emphasis as in the previous cases will be placed upon the comparison of these results with the crop yields.

**A complete study of these plots from the bacteriological standpoint has been reported in Research Bulletin No. 5 of this Station, under the title "Bacteriological Studies of Field Soils. I. The Effects of Lime," and hence merely summaries will be included here for the purpose of correlating the bacterial results with the crop yields.

1. Voorhees and Lipman, Bull. U. S. Dept. Agr. 194. 1907.
2. Brown, P. E., Rsch. Bull. Iowa Agr. Expt. Sta. 11.
3. Science, n. Ser. 27. 704: 991. 1908.
4. New Jersey Agr. Exp. Sta. Report 1908. 129.

closely approximating those in the field as it is possible to secure. The same experiments showed further that fresh soil possessed many advantages over soil in an air-dry condition and its use was recommended.

Recent experiments [5] have suggested that a modified solution method may be of quite as much use as soil itself in testing bacteriological processes, but some of the difficulties attendant upon the use of solutions are not yet obviated. Further improvements are necessary before an artificially prepared solution will represent as satisfactorily as soil itself the physical and chemical conditions in field soils, leaving out of account entirely their bacteriological conditions.

The addition of various materials to soils in laboratory tests to permit of the accumulation of the particular products of bacterial action which it is desired to measure has been studied. Dried blood, cottonseed meal and casein have proven the best for ammonification, dried blood and ammonium sulfate for nitrification, and mannite for azofication. The use of casein for ammonification was suggested in the work of the writer mentioned above and preliminary tests indicated that it would be of value, chiefly because it may be applied to the soil in solution and hence thorough distribution may be accomplished, which is very difficult in the case of the dried blood and cottonseed meal. It is possible, of course, that this material may not always prove satisfactory, but in the experiments reported here no difficulties were encountered and the results are quite satisfactorily comparable with those where dried blood was used.

In the tests of various bacterial activities in field soils reported in this bulletin, several different modifications of the soil method were employed, for the reason that the tests covered a period of several years through which experiments on methods were also being conducted. The results using the different methods are all included, however, as they all tend in the same direction and conclusions are based on a study of the entire mass of data secured.

EXPERIMENTAL

The Rotation Plots. (*1911*)

In the tests of these soils in 1911, their ammonifying power was determined by the use of dried blood (5 gms.), and of cottonseed meal (5 gms.), in air-dry soil (100 gms.), inoculation being accomplished by adding 20 c. c. of infusions of fresh

5. Lohnis and Green, Centbl. f. Bakt., Abt, II, 40: 457. Green, H. H., Centbl. f. Bakt., Abt. II, 41: 577.

soils. The moisture content was made optimum and the inoculation period was 6 to 7 days at room temperature. Nitrification was tested similarly using dried blood (200 mgs.), and ammonium sulfate (100 mgs.) per 100 grams of soil, inoculating similarly with infusions of fresh soils and incubating for four weeks and azofication was measured by adding mannite (5 gms.) to soil, inoculating as before and incubating for ten days.

Four samplings were made during the season, on June 26, July 8, September 16 and October 25. No samplings were made during August, as a severe drought occurred at that time and it was felt that conditions were too extremely abnormal. The complete data obtained at these various samplings are given in another place [1] and only summarized results are included here.

AMMONIFICATION.

The results of the ammonification tests with dried blood and cottonseed meal are given in tables I and II, *respectively.* The variations in amount of moisture in the various plots at the same samplings were very small and the differences in bacterial activities which were found could not, therefore, be

TABLE I. THE AMMONIFICATION OF DRIED BLOOD.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
601	171.11	220.74	108.76	110.58
602	178.07	231.38	117.86	116.54
604	188.82	243.60	133.43	131.11
607	175.22	229.63	129.78	124.82
609	179.96	238.93	118.53	116.84
901	174.75	232.08	117.04	114.88

TABLE II. THE AMMONIFICATION OF COTTONSEED MEAL.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
601	142.01	163.32	102.13	111.08
602	144.54	168.74	110.09	122.17
604	151.18	177.81	120.18	126.64
607	145.49	168.21	131.11	123.49
609	148.50	171.00	105.78	119.02
901	144.07	165.94	112.73	115.55

attributed to the different moisture conditions in the plots.

It will be noted that in every case the ammonifying power of the soil under the two-year rotation of corn and oats (602) was greater than that of the soil under continuous corn (601).

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1. Rsch. Bull. Iowa Agr. Exp. Sta. 6.

Where the three-year rotation of corn, oats and clover was followed (604), the ammonifying power of the soil was still greater. Where the two-year rotation was modified by the introduction of clover (607), cowpeas (609), or rye (901), as a green manure the ammonifying power of the soil was less than that of the soil under the three-year rotation. Where the clover was used greater ammonification was evidenced in most cases than where the two-year rotation was not so modified. In two instances, at the first two samplings where dried blood was used, the clover did not give an increase in ammonifying power, but the differences in both cases were so slight that they should hardly be considered as placing the general tendency of all the other results in question. In all cases except one the soil under the two-year rotation with clover turned under showed a slightly smaller ammonifying power than under the three-year rotation. The differences in most instances were not large, however.

Where compeas were used as the green manure, in every case except two, greater ammonification was found than in soil under the regular two-year rotation, while it was less than that in the soil under the three-year rotation in every instance. The results secured where the cowpeas and the clover were used were so similar that it is impossible to judge definitely of the relative effects of the two; in some cases the clover seemed to give a greater effect on the ammonification and in other instances the cowpeas appeared superior. Conclusions comparing these materials, therefore, cannot be made.

Where the green manure used was rye, in practically every instance the ammonifying power of the soil was less than where the two-year rotation was not so modified. The depressing effect was not pronounced at every sampling, but at least it might be concluded that the rye gave no increase in the ammonifying power of the soil over that occurring where the two-year rotation unmodified was used.

The fact that the green manure crops did not increase the ammonifying power of the soils may have been due to the limitations imposed by the poor moisture conditions in the soil throughout practically the entire season, or possibly to the effect of the organic matter introduced. It is believed that the former explanation is more plausible because the rye crop which was turned under was so much heavier and hence the moisture conditions would be made more unfavorable than where the clover and cowpeas were used.

The ammonification results using dried blood and cottonseed meal did not always run parallel, but the differences were not great and in the majority of cases the same comparisons were secured with the two materials.

TABLE III. THE CROP YIELDS.

Plot No.	Treatment.	Corn. Bushels per Acre.
602	Continuous Corn	35.5
602	Two-year rotation	46.0
604	Three-year rotation	50.7
607	Two-year rotation, clover turned under	52.7
609	Two-year rotation, cowpeas turned under	32.5
901	Two-year rotation, rye turned under	43.2

Comparing now the ammonification results with the crop yields which are given in table III, it will be noted that there is a remarkably good agreement. A greater crop yield was secured where the two-year rotation was followed than on the continuous corn plot, and a still greater yield was secured where the three-year rotation was followed. This corresponds exactly to the ammonification results. Where the clover was introduced into the two-year rotation as a green manure, a greater crop yield was secured than where it was not used. Furthermore a slightly greater yield was obtained than on the three-year rotation plot. This is contrary to the bacteriological results but the difference in yield is hardly large enough to be regarded as appreciable, and it will be recalled that the variations in ammonification, while slightly in favor of the three-year rotation, were not considerable. When cowpeas were used, however, the yield was abnormally depressed, the depression being so great that the yield was less than that on the continuous corn plot. Evidently some unknown factor interfered here, as such a depression is hardly explanable. The ammonification results did not indicate a corresponding depression.

Where the rye was turned under in the two-year rotation the yield was less than on the regular two-year rotation plot and less than on the three-year rotation plot. It was also less than on the plot where clover was used as a green manure. It was greater, however, than where the cowpeas were used but as was mentioned this latter result was undoubtedly ob-normal. The ammonification results checked thus in practically every case the crop yields where the rye was used.

The comparison of the crop yields with the ammonification results as a whole shows a surprisingly close relation between the two and leads to the tentative conclusion that the ammonifying power of soils under normal conditions reflects fairly accurately their crop-producing power, and shows quite correctly the relative yields which will be secured.

NITRIFICATION.

In the nitrification tests air-dry soil with dried blood and ammonium sulfate were used as has been described. The samples were drawn on the same dates as those tested for ammonification and hence the differences in moisture conditions were likewise very slight. The summarized results appear in tables IV and V. The complete data is given in the previous work already mentioned.

The results of the nitrification tests are very largely in accord with those obtained in the ammonification studies. Again, it is noted that the soil under the two-year rotation showed a greater nitrifying power than that under continuous corn, while a still larger nitrifying power was evidenced by the three-year rotation plot. Where clover was introduced into the two-year rotation a gain in nitrifying power was found at the last two samplings, but at the first two dates no increase was evidenced. It will be recalled that a similar situation pertained in the case of ammonification, no gain occurring at the first samplings where clover was used, but at the last two dates considerable increase was found. The nitrifying power of the soil was not increased by the clover in the two-year rotation as much, however, as it was by the use of the three-year rotation.

TABLE IV. THE NITRIFICATION OF DRIED BLOOD.

Plot No.	Mgs. N. I	Mgs. N. II	Mgs. N. III	Mgs. N. IV
601	12,442	19.883	11.864	13.797
602	15.196	23.311	14.629	17.433
604	20.776	27.087	18.173	24.032
607	15.078	22.884	16.410	22.211
609	18.798	25.226	13.453	15.048
901	13.962	20.713	12.711	14.014

TABLE V. THE NITRIFICATION OF AMMONIUM SULFATE.

Plot No.	Mgs. N. I	Mgs. N. II	Mgs. N. III	Mgs. N. IV
601	5.019	17.317	7.565	8.086
602	8.075	21.625	9.788	11.789
604	12.630	24.517	12.903	19.419
607	7.066	21.477	11.357	13.749
609	11.908	22.978	9.101	10.620
901	6.724	21.477	8.310	9.655

When cowpeas were used in the two-year rotation, in most cases there was a slight increase in nitrifying power, but again this increase was less than that brought about under the three-year rotation. Where rye was turned under as a green manure, in every case there was a depression in nitrifying power over that evidenced where the two-year rotation was unmodified. As was suggested in connection with the ammonification results the moisture conditions or the organic matter introduced may have brought about this decrease in bacterial activities. In all these tests the nitrification of the ammonium sulfate and of the dried blood proceeded almost parallel.

It is evident from the results as a whole that nitrification and ammonification proceeded in the same direction and hence the relations to the crop yields are practically identical. Examining table III again it is seen that increases and decreases in nitrifying power are coincident with increases and decreases in crop yields just as was the case in the ammonification results. It seems, therefore, that the nitrifying power of soils may indicate their crop-producing power, or at least the relative crop-producing power of two soils may be shown.

The close agreement with the ammonification results would indicate further that possibly bacteriological tests of soils for only one of these processes need be carried out in order to judge of the fertility of a soil. Many confirmatory results are, of course, necessary before this latter point can be considered as settled, for it is quite possible that special methods of soil treatment may affect nitrification quite considerably and not influence ammonification and vice versa. Nitrification could hardly be encouraged, however, and ammonification depressed, inasmuch as the latter process precedes the former, but it might be depressed and ammonification increased, in which case there would be an accumulation of ammonium salts in the soil.

AZOFICATION.

The summarized azofication tests are given in table VI, and attention is called merely to the fact that the methods of cropping which affected nitrogen transformations in the soil influenced azofication or nitrogen fixation in the same way. Thus the two-year rotation increased the azofying power over that where corn was grown continuously and the three-year rotation gave a still further increase. When clover was used as a green manure in the two year rotation a gain in azofying power was evidenced except in one instance, but it was less than where the three-year rotation was used. When cowpeas were used there was an increase in azofication over that under the unmodified two-year rotation in only two cases, while in the other two instances no increases occurred. The differences were small, however, and it probably should be concluded that little effect was exerted by the cowpeas. The rye, as in the other bacteriological tests, gave a strong depression in azofying power in every case over that where the regular two-year rotation was used.

These results check almost exactly those secured in the ammonification and nitrification tests, and hence the relations to the crop yields are just about the same. Referring again to table III, it will be seen that this is the case and increases and decreases in azofying power correspond with similar increases and decreases in crop yields. It is hardly expected, however, that azofication tests can always be relied upon to indicate the crop producing power or fertility of a soil. Conditions which favor nitrification and ammonification need not necessarily favor azofication and hence unless the nitrogen content of the soil is exceedingly small an addition of nitrogen from the atmosphere would probably not be necessary for the production of a large crop yield, the increase in nitrate formation being sufficient to bring about a greater crop growth.

TABLE VI. THE AZOFICATION TESTS.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
601	9.50	3.93	13.52	10.32
602	17.46	15.07	19.92	17.52
604	20.64	18.25	23.12	20.72
607	14.27	17.46	20.72	18.32
609	18.25	15.87	18.32	16.72
901	14.27	11.88	16.72	15.12

Considering these results as a whole, it is apparent that there is some close relation between crop production and nitrogen transformations in the soil and the possibility of measuring by bacterial tests the fertility of soils is strongly suggested.

THE ROTATION PLOTS. (1912)

The same series of plots was used in 1912 as in 1911, but in some cases different individual plots were employed as again only those cropped to corn were examined. In 1912 601, 603, 605, 608, 610, 902 and 904 were tested, and in 1911, plots 601, 602, 604, 607, 609 and 901. The different rotations studied, with one addition, were however, the same: a two-year rotation of corn and oats; a three-year rotation of corn, oats and clover; a two-year rotation of corn and oats with clover used as a green manure, one with cowpeas as a green manure, and one with rye as a green manure. A four-year rotation plot was also examined in 1912, making one additional plot and constituting the addition to the rotation series mentioned above.

The bacteriological studies during 1912 consisted in an examination of the ammonifying and nitrifying power of the soils at various dates of sampling. The ammonifying power was tested by several different methods; the dried-blood-air-dry-soil method with inoculum from fresh soil was again employed as in 1911 and the casein-fresh-soil method, and the dried-blood-fresh-soil method were also tested at each date of sampling.

These methods are all described in the bulletin already mentioned [1] and need not be discussed here. Some comparisons are possible from these results, therefore, of the relative values of the different methods. Nitrification tests were carried out by the ammonium-sulfate-air-dry-soil method as it was used in 1911 and by the ammonium-sulfate-fresh-soil method so that a comparison of the air-dry and fresh soil methods is secured.

Azofication tests were not made during this season.

Four samplings were made during the year, on August 9, August 19, October 7 and October 23, the samples being drawn in the usual way with all precautions that they be representative and remain uncontaminated. The moisture content of the soils at the various dates of sampling is given in table VII, and it will be seen that the variations at any one date were so slight that they need not be considered. The crop yields on the plots were secured and the comparisons desired may, therefore, be made of the results of bacterial activities and the actual crops produced.

AMMONIFICATION.

The results of the ammonification tests using dried blood in air-dry soil and inoculating with infusions of fresh soils are given in table VIII in the Appendix, while the summarized results appear in table IX. Examining these results, several

TABLE VII. THE MOISTURE IN SAMPLES.

Plot No.	I Aug. 9 percent	II Aug 19 percent	III Oct. 7 percent	IV Oct. 23 percent
601	20.00	20.00	18.00	17.50
603	17.50	20.00	17.50	18.00
605	17.50	20.00	20.00	19.00
608	17.50	19.50	20.00	18.50
610	17.50	20.00	18.00	17.00
902	17.50	18.50	16.00	15.50
904	14.00	18.00	15.00	15.00

TABLE IX. AMMONIFICATION OF DRIED BLOOD IN AIR DRY SOIL.

Plot No.	I Ammonia Mgs. N.	II Ammonia Mgs. N.	III Ammonia Mgs. N.	IV Ammonia Mgs. N.
601	148.33	54.93	124.78	122.42
603	157.55	66.51	130.27	127.92
605	170.69	79.77	138.71	138.71
608	172.65	82.40	141.85	143.42
610	168.53	75.73	136.95	130.67
902	151.27	64.15	125.17	119.09
904	161.08	71.61	131.06	138.21

1. Rsch. Bull. Iowa Agr. Exp. Sta. 11.

facts appear quite distinctly. In every case the two-year rotation of corn and oats (603) showed a greater ammonifying power than the plot under continuous corn (601), and three-year rotation of corn, oats, and clover (605) gave a still greater ammonification. The greatest ammonification in any of the soils was given by the two-year rotation plot where clover was turned under (608). Where the green manure crop in the two-year rotation was cowpeas (610), a smaller ammonifying power was shown than where the three-year rotation was followed, but it was greater than where the two-year rotation was not modified. Where rye was used as the green manure crop in the two-year rotation (902) a pronounced depression in ammonification over that shown where the rye was not used was shown. In only one instance, however, did the ammonifying power fall below that of the continuous corn plot. Where the four-year rotation of corn, corn, oats and clover was used (904), the ammonifying power of the soil was slightly less than that in the three-year rotation plot, but is was greater than in the two-year rotation plot.

The ammonification results using the dried-blood-fresh-soil method appear in table X in the appendix, and the summarized results in table XI. The lower amounts of ammonia produced in this case are due to the shorter period of incubation which was practised here, for by this method the incubation period was five days, while in the previous determinations it was seven days. It will be unnecessary to discuss these results in detail as there is practically absolute agreement with the results secured where the dried-blood-air-dry-soil method was employed. The differences are brought out even more distinctly in these tests and the rank of the soils in ammonifying power is the same.

TABLE XI.
AMMONIFICATION OF DRIED BLOOD IN FRESH SOIL.

Plot No.	I Ammonia Mgs. N.	II Ammonia Mgs. N.	III Ammonia Mgs. N.	IV Ammonia Mgs. N.
601	106.34	68.66	50.81	54.74
603	110.66	80.05	65.14	62.39
605	117.32	86.70	73.77	71.02
608	120.87	88.28	74.02	74.66
610	115.95	78.87	72.59	71.41
902	109.67	73.38	58.86	62.19
904	114.14	82.90	68.28	69.17

The ammonification results, using the casein-fresh-soil method, are given in table XII, in the appendix, and the summarized results in table XIII. The amounts of ammonia produced here are much smaller than where the dried blood methods were used and hence the difficulty in distillation is very much less. Again there is practically uniform agreement with the previous results and these figures will not be discussed in detail. In practically every case the soils stood in the same relationship to each other in ammonifying power as they did where the dried blood was employed.

It is apparent from these results that the ammonification tests with these particular field soils gave practically identical results whether dried blood was used in air-dry inoculated soil or in fresh soil or whether casein was used in fresh soil. There is much greater difficulty in securing the agreement of duplicate determinations where dried blood is employed and it is particularly difficult to mix that material thoroughly with fresh soil samples. Smaller amounts of ammonia were produced where the casein was used, due, of course, mainly to the shorter period of incubation, and the agreement of duplicates was very satisfactory. These results check the previous experiments in indicating that the casein-fresh-soil method may prove of value in ammonification studies.

TABLE XIII. AMMONIFICATION OF CASEIN.

Plot No.	I Ammonia Mgs. N.	II Ammonia Mgs. N.	III Ammonia Mgs. N.	IV Ammonia Mgs. N.
601	61.80	64.84	58.66	55.33
603	67.30	71.80	65.13	66.31
605	71.61	76.52	68.47	69.45
608	72.39	79.07	70.63	72.79
610	68.67	73.87	67.29	69.25
902	62.78	69.06	63.18	62.39
904	67.10	73.37	67.10	68.67

TABLE XIV. THE CROP YIELDS.

Plot No.	Treatment.	Yield per acre (1912)
601	Continuous Corn.	50.25 bu. Corn
603	Corn & Oats	63.12 bu. "
605	Corn, Oats & Clover	69.00 bu. "
608	Corn & Oats, Clover turned over	74.00 bu. "
610	Corn & Oats, Cowpeas turned under	68.50 bu. "
902	Corn & Oats, Rye turned under	59.50 bu. "
904	Corn, Corn, Oats & Clover	67.50 bu. Corn

Comparing now the results of the ammonification studies with the crop yields which appear in table XIV quite striking comparisons are noted. The order of the plots in ammonifying power in all the tests was:

608—Two year rotation—clover turned under.
605—Three year rotation.
610—Two year rotation—cowpeas turned under.
904—Four year rotation.
603—Two year rotation.
902—Two year rotation—rye turned under.
601—Continuous corn.

It will be seen that arranging the plots according to crop yields for this season they would stand in identically the same order. It would seem, therefore, that there must be some close relationship between the ammonifying power of soils and their crop production.

NITRIFICATION.

In the nitrification tests carried out in 1912 the ammonium-sulfate-air-dry soil method and the ammonium-sulfate-fresh-soil method were used. The results with the former method are given in table XV in the appendix, and the summarized results in table XVI. Examining this latter table, it is found that the nitrifying power of the soils apparently varied considerably where different methods of treatment were employed. The continuous corn plot showed the smallest nitrifying power just as it did the smallest ammonifying power. The three-year rotation plot gave a greater nitrification than the two-year rotation plot, while the two-year rotation plot where clover was turned under showed a still greater nitrification. The two-year rotation plot where cowpeas were used as a green manure showed a greater nitrifying power than the unmodified two-year rotation soil, but it was less than that of the soil under the three-year rotation. When rye was used in the two-year rotation

TABLE XVI. NITRIFICATION OF AMMONIUM SULFATE IN AIR DRY SOIL.

Plot No.	I Nitrates Mgs. N.	II Nitrates Mgs. N.	III Nitrates Mgs. N.	IV. Nitrates Mgs. N.
601	10.431	12.443	8.444	7.232
603	13.489	16.751	12.427	11.333
605	15.114	18.941	15.546	14.557
608	15.250	23.931	16.524	15.250
610	14.196	18.110	15.208	14.733
902	12.695	12.893	9.914	10.936
904	14.434	17.410	14.946	14.686

TABLE XVIII. NITRIFICATION OF AMMONIUM SULFATE IN FRESH SOIL.

Plot No.	I. Nitrates Mgs. N.	II. Nitrates Mgs. N.	III. Nitrates Mgs. N.	IV. Nitrates Mgs. N.
601	11.944	15.300	7.183	6.844
603	12.728	16.601	10.695	9.776
605	14.682	22.583	12.462	12.154
608	15.520	25.078	13.784	14.224
610	13.559	18.264	12.233	13.999
902	11.960	15.837	7.789	10.629
904	13.060	17.414	10.981	13.166

just as was noted in the ammonifying studies the nitrifying power was depressed below that of the unmodified two-year rotation soil. The four-year rotation gave a nitrifying power greater than the two-year rotation but less than the three-year rotation and less than the two-year rotation with clover or cowpeas turned under for green manure.

The results of the nitrification tests where the ammonium-sulfate-fresh-soil method was used appear in table XVII in the appendix and the summarized results in table XVIII. It will be unnecessary to discuss these results as they check practically identically the tests with the other method. The soils rank exactly the same in nitrifying power by both methods.

The results of the nitrification tests and the crop yields and the ammonification studies agree exactly. The ranking of the soils in crop yields, in ammonification and in nitrification is identical.

It is evident, therefore, that the ammonification and nitrification of nitrogenous organic material in soils and their crop-producing powers are very closely related and that tests of the power of soils to produce ammonia or nitrates may be an indication of their crop-producing power, or at least of their relative crop-producing ability.

These results also confirm previous observations, that the ammonifying power of soils and their nitrifying powers may be similarly effected such of course may not always be the case as it is possible to conceive of conditions affecting the nitrifying organisms which will not similarly influence the ammonifiers. The latter include a large class of organisms of varying characteristics and requirements for optimum growth while the former include only a comparatively small number of organisms similarly affected by surrounding conditions. Under ordinary conditions in field soils, however, these results in corroboration of others previously secured indicate that soil conditions favoring the one process apparently similarly favor the other. It would seem, therefore, that only the ammonifying power of soils, or their nitrifying power, need be determined.

The Rotation Plots, 1913

The experiments were continued in 1913 on the same series of plots as in 1912, using again only those which were in corn, plots 601, 602, 606, 607, 609, 901 and 904. Ammonification results only were secured as the tests the previous year had indicated that there was practically no difference between the results of ammonification and nitrification tests. The casein-fresh-soil method was the only one employed here partly because of the pressure of the other work and partly because the other methods previously employed had shown similar results to those secured with the casein method. Three samplings were made, on August 15, August 23 and August

26. The moisture content of the soils at the different samplings is given in table XIX, and it is seen that the variations were so small that they may be considered negligible. The crop yields were secured as previously.

TABLE XIX. MOISTURE IN SAMPLES.

Plot No.	I Aug. 15 percent	II Aug. 23 percent	III Aug. 26 percent
601	13.50	17.50	15.00
602	13.50	17.50	14.00
606	14.00	15.00	14.00
607	14.00	11.00	15.00
609	10.00	12.50	13.00
901	12.50	12.50	13.50
904	12.00	11.00	14.00

The ammonification results are given in table XX, in the appendix and are summarized in table XXI. Again the soil under continuous corn showed the smallest ammonification, that under the two-year rotation gave a somewhat greater ammonifying power, and that under the three-year rotation showed a still greater power. In this case, however, the plot under the two-year rotation with clover turned under showed a smaller ammonification than under the three-year rotation, while the reverse was true in 1912. The ammonification was greater, however, than in the two-year rotation plot unmodified.

TABLE XXI. THE AMMONIFICATION OF CASEIN (1913).

Plot No.	August 15 Mgs. N.	August 23 Mgs. N.	August 26 Mgs. N.
601	68.38	60.82	55.67
602	71.56	63.47	59.31
606	78.74	69.59	64.05
607	74.89	66.35	63.15
609	73.53	64.45	60.52
901	75.65	68.15	63.46
904	74.28	65.21	60.97

TABLE XXII. CROP YIELDS 1913.

Plot No.	Treatment	Yield per acre
601	Continuous corn.	30.0 bu.
602	2 yr. rotation, corn and oats	53.3 "
606	3 yr. rotation, corn, oats and clover	68.0 "
607	2 yr. rotation, corn and oats, clover turned under	64.0 "
609	2 yr. rotation, corn & oats, cowpeas turned under	60.0 "
901	2 yr. rotation, corn and oats, rye turned under	65.3 "
904	4 yr. rotation, corn, corn, oats and clover	62.6 "

The soil under the two-year rotation where cowpeas was used as the green manure showed a slightly smaller ammonifying power than that under the two-year rotation where clover was used, but it was likewise greater than that shown by the soil where the two-year rotation was not modified. During this season the rye turned under in the two-year rotation did not depress the ammonifying power as it did in the two previous years. This soil actually showed a greater ammonifying power than those where the clover or the cowpeas were used. It was less, however, than that in the three-year rotation plot. The four-year rotation plot showed a smaller ammonification than the three-year rotation plot or the two-year rotation plot where clover or where rye was used, but it was greater than that in the two-year rotation plot or that where cowpeas were used.

Comparing these results with the crop yields given in table XXII, it is apparent that the indications of fertility given by the ammonification studies are borne out by the actual crops secured. The rank of the soils, both in ammonifying power and in crop production, was thus:

606—Three year rotation.
901—Two year rotation—rye turned under.
607—Two year rotation—clover turned under.
904—Four year rotation.
609—Two year rotation—cowpeas turned under.
602—Two year rotation.
601—continuous corn.

The results of these studies check those of previous years, therefore, and indicate that ammonification and crop production are very closely related and the determinations of the ammonifying power of the soil made during the growing season may show the relative crop producing powers of the soils. The actual amounts of crops produced at the harvest were in complete agreement with the relative amounts indicated by the ammonifying powers of the soils.

The Manured Plots, 1912

The manured plots tested in 1912, consisted of five plots, four of which were treated with various amounts of barnyard manure. The bacteriological tests consisted in studies of the ammonifying powers and nitrifying powers of the soils by the various methods which have been described. The crop yields on the plots were secured and hence a comparison of the tests of bacterial activities and crop production is possible also on these soils. The complete results of these tests having already been published, summarized tables will only be given here.

There are included the results of the ammonification studies, using the casein-fresh-soil, the dried-blood-air-dry-soil, and the dried-blood-fresh-soil methods, and the results of the nitrification tests using the ammonium-sulfate-air-dry-soil, and the ammonium-sulfate-fresh-soil methods. Four samplings were made of these soils during the season of the experiment on August 2, August 15, August 22 and September 9. The moisture content of the soils varied slightly at the different samplings, but there was very slight difference in the amount of water in the different plots at the same dates and hence the differences in ammonification and nitrification must be attributed to the different treatments rather than to any variations in moisture content.

The samples were drawn as usual with all precautions to avoid any contamination and in the manner which has already been described.

AMMONIFICATION.

The results of the ammonification tests appear in tables XXIII, XXIV and XXV. Table XXIII, which gives the results using the casein-fresh-soil method, shows that the soil treated with eight tons of manure per acre (1005) gave a greater ammonifying power than the untreated soil (1004); the soil receiving 12 tons of manure (1006) showed a higher ammonifying power than that receiving the smaller amount of manure, and the soil where 16 tons of manure per acre were used (1007) gave a still higher ammonification. When 20 tons of manure were applied, however, (1008) the ammonification was less than that where the 12 and 16 ton amounts were employed but still greater than that where the eight ton amount was used. Evidently the 20 tons of manure depressed ammonification.

TABLE XXIII. THE AMMONIFICATION OF CASEIN.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
1004	37.87	68.27	67.49	51.60
1005	46.89	73.57	72.79	58.86
1006	51.79	77.50	78.87	66.32
1007	51.99	78.48	79.46	65.72
1008	48.78	75.14	74.75	60.42

TABLE XXIV. THE AMMONIFICATION OF DRIED BLOOD. (FRESH SOIL).

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
1004	66.90	83.97	73.57	66.71
1005	84.76	92.21	83.97	70.63
1006	86.32	106.34	98.88	85.54
1007	97.90	109.47	98.88	84.95
1008	86.72	95.74	87.50	76.91

TABLE XXV. THE AMMONIFICATION OF DRIED BLOOD. (AIR-DRY SOIL).

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
1004	80.44	111.83	106.34	102.81
1005	94.76	117.33	109.47	117.13
1006	100.06	131.25	122.23	127.92
1007	100.85	137.14	124.00	133.02
1008	95.75	128.90	113.80	122.62

Comparing these results with the crop yields given in table XXVI, it will be found that the same effects of the manure were evidenced on the crop as were shown on the ammonification. The 20 ton amount of manure depressed the yield of corn, below that secured where the 12 and 16 ton amounts were used.

Examining the results secured in the ammonification tests where the dried blood methods were used it is seen that the effects of the manure on the ammonifying power of the soil were exactly the same as were shown by the casein method. An increase in ammonification was found when manure was applied up to the 16 ton amount and beyond that point a depression occurred.

The amounts of ammonia secured where the air-dry soil was used were considerably larger than where the fresh soil was employed. This was due as in previous experiments to the different period of incubation employed. The fresh soil tests were incubated for five days while the air-dry soil tests were incubated for seven days.

The comparisons were the same, however, in both cases. It is evident from these tests that the ammonification of casein in fresh soil and of dried blood in fresh soil or in air-dry soil inoculated with infusions of fresh soils proceeded in the same direction and the same differences in the ammonifying powers of soils differently treated were indicated by any of the methods.

TABLE XXVI. THE CROP YIELDS.

Plot No.	Treatment	Corn, (1912)
1004	Check	50.50 Bu.
1005	8 T. Manure	77.62 Bu.
1006	12 T. Manure	86.00 Bu.
1007	16 T. Manure	87.00 Bu.
1008	20 T. Manure	81.00 Bu.

Again it is shown that the ammonifying power of the soils according to any of the methods used indicated quite accurately their relative crop-producing power.

NITRIFICATION.

The results of the nitrification tests using the ammonium-sulfate-air-dry-soil method are given in table XXVII; those secured where the fresh soil was employed are shown in table XXVIII. It will be unnecessary to discuss these results individually as the relations between the nitrifying powers of the different soils were the same in both cases. As has been noted previously similar results were secured in nitrification tests whether the air-dry soil method or the fresh soil method was used.

Just as was noted in ammonification, applications of manure in gradually increasing amounts, up to the 16 ton application, increased the nitrifying power of the soil. Thus the nitrifying power of the soil in plot 1005 was greater than that in 1004, that in 1006 was still greater and in practically every case that in 1007 was larger than that in 1006. When the application of manure was increased beyond 16 tons, however, a depression in nitrification occurred. Thus the nitrifying power of soil 1008 was less than that of 1006 and 1007 where the 12 and 16 ton amounts were used, but it was greater than that of the soil receiving the eight ton application.

TABLE XXVII. THE NITRIFICATION OF $(NH_4)_2 SO_4$

(Air-Dry Soil).

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
1004	8.507	14.794	12.500	9.211
1005	9.326	15.453	13.693	10.262
1006	10.000	17.710	14.392	12.593
1007	11.655	18.712	16.401	12.446
1008	10.064	16.696	14.662	10.444

TABLE XXVIII. THE NITRIFICATION OF $(NH_4)_2 SO_4$ (Fresh Soil).

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
1004	5.576	10.946	10.283	9.141
1005	7.259	12.583	12.543	10.000
1006	8.470	16.733	14.142	12.698
1007	10.282	18.694	15.641	13.011
1008	8.125	16.164	12.949	10.528

Comparison of these results with the crop yields and with the ammonification results, shows exact agreement. Applications of manure up to 16 tons per acre increased the ammonifying power and the nitrifying power of the soil and the crop yield to the same extent. These results check the previous observations that ammonification and nitrification tests may often run parallel. In this case, as in the studies of the rotation plots, the treatment which affected ammonification in a certain way influenced nitrification similarly.

Previous results are also confirmed regarding the relation between crop yields and certain bacterial activities. Tests of the ammonifying power of soils or of their nitrifying powers apparently indicate quite accurately their crop producing powers. There must, therefore, be some close relation between the transformation of nitrogenous material into ammonia and nitrates and the ability of the soil to produce crops.

The Limed Plots. (*1911*)

Three plots were studied in this series of experiments, two of which received applications of limestone at the rate of two and three tons per acre.

The bacteriological tests included studies of ammonification by the dried blood and cottonseed meal methods, tests of nitrification by the ammonium sulfate and dried blood methods, and of azofication by the mannite method. In all these methods air-dry soil was used and an inoculum of infusions of fresh soil added in every case. These methods are the same as those used in the rotation plot studies in the same year. The crop yields were secured as usual and comparisons of these with the results of bacterial activities are, therefore, possible.

Four samplings were made from these plots during the season, on June 21, July 6, September 14 and October 24. The samples were drawn as described in the bulletin already mentioned. The moisture content of the soils is given in table XXIX, which shows the check plot (510) contained more moisture at every date of sampling than the other two; plot 508, receiving the three tons of ground limestone, had the smallest moisture content. This fact is important in explaining the lack of any more pronounced gain in crop yield in that plot over the untreated plot and over that receiving the two ton application.

AMMONIFICATION.

The ammonification of dried blood and of cottonseed meal is shown in tables XXX and XXXI. It is apparent that the application of limestone increased the ammonifying power when tested either by the use of dried blood or of cottonseed meal. Furthermore the three ton application of lime gave a greater increase than the two ton amount in every case, although the greatest increase occurred between the untreated soil and that receiving the two ton application.

TABLE XXIX. MOISTURE IN SAMPLES.

Plot No.	I June 21 Percent.	II July 6 Percent.	III Sept. 14 Percent.	IV Oct. 24 Percent.
510	20.0	15.0	20.0	18.75
509	19.0	12.5	19.5	17.00
508	17.0	11.0	19.5	17.00

TABLE XXX. THE AMMONIFICATION OF DRIED BLOOD.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
510	207.17	206.60	128.06	129.78
509	208.12	207.30	144.51	140.05
508	214.13	235.22	155.59	149.32

TABLE XXXI.
THE AMMONIFICATION OF COTTONSEED MEAL.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
510	131.26	157.22	126.22	124.32
509	132.68	161.06	141.15	130.28
508	142.01	172.58	151.22	137.90

Comparison of these results with the crop yields given in table XXXII shows very good agreement, altho the effect of the lime on the crop yield is not very great. It will be recalled that the moisture content of the limed plots was less than that of the check plot in every case and it appears that this difference in water content prevented any more definite increase in crop. The increases in ammonification due to lime were evidently much less than they should have been had the plots been more uniform in this particular. The data, however, serve to show an agreement between the ammonification tests and the crop yields which check the previous observations along the same line.

NITRIFICATION.

The results of the nitrification tests are given in tables XXXIII and XXXIV, the former showing the tests with dried blood and the latter with ammonium sulfate. The applications of ground limestone increased considerably the nitrifying power of the soil, the three ton amount giving a larger increase than the two ton amount. This was true at every date of sampling and in both series of tests. Evidently the tests for nitrification with dried blood and with ammonium sulfate indicate similar differences in soils differently treated.

Comparing these results with the crop yields and with the ammonification tests there is found to be exact agreement. The nitrification and ammonification tests in this experiment just as has been observed previously run parallel and either therefore may indicate the crop-producing power of the soil.

TABLE XXXII. THE CROP YIELDS.

Plot No.	Treatment	Corn Bu.
510	Check	52.5
509	2 T. Lime	55.0
508	3 T. Lime	55.0

TABLE XXXIII. THE NITRIFICATION OF DRIED BLOOD.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
510	13.745	27.056	20.579	14.570
509	15.844	33.857	23.247	18.434
508	21.911	39.686	29.376	22.946

TABLE XXXIV. THE NITRIFICATION OF AMMONIUM SULFATE.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
510	8.737	24.987	14.298	8.762
509	10.547	25.475	20.146	11.743
508	14.822	29.034	24.061	17.890

AZOFICATION.

The azofication tests were carried out as usual and the results are given in table XXXV. It is apparent here that lime increased considerably the azofying power of the soil and the three ton application gave a greater increase than the two ton amount.

Comparing these results with those of the previous bacteriological studies, it is found that there is complete agreement. There is also agreement with the crop yields, although these, as has been mentioned, are not so distinctive due evidently to the differences in moisture content of the plots which were more pronounced during the latter part of the season.

As a whole, however, these studies check remarkably well the experiments on plots under other methods of treatment and show that bacterial transformations of nitrogenous compounds in the soil or rather the ability of soils to bring about the simplification of nitrogenous materials or the addition of nitrogen may be considerably modified by various methods of soil treatment. Furthermore, they check previous results in showing that certain bacterial activities in the soil may be very closely related to the actual crop-producing power of the soil. The ammonifying power of soils, their nitrifying power or even their azofying power may, therefore, indicate their crop producing power, or at least the relative crop producing power of several soils.

TABLE XXXV. THE AZOFICATION TESTS.

Plot No.	I Mgs. N.	II Mgs. N.	III Mgs. N.	IV Mgs. N.
510	5.52	2.34	11.89	11.09
509	15.07	16.66	25.41	27.00
508	26.21	30.19	38.93	37.34

CONCLUSIONS

These experiments as a whole represent a line of investigations in soil bacteriology which it is believed will ultimately place the subject on a more practical basis, a basis which will permit of direct application of results secured to the solution of soil fertility problems. It was purposed at the commencement of the work to continue the study through a long period of years before attempting to draw any conclusions, but unforseen circumstances demanded the relinquishing of the plots which formed the basis of this work, and hence the tests planned must be discontinued for the present. A new series of plots has been laid out on a new farm, and this work will be continued on these new plots as soon as they have been under special treatment for a long enough period to permit of their satisfactory differentiation.

Furthermore, in this work the relations between the bacterial activities studied and the actual crop yields on these plots have proven so striking and so consistent that it was felt that accidental coincidence had been practically eliminated, and that the results might be considered to give a strong indication that certain bacterial activities in field soils are very closely associated with crop yields.

The work reported in this bulletin, therefore, while of course far from conclusive, permits of the tentative conclusion that bacterial activities involved in the transformation of nitrogenous organic matter in the soil bear a very close relationship to the actual crop yields secured on the same soils.

Furthermore, the results indicate that laboratory tests of such bacterial activities may indicate quite accurately the crop-producing power of a soil, or at least the relative crop-producing power of several soils.

If further tests confirm these conclusions, it may be possible in the more or less distant future to outline definite laboratory tests for the determination of the relative fertility or crop-producing power of soils.

TABLE VIII. THE AMMONIFICATION OF DRIED BLOOD IN AIR-DRY SOIL.

	I			II			III			IV		
Plot No.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.
601	201	150.29		701	58.47		6001	123.21		6129	124.78	
	202	146.37	148.33	702	51.40	54.93	6002	126.35	124.78	6130	120.07	122.42
603	205	158.14		705	62.78		6003	132.24		6131	124.78	
	206	156.96	157 55	706	69.85	66.31	6004	128.31	130.27	6132	131.06	127.92
605	209	175.80		709	78.09		6005	136.56		9133	133.42	
	210	165.59	170.69	710	80.44	79.77	6006	140 87	138.71	6134	144.01	138.71
608	215	176.58		715	85.54		6007	133.02		6135	134.99	
	216	168.73	172.65	716	79.26	82.40	6008	150.68	141.85	6136	151.86	143.42
610	219	167.95		719	78.09		6009	131.85		6137	133.42	
	220	169.12	168.53	720	73.38	75.73	6010	142.05	136.95	6138	127.92	130.67
902	223	146.37		723	65.53		6011	129.49		6139	118.50	
	224	156.18	151.27	724	62.78	64.15	6012	120.86	125.17	6140	119.68	119 09
904	227	165.20		727	68.67		6015	133.02		6143	135.77	
	228	156.96	161.08	728	74.56	71.61	6016	139.10	131.06	6144	141.66	138.21

TABLE X. THE AMMONIFICATION OF DRIED BLOOD IN FRESH SOIL.

Plot No.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.
601	229	108.30		729	69.45		6017	52.19		6145	56.51	
	230	104 38	106.34	730	67.88	68.66	6018	49.44	50 81	6146	52.97	54.74
603	233	109.09		733	78.09		6019	64.75		6147	60.43	
	234	112.23	110,66	734	82.01	80.05	6020	65.53	65.14	6148	64.35	62.39
605	237	118.50		737	86.70		6021	74 16		6149	67.49	
	238	116.15	117.32	738	86.70	86.70	6022	73.38	73.77	6150	74.56	71.02
608	243	124.80		743	89 86		6023	74.66		6151	76.73	
	244	116.94	120.87	744	86.70	88.28	6024	73.38	74.02	6152	72.59	74.66
610	247	117.72		747	82.01		6025	72.99		6153	69.45	
	248	114.19	115.95	748	75.73	78.87	6026	72.20	72.59	6154	73.38	71.41
902	251	108.30		751	76.52		6027	57.29		6155	62.78	
	252	111.05	109 67	752	70.24	73.38	6028	60.43	58.86	6156	61 61	62.19
904	255	115.76		755	83.97		6031	69.85		6159	71.63	
	256	112.53	114 14	756	81.83	82.90	6032	66.71	68.28	6160	66.71	69.17

TABLE XII. THE AMMONIFICATION OF CASEIN.

	I			II			III			IV		
Plot No.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.
601	257	61.61		757	65.33		6033	58.47		6161	55.72	
	258	62.00	61.80	758	64.35	64.84	6034	58.86	58.66	6162	54.94	55.33
603	261	67.89		761	71.02		6035	64.35		6162	66.71	
	262	66.71	67.30	762	72.59	71.80	6036	65.92	65.13	6164	65.92	66.31
605	265	70.63		765	78.09		6037	69.06		0165	68.28	
	266	72.59	71.61	766	74.95	76.52	6038	67.89	68.47	3166	70.63	69.45
608	271	70.63		771	76.52		6039	70.63		6167	72.99	
	272	74.16	72.39	772	81.62	79.07	6040	70.63	70.63	6168	72.59	72.79
610	275	67.49		775	72.59		6041	66.71		6169	69.06	
	276	69.85	68.67	776	74.16	73.37	6042	68.28	67.49	6170	69.45	69.25
902	279	62.78		779	69.85		6043	61.01		6171	62.00	
	280	62.78	62.78	780	68.27	69.06	6044	64.75	63.18	6172	62.78	62.39
904	283	66.71		783	74.16		6047	67.10		6175	68.28	
	284	67.49	67.10	784	72.59	73.37	6048	67.10	67.10	6176	69.06	68.67

TABLE XV. THE NITRIFICATION OF AMMONIUM SULPHATE IN AIR-DRY SOIL.

	I			II			III			IV		
Plot No.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.
601	369	10.862		869	12.500		6097	8.000		6225	7.465	
	370	10.000	10.431	870	12.387	12.443	6098	8.8[illegible]8	8.444	6226	7.000	7.232
603	373	13.682		873	16.665		6099	12.355		6227	11.000	
	374	13.296	13.189	874	16.837	16.751	6100	12.500	12.427	6228	11.667	11.333
605	377	15.000		877	19.000		6101	15.667		6229	14.[illegible]39	
	378	15.228	15.114	878	18.882	18.941	6102	15.425	15.546	0230	14.675	14.557
608	383	15.000		883	23.[illegible]62		6103	16.665		6231	15.500	
	384	15.500	15.250	884	24.000	23.931	6104	16.384	16.524	6232	15.000	15.250
610	387	14.282		887	18.328		6105	15.129		6233	15.000	
	388	14.111	14.196	888	17.892	13.110	6106	15.287	15.208	6234	14.466	14.733
902	391	12.822		891	12.862		6107	10.000		6235	11.000	
	392	12.568	12.695	892	12.925	12.893	6108	9.829	9.914	6236	10.872	10.936
904	395	14.500		895	17.286		6111	14.892		6239	15.000	
	396	14.369	14.434	896	17.534	17.410	6112	15.000	14.946	6240	14.372	14.686

TABLE XVII. THE NITRIFICATION OF AMMONIUM SULPHATE IN FRESH SOIL.

	I			II			III			IV		
Plot No.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.	Lab. No.	Nitrate Mgs. N.	Av. Mgs. N.
601	397	12.000		897	15.600		6113	7.000		6241	6.889	
	398	11.888	11.944	898	15.000	15.300	6114	7.366	7.183	6242	6.800	6.844
603	401	12.568		901	16.665		6115	10.522		6243	9.985	
	402	12.889	12.728	902	16.537	16.601	6116	10.868	10.695	6244	9.568	9.776
605	405	14.682		905	22.500		6117	12.525		6245	11.962	
	406	14.682	14.682	906	22.667	22.583	6118	12.400	12.462	6246	12.346	12.154
608	411	15.682		911	25.000		6119	14.000		6247	14.448	
	412	15.358	15.520	912	25.157	25.078	6120	13.568	13.784	6248	14.000	14.224
610	415	13.822		915	18.000		6121	12.000		6249	13.998	
	416	13.297	13.559	916	18.529	18.264	6122	12.466	12.233	6250	14.000	13.999
902	419	12.000		919	15.800		6123	8.000		6251	10.892	
	420	11.921	11.960	920	15.875	15.837	6124	7.579	7.789	6252	10.367	10.629
904	423	12.896		923	17.828		6127	11.100		6255	13.000	
	424	13.224	13.060	924	17.000	17.414	6128	10.862	10.981	6256	13.333	13.166

TABLE XX. THE AMMONIFICATION OF CASEIN.

	I			II			III		
Plot No.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.	Lab. No.	Ammonia Mgs. N.	Av. Mgs. N.
601	1	68.54		49	61.12		137	55.38	
	2	68.23	68.38	50	60.52	60.82	138	55.98	55.67
602	3	71.87		51	63.39		139	59.31	
	4	71.26	71.56	52	63.55	63.47	140	59.31	59.31
606	5	78.68		53	69.59		141	64.55	
	6	78.83	78.74	54	69.59	69.59	142	63.55	64.05
607	7	76.65		55	66.44		143	63.09	
	8	74.14	74.89	56	66.26	66.35	144	63.24	63.15
609	9	lost		57	64.39		145	60.52	
	10	73.53	73.53	58	64.61	64.45	146	60.52	60.52
901	11	75.65		59	68.08		147	63.54	
	12	75.65	75.65	60	68.23	68.15	148	63.39	63.46
904	15	74.43		63	65.36		151	60.52	
	16	74.14	74.28	64	65.06	65.21	152	61.42	60.97