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STUDIES IN DENITRIFICATION.

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PART I.

SINCE the beginning of these experiments in the early summer of 1898, many contributions have been made toward the better understanding of the various problems of plant nutrition. Among these, the nitrogen question has been receiving the attention of many investigators, and it has been examined from the different standpoints of the soil chemist, the soil physicist, and the soil bacteriologist. Much time and ingenuity have been devoted to the clearing-up of that phase of the nitrogen question known as "denitrification"—the destruction of the nitrates and the setting free of gaseous nitrogen. That deoxidation of combined nitrogen is liable to take place, and actually does take place in anaerobic fermentation, has been known for years, but the question assumed more than a mere scientific interest, since the emphatic declaration of Wagner[1] that applications of cow or horse manure to the soil are often not only unprofitable, but harmful; that, when applied together with the nitrates, they cause, by virtue of the micro-organisms contained in them, the destruction of the nitrates.

More than that, the baneful effects do not stop here, for the nitrates as they are gradually formed from the organic matter of the soil are also attacked by the denitrifying bacteria, and their nitrogen is set free. In a word, then, the animal manure applied is not only useless of itself, but is harmful because of its destructive effects on the oxidized nitrogen derived from other sources.

It is quite apparent that the interests involved are of great moment, that Wagner's theory if it be borne out by practical experience vitally concerns the man of science, the practical farmer, and the world at large. It was in the hope of contributing something to the knowledge of the subject that these experiments were planned. The scope of the work included the study of:

I. The composition of the solid and liquid portions of cow manure, fresh.

II. The composition of the solid and of the solid and liquid portions of cow manure, leached.

III. The availability of the nitrogen in the solid and in the solid and liquid portions of cow manure, fresh.

IV. The availability of the nitrogen in the solid and in the solid and liquid portions of cow manure, leached.

V. The relative availability of the nitrogen in the form of nitrate, of ammonia and of organic matter in dried blood.

VI. The effect of the use of the solid and of the solid and liquid portions of cow manure, fresh and leached, with nitrogen in the form of nitrate, of ammonia, and of organic matter.

DESCRIPTION OF THE EXPERIMENTAL PLANT.

In order that the conditions of the experiment might conform as nearly as possible to those in actual practice, what is known as the "cylinder method" was adopted.

The cylinders were made of galvanized iron, 23.5 inches in diameter and 4 feet long, and were painted inside and out, to retard corrosion. The area of soil surface thus exposed was, therefore, 3 square feet, and its depth was such that the roots of the crop would be practically prevented from obtaining food other than that contained within the cylinders. In order that the conditions for each cylinder might be uniform, the surface soil was first removed entirely, and the subsoil, a mixture of clay and sand.

which was taken from the holes, was thoroughly mixed. The same weight of subsoil was then placed in each one, and thoroughly packed and brought to a uniform height, so as to permit of the addition of 8 inches of surface soil; 120 cylinders were used, divided into two groups of 60 each. Thus in each group there were 20 series of three each, A, B and C, enabling a triplication of crops in each case.

DIAGRAM OF EXPERIMENT.

Series.	A.	B.	C.
1. Check	O	O	O
2. Minerals	O	O	O
3. Manure, solid, fresh	O	O	O
4. Manure, solid and liquid, fresh	O	O	O
5. Manure, solid, leached	O	O	O
6. Manure, solid and liquid, leached	O	O	O
7. Nitrate, 5 grams	O	O	O
8. Nitrate, 10 grams	O	O	O
9. Manure, solid, fresh ; nitrate, 5 grams	O	O	O
10. Manure, solid, fresh ; nitrate, 10 grams	O	O	O
11. Manure, solid and liquid, fresh ; nitrate, 5 grams	O	O	O
12. Manure, solid and liquid, fresh ; nitrate, 10 grams	O	O	O
13. Manure, solid, leached ; nitrate, 5 grams	O	O	O
14. Manure, solid, leached; nitrate, 10 grams	O	O	O
15. Manure, solid and liquid, leached; nitrate, 5 grams	O	O	O
16. Manure, solid and liquid, leached ; nitrate, 10 grams	O	O	O
17. Ammonium sulphate	O	O	O
18. Dried blood	O	O	O
19. Manure, solid, leached ; ammonium sulphate	O	O	O
20. Manure, solid, leached ; dried blood	O	O	O

SURFACE SOIL.

The surface soil for each group was selected to conform to two general standards—first, a medium clay, suitable for the cereals and grass crops, and second, a prepared sandy loam, suitable for the various market-garden crops. The medium clay loam was obtained in the neighborhood of the Station from a field in which no crops had been grown for twenty years or more, and upon which no manure had been applied within the knowledge of those familiar with the land for a longer time. It was practically barren. The soil, however, was sifted, thus removing all stones and large lumps, as well as practically all vegetable matter. It was thoroughly mixed and a definite and equal weight placed to the depth of 8 inches upon the subsoil in each cylinder constituting Group I. The sandy loam was prepared by adding to the medium clay soil, already described, one-half its weight of sand, also obtained in the neighborhood, free from organic matter and practically free from any available mineral substances.

The soils for both cylinders were mixed with sufficient lime to supply any needed requirement, as well as to neutralize acidity, and, with the exception of Series 1, all of the cylinders received a uniform application of the minerals in the form of acid phosphate and muriate of potash, equivalent to 50 pounds of phosphoric acid and 75 pounds of actual potash per acre, which was believed to be sufficient to meet needed requirements. For the manures, the applications were greater than is usually the case in practice, but not so great as to be impracticable. The largest application would be equivalent to about 20 tons to the acre, an amount often exceeded in practice.

In the case of the nitrogen in artificial forms, the nitrates only were applied in two different quantities, in the one case 5 grams per cylinder, equivalent to 160 pounds per acre, which may be regarded as medium, and in the second, 10 grams per cylinder, equivalent to 320 pounds per acre, or a large application. This was done in order that the effect of denitrification, if any, might be more fully studied. In the case of the ammonia and blood, an amount of nitrogen equivalent to that in the larger quantities of nitrate was applied. Similar applications were made in the following years.

At the end of each growing season, determinations were made of the actual dry matter in the different crops, of the percentage of nitrogen contained in them, of the gain in nitrogen due to the materials added, and of the percentage of the applied nitrogen recovered.

The results obtained are definite and clearly point in one direction, in so far as the question of denitrification is concerned, and are in accord with those of other investigators. The experimental data accumulated during the years 1898, 1899, and 1900 will be presented in the second part of this paper.

As the work progressed and the accumulated material was studied, other questions presented themselves. They concern the movement of the plant-food in the soil and in the plant, the relation of the mineral salts to the organic matter, the influence of rainfall, the rapidity of nitrification, etc. While still following the main lines of research, as indicated, the other points have been examined in so far as was practicable, and deductions drawn where the experimental data at hand warranted it. Obviously the many factors that determine the yield of crop are so closely related to one another, that a true understanding of the subject can only come with the careful study of the soil from more than one standpoint. As a recent bulletin aptly expresses it:[2] "Our first object is to determine the *controlling* factor of fertility, whether and when this factor is physical, depending upon the color, texture, or structure of the soil; climatological, depending upon temperature, sunshine, and rainfall; chemical, depending upon the absolute chemical composition, or upon a definite minimum solubility of the soil's constituents", or, we might add, bacteriological, depending upon the activity of soil organisms.

That the latter is not the least important is attested by the numerous researches on their relation to the nitrogen question, both in its constructive and destructive phases. According to Stoklasa,[3] "the assimilation of the nitrogen of the air by bacteria forms one of the most important problems of modern biological research." On the one hand, we have the symbiotic life of the *B. radicicola* with the plants of the leguminous family resulting in the fixation of atmospheric nitrogen; on the other hand, we have organisms like *Clostridium Pasteurianum*, which, as Winogradsky has shown, can assimilate atmospheric nitrogen independently, or Caron's *Bacillus Ellenbachii*, which Stoklasa claims can also assimilate atmospheric nitrogen. These and others probably constantly work to preserve and increase our stock of combined nitrogen in the soil,—they are the constructive agents. At the same time there exist in the soil, and in decaying vegetable matter, numerous micro-organisms that have the power under the proper conditions to break up certain nitrogen compounds, and in this process much or all of the nitrogen is returned to the atmosphere whence it originally came, in the gaseous state. These latter organisms are the destructive agents. It is their activity that concerns the subject of our inquiry more directly, and a brief review of the more important work along these lines will help us to understand better the experimental data submitted in this paper.

As far back as 1867, Froehde had observed[4] that the reduction of nitrates takes place, at times, when they are in contact with certain organic substances. There appeared to be a considerable number of the latter possessing such reducing properties. From that early observation to our present knowledge of the specific micro-organisms causing, under given conditions, the destruction of nitrates, the study of the subject, though gradual, was decidedly irregular. It was only within the last five or six years that a careful and systematic examination of the question enabled us to gain a more definite conception of the processes of denitrification. For all that, there is much that is yet obscure, and much that calls for further study. The latter is particularly true of the denitrification processes as they appear in practical agriculture, since, as has been pointed out repeatedly, the conclusions obtained from laboratory experiments are not always applicable to actual practice, creating as they do abnormal conditions not encountered in the field. As with nitrification, the earlier investigators attempted to explain denitrification by purely chemical reactions, and to the French chemists largely belongs the credit for being the first to point out to us the probable bacterial character of the denitrification processes. However, some years before that, Schoenbein[5] had noticed that nitrates are reduced to nitrites by fungi, and that the presence of nitrites in drinking water might indicate that it contains micro-organisms. Dr. Angus Smith, in 1867, had also noticed[6] that a reduction of nitrates with the evaporation of free nitrogen takes place in the decomposition of sewage.

The work done since then, and leading up to the more detailed recent studies, will be briefly reviewed here. Meusel[7] observed the transformation of nitrates into nitrites in drinking-water, and attributed the formation of nitrites to bacteria. Chabrier states[8] that all soils contain nitrous acid, that in dry weather nitrates accumulate at the surface, and that nitrites occur in larger quantity in the lower layers of the soil. In another place[9] he finds that there is a small loss of nitrogen (liberated as gaseous nitrogen) in nitrification. This latter fact was also observed somewhat later by Boussingault[10] and later by Pickard[11] and subsequently by Godlewski.[12] Jeannel[13] found that when in contact with humus, dead leaves and straw, nitrates are reduced to nitrites; and Schloesing[14] showed that in a large bottle, whose atmosphere was kept free from oxygen, potassium nitrate was reduced to ammonia, and, also, some of the combined nitrogen was set free. Boname,[15] a year later, also came to the conclusion that nitrates are reduced in an atmosphere free from oxygen. To Schloesing,[16] also, belongs the credit of having established the fact that nitrogen is set free in the putrefactive decomposition of urine and in the lactic fermentation of sugar in the presence of potassium nitrate.

Pesci[17] noted that nitrates are reduced to nitrites when the action is allowed to go on under water, and E. W. Davy[18] observed that an excess of animal matter in solution retards nitrification. Hüfner,[19] on the other hand, decided that no gaseous nitrogen is set free in the decay of organic substances.

Deherain and Maquenne[20] had also observed the reduction of nitrates. They attributed this action to anaerobic ferments, and showed that the gases set free contained besides carbon dioxide, also free nitrogen and nitrous oxide. About the same time Gayon and Dupetit[21] studied the reduction of nitrates in the soil. They describe an anaerobic "ferment" capable of reducing nitrates rapidly. In this process, gaseous nitrogen is set free. They also found that the ferments need organic matter for their development, that part of the organic nitrogen is transformed into ammonia, and, perhaps, also into amido derivatives of the organic substance. Heraeus,[22] too, had observed the reduction of nitrates to nitrites and ammonia by bacteria, and Springer[23] studied what he called a "ferment," rod-shaped, rounded at the ends, and capable of reducing nitrates.

In 1886, Gayon and Dupetit[24] isolated two organisms, *B. denitrificans I* and *B. denitrificans II*, capable of reducing nitrates with the evolution of gaseous nitrogen. Besides these they encountered a number of bacteria that could reduce nitrates to nitrites. According to the composition of the nutritive medium the nitrogen of the nitrates may be set free as such, or mixed with nitrous oxide. The oxygen of the nitrates not combined with the nitrogen of the nitrous oxide, unites with the carbon of the organic matter, giving carbon dioxide, which dissolves for the most part forming bicarbonate of potassium (KNO_3 being used). The culture medium containing 10 grams of potassium nitrate begins to ferment on the addition of some soil. The authors think that the decomposition of nitrates by *B. denitrificans* is not a true fermentation, nor a secondary phenomenon, but a "combustion of the organic matter by the nitric oxygen with the liberation of much heat; it is a type of fermentation that can take place only with the simultaneous concurrence of several chemical reactions." Kellner and Yoskii[25] found that although losses of nitrogen occur in the decay of nitrogenous organic matter, yet the losses are slight, even after the decay has progressed for a long time. Ehrenberg[26] in a series of exhaustive experiments showed that "neither in the presence nor absence of free oxygen, neither in solution nor in slightly moistened decaying masses permeable to gases, is elementary nitrogen set free through the agency of micro-organisms." Tacke[27] reaches a similar conclusion, while Immendorf[28] stated distinctly that according to his experiments the setting free of nitrogen from decaying organic matter is not a purely chemical process, but is effected with the aid of micro-organisms. It will be seen from this that while there were still adherents of the chemical theory in Germany, the belief was beginning to prevail that the destruction of nitrates is due to bacteria. Two years later Tacke[29] admits that Berthelot was right when he claimed that there are nitrogen-fixing bacteria in the soil, and adds that there are also present in the soil organisms that set free nitrogen from its compounds.

Holdefleiss[30] was led to believe that even in yard manure constantly compacted by animals, and with the oxygen thus excluded, the nitrification processes take place to some extent. Hence, the greatest loss through the formation of free nitrogen takes place in the manure pile, and not in the stable. By compacting the manure, the nitrification processes can be limited, and we must depend on mechanical treatment to delay nitrification until the manure reaches the soil. Of course, in preventing nitrification in the manure pile, the losses of free nitrogen due to denitrification are largely prevented.

Leme[31] found that the addition of large quantities of fresh manure, not only stops nitrification, but that there is at first a reduction of nitrates to nitrites, and of the latter to ammonia. Breal[32] announced that many substances of organic origin, and especially straw, are the carriers of denitrifying organisms. Obviously the discovery is of far-reaching importance. Since these organisms are carried to the manure in the litter, and later are plowed in the soil with the manure, it becomes interesting to determine to what extent denitrification takes place, either in the manure pile or in the soil. In order that denitrification might take place, it is essential that nitrates be present, and we must assume that where no nitrates are applied as such, nitrification must first take place that denitrification might follow. E. W. Davy,[33] Leme,[34] Pickard,[35] Lipman,[36] and others have shown that large quantities of organic matter either retard or entirely stop nitrification, and for that reason the losses of nitrogen from fresh manure due to the destruction of nitrates cannot be great. On the other hand, losses of nitrogen may take place in other ways, and there is much evidence that confirms this view.

König[37] in his prize essay stated that "the losses of nitrogen from manure due to the volatilization of ammonia appear to be slight," and he is inclined to think that the greater losses are due to the liberation of elementary nitrogen. Immendorf,[38] on the other hand, comes to the conclusion that the chief cause of the loss of combined nitrogen in manure with the usual treatment may be attributed to the volatilization of ammonia, and finds that the formation of elementary nitrogen influences these losses only to a limited extent. Burri, Herfeldt and Stutzer[39] carried out some experimental work to decide as to the causes that lead to losses of nitrogen in decaying organic substances, especially in dung and liquid. They are led to believe that where denitrification takes place it is preceded by nitrification. Hence they conclude that "in the decay of nitrogenous organic substances, there is no setting free of elementary nitrogen as long as the activity of the nitrifying organisms in the decaying substance is suppressed." On the other hand, they believe that a considerable evolution of free nitrogen may take place when nitrates are added to dung or liquid manure, or when opportunity is given to the nitrifying organisms for active development. The splitting off of free nitrogen may be caused by the reduction of nitrates, or by the action of nitrous acid or ammonia or amines. The authors point out later that denitrification is rather due to living organisms than to purely chemical reactions, as Ehrenberg[40] assumes; nitrification, they think, may run to completion without the evolution of free nitrogen; such evolution is more likely to take place in the decaying mass when the supply of oxygen is limited. In such cases the oxygen of the nitrates is utilized and the nitrogen is set free.[41] Since in the fresh manure scarcely any nitrification takes place, the denitrification cannot be considerable. In another communication the same authors suggest that the object of a rational method of conservation should not only consist in preventing the volatilization of ammonia, but also in controlling the course of fermentation, so as to favor the development of bacteria that transform organic nitrogen into ammonium carbonate.

Following the example of Gayon and Dupetit, Burri and Stutzer were led to attempt the isolation of denitrifying organisms. The work appeared the more desirable in view of Breal's[42] discovery already alluded to, and of a communication from Wagner that nitrate of soda yielded inadequate returns when used together with horse manure. In communicating the results of their experiments[43] they call attention to the fact that there are but a limited number of organisms capable of oxidizing nitrates, while of those possessing the power of reduction (deoxidation) the number is great. Of these, however, the greater part can only reduce nitrates to nitrites and the bacteria capable of reducing nitrates to ammonia, or of setting nitrogen free, are not very numerous. Of the work not already referred to, they mention that of Deherain and Maquenne[44] who observed that in the gases set free in denitrification there is contained besides nitrogen, also carbon dioxide and hydrogen. Also the work of Giltay and Aberson[45] is mentioned. The latter describe a bacillus capable of destroying large quantities of nitrate with the evolution of free nitrogen. Burri and Stutzer finally succeeded in isolating two organisms capable of reducing nitrates completely, which they named *B. denitrificans I* and *B. denitrificans II*. Their conclusions[46] may be summed up as follows: "When oxygen is completely excluded *B. denitrificans I*, together with *B. coli*, does not cause the evolution of free nitrogen in culture solutions containing nitrate, but most of the nitrate nitrogen is reduced to nitrite nitrogen. With a limited supply of oxygen, *B. denitrificans I* can develop to such an extent as to be able, together with *B. coli*, to cause the fermentation of nitrate with the evolution of free nitrogen. When once started the fermentation takes its usual rapid course. *B. denitrificans I* uses in this case some of the oxygen derived from the nitrates. With a liberal supply of air *B. denitrificans I*, together with *B. coli*, causes the destruction of nitrites in the normal way. With the complete exclusion of air *B. denitrificans II*, to cause the fermentation of nitrates, is diminished or entirely suppressed.

According to Marchal[47] the behavior of *B. mycoides* in nutritive solutions containing nitrates is rather striking. When inoculated into a solution containing glucose and about 2 grams of potassium nitrate per liter, nitrites and ammonia could be detected in a few days, and in fifteen days ammonia alone. It appears thus that the same organisms may exert either an oxidizing or reducing action. Both processes are intimately connected with the respiration of the organism. In one case albuminoids are normally oxidized with the aid of atmospheric oxygen; in the other, the intramolecular respiration leads to a utilization of the nitrate oxygen to oxidize the sugar.

Attempts to isolate denitrifying organisms were also made by Schirokikh.[48] He was successful in obtaining a pure culture of an organism capable of destroying nitrates. He describes it as a bacillus with rounded ends, having no vacuoles, and one and a half to twice as long as it is wide. It is motile, though not as markedly as, for instance, *B. pyocyaneus*.

A further study of the denitrifying organisms isolated by Burri and Stutzer[49] is contributed by Stutzer and Maul[50]. The authors finally come to the conclusion that *B. denitrificans I*, together with *B. coli*, destroys nitrates in a flask that is merely stoppered, but when air is passed through the liquid in the flask, denitrification is not as active. Also Ampola and Gatino[51] isolated a denitrifying organism which they named *B. denitrificans agilis*. They found that it is capable of destroying nitrates rapidly. In examining the gases evolved they found them to consist of nitrogen and carbon dioxide, the latter being present to the extent of 15 per cent. In searching for practical means to diminish denitrification in manure, the same authors[52] decided that peat prevents denitrification by virtue of the acidity it imparts to the manure, but when the manure again becomes alkaline denitrification takes place.

S. A. Sewerin[53] isolated thirty-two different organisms from horse manure, and studied twenty-nine of these. In one case strong foaming was noticed, and it was found that there were at least two species capable of reducing nitrates completely. Further study showed that there were also nine species capable of reducing nitrates to nitrites, eighteen species being indifferent. By diluting the nitrate solution to 0.1 per cent., two more showed complete reduction, and still further dilution to 0.05 per cent. showed four more organisms capable of complete reduction, in all eight species. It appears also that proportionately larger quantities of potassium nitrate than of sodium nitrate are reduced in a given time, and 0.6 per cent. of sodium nitrate appears to be the limit of reduction. The author also finds that the stirring of the soil and greater aeration tend to diminish denitrification.

His studies of *B. denitrificans II* led Hjalmar Jensen[54] to believe that it can be grown as an aerobe. He finds a certain relation between the nitrate destroyed and the carbon compounds used. No denitrification takes place without a source of carbon being supplied.[55]

P. P. Deherain[56] confirms Breal's claim that there are denitrifying bacteria on straw, and Wagner's that these organisms are found in animal excreta. He finds that they occur in cultivated soils; that the nitrogen set free by them is accompanied by carbon dioxide, and often by nitrous oxide; that the nitrogen used by the organisms to build their tissues are comparatively small; they utilize only the oxygen of the nitrate and more readily exercise their reducing action in a closed space. When ordinary quantities of manure are applied nitrification rather than denitrification takes place. It is hardly necessary to treat the manure with sulphuric acid to destroy the denitrifying organisms.

It has been noted above that of denitrifying, or nitrate-destroying organisms, a large number are known at the present day, and there is no doubt that when a more thorough study is made of the subject many more will be added to the list. Thus Stoklasa[57] enumerates the following bacteria as capable of causing the fermentation of nitrates in the presence of organic acids, or of pentoses and hexoses: *B. humosus*, *B. fluorescens liquefaciens*, *B. pyocyaneus*, *B. denitrificans*, *B. coli communis*, *B. Stutzeri*, and many others that have been studied less carefully. As it is to be expected, these organisms do not possess the power of denitrification in an equal degree. The author just referred to says that the analysis of the gas produced by *B. Hartlebii* showed 70 to 96 per cent. of nitrate nitrogen set free, the rest having been transformed into organic nitrogen. Furthermore, the destructive fermentation of nitrates depends to a great extent on the character of the organic acids in the nutritive medium, some being much better adapted than others to furnish the necessary energy for the breaking-down of the nitrates. Stoklasa also claims that most of the denitrifying bacteria can cause no reduction of nitrates in media where chemically pure *d*-fructose and *d*-galactose are present. The nitrate, he believes, is first reduced to ammonia, and that is oxidized with the liberation of free nitrogen. However, not all of the ammonia is thus oxidized, for a part of its nitrogen is transformed into the organic form, a fact that was long ago noticed by Schloesing[58].

An interesting study of several manure bacteria and of the products of their activity is contributed by T. Severin.[59] Of the several organisms that he isolated from manure, some seem to differ materially from the others. Thus *B. pyocyaneus*, and what he calls *B. No. 2*, will not produce carbon dioxide and ammonia from solid manure alone, but will attack it when it is mixed with liquid manure. On the other hand, one organism which the author designates as *No. 1* seems to be more active in the absence of urine. This fact is significant in that it introduces a new factor in the study of the relative value of solid and of solid and liquid manure in plant nutrition.

Some of the accumulated facts bearing on the conditions most suitable for the growth and development of the denitrifying bacteria we owe to Stutzer. In a recent article[60] he claims that denitrification in nutritive solutions is not favored by glucose, but is promoted by the presence of salts of organic acids, like potassium lactate or potassium citrate.

Turning to the more practical side of the denitrification question, we find that much thought has been given to it. Some years ago the experimental data at hand were so contradictory, and the points to be cleared up so numerous, that Pfeiffer was led to say: "There is scarcely another field of research in agricultural chemistry in which we encounter contradictions as numerous, and as fully unexplained." In order to clear up these contradictions and to throw more light on the doubtful results, the German Agricultural Association called for a united effort on the part of the German experiment stations, offering at the same time to place the necessary means at their disposal.[61] The call was answered and the work undertaken by the experiment stations of Augsburg, Darmstadt, Jena and Rostock, and later on by the Bonn and Göttingen stations. The investigation was to answer two general questions:

1. How are the great losses of nitrogen that take place in the decay of organic substances to be explained? To what extent is the nitrogen liberated in the elementary state, and to what extent as ammonia. and how does the liberation of the first take place?

2. What means do we possess of checking these losses, and how does the material thus employed act?

The publication of the results was to be delayed until the existing uncertainty was cleared up. Since such was far from being the case in 1896, it was decided to publish the results already received at that time, for they contained much that is valuable. and in many respects conclusive. In accordance with this, there appeared in the *Landwirtschaftlichen Versuchs-Stationen*[62] the reports of B. E. Dietzel (Augsburg), of Th. Pfeiffer, E. Franke, C. Götze, and H. Thurmann (Jena), and of J. Aeby, R. Dorsch, Dr. Matz and P. Wagner (Darmstadt). The combined reports make a very valuable contribution to the subject of denitrification, and will well repay a careful study to all who are interested in the nitrogen question.

The Jena and Darmstadt stations have reached similar conclusions in regard to certain phenomena. The experiments of both indicate that with a limited supply of air in the manure, the losses of elementary nitrogen and of organic substance are not very extensive. It might be added here that the results obtained at the Darmstadt station[63] indicate that "solid excreta and straw lose their nitrogen so very slowly. that no conservation materials are needed. It is only the nitrogen of urine that requires conservation."

Pagnoul[64] had found that horse manure, especially in the presence of starch, tends to cause the disappearance of nitrates, but at 30° with a sufficient supply of oxygen and water, there is no loss of free nitrogen, but the conversion of nitrate into organic combinations. It should be added here, perhaps, that the same investigator had some years earlier[65] declared that ordinary quantities of horse manure do not cause denitrification in the soil.

Also Ragoyski[66] found that lime largely prevents the loss of nitrogen. It is very likely that the increase in albuminoid nitrogen was due to the activity of bacteria, for also Street[67] and others have found this to be the case; but as to the availability of the organic nitrogen thus formed, there is a considerable difference of opinion. Nobbe and Hiltner[68] state definitely that the organic nitrogen produced by soil bacteria is not available, at least not immediately available, to the growing crop.

Pfeiffer, Franke, Lemmermann, and Schilbach[69] studied the availability of the nitrogen in different nitrogenous materials in both pot and field experiments. The substances used were sodium nitrate, ammonium sulphate, ground horn, dried blood, meat and bone, and barnyard manure, both treated and untreated.

It would not be out of place here to examine a certain statement of the authors that had a direct bearing on facts brought out in our own experimental work. They attempt to account for the high nitrogen content of plants grown on a soil poor in nitrogen.[70] Quoting Maercker's explanation,[71] "that on a soil very poor in nitrogen, the plants starving for want of nitrogen do not pass their period of infancy; on account of their lack of nitrogen they are not able to form sufficient amounts of carbohydrates, and these result in abnormal plants, which die before they mature, and, therefore, are rich in nitrogen, while containing but a small amount of dry matter." The authors criticize this statement and point out that there must have been some other controlling factor, for with a plentiful supply of the other plant food constituents, there should result a mass of plant food substances of a normal composition. A comparison of Series 1 and 2 in our experiments will show that they are right in this respect.

In an article entitled[72] "The Cause and Significance of the Decomposition of Nitrates in the Soil," Krüger and Schneidewind report the results of their experiments. The work was undertaken in order to solve the following problems: (*a*) Does the loosening of the soil caused by applications of manure have anything to do with the diminution in yield? (*b*) Is it caused by the addition of organisms that destroy nitrates? (*c*) Is it caused by the addition of substances which favor the development of the nitrate-destroying organisms, and thereby favor denitrification?

The investigation included both plot and field experiments, 6 kilos of soil being used in the former. They find that there was denitrification in the plots, there being in every case a smaller yield over the nitrate alone when together with the latter fresh manure is used, and that with varying quantities of nitrates.

The authors express the belief that while the denitrification processes in the field are not as extensive as they are in the cylinders, yet even in field operations the denitrification processes are of considerable significance. The decomposition of nitrates in the field is not usually noticeable, because the nitrification processes here are more intense than they are in the cylinders, and hence denitrification is less marked. Denitrification is also masked on the addition to the field of barnyard manure, because there is more soluble nitrogen added by the latter to the soil than is destroyed by the denitrifying bacteria. "A direct conclusion as to the extent of denitrification in practice can only be obtained by determining the action of liquid manure, or of nitrate for itself on the one hand, and on the other hand the action of either when used together with solid excreta and straw."

Pfeiffer and Lemmermann[73] do not agree with Krüger and Schneidewind in their claim that denitrification caused by manure is due to the organic matter it adds to the soil, rather than to the bacteria contained in it.

Maercker had pointed out[74] that in the course of sterilization of manure, certain substances are formed that are injurious to plant life. It follows, if this be true, that a comparison in vegetation experiments of sterilized and unsterilized manure would not bring out the actual relations. To avoid this difficulty, Pfeiffer and Lemmermann sterilized both lots, and then inoculated one of them with a pure culture of *B. denitrificans II.* given to them by Dr. Kunnemann. They find that there is an increase in the soil nitrogen of all the cylinders on which no nitrogen had been applied, and are inclined to ascribe the cause of it to nitrogen-fixing bacteria. This view is confirmed by the experience of Aeby,[75] of Schneidewind,[76] and of Richter.[77] The latter sums up his conclusions as follows: (1) The several unsterilized vessels to which no nitrogen had been added show an increase in nitrogen. The gain is slight in the first crop, but increases later. (2) In all cases where nitrogen is applied, there is a loss of soil nitrogen. Hence the increase of nitrogen in the soil takes place only when the latter is poor in assimilable nitrogen.

Pfeiffer and Lemmermann are also inclined to think that since a part of the nitrate nitrogen is changed into the organic form, and is later utilized by the plant, it is manifestly unjust to decide on its relative availability from short vegetation experiments. Finally they conclude that there are several factors responsible for the so-called denitrification process. There are at least three such factors, and namely:

1. Direct injury to the growing plants by larger quantities of organic substance.

2. Fixation of soluble nitrogen by the increased activit-- of different organisms.

3. Denitrification proper.

It is still to be learned which one of these factors plays the most important part, economically and how we are to modify and influence such activity.

From his more recent experiments[78] Rogoyski concludes that there is a denitrification of nitrates in the presence of large amounts of manure, the nitrogen being set free in the elementary state, while a part of it transformed into organic combinations. Similar changes occur when soil containing large quantities of manure or straw is mixed with urine or a solution of ammonia salts. The nitrogen thus fixed appears to be readily nitrifiable. When quantities used in practice were applied no denitrification took place, and the urine was nitrified. On the other hand, denitrification did take place when excessive quantities were applied.

The work of Wood[79] indicates that there was considerable denitrification when manure at the rate of 10 to 20 tons per acre was applied, together with nitrate. While there was some denitrification where well-rotted manure was used, the effects were more striking in the case of fresh manure. Thus nitrate alone gave an increase of 9.5 bushels of grain per acre, while nitrate together with fresh manure gave practically no increase.

At present Höflich[80] is reporting studies in which he is trying to differentiate between denitrifying bacteria naturally occurring in soils, straw and manures.

The above represents a brief review of most of the recent research work on denitrification and the changes in manures. The fact that great losses of nitrogen take place when excessive amounts of manure are applied, and that, conversely no denitrification, or very little denitrification, takes place when ordinary quantities are applied, taken together with the experiments of Pfeiffer and Lemmermann to prove that much of the reduction in yield usually attributed to denitrification is really due to the injurious effect of large amounts of organic matter, indicate that there is a phase of the subject that needs very careful investigation.

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PART II.

The work carried on in our own laboratory[1] tends to confirm the claim of the European investigators. It shows clearly that nitrates when in contact with manure are destroyed by the organisms contained in the latter, that this destruction of nitrates is essentially a reducing process, that the larger portion is set free as gaseous nitrogen, and that a part of it is converted into ammonia, and part of it into insoluble organic nitrogen, not suited to supply the immediate nitrogen requirements of the growing crop. It shows, moreover, that other manurial substances, like acid phosphate, kainite, ammonium sulphate, etc., modify the transformation of the nitrate nitrogen. In interpreting these laboratory results, and in studying the conclusions drawn, it becomes necessary to determine their applicability to actual practice. The cylinder experiments whose plan and scope were presented in the first part of this paper are carried on under conditions approximately those in the field, and on a scale extensive enough to permit of conclusions and deductions of great practical importance. The use of fresh and of leached manure intended to answer still another question of direct concern to every farmer; and namely, what relative value they possess when used by themselves, or together with nitrogen salts, or with highly nitrogenous organic substances. The composition of the fresh manures, and of the leached manures, used in the experiment are shown in the accompanying table.

[1] John P. Street: N. J. Sta. Rep., 1899, p. 86, and Rep., 1900, p. 79.

TABLE I.

	Leached manures.		Fresh manures.	
	Solid. Per cent.	Solid and liquid. Per cent.	Solid. Per cent.	Solid and liquid. Per cent.
Water	77.043	78.614	85.794	85.074
Ash	3.176	3.005	1.831	2.645
Organic matter	19.781	18.381	12.375	12.281
Nitrogen (total)	0.431	0.498	0.293	0.463
Nitrogen, water-soluble	0.056	0.169	0.060	0.211
Nitrogen as nitrates	....	....	0.015	0.031
Nitrogen as ammonia	....	0.080	0.031	0.090
Nitrogen as soluble organic	0.056	0.089	0 014	0.090
Nitrogen as insoluble organic	0.375	0.329	0.233	0.252
Phosphoric acid	0.504	0.508	0.372	0.410
Potash	0.350	0.414	0.141	0.199

As already stated, a study not only of the relative effect of the constituent nitrogen in the various manures themselves, but also of its effect when used in connection with nitrogenous materials possessing a known rate of availability, was made the subject of the experiment, thus enabling a comparison of the relative availability of the nitrogen, as well as the denitrifying effect of the various manures.

Since the manure on the farm is so often exposed to the leaching action of rain before it is put on the field, it becomes apparent that the economic interests involved are of great moment.

In the tables presented in this paper, the attempt has been made to arrange logically the experimental data thus far obtained.

THE RESULTS OF THE OAT EXPERIMENT, 1900.

The accompanying table shows the actual dry matter in the different crops, the percentage of nitrogen contained in them, the gain in nitrogen due to materials added, and the percentage of the applied nitrogen recovered. In all cases, the net gains in the different series are derived by subtracting the average gain obtained on Series 2, upon which minerals only were applied, from the average gain for that particular series.

As in the crops of 1898 and 1899, there was a gain in weight of the dry matter of the crops to which nitrogenous materials were applied.

TABLE II.—RESULTS OF THE OAT EXPERIMENT.

Series.		Nitrogen applied. Grams.	Dry matter in crop. Grams.	Nitrogen in dry matter. Per cent.	Nitrogen in crop. Grams.	Increase over check plot. Grams.	Per cent. of nitrogen recovered.	Average per cent. of nitrogen recovered.
1	A	....	81.8	1.397	1.143	...	....	....
	B	....	82.6	1.313	1.085	...	....	....
	C	....	84.8	1.293	1.096	....	....	....
2	A	....	116.9	1.018	1.190	....	....	....
	B	....	106.8	1.061	1.133	(1.152)	....	....
	C	....	107.1	1.058	1.133	....	....	....
3	A	4.05	154.0	1.061	1.634	0.482	11.90	....
	B	....	155.3	1.108	1.721	0.569	14.05	10.81
	C	....	123.8	1.142	1.414	0.262	6.47	....
4	A	3.98	232.4	1.143	2.656	1.504	37.78	....
	B	....	208.3	1.069	2.227	1.075	27.01	30.60
	C	....	213.3	1.044	2.227	1.075	27.01	....
5	A	3.99	128.5	1.145	1.471	0.319	7.99	....
	B	....	121.7	1.121	1.364	0.212	5.31	7.38
	C	....	131.2	1.147	1.505	0.353	8.85	....
6	A	4.04	193.4	1.096	2.120	0.968	23.96	....
	B	....	193.7	1.067	2.067	0.915	22.65	22.06
	C	....	193.7	1.003	1.943	0.791	19.58	....
7	A	0.78	158.0	1.163	1.838	0.686	87.95	...
	B	....	166.3	1.035	1.720	0.568	72.82	80.43
	C	....	174.7	1.019	1.780	0.628	80.51	....
8	A	1.55	202.3	1.178	2.383	1.231	79.42	....
	B	....	184.0	1.252	2.304	1.152	74.32	76.30
	C	....	198.4	1.168	2.317	1.165	75.16	....
9	A	4.83	197.3	1.085	2.132	0.980	20.29	....
	B	....	189.5	1.119	2.121	0.969	20.06	19.97
	C	....	199.2	1.052	2.096	0.944	19.55	....
10	A	5.60	207.0	1.251	2.590	1.438	25.68	....
	B	....	227.2	1.316	2.990	1.838	32.82	27.99
	C	....	232.9	1.107	2.578	1.426	25.46	....
11	A	4.76	265.4	1.277	3.389	2.237	47.00	....
	B	....	260.1	1.077	2.801	1.649	34.64	41.43
	C	....	269.0	1.183	3.182	2.030	42.65	....
12	A	5.53	262.5	1.428	3.949	2.797	50.58	....
	B	....	242.2	1.436	3.478	2.326	42.06	44.68
	C	....	285.9	1.204	3.442	2.290	41.41	....

Series.		Nitrogen applied.	Dry matter in crop.	Nitrogen in dry matter.	Nitrogen in crop.	Increase over check plot.	Per cent. of nitrogen recovered.	Average per cent. of nitrogen recovered.
		Grams.	Grams.	Per cent.	Grams.	Grams.		
13	A	4.77	178.6	1.150	2.004	0.852	17.86	....
	B	....	169.8	1.143	1.941	0.789	16.54	17.50
	C	....	178.5	1.129	2.015	0.863	18.09	....
14	A	5.54	192.6	1.333	2.567	1.415	25.54	....
	B	....	206.4	1.203	2.483	1.331	24.03	24.25
	C	....	196.4	1.241	2.437	1.285	23.19	....
15	A	4.82	217.5	1.335	2.904	1.752	36.35	....
	B	....	211.5	1.236	2.624	1.472	30.54	31.71
	C	....	217.0	1.158	2.513	1.361	28.24	....
16	A	5.59	257.4	1.418	3.650	2.498	44.69	....
	B	....	230.4	1.420	3.272	2.120	37.75	38.32
	C	....	214.1	1.387	2.970	1.818	32.52	....
17	A	1.52	194.5	1.142	2.221	1.069	70.33	....
	B	...	178.3	1.221	2.177	1.025	67.43	68.84
	C	....	191.2	1.149	2.197	1.045	68.75	....
18	A	1.49	173.6	1.094	1.899	0.747	50.13	....
	B	....	187.3	1.060	1.985	0.833	55.91	52.15
	C	....	175.4	1.085	1.903	0.751	60.40	....
19	A	5.51	177.4	1.176	2.086	0.934	16.95	....
	B	....	197.9	1.235	2.444	1.292	23.50	20.63
	C	....	201.8	1.156	2.333	1.181	21.43	....
20	A	5.48	189.5	1.154	2.187	1.035	18.89	....
	B	....	179.2	1.200	2.150	0.998	18.21	19.20
	C	....	198.7	1.145	2.275	1.123	20.49	....

THE AVAILABILITY OF THE NITROGEN IN THE SOLID AND IN THE SOLID AND LIQUID PORTIONS OF FRESH MANURE.

In 1899, the problem was more complicated, because of the varying quantities of nitrogen applied in the manure.[1] Such was not the case, however, in the crop under consideration, for the amounts of nitrogen applied in the manure were practically uniform. In every case where manure was used, enough was applied to furnish nitrogen practically equivalent to 4 grams.

[1] Twenty-First Annual Report N. J. Expt. Sta.

1899.

Series 3, nitrogen applied = 3.32 grams.
Series 3, nitrogen applied = 5.25 grams.
Recovered in crop, 3- 8.3 per cent.
Recovered in crop, 4-40.2 per cent.

1900.

Nitrogen applied = 4.05 grams.
Nitrogen applied = 3.98 grams.
Recovered in crop, 3-10.81 per cent.
Recovered in crop, 4-30.60 per cent.

It appears, then, that in each case the recovery from the solid and liquid, combined, was greater than that from the solid manure alone. However, the relations are not quite the same, for in 1899 the recovery from the solid and liquid was nearly five times that from the solid alone, while in 1900, the recovery from the solid and liquid, combined, was not quite three times that from the solid alone. The fact that the comparative recovery was greater from the solid manure alone, indicates that the greater amounts of moisture rendered greater quantities available. As with the results of 1899, it is quite evident here that a large recovery may be expected from the soluble nitrogen in liquid manures.

The greater yield of dry matter over check (Series 2), was 31 per cent. for the solid, and 97.6 per cent. for the solid and liquid. The corresponding figures for 1899 were 35.9 per cent. and 228.8 per cent. This again indicates that with more rain the solid manure makes a better showing. It should be borne in mind, nevertheless, that the better showing for the solid and liquid manure in 1899 was due in a measure to the larger application of 5.25 grams, as against 3.98 grams in 1900.

THE AVAILABILITY OF THE NITROGEN IN THE SOLID AND IN THE SOLID AND LIQUID MANURE, LEACHED.

1899.

Nitrogen applied in leached manures, Series	5,	1.96 grams.
" " " " " "	6,	4.52 grams.
Recovered in crop.................. "	5,	8.4 per cent.
" " " .... "	6,	13.8 per cent

1900.

Nitrogen applied in leached manures, Series	5,	3.99 grams.
" " " " " "	6,	4.04 grams.
Recovered in crop.................. "	5,	7.38 per cent.
" " " .... "	6,	22.06 per cent.

The differences in recovery in the leached manures between the solid and the solid and liquid portions, are not as great as in the fresh manures. The recovery in the solid leached is proportionately somewhat less in 1900, but in the solid and liquid leached the recovery in 1900 is much greater than that in 1899. In the preceding year, however, the recovery in the leached manures is less than the recovery in the fresh manures; while the differences in recovery between the solid fresh and leached are slight, the differences between the solid and liquid, leached and fresh, are more considerable.

As to the dry matter produced, following are the figures:

1899.		1900.	
Series 5....	20.9 per cent.	Series 5....	15.7 per cent.
Series 6....	83.3 per cent.	Series 6....	57.7 per cent.

It appears from these that in 1899, the increased yield over the check plot was greater in the case of the solid, and of the solid and liquid, leached. Also, here it is evident that the differences in yield from the solid and the solid and liquid, leached, are not as great as they were in 1899. Furthermore, the dry matter produced from the solid manure, leached, is proportionately richer in nitrogen than the dry matter produced from the solid and liquid manure, leached. This is true for both 1899 and 1900.

THE RELATIVE AVAILABILITY OF THE NITROGEN IN THE FORM OF NITRATE, AMMONIA, AND OF ORGANIC MATTER IN DRIED BLOOD.

The same amounts of nitrate nitrogen, of ammonia and of organic nitrogen, as dried blood, were applied on the several series, as in the years 1898 and 1899. Series 8, 10, 12, 14 and 16 received each the double quantity, that is, an amount of sodium nitrate containing 1.55 gram of nitrogen. Series 7 received 0.78 gram of nitrate nitrogen. On 17 and 18, enough ammonium sulphate and dried blood, respectively, were applied to furnish, approximately, the double nitrate quantity of 1.55 grams of nitrogen. The basis of comparison, therefore, will be Series 8. As in 1899, the proportionate recovery from Series 8 is slighter than that from Series 7. The differences, however, are somewhat smaller. The amounts recovered for 7 and 8 are 75.8 per cent. and 69.0 per cent., respectively, the corresponding figures for 1900 being 80.43 and 76.30 per cent. It would seem that the heavy showers in 1900 did not wash the nitrate beyond the reach of the crop. The dry matter in

1900, as was also the case in 1899, is richer in nitrogen on Series 8. In 1899 it was 1.268 per cent. for Series 7, and 1.330 per cent. for Series 8, and in 1900, 1.072 per cent. for Series 7, and 1.199 per cent. for Series 8. The absolute amount of nitrogen taken out is, naturally enough, greater on Series 8 than it is on Series 7. In 1899 it was 1.422 grams on 7, and 1.901 grams on 8—a greater proportionate increase on 7, and a greater absolute increase on 8.

The dry matter on Series 17, where ammonium sulphate was used, is richer in nitrogen than the dry matter on Series 18, where dried blood was used. The corresponding figures are 1.171 per cent. for 17, and 1.079 per cent. for 18, in 1900, as compared with 1.394 per cent. for 17 and 1.366 per cent. for 18, in 1899. It will be noticed that the differences are slighter in 1899. The percentage of nitrogen recovered is greater from the ammonia than it is for the dried blood, which is in agreement with the results of 1899. As with the nitrate, the percentage recovery from the ammonium sulphate and from the dried blood was greater in 1900. The recovery in 1899 was 50.3 for the ammonium sulphate, and 40.4 per cent. for the dried blood. The corresponding figures for 1900 are 68.84 per cent. and 52.15 per cent.; also due, no doubt, to a more generous supply of moisture. It thus follows that the availability of the ammonia and blood nitrogen was increased by the greater precipitation. It is interesting to note here that the recovery from the dried blood in 1900 was greater than that from the ammonium sulphate in 1899, both relatively and absolutely.

THE EFFECT OF THE USE OF THE SOLID AND OF THE SOLID AND LIQUID PORTIONS OF COW MANURE, FRESH AND LEACHED, WITH NITROGEN IN THE FORM OF NITRATE, OF AMMONIA AND OF ORGANIC MATTER.

The object of these combinations was not alone the study of the availability of the different forms of nitrogen when applied together, but also to determine whether the nitrogen of the nitrates applied as such, or formed from the materials applied, would be set free by the deoxidizing action of certain bacteria.[1] As in previous years, the clear manure, free from any admixture of litter was used, and the amount of manure applied was in no case much greater than that applied in actual practice.

[1] N. J. Sta. Rep., 1899, pp. 97–101; 1900, pp. 100–102.

By applying the different forms singly and also in combination, it becomes possible to determine, not only the comparative availability, but also the extent of denitrification, if any should take place. The results of 1898, and of 1899, have shown clearly that, thanks to the combination, the nitrogen in the different forms is even more efficient than where these forms are used singly. The reason for this we must seek in the fact that no single form is so well adapted to nourish the plant continually and uniformly as are the proper combinations. Such uniform feeding not only enables a uniform and healthy growth, but it also makes possible a more thorough utilization of the plant food made available by providing a better root system. It should also be remembered that the character of the season is an important factor in determining the relative availability of the different forms of nitrogen. A more abundant supply of moisture will tend to increase the availability of the organic forms and will also tend to increase to a still greater extent, proportionately, the availability of the nitrogen in the different combinations. However, while the tendency is there, the combinations do not always show a proportionate increase over the forms used singly. The following table shows the actual average percentage recovery of nitrogen, when the materials furnishing it were used singly, as well as when they were used in combination, together with the percentage increase of nitrogen from combinations of two materials, calculated from the increase obtained when they were used singly.

The difference between the percentage of nitrogen actually recovered and the percentage recoverable, calculated, represents the losses due to all causes; the difference is expressed in percentage in the last column. It appears that in 1900, the percentage recovery was greater in nine out of eighteen series, and of these nine, six were in series where the materials applied were used singly. This is particularly true of 6, 7, 8, 17 and 18. On the other hand, the percentage recovery is greater in 1899, in the series where the combinations of the different forms were used, that being especially noticeable in Series 10, 11, 12, 13 and 14. While it may be assumed that the greater availability of the nitrate, ammonia and dried blood was due in 1900 to a greater abundance of moisture, it is more difficult to determine the causes that were responsible for a slighter percentage of recovery on the series where

TABLE III.

	Series.	1899. Nitrogen recovered.	1899. Calculated recovery.	1899. Nitrogen not recovered in the combinations of materials.	1900. Nitrogen recovered.	1900. Calculated recovery.	1900. Nitrogen not recovered in the combinations of material.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Solid manure, fresh	3	8.3	....	....	10.81	....	...
Solid and liquid, fresh	4	40.2	....	....	30.60	....	...
Solid, leached	5	8.4	....	....	7.38	....	...
Solid and liquid, leached	6	13.8	....	....	22.06	....	...
Sodium nitrate	7	75.8	....	....	80.43	....	...
Sodium nitrate	8	69.0	....	....	76.30	....	...
Ammonium sulphate	17	50.3	....	....	68.84	....	...
Dried blood	18	40.4	....	....	52.15	....	...
7 and 3 in	9	16.4	21.12	22.2	19.97	22.10	9.64
8 and 3 in	10	29.4	27.59	....	27.99	28.95	3.32
7 and 4 in	11	46.5	44.74	....	41.43	38.76	...
8 and 4 in	12	46.8	46.71	....	44.68	43.42	...
7 and 5 in	13	21.3	27.59	23.0	17.50	19.33	9.47
8 and 5 in	14	35.1	35.15	....	24.25	26.68	9.11
7 and 6 in	15	21.6	22.92	5.8	31.71	31.41	...
8 and 6 in	16	29.1	27.89	....	38.32	37.10	...
17 and 5 in	19	27.9	27.35	....	20.63	24.24	14.89
18 and 5 in	20	23.3	22.51	....	19.20	19.56	1.84

combinations were used. It is questionable in just how far the difference may be attributed to leaching in 1900, for the fact that the recovery from the double quantity of nitrate on Series 8 was greater in that year than was the case in 1899, would indicate that but little, if any, of the nitrate nitrogen was washed beyond the reach of the plant roots. The differences in the amount of nitrogen applied may have had something to do with it; even that is questionable, for the percentage recovery was slighter in 1900 on Series 11 and 12, where more nitrogen was applied in 1899, as well as on Series 13 and 14, where more nitrogen was applied in 1900. It is possible that the differences were due to denitrification, still for the present this is only surmise.

As it is, the percentage of nitrogen recovered in 1900 exceeds the calculated recovery in four cases out of ten. They are Series 11, with a recovery of 41.43 per cent., calculated 38.76 per cent.;

Series 12, with a recovery of 44.68 per cent., calculated 43.42 per cent.; Series 15, with a recovery of 38.32 per cent., calculated 37.10 per cent. In Series 15 and 16, where leached manure was used with nitrate, the percentage of nitrogen recovered differs to a greater extent from that of 1899. The figures for 1889 were 21.6 per cent. and 29.1 per cent., as against 31.71 per cent. and 38.23 per cent. in 1900. The losses varied from 1.84 per cent. on Series 20, to 14.89 per cent. on Series 19. In 1899 the maximum loss was 23 per cent. on Series 13—the minimum loss, 5.8 per cent. on Series 15.

That the season has much to do with the production and transformation of plant food in the soil is brought out very graphically in the following columns, where the availabilities of the several nitrogenous substances are compared.

TABLE IV.

	Corn. 1898.	Oats. 1899.	Oats and millet. 1899.	Oats. 1900.	Oats and corn. 1900.
Sodium nitrate	100.0	100.0	100.0	100 0	100.0
Ammonium sulphate	99.5	72.9	77.9	90.22	87.75
Dried blood	95.4	58.5	61.3	68.35	73.07
Solid manure, fresh	16.76	12.0	43.1	14.16	26.36
Solid manure, leached	37.87	12.1	46.4	9.67	21.99
Solid and liquid, fresh	49.66	58.2	88.4	40.10	51.46
Solid and liquid, leached	50.38	20.0	33.0	28.91	35.91

As was already pointed out in the report of 1900,[1] the superiority of the solid and liquid manure over the solid manure is brought out strikingly. Moreover, it appears from the later results that the solid manure, fresh, if anything, is superior to the solid manure, leached, which is contrary to what could be drawn from the results obtained in 1898. In 1899, the solid fresh, and the solid leached, showed the same rate of availability. In 1900, the solid fresh, in the oat crop alone, and in the oats and corn taken together, showed a higher rate of availability. Similarly, in the case of the solid and liquid, fresh and leached, the availability was practically the same in 1898. It was higher for the fresh in 1899, and also in 1900.

RESULTS OF THE CORN EXPERIMENT—RESIDUAL EFFECTS.

The oats were harvested on July 6th. A few days later the soil in each cylinder was dug up, and thoroughly stirred. One

[1] N. J. Sta. Rep., 1900, p. 102.

hundred kernels of corn were planted in each cylinder with the twofold object of exhausting the nitrogen left over from the crop just harvested, and also of determining the influence of the residual nitrogen on plant growth. In using a considerable quantity of seed, it was intended to make the exhaustion more rapid and complete, and at the same time, to insure greater uniformity of assimilation by eliminating, to a great extent, the influence of defective individual plants. By this means the average is made more truly representative.

TABLE V.—RESULTS OF THE CORN EXPERIMENT.

Series.		Residual nitrogen.	Dry matter in crop.	Nitrogen in dry matter.	Nitrogen in crop.	Increase over check plot.	Per cent. of nitrogen recovered.	Average per cent. of residual nitrogen recovered.	Both crops. Increase over check plot.	Both crops. Per cent. of nitrogen recovered.	Both crops. Average.
		Grams.	Grams.	Per ct.	Grams.	Grams.			Grams.		
	A	....	145.0	0.617	0.895	....	....	....	....	....	....
1	B	....	117.3	0.691	0.810	....	....	....	....	....	....
	C	....	125.2	0.694	0.868	....	....	....	....	....	....
	A	....	135.1	0.579	0.782	....	....	....	....	....	....
2	B	....	124.4	0.649	0.807	(0.794)	....	...	....	....	....
	C	....	124.0	0.640	0.794	....	...	....	....	....	....
	A	3.57	193.6	0.624	1.207	0.413	11.57	....	0.895	22.10	
3	B	3.48	175.9	0.605	1.064	0.270	7.76	10.02	0.839	20.72	19.78
	C	3.79	201.7	0.596	1.201	0.407	10.74	....	0.669	16.52	
	A	2.48	201.0	0.581	1.168	0.374	15.08	....	1.878	47.19	
4	B	2.90	178.9	0.645	1.153	0.359	12.38	11.75	1.434	36.03	38.61
	C	2.90	159.4	0.640	1.020	0.226	7.79	....	1.301	32.61	
	A	3.67	224.4	0.577	1.294	0.500	13.62	....	0.819	20.53	
5	B	3.78	178.9	0.589	1.055	0.261	6.90	9.86	0.473	11.85	16.50
	C	3.64	169.8	0.662	1.124	0.330	9.07	....	0.683	17.12	
	A	3.07	162.2	0.603	0.977	0.183	5.96	....	1.151	28.49	
6	B	3.12	155.9	0.627	0.978	0.184	5.90	6.25	1.099	27.20	26.94
	C	3.25	139.8	0.729	1.018	0.224	6.89	....	1.015	25.12	
	A	0.11	126.7	0.660	0.836	0.042	38.18	....	0.728	93.33	
7	B	0.21	103.9	0.660	0.685	0.109	....	....	0.459	58.85	72.22
	C	0.15	98.0	0.685	0.671	0.123	....	....	0.503	64.49	
	A	0.32	125.1	0.618	0.773	0.021	....	....	1.210	78.06	
8	B	0.40	133.0	0.630	0.838	0.044	11.00	....	1.196	77.16	75.03
	C	0.38	105.7	0.674	0.712	0.082	....	....	1.083	69.87	

Series.		Residual nitrogen.	Dry matter in crop.	Nitrogen in dry matter.	Nitrogen in crop.	Increase over check plot.	Per cent. of nitrogen recovered.	Average per cent. of residual nitrogen recovered.	Both crops. Increase over check plot.	Both crops. Per cent. of nitrogen recovered.	Both crops. Average.
		Grams.	Grams.	Per. ct.	Grams.	Grams.			Grams.		
	A	3.85	215.4	0.618	1.330	0.536	13.92	....	1.516	31.39	
9	B	3.86	189.6	0.601	1.139	0.345	8.95	9.91	1.314	27.20	27.89
	C	3.89	158.5	0.670	1.061	0.267	6.86	....	1.211	25.07	
	A	4.16	202.2	0.575	1.162	0.368	8.85	....	1.806	32.25	
10	B	3.76	237.6	0.573	1.361	0.567	15.08	10.80	2.405	42.95	35.66
	C	4.17	189.8	0.605	1.147	0.353	8.47	....	1.779	31.77	
	A	2.52	187.8	0.633	1.188	0.394	15.63	....	2.631	55.27	
11	B	3.11	185.1	0.627	1.160	0.366	11.77	11.56	2.015	42.33	48.14
	C	2.73	166.0	0.598	0.993	0.199	7.29	....	2.229	46.83	
	A	2.73	225.0	0.591	1.330	0.536	19.36	....	3.333	60.27	
12	B	3.20	183.6	0.645	1.184	0.390	12.19	12.92	2.716	49.11	51.62
	C	3.24	170.4	0.598	1.019	0.225	6.94	....	2.515	45.48	
	A	3.92	255.3	0.527	1.344	0.550	14.03	....	1.402	29.39	
13	B	3.98	182.4	0.578	1.052	0.258	6.48	11.42	1.047	21.95	26.90
	C	3.91	226.3	0.589	1.332	0.538	13.76	....	1.401	29.37	
	A	4.12	224.8	0.556	1.250	0.456	11.07	....	1.871	33.77	
14	B	4.21	195.6	0.608	1.190	0.396	9.41	9.03	1.727	31.17	31.07
	C	4.25	174.3	0.617	1.075	0.281	6.61	....	1.566	28.27	
	A	3.07	200.0	0.588	1.177	0.383	12.47	....	2.135	44:29	
5	B	3.35	185.9	0.606	1.127	0.333	9.94	10.66	1.805	37.45	38.95
	C	3.46	172.8	0.652	1.125	0.331	9.57	....	1.692	35.10	
	A	3.09	206.6	0.555	1.146	0.352	11.39	....	2.850	50.98	
16	B	3.47	189.7	0.580	1.099	0.305	8.79	8.95	2.425	43.38	43.80
	C	3.77	160.5	0.641	1.046	0.252	6.68	....	2.070	37.03	
	A	0.45	115.9	0.649	0.752	0.042	....	....	1.027	67.57	
17	B	0.49	131.8	0.621	0.819	0.025	5.10	....	1.050	69.08	65.84
	C	0.47	92.7	0.728	0.674	0.120	....	....	0.925	60.86	
	A	0.74	137.2	0.646	0.886	0.092	12.43	....	0.839	56.31	
18	B	0.66	120.6	0.670	0.808	0.014	2.12	5.48	0.847	56.85	54.83
	C	0.74	120.5	0.671	0.808	0.014	1.89	....	0.765	51.34	
	A	4.58	173.7	0.652	1.132	0.338	7.38	....	1.272	23.09	
19	B	4.22	174.1	0.654	1.139	0.345	8.18	8.08	1.637	29.71	27.02
	C	4.33	174.6	0.670	1.170	0.376	8.68	....	1.557	28.26	
	A	4.44	182.9	0.667	1.220	0.426	9.60	....	1.461	26.66	
20	B	4.48	174.9	0.677	1.184	0.390	8.71	9.02	1.388	25.33	26.48
	C	4.36	170.7	0.689	1.175	0.381	8.74	....	1.504	27.45	

TABLE VI.—AMOUNT OF RESIDUAL NITROGEN AND PROPORTION RECOVERED.

Series	Millet, 1899. Taken out by the oats.	Millet, 1899. Residual nitrogen. Grams.	Millet, 1899. Average per cent. of residual nitrogen recovered. Per cent.	Corn, 1900. Taken out by the oats.	Corn, 1900. Residual nitrogen. Grams.	Corn, 1900. Average per cent. of residual nitrogen recovered. Per cent.
1	...	...	...	....	...	....
2	...	...	...	....	...	....
3	8.3	3.04	17.5	10.81	3.61	10.02
4	40.2	3.14	15.9	30.60	2.76	11.75
5	8.4	1.80	19.2	7.38	3.70	9.86
6	13.8	3.90	5.5	22.06	3.15	6.25
7	75.8	0.19	...	80.42	0.16	....
8	69.0	0.48	...	76.30	0.37	....
9	16.4	3.43	12.7	19.97	3.87	9.91
10	29.4	3.44	17.8	27.99	4.03	10.80
11	46.5	3.23	16.8	41.43	2.79	11.56
12	46.8	3.61	21.8	44.68	3.06	12.92
13	21.3	2.16	6.8	17.50	3.94	11.42
14	35.1	2.28	10.6	24.25	4.19	9.03
15	21.6	4.16	5.9	31.71	3.29	10.66
16	29.1	4.31	6.9	38.32	3.44	8.95
17	50.3	0.81	...	68.84	0.47	....
18	40.4	0.92	...	52.15	0.71	5.48
19	27.9	2.58	7.5	20.63	4.38	8.08
20	23.3	2.69	11.1	19.20	4.43	9.02
Average		2.56	12.6		2.91	9.17

The figures again bring out the facts already noted in 1899. In all cases where manure had been applied, the plants were enabled to secure a larger amount of nitrogen than those on the check plot. More than that, the series where solid manure alone was applied, yielded more nitrogen in the residual crops, as compared with the series on which solid and liquid manure was applied. On the other hand, there was no gain over the check plot from the sodium nitrate and ammonium sulphate; in fact, there was even a slight loss. In the case of the dried blood, there was a small gain over the check plot. Hence it may be said here that there was no *residual* effect from the nitrate and the ammonia, and a very slight effect from the dried blood. Owing to a more uniform germination of the seed, the corn produced results also more uniform as compared with the millet of 1899. It will be observed that the yield of nitrogen on Series 2 was even slighter than that on Series 1, differing in this respect from the millet. Also this crop shows a percentage of nitrogen higher than the average in the dry matter on all of the series where there was not residual effect, as well as on the first two series, where no nitrogen was applied. Of the residual nitrogen, proportionately less was recovered in 1900. There was, on the average, 2.56 grams of residual nitrogen in each series in 1899, and 2.91 grams in 1900. Of that, there was recovered 12.6 per cent. in 1899, and 9.71 per cent. in 1900. The last figures represent the average per cent. recovery from fourteen series in 1899 and from fifteen in 1900.

THE AVAILABILITY OF THE RESIDUAL NITROGEN IN THE SOLID AND IN THE SOLID AND LIQUID PORTIONS OF FRESH MANURE, AND ALSO OF LEACHED MANURES.

In 1899 there were 3.04 grams of residual nitrogen on Series 3, and 3.14 grams on Series 4, when the oats were harvested. In 1900, there were 3.61 grams of residual nitrogen on Series 3, and 2.76 grams on Series 4. Of that nitrogen, there was recovered by the millet 17.8 per cent. on Series 3, and 15.9 per cent. on Series 4, while the corn recovered 10.02 per cent. on Series 3 and 11.75 per cent. on Series 4. It appears that the recovery in 1899 was greater than that in 1900, and furthermore the solid manure does not make as good a showing in 1900, as compared with the solid and liquid manure. This is applicable to both the fresh and leached manure. Thus the recovery from the solid and liquid manure, fresh, was greater, relatively than the recovery from the solid manure, which is contrary to the experience of 1899. However, Tables VII and VIII show that the absolute amounts of nitrogen furnished by the solid manure to the residual crops are greater than those supplied by the solid and liquid portions. The same is true of the leached manures. The solid portion yielded in 1899, 1.398 grams of nitrogen, and the solid and liquid portions yielded in 1899, 1.269 grams. The corresponding figures for 1900 are 1.158 grams for the solid, leached, and 0.991 gram for the solid and liquid, leached. In 5 and 6 the residual nitrogen was, in 1899, 1.80 grams and 3.99 grams, respectively, and of that there was recovered 19.2 per cent. for 5, and 5.5 per cent. for 6. In 1900 the residual nitrogen amounted to 3.70 grams in 5, and 3.15 per cent. in 6, and of that there was yielded in the corn 9.86 per cent. for 5, and 6.25 per cent.

TABLE VII.—NITROGEN IN THE CORN OF 1900—THE STUDY OF RESIDUAL EFFECTS.

Series.	Average weight of nitrogen in crop. Grams.	Average per cent. of nitrogen in crop. Per cent.
1	0.858	0.667
2	0.794	0.629
3	1.157	0.608
4	1.114	0.622
5	1.158	0.609
6	0.991	0.653
7	0.731	0.668
8	0.774	0.641
9	1.177	0.629
10	1.223	0.584
11	1.114	0.619
12	1.178	0.611
13	1.243	0.565
14	1.172	0.594
15	1.143	0.615
16	1.097	0.592
17	0.748	0.666
18	0.834	0.662
19	1.147	0.659
20	1.193	0.678

TABLE VIII.—NITROGEN IN THE MILLET OF 1899—THE STUDY OF RESIDUAL EFFECTS.

1	1.000	2.514
2	1.052	1.223
3	1.582	1.176
4	1.558	1.160
5	1.398	1.239
6	1.269	1.322
7	0.878	1.304
8	0.854	1.425
9	1.487	1.441
10	1.661	1.234
11	1.598	1.291
12	1.834	1.132
13	1.199	1.143
14	1.292	1.115
15	1.296	1.256
16	1.347	1.409
17	0.948	1.301
18	0.961	1.305
19	1.245	1.283
20	1.352	1.493

for 6. As in the previous year, the varying amounts of residual nitrogen rendered the problem more complicated; for all that, it appears that the greater the proportionate amount of soluble nitrogen in the manure applied, the smaller the amount of nitrogen recovered in the residual crop. Of the manure applied in 1899, there was contained in the solid portion 0.220 per cent. of soluble nitrogen. The residual crop obtained from Series 3, on the average, 1.582 grams of nitrogen and from Series 4, on the average, 1.558 grams of nitrogen, notwithstanding the fact that there was applied on Series 4, 5.25 grams of nitrogen as against 3.32 grams on Series 3. Similarly in 1900, the solid portion, fresh, contained 0.066 per cent. of soluble nitrogen, and the solid and liquid portion, fresh, 0.269 per cent. of soluble nitrogen. The residual crop obtained from Series 3, 1.157 grams of nitrogen and from Series 4, 1.114 grams of nitrogen; the same relations hold true, even more markedly, in the leached manures. The reason for the above is quite apparent if we consider that it is the soluble nitrogen in the manure that is rapidly changed, and having once undergone the change it is like nitrate in that it is largely lost to the crop if not taken up within a short time. The figures clearly indicate that there is no residual effect from the nitrate, and hence the more rapidly a given manure is nitrified, the smaller, everything else being equal, will be its residual effect. It should also be noted here, that in the case of the solid, leached, the residual crop appropriated more nitrogen than the first crop. This is true of both the millet and the corn. Subtracting the amount of nitrogen obtained from the check plots we find that the oats in 1900 obtained from the solid manure, leached, 0.295 gram of nitrogen, while the corn following the oats obtained from the residue 0.364 gram of nitrogen. Similarly, the oats in 1899 obtained from Series 5, 0.165 gram of nitrogen, while the millet following the oats obtained 0.346 gram of nitrogen.

THE AVAILABILITY OF THE RESIDUAL NITROGEN IN THE FORM OF NITRATE, AMMONIA, AND OF ORGANIC MATTER IN DRIED BLOOD.

It was already noted that from the nitrate, both 5 and 10 grams, and from the ammonia, no residual effect was obtained. The yield of nitrogen on Series 2 was 0.799 gram. On Series 7, where 5 grams of nitrogen were applied, the yield was 0.731 gram, and on

Series 8, with the double quantity of nitrate, the yield of nitrogen in the crop was 0.774 gram, so there was actually less nitrogen gathered by the residual crop from 7 and 8 than there was from the blank series. A similar observation was made in 1899, and the explanation seems to be that with the aid of the minerals and the nitrate, stronger plants are developed on 7 and 8 than there are on 2, and these, because of their better developed root system, are enabled to get more nitrogen out of the soil itself and thus leave it poorer. This view is supported by a comparison of the yields on Series 1 and 2. It will be noticed that the residual corn crop obtained more nitrogen from Series 1 than it did from Series 2. Now, no nitrogen has been added to either for three years, but minerals were applied on Series 2, and these enabled the crops to withdraw more nitrogen from the soil as a study of the analytical data will show. In like manner, on Series 17 there was no residual effect, and the nitrogen gathered by the corn was only 0.748 gram less than that obtained from Series 2. Above all things it seems clear that no residual effect need be expected from ammonium sulphate. It should be remembered that the residual crops were planted within a few days after the oat crops were harvested. On Series 18 there was a slight gain over Series 2, indicating that there was at least a small residue of nitrogen left for the corn. In 1899 no such effect was observed on 18, and should further experience prove that there is some residual effect from dried blood it can by no means be very great. Hence, as in 1899, we are confronted by the fact that although but 52.15 per cent. of nitrogen was recovered from the amount applied as dried blood, but 68.84 per cent. from that applied as ammonium sulphate, and but 76.30 per cent. from that applied as nitrate, no further benefit to succeeding crops need be expected from those particular applications. If anything, the availability of these three forms of nitrogen was slightly exaggerated because of the greater amounts of nitrogen taken out of the soil with their cooperation, nitrogen that was credited to them.

THE EFFECT OF THE USE OF THE SOLID AND OF THE SOLID AND LIQUID PORTIONS OF COW MANURE, FRESH AND LEACHED, ALONE, AND WITH NITROGEN IN THE FORM OF NITRATE, OF AMMONIA AND OF ORGANIC MATTER.

In the table submitted below are given the amounts of nitrogen applied, the percentage of the applied nitrogen recovered in the residual crop, the residual nitrogen after that crop, and the percentage of nitrogen obtained from the residue by the residual crop.

TABLE IX.

Series.	Total nitrogen applied. Grams.	Nitrogen recovered. Per cent.	Residual nitrogen. Grams.	Nitrogen recovered. Per cent.
3	4.05	8.96	3.61	10.02
4	3.98	8.04	2.76	11.75
5	3.99	9.12	3.70	9.86
6	4.04	4.88	3.15	6.25
7	0.78	...	0.16	...
8	1.55	...	0.37	...
17	1.52	...	0.47	...
18	1.49	2.68	0.71	5.48
9	4.83	7.93	3.87	9.91
10	5.60	7.66	4.03	10.80
11	4.76	6.72	2.79	11.56
12	5.53	6.94	3.06	12.92
13	4.77	9.41	3.94	11.42
14	5.54	6.80	4.19	9.03
15	4.82	7.24	3.29	10.66
16	5.59	5.42	3.44	8.95
19	5.51	6.41	4.38	8.08
20	5.48	7.28	4.43	9.02

The relations pointed out in the last report largely hold true also this year. The recovery in the combinations does not differ much from the recovery in the manures alone, which might be expected, since the dried blood shows but a very slight residual effect. It should again be emphasized here that the tabulated figures show less favorably for the manures used in combination than is actually the case, for as a matter of fact the recovery from the nitrate plots was less than from Series 2, which was used as the standard of comparison. In 1899 the solid, leached, showed the greatest variation in recovery, the figures being 19.2 per cent. for 5, and only 6.8 per cent. and 10.6 per cent., respectively, for 13 and 14. In 1900 the results are more uniform. The recovery for 5 is 9.86 per cent. of the residual nitrogen (Table IX), while the average recovery from 13, 14, 19 and 20, where 5 was used in combination with 7, 8, 17 and 18, is 9.37 per cent. Similarly the recovery from 3 is 10.02 per cent., and the average recovery from 9 and 10 is 10.35 per cent. The recovery from 4 is 11.75 per cent., and the average recovery from 11 and 12 is 12.24 per cent. In

Series 6 the recovery was 6.25 per cent., while the average recovery in 15 and 16 was 9.80 per cent., showing a considerable increase for the two, an increase that was not quite as marked in 1899. The maximum residual recovery was 12.92 per cent. in Series 12; the minimum residual recovery was 5.48 per cent. in Series 18. In 1899, the maximum residual recovery was 21.8 per cent. in 12, and the minimum residual recovery 5.5 per cent. in 6.

THE AVAILABILITY OF THE NITROGEN IN THE DIFFERENT MATERIALS USED WHEN THE COMBINED RESULTS OF THE TWO CROPS, OATS AND CORN, ARE CONSIDERED.

Because of a more favorable season, the availability of the nitrate, ammonia, and of the dried blood, was higher than it was in 1899. Not alone was there a greater quantity of nitrogen taken out of the check plots, but it also seems that on the nitrate, ammonia and dried blood plots, there was a proportionately larger quantity taken out of the soil. This assumption is justified by the results obtained from the residual crops on the series named. It follows from this that when the first crop is taken alone, the availability of the three forms mentioned is placed somewhat above its true value. On the other hand, the exhaustion of the humus on these series would modify the soil to such an extent as to influence the yields appreciably. It is for these reasons that the returns from the combinations cannot be expected to be almost exactly equal to the sum for the series where the materials are used singly. Aside from the slight discrepancies, however, the agreements are more than satisfactory.

From quick-acting materials immediate returns are expected, and no residual effects are looked for. Hence, they are at a disadvantage when compared with slowly decaying organic materials through two or more crops. This was already pointed out in last year's report. It was also noted then that on account of the smaller returns in the residual crop from 7, 8, and 17 as compared with Series 2, the percentage recovery of these materials is somewhat lowered, since the losses shown for these materials in the residual crop must be subtracted from the gains made in the oat crops. A more detailed discussion of this point in question was presented elsewhere.[1] The following table shows the percentage recovery of nitrogen for all of the series when the two crops are

[1] N. J. Sta. Rep., 1900, p. 108.

used as the basis of calculating, as well as the calculated recovery of those series where the combinations of materials was used.

TABLE X.

	Series.	Nitrogen recovered. Per cent.	Calculated recovery. Per cent.	Nitrogen not recovered in the combinations of materials. Per cent.
Solid manure, fresh......	3	19.78	....	....
Solid and liquid, fresh ...	4	38.61	....	....
Solid, leached	5	16.50	....	....
Solid and liquid, leached.	6	26.94	....	....
Sodium nitrate...........	7	72.22	....	....
Sodium nitrate...........	8	75.03	....	....
Ammonium sulphate.....	17	65.84	....	....
Dried blood	18	54.83	....	....
7 and 3 in	9	27.89	28.94	1.24
8 and 3 in	10	35.66	35.07	....
7 and 4 in	11	48.14	44.14	....
8 and 4 in	12	51.62	48.84	....
7 and 5 in	13	26.90	25.60	....
8 and 5 in	14	31.07	32.87	5.48
7 and 6 in	15	38.95	34.25	....
8 and 6 in	16	43.80	40.27	....
17 and 5 in	19	27.02	30.11	10.26
18 and 5 in	20	26.48	26.92	1.63

The figures show that in six cases out of ten there was a gain on the combinations over the sum of the increase on the materials when they were used singly. Of the other four, 9 and 20 show but slight differences, and may be disregarded, and on 14 and 19 the losses were 5.48 and 10.25 per cent., respectively. It is evident from the results, that there was no denitrification, and this confirms the experience of last year.

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ON THE COMPOSITION OF THE FERROCYANIDES OF ZINC.

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THIS work was undertaken to determine the ratios of iron, potassium and zinc in the potassium zinc ferrocyanides, when precipitated under certain definite conditions in view of the contradictory statements which have appeared regarding their composition. The precipitates were all formed in large beakers in the