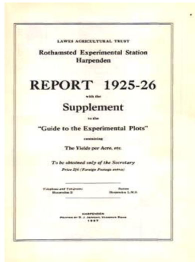
ROTHAMSTED RESEARCH

Report 1925-26 With the Supplement to the Guide to the Experimental Plots



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Soil Microbiology

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SOIL MICROBIOLOGY.

Large as are the quantities of artificial fertilisers used in this country, the amounts of organic manure, such as farmyard manure, animal excretions, green manure, or residues of clover, or seeds leys are much greater. It has been estimated that farmers of this country make farmyard manure of the value of £14,000,000 a year, to say nothing of the value of the clover and other residues ploughed in.

These materials are not in themselves of use as fertilisers. It is only when they have undergone certain changes that they become valuable. During the process they may and often do suffer serious losses; it is estimated, for example, that about half the value of the farmyard manure is lost. These changes, both beneficial and harmful, are brought about by minute organisms living in the soil.

Soil micro-organisms thus play an important part in soil fertility. Among the more important are the following:—

1. They decompose the residues of plants and animals, converting them into simpler substances, such as nitrate, potassium, calcium, and other compounds that serve as plant nutrients, and also producing humus, which greatly improves the soil. The decomposition of cellulose can be effected both by fungi and bacteria. During the past year Dr. Kalnins has found several new bacteria capable of decomposing it aerobically, while Dr. Rege has isolated three common soil fungi which, under aerobic conditions are, in combination, as active as the total soil population and far more active than the soil bacteria alone. No soil organism, however, either fungus or bacterium, has yet been found to decompose lignin, which, on chemical grounds, is now regarded as a probable source of humus.

2. The carbon dioxide produced in the decomposition and during the respiration of the organisms, partly remains in the soil, dissolving certain soil constituents, and thus influencing the supply of mineral substances to the plant; the rest escapes into the air, where it contributes to the supply of carbon for the plant. Measurements have been begun of the amount thus escaping from soils under different manurial treatments.

3. Certain substances formed in soil and harmful to growing plants are decomposed and rendered innocuous by some of the organisms. The decomposition of phenol was dealt with in the last Report; that of indol, a well-known product of the bacterial decomposition of organic matter, has been studied this season. Three soil bacteria found by Mr. Gray have the remarkable power of converting it into indigo. This reaction does not furnish the organisms with all the energy they need, so that some other carbon compound has to be present as well.

4. A few of the soil organisms fix gaseous nitrogen from the air, converting it into protein, which is readily broken down to ammonia, and appears ultimately as nitrate.

5. Most of them, however, obtain their nitrogen from nitrogenous compounds in the soil. Many assimilate nitrate, thus competing with and injuring the plant in spring and early summer. In late autumn and winter, however, the plant does not suffer and the soil gains because the nitrate which they take is converted into

protein, and thus protected from being washed out from the soil; in the following spring the protein decomposes with formation of nitrate once more.

The organisms most directly concerned are bacteria which bring about all these changes, and fungi and algæ which effect some of them. Of the protozoa, the amœbæ, some of the flagellates and, so far as they are active, the ciliates, are indirectly important because they keep down the numbers of bacteria. The action of the rest of the flagellates, which occur in large numbers, is unknown, but all the protozoa, like the fungi, algæ, and bacteria, lock up in their bodies nitrogen compounds which, if not so held, might decompose and be lost from the soil.

The study of soil micro-organisms has for many years been one of the characteristic features of the Rothamsted investigations and post-graduate students come from all parts of the world to take part in the work.

It has been shown that the common bacteria, protozoa, algæ and fungi, are widely distributed, occurring in the soils of widely separated regions, there being apparently less variation in the soil population than in the surface flora or fauna. The numbers of the bacteria* and the protozoa in field soils can be estimated; they are very great, but not steady; they fluctuate continuously, and the fluctuations on adjoining plots of land are similar, though they are not obviously related to changes in soil moisture and temperature. The numbers of bacteria and active amœbæ, however, change in opposite directions; when the active amœbæ increase the bacteria decrease and *vice versa*; this happens both in the field and in laboratory tests where sterile soils are innoculated with various groups of organisms. While the protozoa reduce the numbers of bacteria it is not yet clear how they affect the changes produced in the soil. This year's work by Mr. Cutler and Miss Crump suggests that amœbæ, the flagellate *Cercomonas crassicauda,* diminish the evolution of carbon dioxide from soil and hinder the decomposition of added organic matter (*e.g.*, sugar), which suggests that they may decrease the amount of decomposition of plant and animal residues, though the action is not entirely simple. Dr. Skinner confirmed these observations, using soils partially sterilised by heat, and showed also a decrease in ammonia production. But protozoa increase the amount of nitrogen fixed by Azotobacter, an apparent anomaly which Mr. Cutler explains as the result of the amœbæ feeding on the Azotobacter, and so conserving in their bodies much of the nitrogen already fixed and also maintaining a high efficiency of fixation by keeping the cultures young. This reaction does not stand by itself, since the nitrogen fixing organisms appear generally to work better in company than alone.

Mr. Sandon's systematic examination of the soil protozoa has revealed about 250 different forms; a description and key to their classification has been prepared. (See p. 88.) Most of these are also found in other habitats, but 18 of them, 8 flagellates and 10 amœbæ, have so far been found only in soil.

*Not the total numbers, for no medium allows the development of all the bacteria present in soil. The estimates are, however, comparable with one another.

The soil algæ are studied by Dr. B. M. Bristol Roach. Those which are on the surface in full light obtain their energy and their food from sunlight and carbon dioxide like other green plants; they add to the stock of organic matter in soil. Those which are buried in the soil and so cut off from the light, do not die; they continue to live vegetatively and to multiply slowly, deriving energy and food from the soluble organic substances present there. In intermediate light conditions they can live both saprophytically and photosynthetically. In all conditions they probably assimilate nitrate.

The soil fungi are difficult to study and no quantitative methods have yet been devised for estimating the amount of their mycelium in the soil or the numbers of " individuals " present, so that these may be compared with protozoa or bacteria. Mycelium often occurs, particularly in humus soils, in such quantity as to be visible to the naked eye, and obviously to form a significant part of the soil structure. During the last two years Dr. Brierley has worked out quantitative methods which give results capable under proper conditions, of being repeated. The technique was analysed into its constituent factors such as: (1) Sampling; (2) Suspension; (3) Disintegration; (4) Dilution; (5) Plating; (6) Incubation; (7) Counting; and as many as possible of these were standardized. The method finally evolved has been tested by studying the lateral and vertical distribution of fungi in soils of different character. It records only such fungi as can grow under the conditions provided and, in any single experiment, this is only a small proportion of those present. Even so, the numbers obtained are enormous, but, even in soils under such uniform treatment as the Broadbalk plots, their lateral distribution is very unequal, a sample sometimes containing two or three times the number found in another sample taken from a few yards away. Fungi occur in greatest numbers in the top 1—8 inches, they are still plentiful at 12—18 inches, and even in heavy yellow clay have been found at a depth of 6 feet.

Certain soil fungi studied by Dr. Rege rapidly decompose cellulosic materials and, under certain conditions, species of *Coprinus*, *Aspergillus* and *Acremoniella* decompose straw as rapidly as the whole soil population, and far more rapidly than the soil bacteria alone. Fungi play an important part in soil changes, decomposing plant remains and producing humus, and locking up nitrogen in the form of protein. The exact nature and extent of these changes is still to be explored.

In addition to the above actions, which affect the dead plant-residues in the soil, there are others directly affecting the living plants. Many soil fungi live in active beneficial relation to higher plants, penetrating their tissues and living symbiotically as mycorrhiza. On the other hand the soil is a reservoir of vast numbers of fungi causing disease and death of crop-plants; of these the fungus causing wart disease in potatoes is being studied in detail. Methods to reduce the ill effects produced by these organisms have been devised and are being tested.

Hitherto, investigators in soil microbiology have been greatly handicapped by their inability to sterilise soil without altering it chemically and physically. Dr. McLennan has, however, devised

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a method of drying *in vacuo,* which almost, or completely eliminates living fungi and bacteria, but leaves the soil otherwise unchanged. This is likely to prove of great assistance for future workers.

APPLICATIONS OF SOIL MICROBIOLOGY.

Soil microbiology has already found application in five practical problems :—

1. The inoculation of lucerne and other leguminous crops.
2. The partial sterilisation of glasshouse soils.
3. The fermentation of cellulosic materials with production of a humus manure closely resembling farmyard manure.
4. Overcoming some of the difficulties connected with the preparation of a useful manure from sewage : one of the great unsolved problems of modern civilisation.
5. In the United States the use of sulphur to make a neutral or alkaline soil sufficiently acid to be unsuitable for the development of potato scab (*Actinomyces* scabies), and to render mineral phosphates soluble.

We shall deal with the first four of these in detail.

Inoculation of Lucerne and other Leguminous Crops.

Reference has already been made to the fact that arable husbandry produces the larger output per acre and is therefore the better for the country, while grass husbandry, involving much less expenditure, offers greater possibilities of making some profit and is therefore the safer course for the farmer. The lucerne crop combines the advantages of both systems, giving high output per acre, and at the same time low costs and some hope of profit. It has therefore been the subject of many of our experiments.

Although it was introduced into England nearly 300 years ago, at the same time as the culture of red clover was being advocated, it did not spread beyond a small area in the east; elsewhere it was hardly grown. One important reason for this is that the necessary organism does not occur naturally in our soils while that for red clover does. Mr. Thornton has worked out a method, based on certain continental experiences and some Rothamsted bacteriological investigations, whereby the necessary organisms can be added with the seed; this has been tested during the last two years at about 50 centres in Great Britain, the necessary funds being provided by a grant from the Royal Agricultural Society.

The results fall into two groups : (a) those from the counties where lucerne has been grown so long that the soil has become infected with the proper organism; (b) those from centres where lucerne is rarely grown and the organism is not present in the soil.

In the area where lucerne is an old-established crop, the young plants commonly obtain sufficient nodules for their needs from the "wild" bacteria already present. Inoculation may hasten the appearance of the nodules, because the wild bacteria may be some distance away from the rootlets, but this is of little advantage where there is sufficient nitrogenous plant food in the soil for the young plants. But if the land be weedy or a cover