SOIL INTERPRETATION IN THE SOIL SURVEY

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United States Department of Agriculture **Issued**
Soil Conservation Service **April 1961**

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INTRODUCTION

The purpose of soil survey interpretations

Soil survey interpretations provide users of soil classification and soil maps with predictions about the behavior of each kind of soil under defined situations, especially systems of soil use and methods of manipulation. The interpretations range from such specific items as tile spacing, suitability of soils for highway subgrades, and erodibility to more broadly defined qualities, such as soil productivity for groups of crops, suitability of soils for wildlife, and so on. The more precisely we define alternative conditions of soil use or manipulation the more specific we can make predictions of the results. For most soils that can be cropped there are two or more alternative agricultural uses and several alternative combinations of management practices under each use.

Most commonly the user of soil surveys wants to know how the soils on a tract of land can be expected to behave. First, he locates the tract of interest to him on the soil map. The map shows him the names of the kinds of soil that make it up. From the report he can learn how these soils are expected to behave under the alternative uses, treatments, or systems of management they can support. Other users of soil maps need information for broad areas or for one or more kinds of soil wherever they maybe found. But the main use is for information on specific tracts of land--fields, farms, ranches, watersheds, forests, subdivisions, road-ways, construction sites, public parks, and the like. More and more the users of soil surveys want quantitative interpretations rather than the qualitative "good, " '"fair, " and "poor."

Soil survey interpretations are predictions

Soil survey interpretations are predictions of soil behavior under stated conditions, not recommendations for specific tracts. Interpretations of the soils indicate the reasonable alternatives for their use and management and the expected results. Decisions depend partly on the economic characteristics of the farm or other land tract, not simply on the physical and biological environment.

Reliable interpretations can result only from a synthesis of basic data about the soils themselves, obtained from field and laboratory research, data from field experiments, and the experience of users of soils, especially farmers, ranchers, foresters, and engineers. The more reliable the data, the more reliable are the predictions. The more reliable and abundant the data for interpretations under all reasonable alternatives of use, the more dependable the results in the years ahead.

We must begin with the synthesis of data in quantitative terms. For use on farms predictions of the yield per acre of adapted crops under physically defined systems of management are an important example. Such predictions are also needed for farm budget planning. Other data are needed for engineering, woodland, and range interpretations.

Present difficulties with coordination of interpretations among districts, counties, and States stem mainly from deficiencies of data for either soil correlation or interpretation, or both. Judgment is important to such decisions, of course; but to reach common judgments the data upon which they are based need to be recorded and commonly understood.

Interpretive soil groupings

Interpretive soil groupings are devices for generalizing and presenting interpretations. Beginning with interpretive tables giving separate predictions for each kind of soil, one can group all of the soils of a county or wider area into 3, 5, or some other number of classes, depending on the detail needed, according to some one quality, such as erodibility, suitability for an individual crop under a defined system of management, and so on. Such groupings are a simpler form for presenting interpretations that show easily how the kinds of soil compare with one another. But detail is lost in the process.

Other groupings take into account several soil qualities. The grouping Q soils into capability units, subclasses, and classes is an important example.

To serve the needs of various users, we need several sorts of interpretations, both specific and general. Each interpretation scheme needs to be de-signed for its unique purpose with the greatest possible simplicity of expresion without loss of any necessary exactness. Then its use should be strictly limited to its purpose. Mistakes have resulted from using interpretive groupings for a purpose for which they were not designed. For example, an excellent grouping of soils into capability units and classes as an introduction to the soil map for use in farm, ranch, and watershed planning, cannot be depended upon as a basis for tax assessment. For tax assessment a general productivity rating under current or expected economic conditions is more useful. In two groupings for such unlike purposes, some of the kinds of soil that are placed together in one will fall into separate classes in the other.

For full information about a soil one must always go back to the description of the individual kind of soil and the data about it. As soon as any two kinds of soil are grouped together, some precision has been lost. But if the purpose is narrowly and clearly defined, considerable simplicity can be had without great loss of specificity.

Soils can be grouped, for example, according to their erodibility under cultivated row crops. The soils in any one group are essentially alike in this one quality but perhaps quite unlike in other respects. Where specificity is required, we need a unique grouping for each narrowly defined purpose, not simply a broad grouping for several purposes. If the broad grouping has but few classes, it may be too lacking in specificity to serve any one purpose adequately. If it is complex enough to serve several objectives well, it has no advantage over the basic soil classification itself.

Broad groupings are necessary for developing and interpreting general maps of counties and States used for program planning. These groupings are best made by combining narrower and simpler ones.

J It is assumed that readers have already seen Soils Memorandum SCS-22, dated May 19, 1958 on the land capability classification.

Synthesis

Any useful grouping of soils--interpretive, morphological, or genetic--requires synthesis. In making interpretations we strive to predict the behavior of the whole soil as an entity. We cannot predict the behavior of individual soil characteristics since each one influences the others. We do need to study these individual characteristics, however, to help us understand the whole soil. But neither an individual soil nor a kind of soil is a simple sum of characteristics. Each is a unique combination of characteristics with many potentials for interactions resulting in a unique and predictable behavior.

Thus the direct predictions of soil behavior, or their implication in interpretive groupings, requires the careful synthesis of many data. This is hard work.

In soil classification one deals with a large number of soil characteristics in developing logical combinations as classificational units--what we call soil series, types, and phases. At different times and places schemes have been put forward to sidestep the hard work. Most such schemes avoid the job of classification by using long fractions, not as symbols of integrated classificational units, but as collections of symbols of separate soil characteristics. This procedure is note taking on maps. It is neither soil classification nor soil mapping if the soils themselves are not defined. Although such maps appear to have the relevant data only a skillful map user can make the necessary synthesis and use them. The purpose of classification and interpretations is to make the synthesis for the user.

Beginning with the basis soil classification and correlation, we must assemble the data from research and experience that indicate how the soils behave under the expected range of conditions. A part of such research is carried on during the Soil Survey itself in both the field and the laboratory. Part of it is done separately from the soil survey work but closely related to it. Perhaps the most common example is well-laid out field experiments with farm crops, trees, grasses, or various engineering structures and devices. Long-time records of yields and practices from farmers' fields are of great value. Having accumulated the data, we have the problem of synthesizing them according to units of the classification. If we cannot do this logically then we have made mistakes either in the classification of the soils or in our definitions of the conditions of use or manipulation under which the data were obtained.

Orderly interpretation is an excellent test for a system of soil classification or for the legend of a county soil survey. To understand the, soils we must analyze them, we must take them apart and study the parts. But both classification and interpretation call for synthesis.

BALANCE BETWEEN BASIC AND-APPLIED SCIENCE

Recognition of interpretations as an integral part of the Soil Survey, began about 1930. Before that time some interpretations were made, a few in considerable detail. Their forms varied widely. Most were presented as descriptive statements based on field observations during the course of the field mapping. Some soil survey party leaders were highly skillful in capturing the meaning of the experiences of land users; others were not. In fact, some held the view that "It is the job of the soil scientist to get the facts and someone else should interpret them."

Actually this concept never worked out. Few people besides soil scientists know enough about soils, and about the interactions among the many soil characteristics that define each kind of soil, to do the job by themselves. Then too, few other people have interest in all the uses and interpretations. Once a kind of soil is defined and mapped, few besides the soil scientist are concerned with all the interpretations needed: The field and horticultural crops that can be grown; the erosion hazard; the native plants and their ecological successions; how the soil will serve as subgrade for roads or foundations for buildings; and so on. Experience shows that the soil scientist must take leadership in developing the interpretations. This leadership responsibility includes getting the assistance of others, who may develop all or part of certain interpretations. Commonly the soil scientist prepares a draft for others to react to. Responsibility to see that his work is interpreted for use is inherent in the duties of every soil scientist in the Soil Survey.

The soil scientist must have help and guidance from competent people in the related fields. Agronomists, horticulturists, engineers, foresters, economists, and so on can help him understand what combinations of characteristics and qualities are most important and help him assemble part of the relevant data. To work with them effectively, the soil scientist must learn something of their technical language and points of view. Then after he has made his interpretations in draft they can react to them, help him test them in application, and help improve them.

Finally, his results should be tested in practical application. In fact, the soil scientist always lives in an atmosphere of criticism. If his maps fail in their purpose, he hears about it: Although tiring at times, this criticism has been good for soil. scientists and has resulted in very much better soil surveys than we would have had otherwise.

A balance between basic and applied soil science has not been achieved with-out controversy over the past 30 years. There are those who feel that soil classification and the research upon which it stands is a strictly scientific activity--some say "pure" science. The introduction of interpretations for applied purposes, it is said, tends to dilute the science. Those who reason this way unconsciously assume that men who deal with applied research somehow lower their own academic standings as scientists.

One can understand this point of view without agreeing with it. Basic soil research is essential to good soil surveys. A purely routine soil survey with no research, and especially with no research appreciation by the field soil survey leader, would almost certainly fail in its objectives. It is abundantly clear that further basic research into the nature and behavior of soils promises much further advancement in the effective use of soils than we have had in the past 200 years. But for scientific purposes alone one rarely needs country-wide detailed soil maps. Maps of sample areas suffice.

At the other extreme are those who say that "erudite" scientific material is not needed; what they want is a "practical" map. Neglecting the scientific base would result in strictly routine work, with important problems unresolved and unenlightened by scientific inquiry into soil genesis and behavior. In fact, many problems would not be seen at all. Without the full use of the basic principles of soil science and the skills of orderly inquiry, the results of soil surveys would soon be disappointing. One cannot have reliable interpretations without scientific curiosity and study. Nor can we apply the results of the scientific study without orderly interpretations. Both are essential.

The history of our work affords many examples that the so-called "practical approach" commonly gives impractical results.

We have controversies, however, over the form and content of our interpretations. These can be helpful. We shall continue to have them so long as we are learning and so long as problems of soil use change. We have some gaps and inconsistencies in our theory. We lack specific data for many of the interpretations we want to make. We still have some problems of adjustment between the units as defined in the system of soil classification and some of the classes in the interpretive groups.

RELATION OF INTERPRETATIONS TO SOIL CLASSIFICATION

First of all, we must think of a soil as a 3-dimensional body on the surface of the earth. It has area, shape, and depth. We can dig into a soil, and through it into not-soil beneath. We can walk across it. We can accept it as it is or we can change it. From its characteristics we can discover its history and predict its future behavior.

The general term "soil" is a collective term for all the soil in the world just as the word "vegetation" is a general term for all the plants.

A soil is one of these individual, 3-dimensional soil bodies on the surface of the earth. It cannot be defined by an individual soil profile since a profile occupies little more than a geometric point. A soil has area with a range in profiles limited by our definitions.

The soil individual

To some this concept of the soil individual is difficult because the boundaries are not all clear and sharp. The boundaries of most plants and animals are very clear -- so clear, in fact, that clear boundaries are taken for granted. But many boundaries of other individuals that must be classified are not clear. Those of climatic types are far less clear than those of soil individuals; in fact they are determined wholly by definition -- no one ever saw such a boundary. Thus the placement of those boundaries of soil individuals that are not sharp and clear depends partly on our definitions. Although changes in our definitions change some boundaries, add some, and eliminate some, perhaps more commonly they simply change the identification or sorting of the individuals.

These precise boundaries of the soil individuals that we classify could be plotted only on maps of very large scale, say 50 inches or more to the mile. Rarely can the boundary of a single mapping unit coincide exactly with that of an individual soil. For a mapping unit to carry a single taxonomic nam, such as "Barnes loam, sloping phase," applied to a group of similar soil individuals, we require only that 85 percent or more of the bounded area consist of one individual (or more than one) of this taxonomic group. Thus, at best, the mapping units with single names are approximations of named soil individuals. Those with complex names have two or more different kinds of soil individuals in them.

In making and using interpretations, we must be very careful not to confuse soil individuals with soil mapping units.

Kinds of soil

A kind of soil is a collection of all the individual soils in the world, wherever they are, that are alike according to the definitions that we write. We can speak of kinds of soil at a low level in our classification, such as the phase of some soil type or series. Or we can speak of them at a high level in the classification such as the•Podzols or Chernozems in two of the great soil groups.

It would be hard to overemphasize the fact that useful definitions of kinds of soil. are based upon combinations of soil characteristics. A kind of soil is defined on the basis of a great number of characteristics existing together, each one influencing the effects of the others. No soil can be defined on the basis of one, two, three, or any other small number of characteristics. This point is easily missed in local soil study. The human mind comprehends mostly by comparison. One easily fails to see the many characteristics that all the soils have in common within a local area of nearly uniform climate and vegetation. Yet the characteristics so eas;ly overlooked in local study, are of critical importance in differentiating these soils from those of other places having different climates and capabilities for use.

For example, most wet soils do not show a drastic change in pH when drained, but we cannot assume this for all wet soils. Some high-sulfur soils near sea coasts become extremely acid after drainage. We must recognize this feature in soils where it exists and measure it. Most upland soils are deficient in phosphorus for the most economical crop production but contain abundant cobalt. Yet some soils are rich in phosphorus and some are deficient in cobalt. And so we might go on through a long list of soil characteristics that cannot be over-looked or simply taken for granted.

Characteristics and qualities

Soil-classification, and ultimately interpretation, depend upon many soil characteristics. These can be seen and measured in the field or measured in the laboratory. But soil characteristics differ sharply from what we call soil qualities. Qualities result from interactions between soil characteristics and practices. Soil fertility is an example of an important soil quality that cannot be measured in a strict sense. Soil productivity is another. In practice, so is soil drainage. Through costly instrumentation it is possible to measure soil drainage but it would not be practical to do so on a wide scale as a basis for soil mapping. In actual practice we estimate soil drainage by observing combinations of soil characteristics and their effects, including the color of the horizons of the soil profile, the depth of the water table at various times, the relief, the presence of standing water on the fields, the growing plants, and so on. Assuming that these accessory characteristics used in soil definition and mapping are properly chosen, the results of direct measurements on representative soil individuals can be used to predict the behavior of widely occurring kinds of soil.

Some problems of soil phases

In soil classification traditionally we have set up the units of kinds of soils in the lowest category of the natural system--the soil series--in accord with combinations of characteristics that determine their behavior in the natural environment. Of course, characteristics vary somewhat within these defined combinations. Where the permissible ranges in any of the characteristics are significant under prospective cultural environments it is necessary to make subdivisions, which we call phases, in order to separate different areas of soil belonging to the same natural soil unit but having unlike relations to cultural practices. Thus we make phases of soil types or soil series, or even of great soil groups, in accordance with differences in stoniness, in slope, and so on that must be recognized to develop useful interpretations. 2/

Phases based on differences in climate are among the more difficult to decide on accurately. Where both the soils and the climate have been reasonably stable for a long period, the characteristics of the soil reflect the effects of climate. Yet areas of young soils having similar characteristics, at least so far as our modern methods can determine, may vary widely in climate. Examples include some of the Alluvial soils along large streams that pass from one broad climatic zone to another. Other examples include relatively young soils at various elevations in mountainous regions.

We have many troublesome problems of recognizing specific boundaries between appropriately defined climatic types. Total rainfall, seasonal rainfall, intensity of storms, temperature, and other features of climate commonly change gradually over distance, especially where elevations are similar. Small differences in these factors influence crops and the exposed arable soils much differently than they do the natural vegetation and the protected natural soils. Then too, effects of rainfall, temperature, and the like can be confused with those of variations in length of day, which some also include under the general term "climate."

On similar soils, for example, the hazard of erosion under clean cultivation is greater where rainfall intensity is high than where it is low. We have two alternatives to meet these situations: (1) To have slope phases leading to similar interpretations, which requires that the upper limits for "nearly level" and for "gently sloping" phases must have lower values in terms of percent slope where rainfall intensity is high than where it is low. (2) To have slope phases of soils in each soil family with the same limits in terms of percent slope but somewhat different interpretations in terms of erosion hazard under different rainfall intensities. Under this latter alternative areas of the soils of the lowest slope phase, as shown on the map, might or might not have a significant erosion hazard. That is, the interpretation for the "nearly level" phase might not be clear. This is another example of the kind of problems needing attention. (If I knew the correct answer now, I would give it:)

Because of differences in the effects of climate on native vegetation and soil formation, as contrasted to cotton culture, a line showing the northern limit of cotton in the United States crosses the areas of occurrence of several soil series.

2/ In actual practice this principle has been extended. Soils having similar behavior in the natural environment may be placed in separate series on the basis of characteristics of their sole of great significance to their behavior only under a cultural environment.

In order to harmonize capability units with phases of soil families, several changes may need to be made, such as: (1) Further refinement of climatic phases; (2) more attention to moisture and temperature in soil family definitions; or (3) a broadening of capability unit definitions with subdivisions according to the prevailing crops that can be grown.

In a surprisingly large number of instances, the present climate associated with the soil is not the one under which its principal characteristics were developed. Some of our soils now having a sub-humid or semiarid climate were developed under a humid climate. Thus to make interpretations about plant adaptability for some kinds of soil it is necessary to recognize climatic phases as well as other kinds of phases.

Size and shape of soils

The size or area of the individual soils presents problems of soil interpretation. Where areas of unlike kinds of soil are very small, they cannot be shown separately on maps of reasonable scale. This does not affect the classification of the soils in the natural or genetic system of classification, but it does affect the mapping of them. In some instances two or more kinds of soil, some-times highly contrasting ones, must be included in a single mapping unit called a soil association or soil complex./ The soil association appears to be a difficult concept for some, despite its clear analogy to plant association. Soil associations are not groupings of like soils, but of unlike soils. Their common feature is that they are intermingled with one another in small areas. If they are used for crops with modern techniques, they are normally used together in fields.

The soils within associations are defined and named in the same ways as similar soils are everywhere. Laboratory studies are made on each of the different kinds of soil within the association. We have no other way to take soil samples within an association. But interpretations about soil use to apply to larger areas, such as fields and pastures, are extended to the user on the basis of the mapping unit--the soil complex. On small-scale maps of low intensity soil surveys, the areas of the individual soils in the soil association, even though not indicated separately on the map, may be large enough for fields. In these surveys the interpretations are related to the individual kinds of soil, not the mapping unit; the map user must be able to recognize the individual kinds of soil within the soil association as he walks over the mapped unit on the ground. This is also true of the soil complex as shown in soil surveys of moderate or high intensity when interpretations are made for specific qualities, such as drainage or infiltration, and for individually treated plants, such as fruit trees, garden plants, or hand-treated field crops in unmechanized agriculture.

If "Soil association" is the general term for geographic groups of unlike soils. When such groups must be used as mapping units in high or moderate intensity detailed soil surveys they are called "complexes." (Mapping units that are groups of similar soils are called "undifferentiated soil groups.")

Another important problem is the shape of soil bodies. It is not at all uncommon to find both large, relatively uniform bodies and small, irregularly shaped bodies of the same kind of soil. Let us say that such a kind of soil is highly suitable for corn or cotton. The large bodies are well adapted to the use of large machinery and the irregular ones are not. When soil maps are used in the field in planning, the size and shape of soil areas are obvious and can be taken into account. But no good criteria have been developed for handling this problem in soil interpretations for general comparisons of broad areas. With the continual increase in mechanization, the shape of soil areas is becoming an increasingly important factor in interpretation and we should develop ways to deal with it.

COORDINATION OF INTERPRETATIVE GROUPINGS

Now is the most appropriate time to concentrate on some of these problems. We already have the Seventh Approximation to a new and comprehensive system of soil classification. The big job ahead is to group the soil series into families. We know now that some soil series must be combined and others divided. At the same time it would be helpful to have a reasonably firm relationship between the genetic system of soil classification and the more basic interpretive classes, including capability units, to help guide the making of these interpretations at uniform levels of generalization throughout the country.

It appears now that our best opportunity may lie along the line of using collections of similar phases of one or more soil families, rather than parts of a phase of one or more families, to guide the definition of capability units. To reach these objectives we shall doubtless need to make some adjustments in the definitions of four kinds of units -- phases, series, families, and capability units, so that our boundaries between classes of soils and our boundaries on soil maps may be placed where they have the greatest significance. [J]

Clearly we cannot allow the natural system to be biased for an immediate interpretation. But where more or less arbitrary divisions among taxonomic units and their phases must be made, the needs for interpretation should be thoroughly considered. It may not be practicable to have a strictly mechanical system for relating the capability units or other interpretive classes to the basic soil classification, but certainly we can develop some firm guidelines.

[J] At the same time perhaps thought should also be given the capability classes. More and more it appears that Class V could be dropped. In several States it has not been recognized to date. The kinds of soil now placed in it pould be placed in other classes with slight revisions in them. The only serious difficulty would be the troublesome mechanical one of renumbering the tables and explaining the change. Areas of soils suited to field crops would not be changed but those soils now grouped in classes VI, VII, and VIII would become V, VI, and VII, respectively.

Perhaps it should be added that climatic phases need to be defined, in the last analysis, on soil characteristics -- cycles of moisture and temperature -- not on climatic types. 5 The effects of climate important to soil use and management--crop adaptability, hazards of crop failure, erosion hazard, crop yields, forest site indices, and the like -- result from interactions between the climate and the soil. Even within the area where cotton is grown, not all soils are suited to cotton.

Finally it should be emphasized that soil classification and soil interpretation serve as good checks on one another. If it appears that a certain kind of soil "should" belong in a certain interpretive group but experience indicates otherwise, one or more soil characteristics most probably have been overlooked or improperly evaluated in relation to the others, or the management conditions vary more widely than assumed.

BASIC SOIL CLASSIFICATION AND SOIL INTERPRETATION

In comparing the natural system of classification and any interpretive grouping we must continually recall that the basic system must take account of all characteristics relevant to all the needed interpretations, not simply to one or two of them. Our soil surveys serve many purposes. Any single interpretive grouping should be far simpler than the natural system, else it would have little or no advantage for direct use.

Nothing is permanent, including our basic soil classification; yet it is much more nearly so than our interpretations from it. As we learn more about soils, the new knowledge must be worked into the basic soil classification so we can use it--so we can make more and better interpretations.

While slow changes are to be expected in the basic soil classification, the interpretations are far more changeable. As new chemicals, new machines, new varieties of crops, and other new methods of soil use become available, we find need for changes, within periods of 5 to 10 years, including a few drastic changes, in our evaluations of the productivity of the various kinds of soil under different combinations of practices. Since soils respond unequally to new combinations of practices, we have both absolute and relative changes in their interpretations. Some interpretations are relatively stable, at least for long periods between technological breakthroughs. Interpretations that reflect crops and practices closely related to economic conditions change the most.

The improvements and lowered costs of fertilizers have enormously changed the relative advantage of many soils, especially in the southern States with long growing seasons. Soils considered nearly useless for farming only a few years ago with the practices current at that time are now highly prized. Good fertilizers at low cost, new machines for developing water control practices, and greatly improved varieties--all in proper combination with the local kinds of soil--have made the difference. Other soils that were formerly used for crops are now being used for woodland or other permanent vegetation because they are not responsive to the new methods.

L/ Until recently, there was a tendency among soil scientists not to recognize soil characteristics as such unless they can be preserved in samples. But certainly stoniness, slope, temperature, moisture, oxygen supply, and the like are important soil characteristics. Except at points with special equipment, characteristics like temperature, moisture, and oxygen supply must be inferred from other evidence.

In the northeastern States many contrasting soils supported similarly poor meadows 25 years ago. Yet later, with the wide use of lime, fertilizers, and other improved practices, great differences became evident. Where physical characteristics difficult to change prevented deep rooting and adequate water control, responses to the new practices were small. With this new knowledge, some soils that were placed within the same capability class some 5 to 15 years ago are now placed in 2 or 3 different capability classes. We can expect some other shifts of kinds of soil within the capability groupings.

This illustrates why we avoid putting interpretations on original field sheets or on the published soil map itself; although they are commonly useful on copies of soil maps for immediate use as a basis for decisions about soil use and management. As our interpretations change, the map appears to be wrong.

Some potential confusion can be avoided by continually recalling (1) that tracts having certain kinds of soil, even though properly placed in class IV or higher in the capability system on the basis of their suitability for field crops, are well adapted to certain specialty crops and have a high value per acre where favorably located; and (2) that drastic reclamation can make soils suitable for uses for which they were clearly unsuitable when classified and mapped.

Soil survey interpretation is a continuous process. Changes are needed in order to present alternatives in terms of soil responses with current practices and under current economic conditions. Although not made as they would be today, many published soil surveys -- soil maps and accompanying descriptions -- have remained sound and useful for 4o years, provided re-interpretations are made for or by the user. We expect that maps being made currently will be useful for a great many years, during which the economics and skills of farming are bound to change. Our knowledge of soil behavior helps us to determine which combinations of soil characteristics are important and what ranges in their expression can be allowed within a kind of soil. Yet the classification itself must be limited to soil characteristics. If instead, interpretations should be worked into the soil classification itself, the map will go out of date rapidly, perhaps even soon after it is published and distributed for use. At the same time, we must be sure that our units, especially phases, are defined so they can be interpreted.

This point is one of major importance in planning the basic soil survey of the United States or of any other country. If the classification is soundly based on soil characteristics and our best estimate of future needs for information, the soil survey can be interpreted and reinterpreted again and again with little or no field work for remapping. But if interpretations are worked into the classification and map, and the basic soil characteristics left unrecorded, serious changes in method of use and in economic conditions result in making the whole soil map obsolete.

Difficult as it is, one can achieve uniformity in a classification based on soil characteristics much easier than in one based on interpretations. Men can learn to observe and to measure soil characteristics in the same ways; whereas their judgment on how these interact with a given set of practices to produce cotton yields, for example, vary considerably, especially among those not highly experienced with the crop. Many interpretations, those in engineering for example, require data and skills not possessed by all soil scientists. But even more important, to have soil maps that can be reinterpreted and used under new situations, the soil classification must be based on recorded soil characteristics.

All soil scientists in soil survey work must be concerned with both soil classification and soil survey interpretations. Each helps to check the other. But the systems should not be mixed. Interpretations should not be symbolized directly on a soil map intended for more than immediate use. The soils can be evaluated and grouped in clearly dated interpretive tables that can be revised as needed without changing the map symbols.

THE PRINCIPLE OF INTERACTIONS

The important qualities of soil, which our interpretations are to bring out, result from interactions among the many soil characteristics. That is, erodibility, for example, is not mathematically related to slope, to texture, to structure, or to any single 'feature of soils. Only when all other soil characteristics are held the same can we get a direct relationship between erodibility and variations in one characteristic. Several soil characteristics must be in proper combination for oven a mediocre corn crop. Phosphorus deficient soils with widely varying amounts of water available to plants during the cropping season have similar low yields. But added nutrients give the greatest responses on the ones highest in available water, assuming other favorable characteristics.

Relatively small differences in stoniness on soils otherwise suitable for cultivated crops have a high significance to their suitability for crops. But similar differences may be insignificant to the use of soils unsuitable for crops for other reasons,although wider degrees of stoniness may be significant to other uses. If the small differences in stoniness, used to separate significant phases on deep, arable soils of moderate slope, are used to split units of nonarable soils on steep slopes we get insignificant and unnecessary mapping units. They confuse rather than aid the map user.

In hilly areas, for crop and pasture interpretations, slope phases may be adequate with the upper one defined as "30 percent and steeper." But for interpretations on forest management critical phase boundaries may be needed within this unit, say at 45 or 60 percent.

Other examples of the lack of direct relationships between a single soil characteristic and a soil quality could probably be cited for each of the soil characteristics and differing degrees of its expression.

So first we must emphasize the interactions among soil characteristics. The same principle applies to management practices. The full benefit from terraces to control water are not realized on infertile soils. Nor do dry or waterlogged soils respond to fertilizer. Yet harvests on soils where any nutrient deficiencies are corrected are reduced less during drought than on those soils with deficiencies. In a well planned management system for any soil each practice supplements and supports the others.

Then, of course, the combination of management practices interacts with the combination of soil characteristics. These determine the potential response of a soil to management within the climatic environment. The harvest is the result of both: We cannot say that it is due to the kind of soil or to the management system.

In fact, whether by design or accident, every good harvest on any acre anywhere has a minimum of four properly adjusted sets of practices:

(1) A balanced supply of nutrients at the appropriate level is maintained by manuring, fertilization, and so on.

(2) Within the rooting zone of the soil adequate amounts of both available water and oxygen are maintained through the use of proper tillage, field layouts, water control, and the like.

(3) Those crop varieties are used that have the genetic capabilities to make the maximum response within the environment to the qualities of the arable soil developed by soil management.

(4) Adequate measures are used to protect the crops from insects, diseases, animals, weeds, and other hazards.

These may be subdivided and added to in many situations. Special practices are also used to control erosion, landslides, torrents, soil blowing, and the like. But the point is that none of the four main ones can be omitted; nor is any one effective by itself. Undue emphasis on any one by itself is bound to give disappointing results if the others are neglected. The only way expensive irrigation work can be justified, for example, is where a good job of water control is carried out to eliminate lack of water or waterlogging as limiting factors and where fertility, genetic potential of the seed, and plant protection are assured.

The ideal soil management for one kind of soil is often poor for another. For this reason, one of the uses of a detailed soil survey is to guide the organization (or reorganization) of field boundaries. With two contrasting soils in the same field it is commonly impossible to get the full response from either. A common example is the inclusion of small areas of highly responsive Alluvial soils with potential for high corn yields in the same field with sloping soils ill-adapted to corn. If the first is fenced out for nearly continuous corn at high rates of fertilization, and the other part used for close-growing crops, both soils can give a higher return for the costs.

This principle also means that one must be careful about comparing the results from two combinations of management on different areas of the same kind of soil. Trials have been made, for example, to determine the value of terraces when simply added to the common practice for a rotation of corn, small grain, and two years of meadow on a sloping erodible soil. With no other practice changed, it turned out that the presence of the terraces led to only small increases in yield. This should have been expected. To get the value of the extra available soil water, the fertilizers and plant population must be increased. Terraces must be looked on as providing opportunities for a higher level system of use all the way around.

Decisions among alternative combinations of soil and water conservation practices for a specific tract of land should be based not only on the physical inputs and outputs but also on the costs and returns calculated from them at expected costs and prices. In developing our soil survey interpretations, we must help users to avoid overdesigning as well as underdesigning management practices or structures.

Soil qualities

In practice it is hard to conceive all the facets of soil conditions and the effects of all practices at once. On the few soils already nearly ideal for our purpose, practices are intended merely to maintain the soil in this condition. Far more commonly, however, the combination of practices should be designed to improve the soil -- to approach more nearly the ideal for our purpose. Very few natural soils become ideal arable soils by simple clearing and tillage alone.

Roughly these practices have been grouped into "reclamation" practices and "maintenance" practices. But the distinction is fuzzy to say the least. In the United States reclamation has come to mean mainly the preparation of soils in dry regions for irrigation,although sometimes drainage alone or stone removal are included. Yet actually liming and fertilization may give equally dramatic results and may be about as costly, especially when combined with terraces and-other practices for runoff control.

It is more useful to consider what combinations of practices can be expected to produce an approach to the ideal soil for our purpose, and then balance the costs against the benefits. Such calculations vary from onp kind of soil to another. No practice is universally beneficial.

Since the combinations of characteristics and practices are so many, we carry their synthesis forward in overlapping segments. Thus we appraise separate soil qualities, which we should think of as limited interpretations based upon inferences from soil characteristics. Productivity, fertility, tilth, and erodibility are examples. In actual practice soil drainage, as a soil condition, is mainly an interpretation. These terms have been used so long that some regard them as soil characteristics. But they are not. They cannot be seen or measured directly. We can only appraise them indirectly by inference from soil characteristics, from plant growth, and from the effects of practices on soil stability,

Soil fertility is that quality of a soil that enables it to provide the chemical compounds, other than water and air, in adequate amounts and in proper balance for the growth of specified plants when other growth factors are favorable. This quality varies so widely with past management and treatment, that it is not ordinarily practical to attempt to group kinds of soil according to present fertility. .Kinds of soil can be grouped according to the likelihood and degree of one or more nutrient deficiencies under specific assumptions of management. That is, soils can be grouped according to their potential to respond to fertilizers, but not according to specific annual applications needed.

When using crop yields as a basis for grouping, we need to go to the broader concept of soil productivity, as defined below. It is possible, however, to set approximate fertility standards for various kinds of soil in order to achieve specified yields, provided other factors are favorable.

Kinds of soil can be grouped in accord with such standards in order to interpret soil fertility tests into predicted fertilizer responses. This is highly important. Such tests must be standardized, but different standards are needed for different crops on different kinds of soil. That is, with other factors comparable, a given test result for potash, for example, needs to be interpreted differently in terms of potash fertilizer application on contrasting soils. For such interpretations soil families or subgroups may be used or, better still, specific groupings of soil series for this purpose.

Soil tilth is that quality of a soil that summarizes its physical fitness for the growth of specified plants where other growth factors are favorable.

Somewhat like fertility, this quality depends a great deal on past management. Kinds of soil cannot be grouped according to present tilth, where the individuals vary significantly in past use. But they can be grouped into classes according to certain minimum practices for developing and maintaining specified tilth conditions.

Soil productivity is that quality of a soil that summarizes its potential for producing specified plants or sequences of plants under defined sets of management practices. It is measured in terms of outputs in relation to inputs for a specific kind of soil under physically defined systems of management.

This quality is a further synthesis of soil fertility, soil tilth, and soil water relations. Productivity also varies with past management, but potential productivity can be predicted in terms of crop yields under a specified management system. If current yields vary widely for the same kind of soil under different management systems, we say that such a kind of soil is highly responsive to management. The great change in productivity may result from the change of a single soil characteristic, such as moisture or phosphorus supply; but nearly always several changes are required to produce a highly productive arable soil from any soil of low productivity under simple management or current practice.

A grouping of soils according to potential productivity under assumed systems, which approximate a given level of management,is useful for many purposes. It is useful to indicate to farmers and others what results they can expect. Land appraisers, both for mortgage loans and rural taxes, have need for this kind of grouping. Potential productivity is also a basic component of the grouping of soils into capability units and classes.

Techniques for developing yield predictions of adapted crops -- the first step in developing productivity ratings -- are given in the *Soil Survey Manual* and in several other papers. Since the predicted yields of the adapted crops to be expected from a soil under specified practices are so important in farm planning and in many interpretive soil groupings, a "yield and practice" table is one of the first steps in soil survey interpretations.

It is clear that yield data must be obtained from known soils under defined systems of management. The main sources are farmers' field records and the results of experimental plots.

On experimental plots, arrangements for perfect stands and for complete harvests can be made that are not practical on farms. Thus a good farm manager, following the same defined practice as on an experimental station, can expect about 80 percent of the yield of corn that would be obtained on the same kind of soil by a capable experimenter. Although we should like to have figures for the highest possible yields under the known agricultural arts, the yield predictions we are mainly seeking are those obtainable by good farm managers.

Variations in weather are reflected in year-to-year yields. Roughly a mini-mum record of 10 years is needed in the humid areas and of 20 years in the semiarid regions.

A productivity rating -- as an index number -- can be had by comparing the predicted yield to a standard yield. Yield predictions are needed in planning a farm budget. They are more meaningful than index numbers to farmers. But for those not intimately familiar with normal yields under different situations, the productivity rating or index is more meaningful. From productivity ratings one can get a useful notion of the relative productivity of soils adapted to, or at least used for, unlike crops. And with knowledge of the standardsused, the rating can be converted back to absolute yields in bushels or tons per acre.

In addition to the individual yield predictions and productivity ratings, it is useful to have a general productivity rating for each soil for all adapted crops. Where field crops having roughly similar soil adaptations and management inputs per acre are grown, the individual productivity ratings maybe weighted in accord with the relative acreages of the crops and a fairly good general productivity rating obtained.

Where the crops vary widely, however, no good method has been developed. If the common crops are corn, small grains, pasture, and flue-cured tobacco, for example, one must give weight not only to acreage but also to the relative management inputs; otherwise, flue-cured tobacco gets too little weight. Some soils that are excellent for flue-cured tobacco are not so productive for other crops as are many soils that are ill-suited to that crop.

For dark-colored Prairie soils in the Cornbelt, the ratings for corn alone are fairly close to a general rating, except that soils veil-suited to pasture and ill-suited'to corn get too low a rating.

Thus we do have need for improved methods for developing reliable general productivity ratings where soils have adaptability for a wide range of contrasting crops. Until such a method can be developed, useful general productivity ratings should, like the capability groupings, be limited to the common field crops and so qualified.

<u>Erodibility</u> of a soil (roughly equivalent to "erosion hazard," or "susceptibility to erosion") is a quality that suggests the erosion to be expected under specifieg conditions. A useful example would be a grouping of soils into 5 or 7 classes 6/ of erodibility under clean cultivation to row crops without mechanical devices for runoff control. Others could be made under different specified conditions, such as wheat-fallow, close grazing, and so on.

Several soil factors combine to give this quality, including degree, length, and shape of slope; permeability to water, which depends on structure, texture, and clay mineralogy; depth of permeable soil; and presence of coarse fragments in the surface (erosion pavement). Amount, intensity, and seasonal distribution of rainfall are important. No direct relation exists between erodibility and any one of these factors where the others are allowed to vary. Under clean cultivation some soils are highly erodible if the slope exceeds one percent; others are not erodible with slopes of 20 percent, or even up to 40 percent on certain highly productive Reddish-Brown Latosols of the humid Tropics.

But any meaningful set of groupings must be made under a clearly defined set of assumed management conditions. Simply "good" or "poor" management is too vague for accurate comparisons.

Actually the amount of soil material removed from the soil surface can be and is being measured on small plots at selected locations. The results are helpful in guiding estimates of such loss elsewhere. They aid in estimating either normal or permissive soil loss and in setting up classes of erodibility, as well as in evaluating runoff-control practices. In actual practice in soil classification and mapping, however, erodibility is not directly measured but is inferred from soil characteristics and closely related evidence observed in the field.

6/ For degrees of expression of many soil characteristics and for nearly all soil qualities and interpretive classes it works out most conveniently to use an odd number of classes. The human mind deals with comparisons and it is useful to have the extremes and the middle in a 3-class system or, where more detail is required, with one or two intermediates on each side of the middle in 5- or 7-class systems.

__Soil drainage,__ conceived as the relative degree, frequency, and time of waterlogging in the soil, is a soil quality that can also be measured in spots by proper instruments that have provision for continuous recording or that are read at frequent intervals over a period of years.

Such data are useful in helping to define classes and to correlate waterlogging with observable soil characteristics. In fact, the scarcity of such data is a serious handicap to further progress in the classification, mapping, and interpretation of soils that are waterlogged all or part of the time. Greater effort is urgently needed to obtain them.

In carrying on soil survey field work, kinds of soil are placed in soil drainage classes by interpreting indirect evidence of waterlogging -- the color and other properties of the horizons and lower layers of soil profiles, evidence of standing water, and kind and appearance of vegetation.

__Other qualities for special purposes__ can also be interpreted from the soil survey. Generally the conception and procedures follow the same principles already explained. Each comes from the synthesis of several characteristics interacting with one another in respect to some defined quality.

__Response to management.__ In our modern agriculture we are becoming less and less concerned with the harvest to be expected from a soil that is simply tilled and seeded. Only a relatively small proportion of the soils in the world gives a reasonable harvest with such simple management; certainly there are more examples of highly productive arable soils that have been made so from soils that originally gave very low yields under simple management. This statement applies to the majority of the most productive soils in the Netherlands and other parts of Europe and to a great many of those in the United States. In thinking about the response of a soil to management we are concerned with a wide variety of changes, and how drastic they are to be. For example, we have areas of sand soils of low productivity that need only water control -- combined drainage and irrigation -- and the addition of fertilizers to become highly productive arable soils. In other instances the soil must be terraced, perhaps leveled between terraces, and water control structures provided, as well as heavily fertilized.

FURTHER SYNTHESIS OF SOIL QUALITIES

In the broader interpretations for direct use, such as capability units and classes, range sites, and woodland suitability groupings, several qualities are synthesized to obtain homogeneous groups of soils in terms of some defined purpose.

The capability system is a grouping of kinds of soils without regard to location or to the economic characteristics df land. Since the system has been de-fined in a recent statement [7J] and will be dealt with soon in a special bulletin, it need not be described in detail here.

The system has three categories, not counting t' • soils themselves. The individual kinds of soil, commonly phases of soil. t,,r.s or series, are the building stones of all interpretive groupings. About such units we have the maximum information and can make the greatest number .)f and most specific predictions.

1/ See footnote 1.

1. Capability units include soils having similar responses to soil and water management practices; crop adaptations and yields (within 20 percent of the modal for the group); and risks and limitations for agricultural use.

2. Capability subclasses group soils according to the kind of limitation or problem for long-time use. (These may be regarded as subdivisions of capability classes according to broad kinds of problems of use.)

3. Capability classes are still broader groups of soils according to potentialities and degree of broad limitations for agricultural use.

Soils in capability classes I, II, III, and IV are suitable for the common field crops, as well as for other unspecified uses, with increasing limitations and management problems from I through IV.

Soils in classes V to VIII are not suitable for cultivated field crops except with major reclamation or special practices, although some are suitable for special crops or other uses. Soils in class V have little erosion hazard but have other limitations making crop use impracticable. Soils in class VI are useful for permanent vegetation, forest trees or forage, and maybe expected to return benefits from inputs of soil and water management practices under a normal economic environment. Soils in. class VII are useful for range and woodland but do not normally return benefits from inputs of those management practices aimed at changing the soil for these uses. Soils in class VIII are not expected to return on-site benefits from inputs of management practices for field crops, grasses, or forest trees, except following drastic reclamation, which is not commonly practical.

Broad judgment is required to maintain balance in considering soil qualities. For example, a soil with a high erosion hazard cannot be put in capability classes I or II. But conversely, just because a soil does not have significant erosion hazard, it by no means follows that it belongs in classes I or II. Its droughtiness, difficult structure, or other qualities may cause it to be put in class IV even though erosion control is no problem.

Perhaps it is worth repeating that the capability grouping of soils is guided primarily by the soil and management requirements of the common field crops, including pasture. Different kinds of groupings are required for other plants and also for more specific guidelines for individual field crops or specific combinations of soil management practices that the current state of our knowledge makes possible. Individual areas of many of the kinds of soil grouped into classes above class I -- that is, in classes II to VIII -- can be brought into harmony with a lower class through drastic treatment. In fact, where drastic changes are made through land forming, we now find it necessary to map some areas twice, once to guide the development work and a second time after this is finished to guide soil and water management on the remade arable soils.

It should also be emphasized that the basic units are individual kinds of soil, commonly phases of soil types or soil series. In detailed soil surveys the areas of the majority of the mapping units are each 85 percent or more of a specific classificational (or taxonomic) unit. Such mapping units take the name of the taxonomic unit. To some extent in detailed surveys of moderate or high intensity and to a large extent in low intensity surveys, the mapping units must be complexes, which are associations of unlike soils. The soils may be slightly or strongly contrasting. The common characteristic is their intimate geographic relationship. They may have many, few, or almost no common soil characteristics. Such mapping units have compound names made up of those of two or more taxonomic units.

Thus when kinds of soils are grouped into capability units, range sites, or woodland suitability groups we must recall that these are groups of taxonomic units and not necessarily of mapping units. If soils in class III and class VI, for example, are mapped together as a soil association, we have also an association of capability classes.

Thus it is very important not to confuse mapping units with taxonomic units. Where contrasting kinds of soil are included in one mapping unit, the interpretor must make clear that it is also an association of range sites, of productivity classes, or of whatever other interpretive group he is dealing with.

Now this raises the obvious question: How does one place such mapping units into the interpretive classes? For most interpretive groups there is no need to place the complex mapping units in groups. If the complex is one of both ill-drained and well-drained soils, the map user should realize this. If the mapping unit is a mixture of range sites, he should know it.

The capability system suggests adaptability for field crops. In detailed soil surveys, soil complexes are set up as mapping units where the individual areas of soil are too small and too irregular to be separated on the map. This means that they are too small for separate treatment in fields where soils are handled with machines. If it is necessary, for some reason, to give these complex mapping units a class designation it would be that of the soil which governa.the use of the area. An intimate complex of soils in classes II, IV, and VI should be either unclassified or carry the designation VI on the assumption that the other areas are too small for efficient use.

In other groupings, say according to suitability for cranberries, judgment would be made by whether or not the fact of the presence of the least responsive soil in the complex makes use of the better soils impractical. If it does, the complex should be put in the class with the least responsive soil. But if it does not, the mapping unit as a whole cannot be put into any of the classes.

This problem of the influence of size and shape of soil areas is not limited to complexes. It would be the same even if the separate taxonomic units had been mapped out at a scale of say 1:1,000. As pointed out earlier, we still lack good criteria for evaluating the size and shape of soil areas in our schemes for soil survey interpretation.

Since the capability system does not specifically express the capability of the groups of soils for range, woodland and such crops as rice, fruit and ornamental plants, or others that have quite different soil and cultural requirements from the common field crops, different groupings are needed for those other plants. Some soils not suitable for common field crops are even more productive of range plants or forest trees than are other soils that are suitable for field Crops.

Thus soils are placed into woodland suitability groups on the basis of forest-site indices and the other soil characteristics and qualities that influence tree growth and forest management.

Similar soils are grouped into range sites according to the expected kinds and yields of range plants suitable for grazing.

Kinds of soil are given special ratings according to their productivity for other crops. On the basis of these ratings and cultural requirements, soils may be placed in groups according to their expected suitability for individual special crops, such as rice, cranberries, blueberries, pecans, ornamental heather, macadamia nuts, avocados, citrus, apples, or pears.

The capability groupings are intended to suggest the suitability of potentially arable soils for field crops and pastures under systems of management that prevent soil deterioration at moderately high levels of management. Thus the units in the system are not necessarily directly parallel to productivity ratings according to common practice.

Since any group of soils has a wider range in several characteristics than an individual kind of soil, for the most nearly precise predictions available, the reader should go to specific interpretations for the kind of soil. This is especially important where drastic changes are to be made in the soil by leveling or other earth-moving practices.

GENERAL METHODS OF INTERPRETATION

The harvest from any soil is a result of interactions between the soil with its many characteristics, the other factors of the environment, and the management of the soil, which is made up of a combination of practices. Thus reliable yield predictions can be given only for defined kinds of soil under defined systems of use and management.

For any kind of soil, we can approach the preparation of the yield prediction of a specific crop under a defined set of management practices in two ways: (1) By induction from our knowledge of the interactions involved among the soil characteristics, the needs of the crop, and the management practices; and (2) by empirical observation of yields of the crop produced on the soil under the specified management.

As an example of the inductive method, a competent soil scientist may first examine the soils carefully in the field and in the laboratory and record the results. On the basis of the known principles of soil science, he can estimate the yield to be expected of the adapted kinds of plants under different systems of management. This is risky if he has not seen the plants growing on this kind of soil. But on soils within the limits of his experience and of his knowledge of the interactions between soils and crops he can do a fair job.

This method applies even better to engineering interpretations, say in respect to road construction, spacing and shape of drainage ditches, and the like. This inductive method has the limitations that are inherent to the limitations of our scientific knowledge. Soil research has not been highly developed everywhere. Many principles that hold quite well in one locality do not hold for quite different kinds of soil. For example, we do not have so firm principles for the soils of the Tropics, of the Arctic, and of the high mountains as we have for those of well-developed temperate regions. In engineering interpretations, for example, there is a tendency to put great weight on particle size. But clays have quite different properties, depending on the cations of the absorbing complex and especially on the kinds of clay minerals, which influence engineering interpretations.

In a more strictly empirical way, we can observe the results on different examples of the same kind of soil. If we have enough observations, and especially if these are supplemented by controlled field experiments, we can reach rather dependable predictions of the results of soil management or soil manipulation without knowing much about what is actually going on within a soil.

This method has some severe limitations because we can get observations of experience only within the existing environment. We are greatly limited in making interpretations about how the soil would behave under quite different economic environments where machines and chemicals are either more or less easily available. Unfortunately for our work now, until recently many of our field experiments were also limited by the present economic environment. In other words, many experimenters did not try more fertilizer than they thought farmers would want to use.

I recall some experiments laid out about 40 years ago in which the amount of phosphate fertilizer applied per acre on the experimental plots was determined by how much of this fertilizer one could buy for a fixed sum of money: As fertilizers have improved in quality and declined in price, many of our older fertilizer results are entirely inadequate. It is highly important to include in experiments in the present economic environment, combinations of practices over a wide universe so that if the economic environment changes we will have data for applicable predictions.

During the 1920's in Michigan much progress was made by using the empirical method, supplemented by inductive reasoning from data, to arrive at some engineering interpretations. By observing the conditions of concrete pavements built with different designs on known kinds of soil, information of high prediction value was obtained for new highway designs according to the kinds of soil they passed over.

In actual practice we combine both the inductive and the empirical approaches. The results from one approach serve as a check against the results of the other. In making a prediction of say 75 bushels of corn per acre on a certain kind of soil under a defined system of management, we want the result to be reasonable when tested against our knowledge of soil behavior and plant response and against the summary of results of farmer experience and of field experiments.

As our agriculture becomes more efficient errors of yield prediction become more costly to the farm manager.

FORMS OF INTERPRETATIONS

As pointed out earlier, the whole process of interpretations is one of synthesis. We must be as specific as possible. Farmers do not grow crops in general; they grow specific crops under specific systems of management. Yield predictions need to be specific for the crop or sequence of crops, the kind of soil, and the system of management if they are to be useful. And the demand is for increasingly specific information. This demand will continue to increase as agriculture be-comes more competitive and requires still more investments in technological de-vices and materials.

To take a simple illustration in developing a farm plan on a mixed farm with livestock: The successful operator must have a reasonable balance among his grain supply, forage supply, and numbers of animal units. He needs to know the expected yields of these forages over the whole growing season and he must be able to calculate his winter feed requirements and determine what part of these to raise on the farm and what part to buy from the outside. These are very important calculations to the farmer and good yield predictions are required.

Generally the interpretations take two forms. One may be illustrated by tables giving effects of specifically defined systems of alternative management on crop yields and soil productivity. In this form the reader gets figures in bushels, tons, and the like, or an index number, for each crop under each alternative system for producing the crop. The site indices for different species of pine by soil types would be another example of a specific interpretation.

Most engineering interpretations are set forth in tables with specific figures or class intervals for each kind of soil. For some interpretations, individual horizons of soils may need to be treated separately from other horizons.

The other form of interpretation is the grouping of the kinds of soil in the soil survey legend in accordance with any one of a large number of iiterpretations. To do a good job of grouping one must have specific estimates [J] about each kind of soil. As an introduction to the more detailed predictions for each kind of soil, groupings can be useful if well made. The more general these groupings become the more difficult is the job of making consistent interpretations. The larger the number of practical purposes one expects of a grouping, the more it loses specificity for any one purpose.

Perhaps this can be illustrated conveniently with the grouping of soils into capability units, subclasses, and classes. The soils within a capability unit should give about the same responses to the same general combination of practices. For groupings to be uniform, the soils must be interpreted the same wherever they occur. In detailed soil surveys of the same intensity, phase distinctions, for example, must be made in the same way within any one soil series. Wider ranges in characteristics and in qualities are permitted within a capability unit than within an individual kind of soil. But within a capability unit a wide range is not permitted in any soil quality that is relevant to its interpretation, although other qualities can vary. Thus we are considering permeability, drainage, erosion hazard, and so on at the same time. If in one area a man should give much weight to erosion hazard and too little to crop yields or problems of tillage he would place the soils in different capability classes than the man who gives little weight to erosion hazard and much to yields and tilth maintenance. Through study of soils over wide areas such errors are prevented.

In looking over the experience so far it seems that quite good groupings have been made within local areas -- counties, groups of counties, and even States. But our standards for uniformity over wider areas lack precision. For this reason we need to relate the capability units to soil classificational units at a somewhat higher level in the system of soil classification than soil series. By grouping soil series together into families we get some broadening of the range of the characteristics. Perhaps comparable phases of all of the series in the soil family should fall in the same capability unit. Among non-arable soils, comparable phases in two or more families can fall in the same capability unit., Possibly other groupings rather than capability units may be more useful in areas having mainly non-arable soils. A grouping of soils within class VI according to their response to range reseeding is an example.

J This does not mean specific test data on each kind of soil. See discussion on benchmark soils.

INDIVIDUAL CHARACTERISTICS

Besides interpretations resulting from **synthesis, one can group** soils **in accordance** with **their individual** characteristics. For example, we **might emphasize** slope and place soils into 3 groups as (1) nearly level soils, (2) sloping soils, and (3) hilly soils. Or we can place soils into 2 groups, (1) those that are too stony for the use of mechanical tillage equipment, and (2) those that are not too stony.

A few years ago there was more of this selection of actual soil characteristics for emphasis than now. Rarely are groupings by single characteristics (not qualities) helpful. Most users of soil surveys need interpretations resulting from **synthesis** rather than analysis.

Some interpretations cannot be consistent without considering a soil characteristic all the way through the grouping. The following is an example of a useful grouping that **approaches** the single-factor type: During a period of the last war more disk harrows were available for allotment to farmers than spring-tooth harrows. It was necessary to use the small supply of **spring-tooth** harrows **primarily** in communities having soils too stony for disk harrows. Estimates of such soils were made by counties. This was not simply a matter of stoniness. It was the stoniness of the soils otherwise suitable for field crops. A consistent **appraisal** of stoniness of the arable soils was essential to a good interpretation.

In legends of **detailed** soil surveys soil phases for stoniness are separations within soil series, or within other **phases** of **the** soil series. **They are** mat **arbitrary classes** of **stoniness,** as **a** soil **characteristic,** for all soils. On **the contrary, the phase** definitions **are made to separate** degrees **of stoniness that affect the use of the** soils within the series, **type,** or **other phase. Within** a soil **series** with a wide **slope** range, for example, **degrees** of **stoniness** significant **at about 5 percent slope may not be significant above 20 or 25 percent** slope.

The same principle applies to other **phase** criteria. We try to **make** the definitions **so that** the **boundaries** fall in the most **significant** places. One **may** criticize this procedure **because** the interpretation **does** influence **the** classification. **Actually** there are an infinite number of places to **make definitions between** zero **stoniness and** complete stone **cover** or between **zero slope and** 90 **degrees. Any** selection is arbitrary so we choose **the** ones **that permit the most precise interpretations now. Arbitrary classes (in terms of percent slope)** of 0 to 5, 5-10, 10-15, **and** so on are no more "scientific" than 0-2, 2-6, **and** so on for one soil **and** 0-5, 6-12, **and** so on for **another. By adjusting the definitions appropriately one has a far more useful soil map for predicting soil behavior.**

It is important to make many interpretations of soil qualities, particularly in educational programs and to focus attention on certain neglected problems or neglected **potentialities. That** is, it is often useful **to make** a **grouping of** soils **according to erodibility** or erosion **hazard.** This **can be done accurately only by defining use and management, such as, for example, erosion hazard under clean cultivated row** crops. **Such** groupings **can be quite** useful. It is **often** useful to **give ratings by individual** crops, **especially** crops **that one may think** it **desirable** to **introduce** into a **community. Thus we may have either** a 3-class **grouping or a** 5-class **grouping of** soils **according to their suitability for some specialty crop. Groupings according to response to lime, to lime and phosphate, and the like can be useful in planning educational programs.**

BENCHMARK SOILS

Many data are needed for making a modern soil survey that will endure and be capable of accurate reinterpretation with changes in economic condition and agricultural arts. The work to obtain the data must be organized. Representative examples of the various groups of important soils, selected for concentrated study and complete interpretation, usually by workers from several agencies, are called "benchmark" soils.

First, let us see what data are needed. We must have data about the soils in the survey areas. We need to know the combinations of soil characteristics, and the allowable ranges in them, in order to define a soil. Then we need to know how these defined kinds of soil are related to other kinds so we can give them names and places in the system of soil classification. We must know the relationsh4ps between the soils and the other correlated features of the landscape -- climate and natural vegetation; the age, shape, and lithology of the land forms; and the experiences of use and management.

Part of these data are obtained during the survey itself by the soil scientists doing the field work. Some are obtained in the laboratory and from special researches during the course of the soil survey. To varying degrees, data are already available from earlier soil surveys and other studies in nearly every county in the United States. In areas that },ve been fairly closely settled for many years, a great deal may be known. With close attention to soil similarity and climate one can make excellent use of data from outside the survey area. The problem is one of collecting and especially of relating these data from the literature to the specific kinds of soil as now defined.

All of these data are used in soil survey interpretation; but more are required for developing a full set of predictions about alternative management systems and for modern engineering interpretations. Many of our studies of soil management were made in an older and different economic environment than now and do not help much to predict yields with the modern combinations of practices. Considering the scope of our soil survey program and the total soil research facilities available, it is not possible to have good field experiments, or even good "experience" data from field records, on each of the many tens of thousands of kinds of soil we must deal with in the United States.

Although accurate yield data are lacking for many soils, the data obtained during the soil survey of an area allow the development of a fairly good array of the soils according to their probable responses to management. That is, field soil scientists experienced in the use of the inductive method of interpretation already explained can list the various kinds of soil in accordance with soil qualities and in the order of their responses to management. Yet they need some specific yield records of adapted crops under physically defined combinations of practices in order to quantify their arrays in bushels, tons, and the like, and to check their estimates from induction.

To develop a reliable yield-and-practice table, one does not need long-time field records for each crop on each kind of soil under all alternative management systems. With a few sets of fairly complete data over the range of soils, reliable predictions can be given for the whole array of soils.

2/ It should be mentioned that soil scientists working with uncultivated soils west of the eastern foothills of the Rocky Mountains (and in Alaska) have far fewer data for either classification or interpretation than those working east of the Rocky Mountains.

For about 10 years now representative soils have been specially collected for engineering tests. Now full data are available for many kinds of soil. These serve as "benchmarks" for the engineering interpretations. As more soils are fully sampled, the grid of such benchmarks becomes finer and more useful.

This important principle should guide the selection of kinds of soil for concentrated study, including field experiments. Unhappily, such selection has formerly been left largely to chance. Ease of plot layout and of field experiment often have been the controlling factors. As a result, among the available data from field experiments, the most productive, level to gently sloping, soils are over represented. Much fewer data are available for the stony, hilly, and partly eroded arable soils.

By the selection of benchmark soils for concentrated study it is hoped to meet the needs of soil survey interpretation for field crops, special crops, engineering, forestry, range, and wildlife habitat with the facilities at hand. The plan does not hamper the going soil research programs of the USDA or of the State experiment stations. In fact, it can make them even more effective. By selecting, over a range of soil conditions, a few soils about which nearly complete information can be had, we can make further progress than by having scattered data on a much larger number of soils. Besides having field experiments and field records of farmer experience on fair examples of the benchmark soils, we can have good physical, chemical, and mineralogical data to go with the soil morphology and other field data.

It should be possible to study the interactions among the characteristics of and among practices for well defined soils. Full consideration can be given to soil moisture, plant nutrients, plant population, erosion hazard, engineering practices, and the like. In this way we can discover the most practical approach toward the ideal arable soil that will capture the full benefits of the inter-actions without under- or overdesigning any one practice in relation to the others. That is, even though expensive drop inlets are required for some highly erodible soils, we need to use the less expensive ones that will do as well on the less erodible soils. Nor should the farmer use one fertilizer out of balance with soil water or other growing conditions.

We hope that the selection of benchmark soils will continue cooperatively among the States. It should be a major activity of the Regional Soil Survey Work-Planning Conferences.

As the results become available they need to be compiled and published cooperatively. Such bulletins serve to give data useful in quantifying the predictions for soils already arrayed relatively to one another.

ECONOMIC RELATIONS

The economic environment influences our soil survey interpretation both directly and indirectly. It has partly determined what data are already available for synthesis into interpretations. And it partly determines the need for and applicability of alternative interpretations for the same kinds of soil in different places.

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In most situations for which soil survey interpretations are needed we hope to consider all reasonable alternatives for each kind of soil so that the operator can select the ones that will give him the greatest output on a sustained basis for the inputs of labor and materials. Usually this means building up the productivity of the soil, commonly through rather expensive practices. Thus the definitions of expected outputs and expected inputs need to be reasonably precise so that the operator can calculate the value of the outputs and the cost of the inputs. These costs for the same kind of soil vary with the local economic environment. Thus fertilizers and machines are most commonly used where they are cheapest and most easily available.

In deciding among competing uses in broad land-use planning, however, we cannot always follow this principle of comparing outputs with inputs in deciding the best use. For a tract of land that can be used for horticultural crops, field crops, or forestry, one can calculate the input-output relations and arrive at estimates that suggest which use would give the greatest income. But in a modern society we need living space for cities, recreational areas, transport facilities, and the like which do not lend themselves to this kind of calculation. Based on the known social needs one can calculate the requirements for these purposes and then meet them in ways that appear to be reasonable. Judgment among the claimants cannot be replaced by formulae. Even the common methods of,appraisal for uses in agriculture and forestry, however, are good only for a short run. No exact methods exist for estimating long-time benefits or costs to society from developing or losing productive tracts of land.

The data we have from both research and experience vary widely according to the level of the general economy. And so does the need for interpretations. The most efficient agriculture in the world is in those areas of high general economic development. Agriculture is most efficient where managers have easily available the industrial products that give high returns. There are other related factors such as the security of tenure for the operator and his access to both'local and foreign markets. It would be difficult to find data from experience or interpretations under management practices involving high returns of fertilization in Central Africa. Nor are such interpretations urgently needed by cultivators in Central Africa right now. But in making soil surveys we should try to look far enough ahead to have at least the most likely interpretations even though they may not be used much during the next few years.

RELATION TO LAND CLASSIFICATION

Besides grouping individual kinds of soils, soil survey interpretations are used, along with additional data, for both the appraisal and classification of tracts of land. Location, size of tract, and other economic characteristics of land are highly significant in land classification. We must continually recall that areas of kinds of soil have natural boundaries and are commonly found in contrasting economic environments. A grouping of like soils commonly places together areas with unlike economic characteristics.

The overlapping use of the terms "soil" and "land" should not be permitted to lead to confusion in soil survey interpretation. "Land"is an old word that has been widely used in geology, agriculture, economics, and other fields in different senses. The physical, chemical, biological, and geological characteristics of the upper regolith that affect plant growth and water movement are included under the conept "soil." "Land" is more than that; it has other important characteristics not associated with soil. For example, every tract of land has a unique latitude and longitude. In an economic sense, land is the area in which production takes place. Production is organized by management units of separate tracts of land such as farms, plantations, gardens, forests, and the like. For that reason size is an important characteristic for the classification of tracts of land.

The size of the land tract should be large enough to permit the organization of a reasonably efficient management scheme. We can find areas of the same kind of soil in urban centers, in well-developed agricultural areas, and in undeveloped agricultural areas far from transport; and these tracts have different potentialities for use and contrasting values within their economic environments. Although they may represent the same kind of soil they are quite different kinds of land, in an economic sense. A tract of land of only 80 acres in a region where one needs a minimum of 400 acres for successful operation of a farm may have little value except as it can be attached to some other unit for operation.

As already pointed out, for most arable soils there are several alternatives for use and management. We do not expect, therefore, the same use for areas of the same kinds of soil in different land tracts. The alternative selected depends on the economic characteristics of the tract and the skills and resources of the manager. Thus the input-output relations and values per acre are not the same for all areas of the same kind of soil. Although placed together in soil classification and in interpretive soil groupings. the land tracts of which they are a part could have very different economic potentialities and different appraisals. They should fall into quite different groups in a classification of the land tracts.

Yet well-interpreted soil surveys are the best primary basis for the classification of non-urban land tracts. Present land use is a poor basis. The present use of any tract is partly a matter of accident. The manager may be unskilled or he may be above average in skill. The land may be idle for institutional reasons.

The classification should be based on potential under the current or expected economic environment, considering the location and size of tracts as well as soil. In new settlement areas one first has the job of establishing minimum and maximum sizes of potential tracts for economic use under the expected economic environment.

The distinction I am trying to draw between soil survey interpretation and land classification -- in the sense of land tracts or potential tracts -- is highly important for understanding the results of interpretation and for reaching objectives. In addition to soil survey interpretation, soil scientists are able to. make excellent land classifications. Where they have done so, full consideration has been given the size of land tracts, or potential land tracts, and their location in relation to water, to other land, to transport facilities, and to markets.