SOIL RESEARCH IN NATURAL AREAS

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Most soil scientists spend most of their time trying to find out wl kinds of soil we have, what plants are adapted to them, and what com nations of practices will give optimum sustained production. General we try to work out the most economically productive system that the ki of soil and the state of the agricultural arts will permit—the so-call "highest use." And, in the practical world, as distinguished perhaps fr the purely aesthetic or scientific, this is soil conservation.

Yet soils are as interesting, as complicated, and as individual as otl natural objects of scientific study, such as plants, birds, or stars. For long time now soil scientists have been devoting a small part of th time to basic studies; although I think not nearly enough, even for most effective practical results. Until we know the basic morpholo genesis, and behavior of a soil, we are greatly handicapped to discover optimum use. We have available only the trial-and-error method w varying degrees of technical control. This method is both slow and cost Most of the really great improvements have come from the application new combinations of the principles developed from basic research.

We have known for a long time that each kind of soil is a dynan living thing. At any moment it represents the combined effect of five ma factors: (1) climate and (2) living matter, acting upon (3) the par material, as conditioned by (4) relief, over periods of (5) time. With change in any part of the environment, these soil-forming forces combi to change the soil, to move it toward a new equilibrium point. But rar can any soil be said to have reached an equilibrium. That is, the relati ship between the soil and the factors of the environment is a function dynamic one, not a settled state of equilibrium.

Of these relationships the most important, most interesting, and m complicated is that between the soil and the living matter, not only higher plants—the shrubs, grasses, and trees—but also the micro-fl and fauna. We cannot properly say that a soil causes a particular co bination of living matter or that living matter produces the soil; th evolve together.

In agriculture and forestry we have long been aware of the need selecting plants to fit the kind of soil that we have, or at least the mo fied soil that we can produce from the natural soil by economical tre ment, such as liming, fertilization, water control, and the like.

We have given far less attention to the processes by which livi matter reacts on the soil. We know from observation that quite differ soils form under forest than under grass in otherwise similar envir ments. And we know that in different climates this contrast between gr and forest is unlike. That is, near the tension zone between forest a grasses in the temperate region we expect soils more fertile for cr under the grass than under the forest. Yet in the humid tropics the reverse is true. Millions of native farmers in the tropics renew the fertility of their soils through the "bush" or forest fallow. Other great areas of soil in the tropics that were once forested have been invaded by savanna, anthropic savanna that has followed forest clearing and overcropping. Since the savanna burns each dry season, killing young tree seedlings, the forest never returns to restore the productivity of the soil.

One could give a great many other examples of relationships that have been learned mainly from orderly observations in the field through comparing one defined combination of soil and its environmental factors with another combination. This method, often called the method of geographic correlation, is perhaps the most important one in soil science; but success in its use depends upon accurately defined sample soil areas for comparison in which the mechanisms have been discovered through careful observation and experiment. And first of all we should begin with the natural soil in the natural landscape. It is as one of these local natural laboratories, supplemented by the full array of scientific apparatus, that I can see a great role in soil science for an area like Mettler's Woods, now the William L. Hutcheson Memorial Forest.

THE WHOLE LANDSCAPE AS OBJECT OF STUDY

The useful studies that can be made at such a site cover a very wide range. Research to develop or to sharpen basic principles of soil genesis and behavior must deal with several factors at once. The whole system is living and dynamic. We find daily cycles of sunlight, temperature, humidity, and growth. We find rhythms of change from the start of one rain to the next. We have seasonal cycles, each only approximately like the one before and the one to follow. We have great swings of climatic change, and the "accidents" of hurricanes, floods, earthquakes, volcanic eruptions, diseases, and fires.

Then too, each organism is a part of the environment for other organisms, and is influenced by micro-climates and micro-accidents of great importance to it and consequently to other organisms and to the soil that directly or indirectly supports it.

I do not mean to imply that we can study each factor, each organism, and each part of the soil all at the same time. Much research needs to be very specialized and carried out not only at the site but also in the laboratory.

I do mean to emphasize the need for a broad point of view. One hears a lot these days about "over specialization." Intense specialization is good and necessary, even, or rather especially, in the study of so complicated an assemblage as a natural landscape. What is evil is not specialization but narrowness of viewpoint—the study of a single organism or soil, or some part of an organism or of a soil, with little regard to the whole. Unfortunately too, a descriptive study of any part, or even of the whole, is valid only for that moment, like one single picture of a movie film. In fact, for many necessary studies we must "kill" the organism or destroy the soil. Then we have lost movement—the living part. But we must weigh and measure. Science is scientific only when it is quantitative.

The soil scientist is thus caught in a dilemma similar to that of the physicist, who can measure either the position of an electron or its velocity but not both at the same time.

The broad point of view needed for successful soil research is not meant to imply emotionalism or even "natural history" by itself. Results must be quantitative. We need to answer the question of "how much?"

SOIL-PLANT RELATIONSHIPS

I should like to illustrate the kinds of relationships involved with examples.

Nutrient cycle. It is generally assumed that plants take three essential elements—carbon, hydrogen, and oxygen—from air and water; and that at least 13 other essential elements are taken mainly from the soil. These are phosphorus, potassium, nitrogen, calcium, magnesium, sulphur, iron, manganese, copper, boron, zinc, molybdenum, and vanadium. Perhaps chlorine is also essential. Besides these, several others are taken in that may have some unproved function in plants. At least cobalt and iodine are important to animals, and sodium and silicon can be used by plants as partial substitutes for other elements.

We also know that compounds containing these elements are synthesized into foods by the plants and returned again to the soil as excretions of the living cells and especially as dead tissue, leaves, twigs, and other parts. Thus we have a natural cycle of nutrients from the soil, to the plant, and back again to the soil.

Actually, however, the cycle is not so simple. Part of the nitrogen and sulphur comes into the soil as compounds released to the air by burning coal and other compounds. Such compounds of nitrogen and sulphur are absorbed by the rain falling through the air or directly from the air by moist soil. Some nitrogen is fixed during electrical storms and comes into the soil with the rain. Some nitrogen is fixed by micro-organisms into forms that can be used by plants.

Although these processes are fairly well known, estimates of the amounts involved under different conditions vary within exceedingly wide limits. The amounts gained and lost in many soils cannot yet be accounted for. This is especially true of the nitrogen available to plants in many soils of the tropics and subtropics. Suggestions of substantial additions of nutrients to both plants and soil through dusts and aeresols have scarcely been investigated at all. Nor have all the biological processes involving the nitrogen and sulphur of the soil been explored.

Then too, soils lose material through leaching, by removal from the surface with running water or wind, and by exchanges of air between the soil and the atmosphere.

The more nearly quantitatively we can measure these relationships among the nutrients the more nearly we may come to finding principles that will lead to improving the economy of nature. The plants, micro-organisms, and animals condition the relationships in many ways; and their activities are modified by the micro-climate at the surface and within the soil.

Physical relations. Living matter and climate modify not only the chemical nature of the soil but also its physical condition. As soils develop from their parent materials, the soil body, down to the limit of the biological influences, becomes differentiated into layers. If we dig a deep pit we cross these layers, or soil horizons. Collectively, these horizons make up the soil profile, which is unique for each soil type.

Roots sort over the material beneath and open up the soil, or fail to do so, depending upon the kind of plant, the character of the soil material, and the amounts of air and water relative to one another.

The surface layers usually receive continual additions of organic matter. Here changes in temperature and wetness are greatest. Organisms are most abundant.

The effects of these reactions under different sets of conditions are quite unlike. Generally in this part of the world, soils under forests gradually become acid. The decomposing organic matter produces reducing conditions. The tiny clay particles tend to become destroyed, and iron oxides and part of the colloidal organic matter accumulate in the subsoil, or B horizon. On acid sandy material this process goes rapidly. On limy, clayey material it procéeds slowly, often through a stage during which clay accumulates in the subsoil, as it does normally farther south and west of here.

As the soil-forming processes continue hardpans may form, even ones that inhibit the growth of roots. Some kinds form through the cementing of soil particles by the iron and organic matter. A common hard horizon in this section is called a fragipan because it is hard in place but is not cemented. It probably forms slowly as a result of wetting and drying plus downward movement of fine particles of silica. Dr. Carlisle has suggested that in the lower soil, above the continually moist zone, the soil dries in summer and cracks slightly. As the rains come on later, fine silica particles may be carried into the cracks before the whole layer is wetted. Then when it does wet, and the cracks close, the layer is compacted by the extra material in the cracks. Through the long-continued action of such a process, very dense soil horizons are formed through which water passes only very slowly and roots scarcely at all. This suggestion may or may not account entirely for the observed fragipans. But we do know that many kinds of soil of our northeastern states (as well as elsewhere) have these horizons. Some are weakly developed, while others are thick and hard; some are shallow and others deep. Under low levels of nutrient supply, their effects may pass unnoticed; but with normal liming and fertilization, shallow ones limit yields markedly.

We have already mentioned the great importance of roots to soil formation. The deep roots of trees swayed by the wind gently move the soil. This process maintains a blocky structure, even in heavy clays, through which water may pass. If the forest is removed from a soil requiring this process to maintain the structure of the subsoil and is replaced with shallow-rooted plants, the particles in the lower soil gradually flow together as the old roots rot away; the structure is lost; and the soil becomes less pervious to water and roots. In this way many soils that are well drained under the natural forest become water logged after a few years of cultivation.

In this general region, the great hurricanes, although infrequent, have a great effect on soil formation. Recent research at the Harvard Forest suggests the impossibility of a truly climax forest in much of New England; the soils are so churned by overturning trees that few spots of soil would escape mixing for more than 300 to 400 years. Similar research needs repeating on other kinds of soil.

Perhaps these examples are sufficient to show the kind of relationships I have in mind. We could discuss the very important function of the micro-organisms and the factors that influence them—the food supply, temperature, light, and moisture.

The roots of rapidly growing trees in the humid tropics push much of the soil aside. With their death and rapid decay, the termites move it back. Thus in these natural soils we find rapid natural tillage.

We cannot complete the picture without knowing what happens to the water, not simply as water in the well-known hydrologic cycle, but how it moves both dissolved and suspended organic and mineral matter.

EXAMPLES OF PRACTICAL IMPLICATIONS

As an agriculturist, I think of soil research as purposeful. But the directing of research toward immediate practical problems, at the expense of fundamental research for basic principles, can be wasteful. This has been our record in the United States. For a long time we have depended mainly on Europe for fundamental research and spent most of our own effort in applied research and testing. But for further advances we must carry on more fundamental research ourselves. I am confident that our total effort will then be much more effective in producing practical research results.

Our aim in agriculture and forestry is to develop new combinations of practices and treatments of soil, plants, and animals that are superior to those found in nature. Certainly we have done that; yet I feel that we have only begun to apply our great resources of power, engineering, and scientific skill to this objective. The chief limiting factor is our poor understanding of the basic scientific principles of soil behavior—principles from which new combinations may be invented.

Let me illustrate briefly with a few examples.

1. What do the various sources of plant nutrients contribute to plant growth and how are the amounts modified under different conditions? For example, we cannot yet account for all of the nitrogen that gets into plants; and we have little data on the contributions of fine dust from the air to supplies of phosphorus and other nutrients.

2. What are the effects of kind of soil, considering the total environment, on plant composition and how can the composition be changed and improved? Centuries ago Pliny observed that plant quality depends more on the kind of soil than on management. Why is it so hard to modify plant composition through soil treatment? Can we find ways to do it?

3. What are the effects of various kinds of plants or groups of plants on soil productivity for the same plants or other plants? Some plants can be and are grown continuously without loss of yield or soil productivity. Others do best when rotated with other plants, or when grown in mixed culture, even when fertilizers are used. The reasons for many such experiences are fairly well known while others are obscure.

4. How can we increase the efficiency of use of the water in soils, including the management of plant cover in catchment areas for optimum water yield?

These are examples of very broad problems about which we know something from experience—from comparing various combinations in different places and from empirical testing. We have made some important beginnings in basic research on a few segments of the problems, but generally the basic principles are still elusive.

Basic research in natural areas can play a very significant role in the development of such basic principles. True, we have in them a dynamic system; but the soils are relatively stable as compared with man-made combinations. We now have tools for the long-time dating of geological formations, soils, plants, and water, and for the continuous measurement of many of the dynamic factors that change from day to day and year to year.

It is along these lines that I can visualize significant contributions from Mettler's Woods to basic soil science.