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Soil Microbiology

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it is much increased by farmyard manure. A method is badly needed for estimating the extent to which the soil is saturated with bases, or, alternatively, the extent to which the bases have been replaced by acid hydrogen: attempts are being made to solve this problem by mixing the soil with excess of calcium carbonate and extracting with sodium chloride.

The most widely used and most convenient way of measuring the reaction of the soil is the quinhydrone electrometric method. Miss Heintze and Dr. Crowther used it for a series of Gold Coast soils and obtained clear and definite results at least one-third of which subsequently proved to be quite erroneous.

The trouble was traced to the manganese dioxide present in certain soils in a form which reacts with the quinhydrone producing a base and a corresponding reduction in acidity. Similar errors have been found in English soils and methods of detecting and avoiding them are being worked out.

SOIL MICROBIOLOGY.

The investigations in soil microbiology fall into two main divisions: (1) the study of the micro-organisms living in the soil, their kinds, numbers, mode of life, their various activities and their relation to one another.

(2) A detailed study of soil micro-organisms directly affecting plants: the nodule organisms of the leguminosæ, organisms parasitic on plants and producing diseases.

The chief groups of soil micro-organisms are: bacteria, fungi, including actinomycetes, algæ, protozoa and nematodes: all are studied at Rothamsted except the nematodes, which are left to the Institute of Helminthology, St. Albans, though it is hoped to effect some co-operation with this body as the work is now beginning to suffer through so artificial a restriction.

All the organisms, except some of the protozoa, feed on the organic matter in the soil, some of them also ferment part of it: in either case, they decompose it, producing humus, nitrates, phosphates and compounds of calcium, potassium and other elements of great importance in soil fertility. Soil micro-organisms are, to a large extent, the producers of soil fertility, though they also reduce it by assimilating to themselves nitrates and phosphates that would otherwise serve for plants. It is this close connection with soil fertility that justifies the extended study made of them at Rothamsted.

Broadly speaking, fungi predominate in acid soils and bacteria in neutral soils, and of the substances they decompose fungi assimilate more, build up more protoplasm and retain more nitrogen than do bacteria: they are less economical as plant food producers because bacteria convert more of the organic matter into carbon dioxide, water and ammonia. For this reason less of the nitrogen can be nitrified in an acid than in a neutral soil.

There is considerable difficulty about estimating the numbers of fungi and studying their activity: Dr. Brierley has shown how to obtain comparable data under strictly controlled conditions, but the results have no absolute value and the higher figures are not intrinsically more probable than the lower ones. More

can be done with the bacteria. Their numbers can now be estimated by Messrs. Thornton and Gray's direct method much more rapidly and completely than before: when the counts were first made at Rothamsted by the old plating method, a usual estimate (known, however, to be very incomplete) was 10-30 millions per gram, and the experiment took ten days to complete: now the estimate (which, however, includes dead organisms) is 1,000-5,000 million per gram, and the experiment takes only two hours. The numbers are related to those of the protozoa; they are high when the protozoan numbers are low, and low when the protozoan numbers are high: this is because the protozoa feed on the bacteria. The "nutritive values" of the various bacteria differ; for one of the most "nutritious" an increase of 3,400 amœbæ (*Hartmanella hyalina*) per gram involved the disappearance of 1,444,000 bacteria, *i.e.*, something over 400 bacteria were consumed to produce one amœba. The effect of the protozoa on the decomposition of plant residues by bacteria and fungi is being studied: it apparently differs according as the action is a fermentation or a consumption for food.

One of the most far-reaching factors in the situation is that micro-organisms need adequate supplies of nitrogen and of phosphate and can decompose carbohydrate only in proportion to the amounts of these substances present. This is the fundamental principle underlying the making of farmyard manure. Straw is put under the animals as litter and, being mingled with their excretions, is decomposed by micro-organisms to form the familiar black, sticky substance known as humus. In doing so, however, the organisms assimilate some of the ammonia of the excretions, converting it into their body tissue, in which form it is insoluble and some of it is not easily nitrifiable. Thus the nitrogen in farmyard manure is of three kinds: the original complex nitrogen compounds of the straw and solid excreta; simple and easily nitrifiable compounds (urea and ammonia) of the liquid excreta; and complex nitrogen compounds of the bodies of the micro-organisms derived from these simple compounds. Not all of this nitrogen is readily nitrified; Dr. Jensen, in the Bacteriological Department, shows that only the excess of nitrogen over a certain amount is quickly nitrifiable, the proportion of non-nitrifiable and therefore less useful nitrogen depending on the amount of carbon present and also on the reaction of the soil. In a neutral or alkaline soil, for every 20-25 parts of carbon, one part of nitrogen nitrifies only slowly; for an acid soil the figures are one part nitrogen for every 13-18 parts of carbon. This accords with the observation that farmyard manure is much more effective in a neutral than in an acid soil, and it explains why farmyard manure and other plant residues containing less than about 1.5 per cent. nitrogen in the dry matter supply very little nitrate and are therefore of little help in soil fertility, thus emphasising the very serious nature of the losses when the soluble nitrogen compounds in farmyard manure are leached out by rain.

Artificial farmyard manure. This fuller knowledge of the mechanism of the decomposition of cellulosic materials is not only useful in the management of farmyard manure: it forms the basis of a method of producing an artificial farmyard manure, closely resembling the ordinary material. Straw need not be

put under the animals for the purpose of effecting its decomposition; the organisms work equally well if it is wetted with a solution of a nitrogen compound such as an ammonium salt or cyanamide containing sufficient phosphate. The important factors are the presence of sufficient nitrogen (0.75 parts to each 100 parts of ripe cellulosic material) and of pentosans at least equal in amount to the lignin; when these are correctly adjusted, the organisms rot down the material and give a black humus manure. The method has proved of value where insufficient live stock is kept to make enough manure, as in market gardens, plantations, and some special types of arable farming: it is now used extensively in many countries, and new waste materials are continuously being tested. Coconut husk has this year been successfully converted into a manure containing 0.4 per cent. nitrogen, and little, if at all, inferior to farmyard manure. Rye straw presents special difficulties, because it cannot readily be wetted: means are being tested to overcome this.

Another practical application is, perhaps, somewhat unexpected. The chain of processes beginning with plant residues and ending up with carbon dioxide and ammonia is the basis of the purification of sewage and other effluents. Sewage has on several occasions been the subject of investigation at Rothamsted, the purpose being to obtain from it, if possible, a useful manure. For the moment this investigation is suspended pending the successful drying of the very promising sludge finally obtained. During the past two years, the same problem has appeared under another form. The effluents from sugar factories have usually been run direct into rivers where they have caused considerable nuisance and damage to fish. At the request of the Department of Scientific and Industrial Research, an investigation was begun to discover some suitable and effective methods of treatment. The work is being done partly at Rothamsted and partly at the sugar factory at Colwick, Nottingham; the problem is to remove the waste roots and tails of the beets and to convert the plant juices contained in the effluent into carbon dioxide, water and ammonia as rapidly and economically as possible. The experience gained at Rothamsted with this particular decomposition enabled Messrs. Cutler and Richards to start several lines of experiment as a result of which a microbiological process was devised that gives almost complete purification. The effluent is run through a clinker filter on which a film of organisms develops, including bacteria, protozoa, yeast-like bodies and, probably, other fungi: some of the bacteria decompose the sugar rapidly to produce acids and gas; others do not decompose sugar, but presumably attack the products formed by the first. Nearly 750 different strains of bacteria have been isolated and studied, and the remaining population of the film is also being investigated. The film is well suited for the development of protozoa—better, indeed, than the ordinary nutrient agar of the laboratory—but it can also be attacked by the larvæ of the “sewage fly” (*Collembola Acheureutes*).

The problem now is to cheapen the process and to discover what degree of purification is in fact necessary, for every per cent. of purification beyond a certain point adds to the expense.

Organisms directly affecting plants : Lucerne and its nodule organism.

In the Bacteriological Department, Mr. Thornton has continued his studies of the relations of the nodule organism to the lucerne plant. The organisms enter the root hairs, they travel along into the root, then multiply and cause the cells to multiply and form a nodule. Very few nodules are formed so long as the seedling leaves alone are present: they suddenly appear when the true leaves emerge. Apparently the opening of the leaf is accompanied by the extrusion from the root of some substance which stimulates the bacteria and enables them to infect the root hairs. This substance can be found in the medium surrounding the root: a water extract of sand in which lucerne seedlings have just formed their true leaves, stimulates the growth of the organism in artificial cultures more than a water extract made just before the leaves open. Attempts are now being made to discover the nature of this substance.

Earlier experiments of Mr. Thornton and Miss Brenchley showed that the co-operation between plant and organism remained effective only so long as connecting channels were made between the nodule and the circulating system of the plant; these are needed to convey carbohydrate from the plant to feed the organisms and to remove the nitrogen compounds made by the organisms. It is still a mystery how the plant comes to make the connection as soon as the nodule is ready, and the mystery is deepened by the discovery that a minute trace of boron is essential: unless this is present, no connection is made, and the nodule bacteria can neither pass on to the plant the nitrogen compounds they have prepared, nor draw their necessary carbohydrates from the plant; they therefore decompose the cells of the plant root, thus becoming harmful. Mr. Thornton now shows that the same result is obtained if the carbohydrate supply to the nodule is cut off by keeping the plants in the dark.

Soil algæ. Dr. Bristol Roach has collected and summarised her work on the soil algæ. The mode of life of these organisms differs according as they are on the surface exposed to light or below the surface in darkness. When they occur on the surface they function like other green plants, assimilating nitrate, phosphate and other plant foods from the soil and carbon dioxide from the air, which by photosynthesis they transform into organic matter rich in potential energy. All this is added to the soil when they die. When they are carried down below the surface they do not necessarily die: they can change their mode of life, become saprophytic and feed on some of the organic matter already existing in the soil, apparently the soluble or easily decomposable organic compounds: they can, for example, secrete an enzyme that liquifies gelatine. There is no evidence of any excess of decomposition products that could contribute to plant nutrition, and the general functions of the algæ in relation to soil fertility seem to be:—

- (1) they assimilate nitrate and phosphate from the soil, converting them into insoluble nitrogen and phosphorus compounds;

- (2) when living at the surface of the soil they increase the supply of easily decomposable organic matter rich in energy;
- (3) when living below the surface, they assimilate soluble or easily decomposable organic matter in addition to the nitrate and other nutrients referred to above;
- (4) they can thus be regarded as agents for increasing the stock of energy material in the soil and for immobilising soluble nutrients and organic compounds, converting them into an insoluble but readily decomposable form.

DISEASE ORGANISMS AND PESTS.

Disease in plants may result from several causes: from insufficiency or excess of some essential requirement, from the attack of a parasite, either fungus, bacterium or insect, or from a virus, a name given to some obscure agent, the nature of which is not understood. For the present, the first group, the so-called physiological diseases, are not studied although numerous instances occur on our plots where deficiencies or excess of the various nutrients have become intensified by long continuance on the same land of an unaltered scheme of cropping or manuring.

One of the difficulties of the work is that some of the organisms, especially, perhaps among the fungi and bacteria, may not be fixed in their relationship to the plant or, indeed, in their own characters. Under constant or changed conditions a species may assume a different form, sometimes with different properties and, indeed, may be mistaken for a new or another species; further, while harmful in some conditions, it may be relatively harmless in others.

Dr. Brierley is studying the nature and the extent of the changes that can be induced in the common parasitic fungus *Botrytis cinerea*, by alteration in its food and other environmental factors. He finds that some of these changes are purely temporary, disappearing at once when the old conditions are restored; some are more permanent, lasting for a number of generations and showing gradual reversion whilst still others are apparently quite permanent. Further work is necessary to ascertain the consequence of these important results and their relation to the incidence of disease in crop plants. Further changes in conditions may influence greatly the effectiveness of a fungus in attacking plants.

Dr. and Mrs. Brierley find that certain species of *Fusarium* which cause root disease in wheat behave differently in pure culture and in soil: in pure culture the development of the fungi shows a marked relation with temperature, being slow at 13° C., more rapid at higher temperatures, but ceasing above 30° C. In soil, however, no difference could be observed, the amount of disease produced at 30° C. being apparently just as much as at lower temperatures.

These and other observations show the necessity for close study of the conditions in which a disease organism is acting, and they have led some to adopt the view that studies of crop diseases can be made only in the actual district where the disease occurs.

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