authoritative information of this type seemingly has met with success, and other guidebooks in this series will follow in other years. More than that, however, the reflex influence of this innovation is already felt, and the evident appreciation by the general public of this type of popular description is encouraging the Survey writers. The educational responsibility of this federal service is being more fully realized, and we intend to give much more attention both to the simplification of the language of the professional publications and to the issue of reports that shall be popularly descriptive and instructive without loss of exactness. Even if plain language is used our reports should be no less efficient vehicles for professional discussion or for the announcement of geologic discoveries.

For thirty-six years the United States Geological Survey has reached an ever widening circle of readers, and even in the early years of the Survey's life King and Emmons and Gilbert gave to the West the results of their work in strong and forceful English. Yet with the growth of the organization and the development of the science the tendency toward highly specialized writing has been too marked and the present plea for plain writing has become necessary. The government scientist has at least two obligations: first, that of making his investigations more and more exact in method and direct in result; second, that of making his product, the written report, such as to meet the needs of not only his professional associates but also the general public. It is our ambition that the reports of the United States Geological Survey shall be written in the language of the people.

George Otis Smith
U. S. Geological Survey

SOIL FERTILITY

As long as a soil continues to produce moderate crops, the question of its fertility arouses no concern, but when the yield falls below normal the reason for this decrease is immediately sought. Until a short time ago it was believed that this difficulty admitted of an easy solution, but when the farmer saw his crops decreasing and sought the cause, the type of answer which he received depended on whether he consulted a soil physicist, a soil chemist, or a soil bacteriologist. In any case it was generally conceded that the supply of "plant food" had been exhausted and the only question remaining was how to replenish it.

The soil physicist saw in this undesirable condition, from his standpoint, a violation of the maintenance of one of the following requirements for the soil under examination. First, the proper temperature had not been established in the soil to admit of the rapid growth of crops; second, the proper ventilation of the soil had been interfered with, either by a change in the porosity of the soil due to physical or chemical changes, or to the deposition and retention of the by-products of the crops; or third, the plant did not receive sufficient moisture and this was due to the non-operation of one of the following agencies, osmosis, surface-tension or transpiration. The importance of this third point is very apparent when we remember that all plant food taken from the soil must be in solution.

The following quotation from Johnson's "Agricultural Chemistry" illustrates the standpoint of the chemist of a few years ago in regard to soil problems.

> The art of culture is almost entirely a chemical art, since nearly all its processes are to be explained only on chemical principles. If you add lime or gypsum to your land, you introduce new chemical agents. If you irrigate your meadows, you must demand a reason from the chemist for the abundant growth of grass which follows.

The extension of such ideas as are contained in the above quotations led to the belief that there is a certain definite relation between the productiveness of the soil and its content of nitrogen, potash, phosphoric acid or other chemical constituent, and many persons believe at the present time that from a chemical analysis of a soil the analyst can tell just the kind and amount of fertilizer to be added in order to increase its productiveness.

With the introduction of more exact methods in bacteriology and the perfecting of bacteriological technique, all of which has taken place in the last half century, the relation of bacteria to soil cultivation has been carefully studied. There are myriads of bacteria in the soil and from the standpoint of the agriculturalist, they naturally fall into two classes: Those concerned in increasing the fertility of the soil, and those which deplete the soil of the necessary constituents to sustain plant life. Two groups of bacteria (*Clostridium* and *Azotobacter*) have the ability of taking nitrogen directly from the air and incorporating it into their own protoplasm, and it is believed that these organisms are responsible to a large extent for keeping the nitrogen content of a soil nearly constant, as they replace that lost from the soil by the removal of crops, dentrification (which will be considered later) and seepage. Another method by which the nitrogen content of a soil is increased is that of a symbiotic relationship between certain bacteria and plants; *Ps. radicicola* has the ability of penetrating the roots of the legumes and forming nodules thereon. Under this special condition, the bacteria above mentioned are able to "fix" atmospheric nitrogen. This element is rarely, if at all, available to plants in the form of ammonia, but must be built into nitrates first. Here other types of bacteria (nitrifying organisms) take the "fixed" nitrogen and build it up to nitrites and nitrates.

It is upon these facts that the excellent results of crop "rotation" depend and this is responsible for the success in intensive farming. In the "rotation" of crops the farmer sows the land between "money crops" with one of the legumes (peas, beans and especially clover are used) and these plants are those above referred to as being capable of a symbiotic relationship with the nitrogen-fixing bacteria. When these legumes have grown up, they are ploughed under, thus returning much nitrogen, which has been accumulated during their growth to the soil, and replacing that lost by the removal of the "money crops." This process is known as "green manuring" and it is fast becoming the practise to spray the seeds of these legumes with pure cultures of nitrogen-fixing organisms, so that the proper bacteria may be present when the seeds are planted.

The question naturally arises that if nitrogen must be in the form of nitrates in order to be available to plant life, why is it that we often add materials as fertilizers which contain nitrogen in a much more complex form? Bacteriology again answers this query. These complex nitrogenous substances which we add as fertilizers are broken down by the saprogenic and saprophilic bacteria to the ammonia stage from which they are built up, through the agency of the nitrifying bacteria to the nitrite and finally nitrate form, and are now in a condition to be assimilated by plant life. Through the agency of other bacteria cellulose, starches and sugars are transformed to organic acids and carbonic acid, which attack otherwise insoluble minerals and get them into solution ready for absorption by the plant. Bacteria are also involved in the oxidation of hydrogen sulphide and iron compounds.

So far, we have discussed only those organisms which are beneficial to plant life, but there are others which are detrimental and these naturally fall into two classes; first, those bacteria which are pathogenic to plants, like those causing tobacco and cucumber wilt, potato rot, pear blight, etc., second, those bacteria which are indirectly harmful to plants because they rob the soil of the constituents necessary to support plant life. These latter fall in the group above referred to as denitrifying organisms and they have the ability to break down nitrates, either partially or wholly to the ammonia stage, thus robbing the plant of what was originally available nitrogen. This type of organism was much feared by the agriculturalist for some time after its discovery, but it is now known that it requires an entirely different environment from the nitrifying organisms and that it seldom occurs in a well-ventilated soil.

The single view of the soil physicist must appear untenable, for while plants need water, air and a proper temperature, these are not the only requirements to be met, for if it is desired to have a fertile soil to insure our crops, "plant food" must be present and also the agencies whereby this food will be replaced when that which is now present is consumed. We must also recall that water, air and temperature greatly influence the bacterial content of the soil and they are probably more sensitive to changes in respect to these three requirements than are the plants themselves. As will be seen later, it is possible to meet all the demands of the physicist and yet have an unproductive soil.

The single standpoint of the chemist is also open to criticism, for, granting that the right amounts of the necessary elements are present in the soil and are in an available form at the time of examination, they will soon become exhausted unless replaced by bacterial activity. The amount and kind of material in the soil solution is one that has caused considerable discussion and for which we can set no arbitrary standards, knowing that this is intimately related to the composition of the soil, which is dependent upon the original nature of the rock of this place and the care of the land since it has been cultivated. Would it, remembering that different animals require different kinds and amounts of foods to repair their protoplasms, be quite correct to assume that all plants require exactly the same amounts of various substances to repair their equally diversified protoplasms?

While it may be claimed that the bacteriological content of a soil is a very delicate index of its fertility, we must not forget that the chemistry and physics of the soil are also important. It is true that from the type of bacteria present we can form a good idea of the fertility of the soil, but without the knowledge gained from a physical and chemical examination we have no means of knowing how long these conditions will persist.

The problem of soil fertility then is a composite one which needs for its solution a knowledge of the interrelated subjects physics, chemistry and bacteriology. With these points in view, it becomes a very simple matter to harmonize statements which on the surface seem conflicting. We now know that it is necessary to provide the proper laboratory (physical conditions) and the necessary raw material (chemicals, etc.) in order that the particular bacterial cell which we desire may do its work in increasing the fertility of the soil. In order to show the dependence of the bacterial cell on physical factors, we may cite the physicist's demand for a porous soil and remember at the same time that the organisms beneficial to plant life require oxygen in order to continue their reactions. Again the necessity for moisture is clear when we remember that bacteria can use only food that is in solution, and the question of a proper temperature is explained when we remember that at the optimum temperature of the bacteria in question, their reactions are greatly accelerated.

To discuss in detail the tenets of the chemist would require too much space here, but one simple illustration may suffice to show the close relationship between the chemical composition of a soil and its bacteriological content. The adding of chemicals to a soil affects the physical and bacteriological nature of the soil as well as the chemical content. When we remember that the activity of bacteria often produces acid end-products, which if not neutralized will inhibit their activity and finally cause their death, the reason for the addition of lime to a soil is easily understood.

If we provide all the conditions above outlined and the soil continues to be unfertile, we may be sure that we have not the proper bacteria present or else some enemy such as certain protozoa are present and are preying on those bacteria which make plant life possible upon the earth. As animals are in the last analysis dependent upon the plants for food, and as plants are dependent upon the nitrifying bacteria, we can easily see that no life could long exist upon the earth without the aid of these organisms.

J. E. Rush

Department of Biology,
Carnegie Institute of Technology

THE THIRTEENTH NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL EXCURSION

The annual meeting of the Geologists and Geographers of the New England Colleges and Universities was held under the direction of