Bacteria and Soil Fertility

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Abstract
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BACTERIA AND SOIL FERTILITY

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BACTERIA IN RELATION TO SOIL FERTILITY

BY P. E. BROWN.

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Therefore, a study of soil fertility, or the crop producing power of a soil under given climatic conditions is of vast importance. Men must have knowledge of the fertility of a soil if they would properly regulate its support power so that the needed supply of plant food may be available for crop production.

Plant food consists of those chemical elements which are essential for the growth of plants and includes a large number of substances. Among these, nitrogen, potassium, phosphorus, and sulfur are most likely to be lacking in soils. In rare cases other elements may be deficient, but in normal soils, if enough of these four elements is present in a soluble, available form, the support power of the soil is satisfactory.

Many soils contain enough of these four necessary elements but they are locked up in an insoluble and unavailable form and hence must be changed and made soluble to be of use to crops. How is this change accomplished? What determines the production of soluble plant food in the soil? What regulates the support power of the soil? These are the questions which require a definite answer.

The factors which bring about the change of insoluble substances into soluble in the soil, may be grouped into three classes, physical, chemical and bacteriological.

The physical factors, such as light, heat, water, air, etc., and the chemical factors, such as soil acidity or sourness, the character of the chemical compounds present, etc., have been known and studied for many years. The bacteriological factors have come into prominence only quite recently, but now they are recognized to be of as much, if not more importance than the other two groups.

It has been well said that these three groups of factors working
together constitute the "commissary department for the army of plant life."

While, therefore, it is quite generally known now that the soil is the home of myriads of microscopic plants called bacteria, and that these have much to do with fertility, there is still a great deal of haziness about the subject in the public mind.

This circular is intended to clear up this haziness and to present in plain terms our present knowledge about bacteria in the soil and the part they play in making plant food available.

**FACTS ABOUT BACTERIA**

Before considering the part which bacteria take in liberating plant food it is well to bear in mind the fundamental facts about bacteria.

Bacteria are minute plants, consisting of single cells. These cells are made up of a cell-wall, and the living substance or protoplasm within the cell-wall. In the protoplasm the life processes are carried on. When food is absorbed, it passes into the cell through the cell-wall and the necessary portions are taken up by the protoplasm while the waste is eliminated, passing out through the cell-wall.

**FIG. 1.—Types of Bacteria, Cocci, Bacilli and Spirilla from left to right, many times magnified.**

**Types.** There are three main types of bacteria grouped according to form. They are the **cocci** or spheres, the **bacilli** or rods, and the **spirilla** or spirals. These groups have been popularly described as billiard balls, lead pencils and corkscrews. By far the largest number of soil bacteria belong to the group of bacilli or rods.

**Multiplication...** These simple organisms multiply by fission, that is, one cell divides into two equal parts, which may separate or may remain united. The spherical bacteria, due to their method of multiplication, frequently appear as packets of varying numbers of organisms, while the rods and spirals appear singly or in chains.

**Rate of Increase.** The splitting of one organism into two may be completed in twenty minutes to one half hour under very favorable conditions. At this rate, in one day one organism would become about $300,000,000,000,000$. As a matter of fact, however, such a rapid multi-
plication cannot occur, as food conditions do not remain satisfactory and the growth of the organisms gives products that restrict development.

Size. Bacteria are very small, ranging from 1-50,000 to 1-1,000 of an inch in length and averaging about 1-25,000 of an inch.

Motility. Many bacteria have flagella, or long thread-like appendages, by means of which they move about freely in any liquid in which they may be growing. These flagella may be attached in various ways, singly at the end of the organism, in tufts of several at one or both ends, or scattered indiscriminately over the organism.

Sporulation. Some bacteria under certain conditions, produce so-called spores, or cells surrounded by a very resistant cell-wall. They will remain alive practically indefinitely if not exposed to extremes of heat or cold and if kept dry; and when placed under favorable conditions will germinate and produce active bacteria again.

Sterilization. Sterilization is any process whereby bacteria are killed. The methods of sterilization which may be employed, depending on the materials which are to be freed from bacteria, are dry heat, steam under pressure, intermittent sterilization, which consists in heating at the temperature of boiling water for one-half hour on three successive days, chemical substances, sunlight, etc.

Cultures. Knowledge about sterilization, the food needed by bacteria, and other necessities for their growth, is used in the laboratory by growing bacteria on culture media, that is, any substance which will support their growth. Such a growth is called a culture, and when only one kind of organism is present, such a culture becomes a pure culture.
Classes. All bacteria may be included in one of two large classes depending on their functions, or the character of their activities. These are the parasites and the saprophytes. The parasites include all the disease producers. The saprophytes are the decay producers. Many people think of all bacteria as connected with disease. They know that typhoid, diphtheria, tuberculosis and other diseases are caused by bacteria and fall into the error of believing that all organisms are active in causing some dread disease. Such is far from being the case, however. The saprophytic, or decay bacteria, are invaluable. They have been called the "link between the world of the living and the dead." They transform dead materials back into living matter and thus complete the cycles through which, in nature, all substances must go. Bacteria are everywhere, in the air, the water, the soil, but contrary to the popular belief, which is that we are becoming "bacteria crazy," such general distribution is no cause for alarm but rather a source of benefit. A bacteria-free world would soon be a dead world.

BACTERIA IN THE SOIL

Enormous numbers of bacteria inhabit the soil, some of them harmful, but the vast majority beneficial. Actual counts have shown that the numbers present in soils may vary from a few thousand per gram (about 1-30 of an ounce) to over fifty million per gram.

CONDITIONS AFFECTING THE GROWTH OF BACTERIA.

There are certain conditions affecting the growth of bacteria. A discussion of these has purposely been omitted up to this point in

FIG. 4.—A pure culture of Bacillus prodigious, an organism that produces red pigment.
order to consider them from the standpoint of the soil. In other words, the bacteria in the soil, just as in any other environment, are greatly influenced by certain physical and chemical conditions. These conditions are moisture, temperature, aeration, reaction, and food supply.

Moisture. A proper amount of water in the soil is as necessary for the growth of bacteria as for crops. Either excessive moisture or severe drought interferes with bacterial growth very considerably. Many organisms are killed by too much moisture, many others, by insufficient moisture. Merely drying out a soil by exposing it to the air, however, will not kill the bacteria present. Such soils, kept for years in an air-dry state, have been shown to contain certain bacteria which had evidently been in a dormant condition. Such farm practices as drainage, which removes excessive water, or cultivation, which prevents undue loss of water by evaporation, have an important influence on the bacteria in the soil. Recent work has shown that small variations in moisture are of little influence on bacteria in the field, other factors apparently being of greater importance, but when variations are large, then moisture becomes the governing factor.

Temperature. Every organism grows the best at a certain temperature which is called its optimum temperature. Each also has so-called maximum and minimum temperatures at which points growth ceases. The optimum temperature for most soil organisms ranges from 65°-90° F., although of course there are exceptions to this statement. Most organisms are not killed by excessive cold but merely remain dormant. In fact, it has been shown recently that certain

FIG. 5—Nodules on Alfalfa roots.
bacteria are alive and active in soil in late winter, at a soil temperature somewhat below the freezing point. It is generally considered, however, and with reason, that the greatest bacterial activities occur in the soil during the summer and are then of the most significance. Those occurring during the winter are of importance only when fall applications of manure are made.

Aeration. Depending upon their requirements as to air, bacteria may be divided into three classes: the aerobes, which require air for their growth; the anaerobes, which grow only in the absence of air, and facultative anaerobes, which prefer air, but will grow without it. In general it may be said that the beneficial bacteria in the soil need air. Hence in heavy clay soils where there is not enough air, methods which increase the circulation of oxygen in the soil, increase bacterial activities; these increase the solution of plant food and this ultimately increases crop production. On the other hand, if there is too much air present, as in light sandy soils, the bacterial activities will be too great and the humus will be burned up too rapidly, plant food will be produced in too large quantities to be utilized by the crops, and more or less extensive losses of valuable soil elements will occur. Methods must be practiced with such soil, which will make it more compact and prevent the excessive circulation of air, reducing bacterial activities to what is best.

Reaction. The reaction of a soil is its relative acidity, or "sourness" or alkalinity. The reaction means much from the bacterial standpoint. Soils which have become acid or sour are notably unproductive and this is largely due to the fact that the growth of beneficial bacteria in such soils is checked. Some bacteria are probably favored by acid conditions but those organisms which bring about the solution of the important plant food constituents refuse to develop in acid soils. Such an unfavorable condition may be remedied by application of ground limestone or caustic lime in varying amounts. Applications of ground limestone to sour soils have been shown to be followed by increased beneficial bacterial activities and later by increased crop production. (Further information regarding application of lime to Iowa soils may be found in Circular No. 2 of the Iowa Agricultural Experiment Station.)

Food Supply. Bacteria require food for growth just as truly as do crops, and it is because of this need that they influence fertility. In the process of taking up food from the chemical compounds in the soil, the bacteria cause changes in the compounds, making them soluble and hence available for the growth of plants. Most soil bacteria live principally on organic matter, or humus, and the products of their own activity. Some few species are known which live in the absence of organic materials. Usually, however, soils without humus are without bacteria. Increasing the humus content, therefore, may be expected to increase the bacterial life. That is actually the case up to a certain limit, which varies widely for different soils.
Beyond a certain point, however, the amount of food ceases to govern bacterial growth and a lack of moisture or the presence of acidity or sourness may offset the benefits of a greater food supply. The minerals in the soil solution also have some influence on the bacteria. Certain groups are favored by some substances and others restricted or killed by certain other chemicals. Thus the bacterial floras of the soils of wet and dry regions are quite different.

The bacteria furthermore not only act on the humus or organic matter in the soil and bring about its solution in the process of obtaining their food, but they also attack the mineral portion of the soil and change insoluble portions of that into soluble.

**BACTERIA AND THE TRANSFORMATION OF PLANT FOOD**

We have considered the fact that the fertility of a soil is determined very largely by the bacterial activities going on therein. We have discussed briefly the nature of bacteria, their form, size, multiplication, etc., the numbers present in the soil and the effect of various physical and chemical conditions in the soil on their development. We have found also that in the course of their life activities, bacteria attack the organic and mineral portions of the soil and transform insoluble constituents into forms soluble and available for crop nourishment. It now remains to show how this change is ac-
complished, to consider the various stages through which the transformation proceeds, to discuss the bacteria involved, and to reach some conclusion regarding the importance from the fertility standpoint of the changes brought about in this way in the store of plant food constituents.

THE NITROGEN PROBLEM AND ITS SOLUTION.

Soils are very apt to be deficient in nitrogen. This element, then, is generally the limiting factor in the growth of crops. Formerly the lack of nitrogen in a soil was supplied by application of nitrate of soda, which was obtained from the nitrate beds in Chili. With the increasing demands for nitrates, the amounts taken yearly from the nitrate beds were enormous and it was estimated that in a very short time the deposits would be exhausted and the world would face a nitrogen famine. Of course, other nitrogenous materials were available for manure, but in such small amounts that they would be merely a drop in the bucket in supplying the demands of the world.

It was just at this crucial time that soil bacteriologists came to the rescue and quieted the general fears by showing that certain species of bacteria living in soils have the ability to draw upon the inexhaustible supply of nitrogen in the air (which contains 79% nitrogen) and fix it in the soil in a form available for plants. Thus the nitrogen problem was solved and there need be no fear of a nitrogen famine.

NITROGEN FIXATION.

There are two classes of bacteria which are thus able to utilize
the nitrogen of the air in their growth: First, those which live entirely dependent on their own resources, and second, those which grow on the roots of legumes such as clover, alfalfa, etc. The first are said to live non-symbiotically, or independently, and are known as non-symbiotic; the second are said to live in symbiosis with the legumes, or in a state of mutual helpfulness and are called symbiotic.

NON-SYMBIOTIC NITROGEN FIXATION.

The first group of nitrogen fixers, or azotobacter as they are called is present in most soils. These bacteria fix nitrogen in amounts which have been estimated at from 15 to 40 lbs. per acre per year under ordinary conditions. One instance is on record where fixation took place to the extent of 100 tons per acre to a depth of a few inches. This of course was excessive and all vegetation was killed.

This single instance of "too much of a good thing" is not to be taken however as an argument against encouraging the activities of the azotobacter. Proper farm management includes many practices which encourage the fixation of nitrogen from the atmosphere. Thus the ordinary operations of tillage, which open up the soil and admit of a free circulation of air, encourage the growth of these free-living bacteria and bring about greater fixation of nitrogen from the atmosphere. So also liming as a remedy for acidity increases the amount of nitrogen in the soil by causing a greater growth of azotobacter.

In other words, any practice which brings about better physical and chemical conditions in the soil for the growth of bacteria increases the activities of this particular group of organisms and the soil gains in nitrogen content.

SYMBIOTIC NITROGEN FIXATION.

The beneficial effect of clover growing on soils was known many years before it was satisfactorily explained. The mystery was not cleared up until the bacteriologists found that certain bacteria were associated with legumes and that these bacteria took nitrogen from the air and fixed it in the soil.

Legumes will grow and flourish on soils that have absolutely no nitrogen if the proper bacteria are present and the legumes become inoculated with these bacteria. In this process of inoculation the bacteria enter the roots of the legumes. The plants aid the process by a softening of their tissue and then in so-called "infection-threads" the bacteria pass from cell to cell. They gather at a particular spot and, nourished by the plant, multiply to a large extent and form what are known as nodules, or swellings on the roots. As soon as the organisms begin to multiply they begin to take nitrogen from the atmosphere and to supply it to the plant. The plant in return supplies the bacteria with the necessary carbonaceous food and a close union for mutual benefit is thereby established. So the legumes draw but a small proportion of their nitrogen from the soil and if the
entire crop is turned under for a green manure, which is a common practice, there is a large gain to the soil in nitrogen.

Legumes will often grow without inoculation and in soils very rich in nitrogen will yield good crops. They then draw their entire nourishment from the soil. When that is the case the legumes have no advantage over the non-leguminous crop. But when legumes are inoculated they contain a larger percentage of nitrogen and the soil is not robbed of its stock of nitrogen.

SOIL INOCULATION.

The bacteria necessary for the inoculation of legumes are not always present in soils and hence we have to resort to what is known as soil inoculation, which consists in introducing the proper organisms into the soil. This may be done in two ways: By inoculating the seed with pure cultures, that is, cultures of the particular organism grown on some convenient medium, or by spreading on the land to be seeded, soil from a field where the particular legume to be grown has been successfully grown previously.

Several commercial concerns, the United States department of agriculture, and some experiment stations prepare cultures for the inoculation of legumes but none has as yet proved to be absolutely satisfactory. Cultures are not always certain of accomplishing inoculation and consequently we still recommend the use of soil for

![Nodules on Crimson Clover roots.](image-url)
the purpose. Three hundred to 500 pounds of soil per acre should be uniformly distributed, just previous to seeding over the field to be inoculated, and disked in. In this way bacteria in an active state of multiplication are introduced without material change in the character of their surroundings and they become vigorous and easily enter the roots of the legume, insuring inoculation and a good crop.

AMMONIFICATION.

The activities of soil bacteria with regard to the nitrogen problem are important not only from the standpoint of increasing the nitrogen content of soils through additions from the atmosphere but also in the change of organic materials into available forms.

Plant and animal remains in the soil, farmyard manure, green manures, or other organic materials added to the soil contain insoluble organic nitrogenous matter known as protein and these must be changed into soluble nitrates to be of use to plants. This solution is accomplished by the process of decay. Bacteria are the active agents bringing about this decay in the soil. Various groups of universally distributed organisms are involved. In the first place the insoluble proteins are changed into soluble peptones, these are changed to amino acids and these in turn to ammonia. This change of protein into ammonia is called ammonification, and it constitutes a vital stage in the production of nitrates in the soil. It is important also in that it brings about the formation and later the destruction of humus.

Humus is decaying organic matter in the soil. We know that the presence of a proper amount of humus and also the best rate of destruction are important factors from the physical and chemical standpoint in determining the fertility of a soil. The ammonifying bacteria attack the organic materials in the soil and bring about the
formation of humus. This action continues and if no more organic substances are supplied, the humus in the soil is used up. Furthermore, if the soil is too open, too much air is admitted and the bacterial activities are so strong that the humus is destroyed and fertility is lost. Thus in sandy soils it is very difficult to keep up the humus content and recourse is had to green manuring for upbuilding purposes. In ordinary soils, however, the destruction of the humus is not so rapid, but in any case if the soil does not receive additions of organic matter at more or less frequent intervals, it will become deficient in humus.

Introduction of barnyard manure brings about vastly increased bacterial action due to the large amount of organic matter added and also the large number of bacteria introduced. Thus the ammonifying power of a soil is increased by addition of manure. Liming also has been shown to increase the activities of the ammonifying bacteria and consequently to hasten the production of plant food. All tillage which admits air to the soil increases the ammonia producing power of the soil and later the nitrate production.

NITRIFICATION.

Ammonium compounds produced in the soil as just described never accumulate to any appreciable extent but are transformed into nitrates almost as rapidly as they are formed. This transformation is called nitrification and includes two stages: the change of ammonia to nitrates and then the oxidation of nitrates to nitrates. Two distinct classes of organisms are involved in the process and they are both of practically universal distribution.

All the farming operations which increase ammonification have a similar effect on nitrification, since nitrification starts where ammonification leaves off. Particularly necessary for nitrification, however, is the presence of lime in soils. This is due to the fact that nitrous and nitric acids are produced in the process of nitrification and if they are not neutralized by lime they accumulate and very quickly stop bacterial action.

The nitrifying bacteria are also sensitive to an excess of organic matter but the amounts present in ordinary soils are never large enough to depress nitrification.

It is evident then that the activities of both the ammonifying and the nitrifying bacteria are governed very closely by the climatic and farming conditions with regard to moisture, temperature, acidity, aeration, and food supply.

DENITRIFICATION.

There is one process which is the result of bacterial action and is deserving of mention here, if for no other reason than to set aside suspicions as to its common occurrence in the soil. It is denitrification. Denitrification is a process brought about by certain bacteria
leading to the loss of gaseous nitrogen into the atmosphere. If this loss in the field were considerable the importance of the process would be evident. As a matter of fact, however, the danger of loss is very remote. The conditions necessary for denitrification, which are excessive organic matter, large amounts of water, nitrates and the proper bacteria, are rarely met with in the soil. Only when exceedingly large amounts of fresh barnyard manure and sodium nitrate are applied together, a practice which is commonly condemned, could denitrification occur. Depression in crop yields which have sometimes been observed when large quantities of manure have been applied and which have been attributed to denitrification were more likely due to some other cause, perhaps to the soluble organic matter introduced. With ordinary applications of barnyard manure, the farmer need have no fear of losing nitrogen from his soil by this process.

**BACTERIA AND MINERALS IN THE SOIL.**

In the process of decay of which we have spoken, the destruction of the organic nitrogenous materials leads to the production of other compounds than ammonia and nitrates. Chief among these is carbon dioxide. Furthermore, the organic non-nitrogenous substances, such as starches, sugars, cellulose, etc., are destroyed in the general decay which occurs in the organic matter and among the variety of products which result we find various organic acids and particularly carbon dioxide. These organic acids and the carbon dioxide have the power of attacking insoluble mineral compounds in the soil and transforming them into soluble forms, available for plant food. Thus insoluble phosphates and potash compounds are acted upon and changed into soluble forms by the soil water carrying the carbon dioxide and organic acids in solution. Again we see that bacterial activities bring about the preparation of plant food.

The demands of various crops for sulfur has been the subject of recent investigations and it has been estimated that the supply of sulfates in the soil may be insufficient in many cases for the proper feeding of certain crops. A group of organisms occurring in the soil and known as the sulfur bacteria come into prominence here as the agency keeping up the proper supply of sulfates. When proteins decay, hydrogen sulfide gas is set free. This is taken up by the sulfur bacteria and oxidized to free sulfur which is in turn oxidized to sulfates. Increased decay therefore leads to increased hydrogen sulfide and this in turn to increased sulfates for plant food.

We may conclude, therefore, that all methods which increase the activities of the decay bacteria lead directly to an increased supply of available nitrogen, and indirectly to larger amounts of phosphorus, potassium, and sulfur becoming available for plant food.
CONCLUSION.

In conclusion the fact must be emphasized that the bacterial processes going on in the soil cannot be ignored in a consideration of its fertility. The physical and chemical character of the soil alone will not tell us its crop producing power and we must depend on the results of tests of bacterial activities. The recent development of methods in this direction gives us reason to hope that in the near future bacterial tests of fertility may become of considerable practical value.

From the practical standpoint, it should be evident that the greatest care ought to be exercised on every farm to maintain conditions satisfactory for the best growth of beneficial bacterial species. Moisture conditions should be governed as far as possible by drainage or cultivation, aeration should be carefully regulated to keep the destruction of the humus from proceeding too rapidly; and the reaction of the soil should not be allowed to become acid, adding lime if necessary to prevent it. If these conditions are carefully governed and the humus content of the soil is properly maintained by manuring with farmyard or green manure, and proper rotations containing a legume are employed, the bacteria can be depended upon to perform their part faithfully and well and the crop will not fail for lack of sufficient available nitrogen.

Furthermore, if chemical analyses have shown sufficient amounts of the necessary mineral plant food constituents, the bacteria under the optimum conditions just outlined will transform it into an available form to satisfy the needs of the growing crop.

In short, the relation between bacteria and soil fertility is very close and very vital and systems of permanent agriculture must rest firmly on a bacteriological basis to be of any value.