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Soil Bacteriology or Soil Microbiology as it is often called is the science which treats of the microorganisms in soils, their character, life-history and functions and their relationship to the fertility or crop-producing power of the soil.

It is one of the newer sciences which has appeared comparatively recently as a direct outcome of the intense scientific activity of the present "Golden Age of Scientific Discovery." It is, in fact, hardly half a century old, but it has developed so rapidly, due to the devoted labors of many investigators, and its importance has been so generally recognized that in spite of its youth, it is mature, or at least it is approaching maturity, interpreting maturity in the scientific sense.

After all, age in years, has little to do with the status of any science, at least within certain limits. Obviously no science can spring into existence, full-grown, but when there has been a rapid accumulation of a vast amount of facts, comparisons, classifications and deductions have been made and the stage of verification is reached — following Huxley's analysis of scientific methods — then the particular science or branch of knowledge is certainly approaching maturity. According to this criterion, Soil Bacteriology is indeed full-grown.

The rapid development and maturing of a science is no longer considered unusual. Many sciences have come into existence during the past century and are now firmly established and functioning as separate branches of human knowledge. In fact if the history of science as a whole is reviewed, it will be found that, with the exception of a few sciences, such as Mathematics and Astronomy which date back to antiquity, most of the present-day science is essentially modern. True Zoology was first studied by Aristotle, the beginnings of the biological sciences appeared in the seventeenth century and Chemistry developed in the eighteenth century, but it was not until the nineteenth century that the "Scientific Era" really began and there came a real development even of these basic sciences.

But now, as a result of this development, what a vast change has

appeared in the whole realm of science. No longer can the classification of science, as devised by Comte, be even considered. His six divisions into Mathematics, Astronomy, Chemistry, Physics, Biology and Sociology have grown until their progeny is legion. How many sciences can now be recognized? Who can say? Truly the scientific development in the present era surpasses the wildest dreams of the early investigators. The accumulation of knowledge has been tremendous. It really seems doubtful if any future age will measure up to the present in amount and scope of scientific achievements.

The newer sciences have generally developed as an outgrowth from some one of the somewhat older, basic sciences, and in some cases they still carry in their name, the term applied to the fundamental science. However, in many instances there is considerable confusion regarding the names of certain of the newer branches of science and terms have been applied quite arbitrarily. Soil Bacteriology has developed from Bacteriology, or rather along with Bacteriology, which in turn is a child of Botany, itself one of the newer biological sciences. From Bacteriology it has taken its name. But the science has also developed from Soil Science or Pedology, or along with it, and Pedology is one of the newer Agricultural Sciences, which has developed from Agricultural Chemistry, Geology and Physics with certain Botanical relationships. Certain phases of the science have been developed along with Protozoology, a branch of Zoology. There are definite relationships also to Plant Physiology, to Plant Pathology, to Ecology, and to many of the agricultural sciences.

Probably no other science has any more complex relationships to other fields of knowledge. It has led to much confusion, in the minds of scientists in other fields, as to the place of Soil Bacteriology in the whole scheme of science, as to the subject matter involved, the technique employed and the importance of the subject. The bacteriologist expects a bacteriological technique, a bacteriological viewpoint, a bacteriological tie-up. The chemist looks for a chemical technique, a chemical viewpoint, a chemical relationship in organization. The Soil Scientist or pedologist wants a soils technique, a soils viewpoint, a soils organization. And so the situation with regard to Soil Bacteriology often becomes complicated. What is the solution?

A realization of the fact that Soil Bacteriology is a separate and distinct branch of science, will serve to iron out all organization, viewpoint and technique difficulties. It is not *just* a part of Bac-

teriology, it is not a branch of Chemistry, it is not merely a phase of Pedology, it is not Botany, it is not Zoology, it is Soil Bacteriology. As a definite branch of science it has certain relationships to other sciences, often very intimate. There has been a borrowing of some techniques, a utilization of certain methods, an adaptation of various views and a development of a distinct field of knowledge. All the sciences are so closely related, so interwoven in viewpoints and in methods of study that it is often difficult to draw distinct boundary lines. This is true of Soil Bacteriology. There are some problems which overlap into other fields. There are some techniques which have been transferred bodily to the soil bacteriological laboratory from Bacteriology, from Chemistry, from Soils, from Botany or from Zoology. In general, however, there have been modifications in methods and a new technique has been devised. But regardless of origin, and history of development, regardless of overlapping in problems, regardless of the source from which techniques, modified or unchanged, have been secured, it is obvious that Soil Bacteriology is a science of and by itself, with its own peculiar and distinct problems, its special viewpoint and purposes, its different and individual technique. It could not have developed as it has, had its scope been limited to any of the allied fields of science. It has grown so rapidly and extensively largely because of its unique position with relation to some of the older sciences, because of its interest and because of its technical and practical significance.

The years which have elapsed since the work of Pasteur, Schloesing and Müntz and Robert Koch, which marked the beginnings of Soil Bacteriology have been filled with intense study of the subject. There has been an enormous accumulation of facts, there has been a correlation and a classification of the data secured and many scientific and practical deductions have been drawn. Methods have been devised and in fact through the whole record of soil bacteriological investigations there runs a trail of new methods, new techniques, modifications and adaptations. Most of the problems attacked have first required a long, painstaking hunt for methods which would serve the purpose. Thus through necessity a real soil bacteriological technique has been developed. For the study of the various processes special methods have been devised and even the bacteriological, chemical and pedological operations must generally be materially modified to be of value. I would emphasize again the point that soil bacteriology is not chemistry,

not bacteriology, not botany, not soils, it is a separate entity in the scientific world.

But the questions may be asked "What has it accomplished, what is its significance?" Time will not permit of any extended discussion in answer to these questions. I will merely attempt very briefly to present some of the more important phases of the work to emphasize the importance of the science and to call attention to its accomplishments.

In the first place, it may be said that Soil Bacteriology has definitely proven the fact that soils are dynamic and not static; that they are a place of life; that they are teeming with microorganisms and that as a result of the life and activity of these living organisms, various important and far-reaching changes take place in the soil, from day to day, week to week or year to year. Hence there is a definite pedological significance attached to the work, but there is also a very significant practical value. Soils which are low in bacterial content or which contain the wrong kinds of organisms, do not show the best production of plant food in an available form and give low crop yields. There has been found to be a correlation between numbers of microorganisms and such activities as ammonification, nitrification and carbon dioxide evolution and the fertility or crop-producing power of the soil. Intensive and extensive studies of these processes have developed methods of measuring the products of bacterial action, determining the vigor or efficiency of the processes occurring in different soils under various treatments and have definitely shown that certain fertilizers added to soils and certain methods of soil management affect crop yields and bacterial processes in a relatively similar way. It is possible now to secure a fairly accurate idea of the crop producing power of a soil by studying it bacteriologically. The scientific explanation of many phenomena long noted in the field has been provided. In short the whole viewpoint of soils in relation to crop production has been changed. The practical significance of this change is very evident, the technical importance is also being shown in studies which are now under way.

Probably the most important contribution of Soil Bacteriology to practical agricultural science is in connection with legume inoculation. The discovery of the ability of legumes when properly inoculated, to utilize the free nitrogen of the atmosphere has made it possible for farmers to secure the expensive nitrogen needed by plants, from a free and unlimited source. Inoculated legumes as green manures are valuable nitrogen fertilizers. The technical

aspects of the legume inoculation problem are many and complex. Studies on Rhizobium are now in progress to determine the different characteristics of the organisms which infect different legumes, the mechanism by which the nitrogen is fixed and the form in which it is supplied to the plant. Methods by which the various organisms may be recognized, the efficiency of cultures for inoculation may be measured and the need of inoculation may be determined, are now being investigated. The future practical value of such studies is evident.

Many other phases of soil bacteriological work are of significance. Studies on the Azotobacter and Clostridia have shown the ability of these free living organisms to fix the free nitrogen of the atmosphere and increase the supply in the soil. The significance of this process of non-symbiotic nitrogen fixation or azofication may be very great practically. Studies of these organisms by the Winogradski spontaneous culture method give quite accurate indications of lime and phosphorus needs of soils. In general it may be said that bacteriological tests may be more accurate for the determination of soil needs than any chemical methods which have been devised. In addition to the tests referred to above, other bacteriological tests have been proposed. The possibility of increasing the nitrogen content of soil through inoculation with cultures of Azotobacter is being studied. Practical results will undoubtedly be secured at some future time but have not yet been obtained.

Studies of the relation of bacteria to organic matter in soils have shown how the various types of organic compounds are decomposed and the products which are formed, the organisms which are involved and the various activities which they bring about. The value of various sources of organic matter for field soils has been shown. The reasons for the greater value of leguminous green manures compared with non legumes, for the injurious effects of straw, and for the varying influence of other natural organic materials, have been found. The effects on bacteriological conditions in soils from organic matter additions are very extensive and of large practical importance. Studies on the cellulose destroyers, the nitrate assimilators, the nitrogen fixers and other important groups of soil organisms have thrown much light on the practical problem of fertilization of soils with organic materials.

Studies of the molds, actinomyces, algae and protozoa in soils have been carried out in connection with soil bacteriological investigations and are really a part of the subject of soil bacteriology.

Later, divisions may be made into soil mycology, soil algology and soil protozoology but as yet they should probably be included with soil microbiology. Studies on these groups of organisms have yielded many interesting and important results. Molds in acid soils, their ability to produce ammonia and other products, actinomyces which nitrify or fix nitrogen, their occurrence and action, algae as an aid to Azotobacter in fixing nitrogen, protozoa as active agents limiting bacterial development in soils, are some of the problems which have received attention. The presence and action of these organisms are of importance technically and may be of much significance practically, at least in certain soils.

Many other phases of soil bacteriological work might be mentioned, such as sulfofication, or the production of sulfates in soil, ferrification, the production of available phosphorus and potassium, the undesirable processes of denitrification, desulfofication and other reduction processes. Studies on groupings of soil organisms on a physiological basis, on the characteristics of the organisms growing in soils, life cycles of certain important organisms, energy relations and enzyme production, are all of great scientific interest and in many cases there are possibilities of practical value from such work.

Sufficient has been said undoubtedly to show the extent of the work done, the scope of the investigations, the large amount of data secured and the practical as well as technical importance of the results which have been obtained.

Soil Bacteriology is a science which by its nature and status is certainly a distinct branch of science. It has many complex relationships but is most closely allied to Soil Science or Pedology as a part of the large group of agricultural sciences. It is developed from Bacteriology and Botany, from Chemistry and Geology, from Zoology and Pedology. It utilizes methods and viewpoints adapted from all these sources. But it has developed a technique all its own, it has accumulated facts, correlated and classified them, drawn deductions from them and definitely demonstrated its place among present day sciences. Its importance practically, lies in the fact that microorganisms in soils play a large part in crop production. Thus the science is of importance to all people everywhere in connection with food production and it will, therefore, have an influence on all living conditions and hence on civilization. What more can be claimed for any science?

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