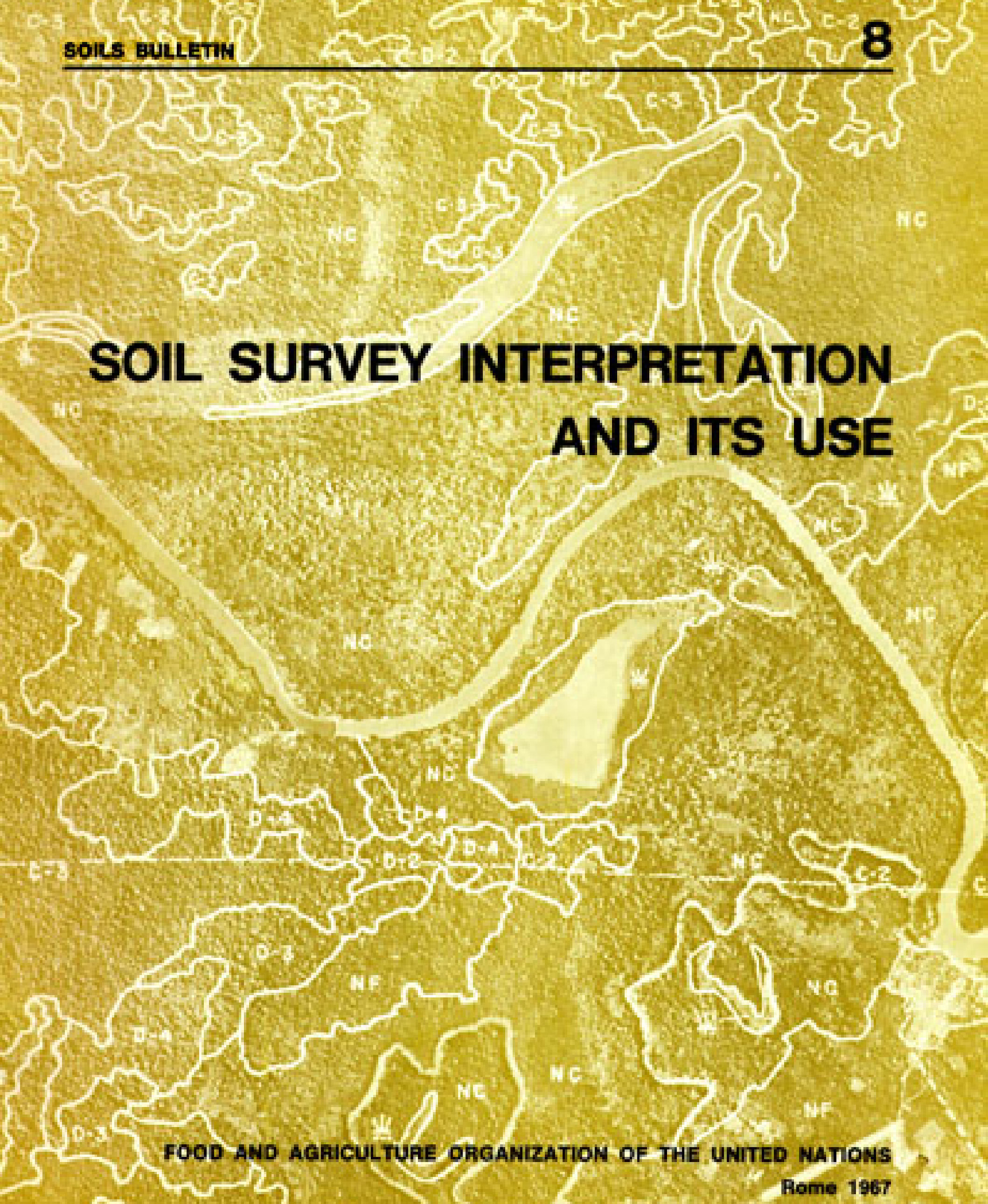
SOILS BULLETIN 8



SOIL SURVEY INTERPRETATION AND ITS USE

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INTRODUCTION

Soil survey interpretations are predictions of performance, not recommendations for the use of soils. The best way of using a soil depends on many economic, social, political, and sometimes even religious, considerations in addition to the soil characteristics and responses. Soil maps, soil characteristics, soil classification, and technical groupings of soils are important in selecting a type of land use and in classifying land. Land in the economic sense, however, has many attributes other than soil, and includes the size of tracts or potential tracts and their relation to water, to other land, to transport facilities, and to markets. Preference of the owner or operator, and his resources in capital and skill, also play a big part in the selection of land uses, cropping systems, or soil-management practices.

Natural soils differ greatly from place to place. Yields of crops almost everywhere can be improved through better soil management, but the practices needed depend on the kind of soil.

Farmers for many centuries have known about differences in their soils, but only in the last few decades have they had the results of soil surveys and related studies of soil performance. Soil classification and mapping advanced rapidly after the end of the second world war. Soil surveys now have high priority in the development plans of many countries. Many soil maps of high quality are being made, and the characteristics and responses of thousands of kinds of soil are being studied, tabulated, and used in making land-management decisions. Interpretation of soils, however, can easily be allowed to lag behind the production of soil maps.

A soil map has little value unless the information from it is used in farming or in some other soil managing activity. Good use of a soil survey requires some technical guidance, and such guidance has not always been available to the cultivators in an area covered by a new soil survey. Soil classification and mapping are necessarily done by specialists. The same technical specialists who make a soil survey are best able to do much of the work needed to study the soils and their responses to management. Too often, however, a soil scientist must be diverted to make a new soil survey before he has gathered and tested the facts needed to interpret one just completed. Coulter emphasized in 1964 (8) that, especially in the tropics, progress in soil mapping is far ahead of the progress in gathering knowledge of soil fertility. Several other factors in management of tropical soils, such as the conservation of moisture, control of soil temperature, maintenance of good tilth, and limitations imposed by length of day or by clouds, are less well understood than soil fertility. In many places outside the tropics much progress has been made in soil survey interpretation, but a great deal still remains to be done.

A good soil survey must be both practical in its purpose and scientific in its construction. Nearly all soil surveys are made by agencies of governments, and unless the resulting soil maps serve practical purposes the government may not long support the work. Unless the mapping units are scientifically conceived, the soil map is almost sure to lose its usefulness as technology advances.

Soils are three-dimensional individual pieces of landscapes. A soil has depth and area, and it occupies a slope or a pattern of slopes. Each soil has many characteristics, and in one way or another its characteristics reflect its entire history. Each soil evolved in and along with its environment, and it interacts in many ways with its present environment. Soil scientists study soils and classify them, and they make soil maps to show the distribution of soils of different kinds. A soil of any kind in its particular environment has a predictable response to management or to any kind of manipulation. The job of soil survey interpretation is to predict how the soils of a given kind respond when they are used.

This bulletin brings together some of the methods which have been developed and tested in countries that have active programs of making and using soil surveys, and a summary of some of the principles of soil survey interpretation. It is mainly for the soil scientist who is making and interpreting a soil survey, or who is re-interpreting a soil survey already completed. Methods are suggested, with examples, for comparative ratings of soils, capability grouping of soils for the common crops, estimating yields of crops on different kinds of soil under defined sets of other growth factors, groupings of soils for range and for woodland management, and use of soil maps and reports in engineering work that involves soils as foundations or as construction material. There are also brief discussions of soil maps for planning, use of soil maps in appraisal of land, and the preparation and use of general soil maps.

Soil survey interpretations should be arranged for easy reference and use by people who work with soils, or advise those who work with soils, and are not especially trained in soil science. Interpretations generally take the form of ratings, tables, charts, interpretive maps, and interpretive statements. The soil map shows the location and extent of each kind of soil. The interpretations should tell an agriculturist, forester, engineer, or other specialist the main characteristics and responses of the soils that are important in his work. The soil user generally wants to apply the most profitable management on each kind of soil, and good soil survey interpretations should help him to do that.

BACKGROUND AND PRINCIPLES FOR SOIL SURVEY INTEPRETATIONS

Kinds of Soil Survey and Soil Maps

To make a soil survey, scientists examine and classify soils in the field, locate soil boundaries and plot these on a map, describe the soils shown on the map, including statements about their morphology and their important characteristics and qualities; and finally, they interpret the map units to serve especially the purpose for which the soil survey was made.

Soil surveys can be made at any of several levels of intensity, depending on the nature of the area and its stage of development, the time, money, and personnel available, and the uses that are to be made of the information (28).

Detailed soil surveys are the most intensive. Generally, on a detailed soil survey each soil boundary is plotted after observing the soil surface throughout its course. Some exceptions may need to be made if the ground is covered with dense vegetation.

Detailed soil surveys are further classified according to the intensity of coverage, which is in turn partly reflected in the scale of the map. Soil surveys of high intensity are made where the land is to be used so intensively that all the significant soil areas need to be known. Such soil surveys may be made for development of an irrigation project or in areas where much of the land is to be used for housing. Soils and geologic materials to a depth of a few meters generally must be examined. The scale of mapping is frequently 1:7920, and for some purposes may be even larger. Mapping units generally are phases of soil types.

Detailed soil surveys of medium intensity are the most common kind in many countries. Mapping units generally are phases of soil types; but if patterns of soils are intricate, some may need to be complexes of more than one kind of soil. Routine examination of the soil generally ends at a depth of about one meter or one and a half meters; enough to see the solum and the material next under it, except where deeper cuts are available. Scale of these soil maps generally ranges from 1:15,000 to 1:30,000.

Soil surveys of low intensity are often made in arid regions where grazing is the principal use of the soils, and in mountainous forest land. Mapping units often are associations of phases of soil series. Scale of maps is likely to range from 1:30,000 to 1:60,000.

Soil surveys called semi-detailed in some countries have the characteristics of medium to low intensity as described above. Mapping units often are phases of soil types, but some may be associations of defined kinds of soil. Scale of mapping is likely to range from 1:20,000 to 1:60,000. In some places where vegetation is dense, the boundaries of mapping units cannot be observed strictly throughout their course, but must be extended between lines of observation cut through the bush.

Reconnaissance soil surveys are made by observing soils and soil boundaries along traverse lines through an area; then extending the boundaries of mapping units between traverses after study of available maps and aerial photographs. Mapping units generally are associations of phases, either of soil series or of classes in higher categories.

The scale of published reconnaissance soil surveys can vary widely from around 1:62,500 to 1:500,000.

Exploratory soil surveys, resulting in schematic soil maps, are made largely by drawing inferences and locating boundaries of mapping units after study of available maps and information concerning the climate, vegetation, geology, relief and other factors, checked if possible by traverses through the area. Mapping units normally are associations of phases of great soil groups.

Field scales of 1:1,000,000 can be used for very broad exploratory surveys, but that scale is too small for sketching boundaries from field observations.

General soil maps can be made by reconnaissance or exploratory methods, by generalization from detailed soil maps, or most commonly by a combination of the two methods. The scale and type of mapping unit are chosen to match the uses that are to be made of the map. In many countries, general soil maps at a scale usually between 1:100,000 and 1:350,000 are published along with the reports of detailed soil surveys of medium or low intensity. General soil maps on a smaller scale, some at 1:5,000,000 or even smaller, are useful for purposes of general planning and geographic correlation.

Soil Characteristics and Qualities

Characteristics and qualities of a soil affect its performance (16). Soil characteristics are the items that can be seen or measured, such as thickness of a horizon, grain size distribution, amount of organic matter, reaction, kind of clay, content of plant nutrients, type, grade, and class of soil structure, and the capacity to hold water. In most soils many of these characteristics differ significantly for different horizons in the soil profile.

Soil qualities are the results of interactions between soil characteristics and soil-using practices, or between soil characteristics and the environment. Examples are soil fertility and soil productivity. The class of natural soil drainage, much used as a criterion for classification and for practical grouping of soils, is a quality based on visible results of interactions between soil permeability, changes in position of the water table, and the amount of water that enters a soil by infiltration and lateral seepage. Soil qualities cannot be measured directly, but must be inferred from characteristics that can be seen or measured.

Any use of a soil produces changes in it. A cultivator who plants a crop must clear the native plants or weeds, and prepare a seedbed. Often he must supply part, and sometimes nearly all of the nutrients that the crop needs; and remove other plants that compete with the crop for light, water, or nutrients. On many soils he must remove excess water by drainage, bring water to the crop by irrigation, or control speed of runoff water so the soil does not wash away. From many of these practices and others, the cultivator, even though perhaps unconsciously, chooses his level of management in relation to the cost, his resources, and the expected responses.

A cultivator can change some soil characteristics, but in many ways he must fit his practices to the requirements of the soil. If the native supply of plant nutrients is low he can in many parts of the world obtain fertilizer at a cost that is more than repaid by the increased yields. He cannot change easily, however, the slope, soil texture, kind of clay, depth of useful soil, water-holding capacity, or the permeability of subsoil layers. The permanent soil characteristics and the climate limit in many ways the performance of a soil and largely determine the response that it makes to a particular kind and level of management.

An ideal arable soil for most crop plants has a deep rooting zone that is easily penetrated by air, water, and roots. It holds water between rains, but allows the excess to pass through and drain away freely. It has a balanced and adequate supply of plant nutrients. It can be kept from washing away during rains and from blowing away during high winds. Rice has special water requirements and tolerance, and the ideal soil for submerged rice is nearly level or can be made so, contains a balanced supply of nutrients, can be flooded while the crop is growing, and does not allow the water to pass through and drain away too readily.

Most soils in their natural state fall short of the ideals that have just been described. To manage a soil for crops, the cultivator chooses a crop that he believes will grow well. He chooses practices that are within his means and skills to change such characteristics as the fertility level, soil tilth, and sometimes the water supply. Other practices are chosen to counteract effects of permanent soil limitations; for example, to reduce hazards of soil erosion, soil blowing, and damage by drought.

Statements about performance of a soil mean little unless the level of management is described. With a high enough level of inputs, almost any use can be made of any soil. A botanic garden near the Arctic Circle, for example, might change the environment of a plot of soil by building a glass house and controlling the temperature, and might grow bananas; but of course cannot produce the fruit at a reasonable cost. This extreme example helps emphasize the fact that every statement about yields or other performance of a soil has back of it several economic assumptions, whether they are stated or not. The assumptions need to be examined from time to time. New interpretations are needed whenever new varieties of crops or new systems of crop-producing technology make the old assumptions and interpretations out of date. Most of the data for soil interpretations need to be assembled for kinds of soil at a detailed level in the system of classification; generally for soil types or phases of soil types. Yields of crop under defined management, for example, should be estimated separately for the components of a soil complex; even if average yields for areas of the complex are to be estimated also. Then, the interpretations generally are stated for soil mapping units. A practical unit of soil management often is a field that contains more than one kind of soil; perhaps several mapping units. The land operator needs to know the expected performance of each kind of soil, and must decide whether to vary the treatments or to treat the field uniformly and expect different responses.

The Principle of Interactions

The effects of soil characteristics, soil qualities, the environment, and applied practices cannot be considered alone, but only in relation to each other and to the growing plants. These interactions produce crop responses that are desired to give a high yield of good quality; or those not desired, such as reduced yield or failure because of insects, drought, or too few nutrients. A soil and its environment have many separate but related characteristics. Some of them, such as rainfall, vary from season to season. Generally, any of several combinations of management practices can be selected, and the total number of interactions is extremely large.

Plants need root space, nutrients, water, air, and light. For a high yield of any crop the cultivator must have suitable planting material; a root zone deep enough to hold the plants; an ample, balanced supply of nutrients; an ample supply of water at all times; suitable soil aeration; protection from diseases and pests; and protection from competing plants that might reduce available nutrients, water or light below the optimum amounts.

Results of the many factors that affect growth of plants cannot be added up by simple arithmetic, for each one depends on many of the others. In particular, responses of a new or untried treatment cannot be predicted, but must be learned from experience.

Hauck quoted results of an experiment with groundnuts in Ghana that show results of the combination of fertilizers with other production factors (14). The normal yield of groundnuts under prevailing practices was 400 kilograms per hectare. Close spacing (90 x 15 centimetres) raised the yield to 800 kilograms. With close spacing, plus 100 kilograms per hectare of superphosphate (20% P_2O_5), the yield was 1,200 kilograms. Close spacing, superphosphate, and seed dressing with a fungicide produced 1,320 kilograms. Finally, the same three treatments with seed of an improved variety produced a yield of 1,580 kilograms per hectare.

As another example of interactions, Guy D. Smith (25), cited yields of maize in southeastern United States. The climate there is humid and nearly subtropical. Maize is grown without irrigation. With old varieties and small amounts of fertilizer yields averaged about 800 kilos per hectare. Heavy applications of fertilizer increased yields of these varieties by about 600 kilos, or to 1,400 kilos per hectare. Improved hybrid varieties, without extra fertilizer, added about 200 kilos. Control of water by terracing the gently sloping fields added about 150 kilos. These increases obtained by separate practices, added to the original yield, suggest a possible yield of about 1,750 kilos per hectare. The practices combined, however, produce yields of 8,000 kilos.

COMPILATION OF DATA FOR KEY SOILS

Soil survey intepretations are predictions of soil performance under stated conditions. The predictions begin with observations and measurements of performance of a few representative soils, and must always be extended in the form of estimates to cover other kinds of soil and other kinds and combinations of management. The more reliable and abundant the data, the more reliable are the predictions.

Soil scientists and the others who work on soil survey interpretations never have as much data as they would like about characteristics and performance of the soils. They must continually acquire more data, through field experiments and trials, laboratory analyses, and results obtained by farmers.

Methods for orderly collection and preservation of data are essential. A good procedure is to collect data, and to plan further experiments and trials on key soils, sometimes called "benchmark soils". These are typical examples of prominent kinds of soil, chosen to represent different combinations of the whole range of soil conditions and management. Data are obtained on responses of each of the key soils when used for crops, grasses, or trees; also, if significant, on the responses in engineering and in various non-farming uses. It is better to have full field and laboratory studies, including field experiments, on a few key kinds of soil than scattered data from many kinds. The data from key soils can be organized to bring important interactions into focus (Kellogg, 16, 17).

Data for key soils generally are assembled by soil series. Soil type and phase, however, should be recorded for the individual soils that are described, sampled, or studied in any way.

Kinds of data to be collected and preserved include all that are helpful in characterizing or interpreting the soils. A description of the soil series, including facts about the parent material, the setting, and the climate, is essential. The geographic range of the series should be stated if it is known. A block diagram showing physiographic and if practicable, parent material relationships is helpful. Climatic data should include all that can be learned about temperature, precipitation and its distribution, wind, humidity, length of day, and cloud cover; also whatever can be obtained locally on such items as air drainage and other characteristics that affect growth of plants.

Physical and chemical data that are desirable include mechanical analysis, amount of coarse fragments, bulk density, water-holding capacity at critical tensions, permeability (of undisturbed soil), amount and stability of aggregates, maximum density, liquid and plastic limits, optimum moisture for compaction, clay mineralogy, petrographic data for the sand fraction, reaction (pH), concentration and kinds of salts, extractable cations or organic carbon, C/N ration, available phosphorus, total gypsum, free iron oxides, and deficiencies or excesses of minor elements. Such complete data, of course, will seldom be obtainable; but the data which are obtained should be kept available, by kinds of soil, for reference and study.

Soil qualities that can be inferred or interpreted include the fertility status, erodibility, available moisture capacity, effective root zone, permeability of the whole soil or of specified horizons, length of time the soil is saturated with water, movements of the water table, and flooding experience.

Yields that can be obtained of the common crops, of range forage, of woodland products, and of any special crops should be recorded, along with records of management under which the reported yields were obtained.

From such descriptions and data, even if they are fragmentary, the yield predictions and other interpretations, are synthesized. Records should be kept of all the interpretations that are made. They can be lost easily unless several copies are preserved in a central file. Moreover, the best interpretations get out of date as advances are made in soil using technology, and good records of past work are needed for comparison and study whenever new interpretations must be made.

RATINGS OF SUITABILITY FOR CROPS

In many places, ratings of the kinds of soil for selected crops are the first interpretations that can be made from a soil survey. Even though such ratings cannot be based on measured yields or other data, they can be of great value in the first steps of a land development or other soil using program. Estimates of yields are also needed, as soon as they can be obtained, to permit calculation of input-output relationships; but these may have to wait until data can be assembled. Ratings of soils for particular crops are generally made on the basis of four or five grades of suitability, assuming a given level of management practices. Estimates of yields permit more quantitative expression of the differences in soils, and can be made later in relation to two or more levels of management.

Ratings and the rating process can be illustrated by work that was done in Guyana, South America, from 1961 eto 1964 (2). In 1963, soil surveys of semi-detailed intensity were nearing completion for three large areas amounting to about 2,100,000 acres, and interpretations of the soils were needed. Members of the soil survey project consulted many specialists, including several from other countries, reconciled to the best of their ability the differences of opinion that were brought forth, and arrived at a set of ratings. The ratings show suitability of the soils for common crops under a level of management higher than that which prevails on most small farms, but one attainable by farmers who can obtain fertilizer.

In any such rating process, several assumptions about sets and levels of management and related items need to be stated in definite form. Much of the procedure followed in Guyana can be shown by listing the assumptions made by the group working there. Significance of the four levels of suitability is next explained, and examples are given of the ratings of six of the kinds of soil for five crops or groups of crops.

Assumptions and guide lines adopted in making the ratings were stated as follows (2):

1. It is assumed that crops will be grown with at least a moderate level of management; that lime and fertilizers will be used according to soil tests and the needs of the crop; and that runoff and erosion will be controlled on the sloping soils. This is a level of management that can be followed readily by a good farmer. A very high level of management, such as that practiced on the Government agricultural stations and the sugar estates, is not assumed.

2. It is assumed that the main drainage and irrigation works are installed where necessary. Adequate irrigation and water control are implied, for example, by a rating for rice of 1 or 2 (well suited or moderately well suited).

3. For a rating of 1 or 2 it is assumed that the cost of management needed to grow the crop, including farm drainage and irrigation where required, is less than the returns that can normally be expected. That is, over the long run the value of the crop is expected to exceed the cost of producing it. Detailed economic studies have not been made, however, and the ratings will need to be improved from time to time whenever new data become available.

4. The ratings are based on presently known levels of agricultural technology. As technology advances the ratings may need to be changed.

5. Most of the ratings were made in 1961-64 by a group of soil scientists after consultation with local and international specialists. Many differences of opinion were brought forth, but the results represent a reasonable consensus. The ratings must be regarded as general guides rather than precise evaluations of relative yields. In particular, new or untried crops, or familiar crops on soils where experience is lacking, should be planted first in field trials or on a pilot farm.

6. The list of crops covers only those that are widely grown or that have been considered for commercial production. Absence of a crop from the list should not be taken as indicating that the crop cannot be grown.

7. Under an extremely high level of management, applied with unusual skill, satisfactory but often not economic yields of crops can sometimes be obtained on highly unfavourable soils. The ratings do not reflect any such extreme level of management.

In line with the principles and assumptions just stated, each kind of soil was rated in one of four degrees of suitability for 21 crops or groups of crops. The ratings were based on observations of the crops; information obtained from research workers, farmers, and others; and from inference suggested by the soil characteristics or the performance of similar soils.

Significance of ratings at the four levels is explained in the following statements.

1. Well suited. With a moderate or better level of management the named crop grows well and produces a moderate or high yield. For the crop named, the soil has favourable physical characteristics, can be brought to a reasonable level of fertility, and is responsive to good management.

2. Moderately well suited. With about the same level, but not necessarily the same kind of management as described for class 1 (well suited), the crop can be expected to produce at least moderate yields. The soil may have only moderately favourable physical or chemical characteristics for the crop named, or it may be only moderately responsive to the management practices.

3. Poorly suited. With a moderate or better level of management, about the same level but not necessarily the same kind as described for class 1, the named crop produces only poor yields. Response to management is generally low, or the requirements for management are high. Soil factors such as wetness, water-holding capacity, supply of plant nutrients, and the amount of toxic salts are unfavourable for the crop named.

4. Not suited. With a moderate or better level of management, about the same level but not necessarily the same kind as described for class 1, little if any production of the named crop can be expected.

As these classes are defined, a rating of 1 or 2 suggests that economic production of the crop can be achieved with a moderate or high level of management. A rating or 3 or 4 suggests that, as a rule, commercial production of the crop should not be attempted.

Ratings in this system of six kinds of soil for five of the crops or groups of crops commonly grown in Guyana are given in Table 1.

TABLE 1 - RATINGS OF SOILS IN GUYANA FOR PRODUCTION OF CROPS

(adapted from reports of soil surveys (2))

NAME OF SOIL	Suitability for				
	Rice	Sugar	Coconuts	Ground provisions	Tomatoes and other vegetables
Corentyne clay	1	1	3	1	1
Lichfield clay	1	1	2	1	1
DeVelde silt loam	2	1	2	1	1
Vryberg clay	2	2	3	2	3
Novar loamy sand	4	3	1	1	1
Kasarama loamy sand	4	2	1	2	1

"Ground provisions" is a local term that includes the starchy root crops grown for food, primarily yams, sweet potatoes, eddoes, and tannias. "Other vegetables" does not include onions, for which the soils were given separate ratings.

The first four soils listed in Table 1 are wet soils, which must be drained artificially before crops are grown. Corentyne soils consist of marine clays and have a soft consistence. Lichfield soils are also marine clays but have a firmer consistence. DeVelde soils and Vryberg soils are acid soils in alluvial sediments; the former have faint horizons and the latter have well developed horizons and firm, very slowly permeable subsoil. Novar soils are on low, sandy ridges flanked by the wet soils in marine sediments. Kasarama soils are well drained, undulating, sandy soils of the uplands; they have much lower native fertility than any of the other soils listed, and must be fertilized heavily if crops are grown.

CAPABILITY GROUPS OF SOILS

Some interpretations, such as suitability for crops and expected yields of the common crops, are needed for single kinds of soil. Other, including the cropping systems and related practices that will conserve and improve the soil, can be organized best by groups of similar soils. The amount of detail becomes too great to be managed easily if the choices of cropping systems, sets of practices, and levels of management are compiled separately for each kind of soil. Differences among soils are likely to be too great, however, to permit generalization about soil management for all the arable soils of a soil survey area.

Groups of soils should take into account the important differences and similarities among the soils in relation to the purpose of the grouping. It must be remembered that each kind of soil has a combination of characteristics that makes it unique, and that in any grouping some details are emphasized and others are lost. A grouping should serve well the purpose for which it is made, but for full information about a soil one must always go back to the description of the kind of soil and the data about it.

Groups of soils for a practical purpose, sometimes called technical groupings, often are fewer in number and hence more inclusive than those made in a natural classification of the soils. Both kinds of groupings are based on soil characteristics, but the characteristics selected for emphasis are likely to be different. One common practical grouping of soils, by their capability for use without damage under cultivation or other intensive treatment, includes the characteristics of slope and stoniness among those used for separating soils at the highest categorical level. In the natural classification these same characteristics are considered as phase criteria, significant in the cultural environment but outside the scope of the natural classification itself.

The need for practical interpretations and groupings is recognized in mapping soils. Mapping units are set up as phases of natural classification units wherever the natural units cover a range too broad in those characteristics which affect the use and conservation of the soils; and in the interpretations which should be made from that particular soil map.

Groupings of soils for a limited purpose can be made on the basis of a single characteristic or any combination of characteristics. A grouping into stony soils and non-stony soils may be useful in judging the market for certain farm machines; but the number and size of stones permitted in the "non-stony" class would have to be defined. Swamp or marsh soils might be grouped to show those suitable and those not suitable for drainage; if so grouped, then the criteria for judging suitability must be defined. Another kind of limited grouping, used in some places as a basis for assessment of taxes, places soils in grades according to their productivity for a certain crop or group of crops under present or expected economic conditions. Other groupings can be based on such diverse interpretations as hazard of erosion, rate of infiltration or of percolation, risk of flooding, amount of runoff, or stability in a dike or embankment. The list could be extended almost indefinitely.

Broad groupings of soils are useful for developing and interpreting general soil maps, and for making generalizations about types of land use that are within the capability of the soils. The broad groupings are best made by combining those that are more narrow and simple.

Systems of grouping soils according to their capability are in widespread use. The systems differ in details but have several features in common. Soils are grouped in most of the systems at three levels of generalization. Classes at the most general level range in number from five to eight. They are based on general suitability of the soils for long time production of the common crops, and are separated according to the degree of permanent limitations fixed by the soil characteristics. One class is generally defined as having few or no limitations other than the need for good crop husbandry and for normal maintenance of the soil. Other classes have increasing degrees of permanent limitations caused by soil characteristics. The broad capability classes are often designated by Roman numerals, beginning with Class I for the soils that have the fewest limitations. For such capability classes see Appendix 4.

Summaries of acreage or other surface units at the level of capability classes are useful for a general appraisal of the agricultural potential of a farm, district, region, or nation. Such a summary reveals the area classified as suitable for cultivation; and the area in each class, according to the defined degrees of limitations. Since the limitations may be any of several kinds or a combination, the broad classes have little or no prediction value for choice of crops, arrangement of cropping systems, choice of management practices, or estimation of yields.

Subclasses in nearly all the systems are based on the kinds of limitations, in use of the soil or in management requirements, which are imposed by the soil characteristics. The subclass is often designated by a small letter added to the class number. Several systems recognize four major kinds of limitations: the hazard of erosion (e), wetness (w), unfavourable soil depth, texture, or other feature(s), and a climate that is unusually cold or dry (c). The symbol IIe, for example, indicates soils in capability class II, moderately limited by their characteristics, and in subclass IIe, limited chiefly by the need for practices to control runoff and erosion.

Although subclasses are more narrowly defined than the classes, they also are generally too broad to be useful groups of soils for generalizations about cropping systems, sets of management practices, and levels of management. Most systems of capability classification provide for further groups within the subclasses; these are called capability units. In some places, the groups at the lowest level are called simply management groups of soils. A capability unit, or management group, may contain several similar kinds of soil or may consist of a single kind.

Any capability grouping of soils is made in relation to an assumed set of technological and economic conditions. The conditions generally are those prevailing in the country where the work is done, and sometimes are assumed without formal statement. In a developing country two or more groupings are likely to be useful; one assuming the present level of technology and resources, and one or more to match more advanced levels.

As with all the interpretative groupings the capability classification begins with the individual soil mapping units, which are the building stones of the system. Table 2 shows the relationship of soil mapping units to capability classification.

TABLE 2 - **RELATIONSHIP OF SOIL-MAPPING UNIT TO CAPABILITY CLASSIFICATION**

Soil-mapping unit	Capability unit	Capability subclass	Capability class
A soil mapping unit is a portion of the landscape that has similar characteristics and qualities and whose limits are fixed by precise definitions. Within the cartographic limitations and considering the purpose for which the map is made, the soil mapping unit is the unit about which the greatest number of precise statements and predictions can be made. The soil mapping units provide the most detailed soils information. The basic mapping units are the basis for all interpretive groupings of soils. They furnish the information needed for developing capability units, forest site groupings, crop suitability groupings, range site groupings, engineering groupings, and other interpretive groupings. The most specific management practices and estimated yields are related to the individual mapping unit.	A capability unit is a grouping of one or more individual soil mapping units having similar potentials and continuing limitations or hazards. The soils in a capability unit are sufficiently uniform to (a) produce similar kinds of cultivated crops and pasture plants with similar management practices, (b) require similar conservation treatment and management under the same kind and condition of vegetative cover (c) have comparable potential productivity. The capability unit condenses and simplifies soils information for planning individual tracts of land, field by field. Capability units with the class and subclass furnish information about the degree of limitation, kind of conservation problems and the management practices needed.	Subclasses are groups of capability units which have the same major conservation problem, such as: e - Erosion and runoff. w - Excess water. s - Root-zone limitations. c - Climatic limitations. The capability subclass provides information as to the kind of conservation problem or limitations involved. The class and subclass together provide the map user information about both the degree of limitation and kind of problem involved for broad program planning, conservation need studies, and similar purposes.	Capability classes are groupes of capability subclasses or capability units that have the same relative degree of hazard or limitation. The risks of soil damage or limitation in use become progressively greater from class I to class VIII. The capability classes are useful as a means of introducing the map user to the more detailed information on the soil map. The classes show the location, amount and general suitability of the soils for agricultural use. Only information concerning general agricultural limitations in soil use are obtained at the capability class level.

Capability groupings of soils under two sets of management assumptions were made in Brazil by Bennema, Beek and Camargo, in work not yet published. They described what they called the second level of management, in which capital is not invested in soil improvement, and the level of technology is low; and a first level, in which restricted use is made of capital, and extension information and technical assistance services from competent institutions are accepted. Soils were grouped, under each set of assumptions, into three capability classes for crop production and livestock management. Soil and ecological limitations, present in some soils and subject to different degrees of correction under the two levels of management in the two types of farming, are listed as soil-water deficiency, soil-air deficiency (excess water), natural soil fertility, hazard of soil erosion, and impediments to use of implements or machines.

Somewhat similar groups of soils, called productivity classes, were made under two sets of assumptions for East Africa by Beek and Costa de Lemos (5). Their classification was proposed for the interpretation of general soil maps. At the traditional level of management, little capital is employed, work is done by hand with the help of animal traction, implements are simple hand tools, drainage practices are simple, few crops are irrigated, and no fertilizer is applied. At the modern level, intensive use is made of capital, and the level of technology is high.

Several systems have been devised for listing and rating soil characteristics to aid in grouping kinds of soil into capability classes, sub-classes, and units. Such systems are useful, but each one can cover only a limited range of soils and related factors. The soil scientist must remember that effects of different soil characteristics are not additive, and the significance of any one characteristic often depends on others. Slope limits of soils in the different capability classes, for example, depend on erodibility; which in turn depends on ease of dispersion, size of aggregates, and stability of aggregates in the surface soil. Orderly appraisal of the factors affecting capability of soils is necessary; but any system for assigning relative values to individual soil or environmental characteristics needs to be studied critically and applied with care.

Klingebiel and Montgomery (18) discussed the criteria for placing soils in capability classes as they are applied in the United States. The principal limitations are climatic limitations (temperature and moisture), wetness limitations (internal water and overflow), toxic salts, slope and hazard of erosion, soil depth and stoniness, previous erosion, and available moisture-holding capacity. They also listed the important assumptions as a basis for capability groupings. The substance of their assumptions, re-arranged and shortened to omit some items that apply mostly in the United States is given in the following list. It is not suggested that the same assumptions will apply in developing countries; but a set of assumptions should be stated as a basis for the grouping of soils.

1. The capability classification (unit, sub-class, and class), is an interpretive grouping of kinds of soil. It is based on the effect of combinations of climate and permanent soil characteristics on risks of soil damage, limitations in use, productive capacity, and soil management requirements; shrubs, trees, or stumps are not considered permanent characteristics.

2. The soils within a capability class are similar only with respect to degree of limitations in soil use for agricultural purposes or hazards to the soil when it is so used. Each of the broad classes includes many different kinds of soil. Valid generalization about suitable kind of crops or other management needs cannot be made at the class level.

3. A favourable ratio of output to input, on the average, is one of several criteria used for placing any soil in a class suitable for cultivated crop, grazing, or woodland use, but no further relationship is assumed or implied between classes (I to VIII in that system) and output-input ratios.

4. A moderately high level of management is assumed; one that is practical and within the ability of a majority of the farmers and ranchers.

5. The capability classification does not suggest the most profitable use of soils. Many soils classified as suitable for several uses including cultivation, especially in the classes characterized by severe or very severe limitations, may be more profitably used for grass or trees than for cultivated crops.

6. Limitations which can be corrected by operations that are feasible (physically and economically) are not considered permanent limitations. Examples are excess water, lack of water for adequate crop production, presence of stones, presence of soluble salts or exchangeable sodium, or both, and hazard of overflow.

7. Soils considered feasible for improvement and those already improved. These are classified according to their continuing limitations in use or the risks of soil damage, or both, after the improvements have been installed. Differences in initial costs of the systems do not influence the classification. Soils on which such major improvements are not feasible are classified according to present limitations in use.

8. The capability classification may be changed if major projects of reclamation or improvement change permanently the limitations of the soils. Examples are major drainage or irrigation projects, levees or flood-retarding structures, removal of stones, or large-scale grading of gullied land.

9. The groupings are subject to change as new information about the soils and their responses becomes available.

10. Machines can be used for preparing land and harvesting common field crops on the soils classified as suited to cultivation (classes I, II, III, and IV in the United States - see Appendix 4 for definition of these classes). This does not imply that mechanical equipment cannot be used on some soils in the other capability classes.

11. Soils suited to cultivation are also suited to other uses, such as pasture, range, forest, and wildlife. In groupings of soils for any of those uses, a single group may include soils from more than one capability class.

12. Research data, recorded observations, and experience are used for placing soils in capability classes, sub-classes, and units. If data are lacking, soils are classified by interpretation of the soil characteristics and qualities in accord with general principles and experience elsewhere.

13. Distance to markets, kinds of roads, size and shape of the soil areas, locations within fields or farms, skill or resources of individual operators, and other characteristics of land-ownership or land-management patterns are not criteria for capability groupings.

Assumptions that differ from these are needed for capability grouping of soils in many countries. In particular, the assumed levels of technology need to be defined with care. It is important, however, that the last assumption be recognized. An economic classification of parcels or tracts of land might be needed; but it should be kept apart from any of the interpretative groupings of kinds of soil or of soil mapping units.

Example of a Capability Grouping:

The capability grouping of soils in Guyana, South America, illustrates placement of soils in classes and sub-classes, and shows also the need for groups of soils at the level of capability units in order to have significant management groups (2).

Soil surveys at the semi-detailed level, or at medium to low intensity as defined in this bulletin, were made on about 2,100,000 acres in Guyana in 1961-64. Mapping units were mostly soil types. Slope phases are not significant in the wet soils of the extensive coastal and alluvial plains, but will need to be recognized for proper capability classification of soils outside the coastal areas. In the extensive areas of nearly level, wet soils, some phases were named because of salinity, soft clay substratum, or sandy substratum.

The capability grouping in Guyana contains five classes at the most general level; as a result, the classes are defined somewhat more broadly than in the systems that contain seven or eight classes. Some of the basic assumptions differ from those made in other countries; for example, the need for major drainage works was not considered in classifying the wet soils. The classification of wet soils applies to those for which main drainage works have been provided. Most soils of the nearly level marine and alluvial plains are naturally wet and must be drained if crops are grown. Moreover, the best soils in the country require artificial drainage, or fertilizer, or both; and it did not seem reasonable to begin the classification with class II.

Also in the Guyana grouping, more subclasses were recognized than those given in the foregoing list, and some of the designations are different. Sub-classes are designated by m, for physical limitations of heavy soil texture and moderate difficulty in working the soil and obtaining proper drainage; f, for level or nearly level soils on which the chief limitation is low natural fertility and a high requirement for fertilizer and lime; t, for the probable presence of toxic salts, probably sulphides or acid sulphates (cat clay); s, for the probable presence of excess soluble salts, generally chlorides, that would not be toxic in lesser concentration; w, for wet soils that can be drained only with great difficulty or perhaps not at all; and e, for sloping soils on which the risk of runoff and soil erosion are major hazards.

The capability classes and subclasses recognized in Guyana in 1966 are the following:

Class I: Soils in class I have few limitations that restrict their use.

Subclass Im. Clay soils of moderate fertility (6 soil mapping units).

Subclass If. Silty, clayey, or sandy soils, easy to drain and work, moderate or low fertility (11 soil mapping units).

Class II: Soils in class II have moderate limitations that reduce the choice of crops or require moderate conservation or management practices.

Subclass IIm. Clay soils, slowly permeable, low fertility (3 soils).

Subclass IIf. Sandy or silty soils, gently sloping, very low fertility (8 soils).

Subclass IIw. Wet clayey or loamy soils, low fertility, drainage is moderately difficult (9 soils).

Subclass IIs. Soils affected by moderate salinity (12 soils).

Class III: Soils in class III have severe limitations that reduce the choice of crops, or require special conservation or management practices, or both. They can be cultivated, but with considerable difficulty and high risk.

Subclass IIIm. Organic soils and silty wet soils, difficult to farm if drained (5 soils).

Subclass IIIf. Very sandy soils, low fertility (gently sloping phases of one soil series).

Subclass IIIt. Wet clay soils severely limited by toxic salts and low fertility (4 soils).

Subclass IIIw. Wet soils, usable if artificial drainage can be established, otherwise in dry seasons only (5 soils).

Subclass IIIe. Sloping soils of low fertility, subject to erosion (phases of 8 soil series recognized in 1966).

Class IV: Soils in class IV are severely limited for cultivation. If cultivated, they need extreme treatment to modify or counteract the natural limitations.

Subclass IVf. Extremely sandy or gravelly soils (3 soils).

Subclass IVw. Wet soils, not drained, and feasibility of drainage is doubtful (8 soils).

Subclass IVe. Steep soils and shallow or rocky soils (steep phases of several soil series, and several shallow or rocky soils). Some can be used for tree crops.

Class V: Soils in class V have limitations that prevent their use for production of ordinary commercial plants.

Subclass Vs. Tidal flats.

Subclass Ve. Steep rocky slopes and rock outcrops.

These brief designations suggest that many, and probably all, of the capability subclasses in Guyana contain such a wide range of soils that they must be divided to obtain practical management groups. One example illustrates the point. Subclass If consists of 11 soil types, members of 10 soil series, designated collectively as silty, clayey, or sandy soils, easy to drain and work, and having moderate or low fertility. Study of the characteristics of these 11 soils suggests the need for division into at least 5 management groups. Two of the soil types, a silt loam and a clay classified in the same series, are poorly drained, acid soils on the natural alluvial levees. Two other soils are somewhat similar but have neutral substratum, lie somewhat lower, and are more difficult to drain. Another soil is a moderately well drained, silty alluvial soil, better than the wettest soils for many crops, but not suitable for rice. Four soils are firm or moderately firm, consist of alluvial clays or silts, and are more difficult to work than the first two soils mentioned. Two soils are extremely sandy soils on low ridges in areas of marine clay, much more suitable than the wet clays or silty soils for coconuts or for vegetables, but not at all suitable for rice.

Example of Capability Units

Capability units, which are management groups of soils within the capability subclasses, generally are not numbered or named by any uniform system from one area to another. They are numbered consecutively within subclasses in each soil survey area, and are given descriptive names that express as well as can be done in a few words some of the key soil characteristics.

In one soil survey report (21), capability subclass IIe is divided into 8 capability units and interpretations for use of the soils are given for each unit. Cropping systems and supporting practices are listed for two classes of length of slope (all the soils in this subclass are gently sloping). Other interpretations, especially the yields of crops and the engineering properties of the soils, are given for the individual mapping units and not for groups of soils. Different groupings of the soils are made for other purposes.

In this soil survey area there are 8 capability classes. Each of the classes, other than class I, contains from 1 to 3 subclasses, for a total of 13 subclasses in the area. These subclasses contain 53 capability units, and the soils in class I make another unit, a total of 54 capability units in the area.

Capability units in subclass IIe were given the following descriptive designations. To show part of the structure of the system, designations of the class and subclass are quoted also.

Class II. Soils that have some limitations that reduce the choice of plants or require moderate conservation practices.

Subclass IIe.	Soils subject to moderate erosion if they are not protected.
Unit IIe-1.	Deep, well-drained soils that are slightly acid or neutral in the subsoil (2 mapping units).
Unit IIe-2.	Deep, well-drained soils on old alluvial fans (1 mapping unit).
Unit IIe-3.	Deep, well-drained, acid soils in which the lime content generally increases with depth (1 mapping unit).
Unit IIe-4.	Deep, moderately well drained, acid soils that have a well-expressed fragipan (compact brittle layer), at a depth of 15 to 24 inches (2 mapping units).
Unit IIe-5.	Deep, moderately well-drained, slightly acid or medium acid soils, in which lime content increases with depth (1 mapping unit).
Unit IIe-6.	Deep, moderately well-drained, acid, very silty soils (1 mapping unit).
Unit IIe-7.	Deep, moderately well drained, acid or slightly acid soils that have loamy to clayey subsoil. They contain free lime at a depth between 16 and 18 inches (2 mapping units).
Unit IIe-8.	Deep, moderately well drained to well drained soils that have clayey subsoil. The surface soil is acid to slightly acid. The lime content increases with depth (3 mapping units).

YIELDS OF CROPS UNDER DEFINED MANAGEMENT

Expected yields of crops on each kind of soil are desired by many people who make use of soil survey interpretations, and which must be estimated to bring together the results of soil mapping and other soil research in specific terms for each cultivator. Soil scientists need to assemble the basic facts and relationships. Few other people can study the soils closely enough to consider all their characteristics collectively, along with available records of yields, and make accurate predictions of their performance.

Estimates of yields and of other performance of soils are arrived at in two principal ways: 1) Through judgments based on evidence afforded by actual yield data from sample areas of the soil mapping units; and 2) through judgments based on comparison of the characteristics of soils and basic knowledge of plant requirements. In many developing countries, estimates for most of the kinds of soil must be made by comparative judgments, but data for at least a few of the key soils need to be obtained from plot experiments, field trials, or experience of cultivators.

Combinations and Levels of Management

Expected yields need to be stated for specific crops in relation to defined sets of management practices and levels of management.

Management practices and levels of management refer to growth factors rather than soil and climate. They are mainly the crop characteristics, soil and water management practices, crop protection and management skill.

Estimates for the common crops are needed most. Those for a crop newly introduced, or for one not yet grown in a locality, may also be desired by a government or by some other agency. Estimates for a new crop need to be made and used with extreme caution until experience with that crop has been obtained for several years through field trials or other plantings.

The variety or strain of the crop is important and needs to be specified. Improvements in varieties, along with those in management, have produced notable increases in yields of many crops in all parts of the world. Work with hybrids of maize and with new or improved varieties of wheat, potatoes, rice, and sugar cane has been outstanding, especially when the crops are grown at a high level of management. It is also true that a superior variety, responsive to good management, might be worthless at a low level of nutrients and other management where a proven local variety survives and gives some return.

Sets of management practices are the combinations of cropping systems, tillage, fertilizing and manuring, soil conservation practices, water management, crop protection, etc. that when applied to a plot or field produce a crop or a group of crops. The combinations of practices are almost endless in number. Sets of practices already in use or suitable for use in practical farming should be selected to guide the estimates of yields.

The level of management depends partly on the set of practices chosen by the cultivator, but also on items such as the amounts and kinds of fertilizer and lime, the intensity of drainage or irrigation, and the degree of control of runoff and evaporation. Sets of practices and levels of management should be defined for the various systems or combinations of field crops, pasture plants, and fruits or other tree crops.

The most successful cropping systems in many humid temperate regions have traditionally employed crop rotations in which crops are grown in a planned sequence, and a single crop occupies each field, plot or strip during one growing season. In arid or semi-arid regions the selection of crops is much more limited, and a single crop such as wheat may be grown year after year. If that is done, care must be taken to prevent damage to the soil, especially soil blowing.

In tropical regions, several kinds of cropping systems have been developed, and others are likely to be needed. Some crops, sugar cane for example, are grown successfully on plantations in monoculture with intensive management. Crops that offer less protection to the soil, such as ground nuts, require a crop rotation or other soil saving practices, especially on sloping soils. In many places crops are grown in mixed culture, largely by hand methods. There is evidence that total yields are greater and damage to the soil is less under mixed culture than in fields of a single crop. Shifting cultivation also called bush fallow in which a field is cleared, farmed for a few years, and than allowed to grow up in trees or brush is a practicable cropping system in places where labor is plentiful and fertilizers are scarce or unobtainable. Less laborious systems are likely to be needed, however, as the value of labor increases in relation to other inputs, and as the demand for food and other products of the soil becomes greater.

Yields of common crops on the soils under usual management furnish an important base for interpretation of soil surveys. If present practices produce yields known to be low, results at a higher but readily attainable level are also needed. An example is furnished by results of the Freedom from Hunger Campaign (23). About 45,000 demonstrations and trials in 1961-64, in three large regions or subregions in developing parts of the world, produced increases in yields worth, on the average, from two to seven times the cost of the fertilizer. Results varied enormously, however, with different soils, crops, and fertilizers. In many developing countries, introduction of fertilizer can be an opening wedge toward adoption of better cropping systems, practices to save soil and water, and other improvements.

The fertilizer has certain advantages as the first stage of development. It can easily be applied, its effect is clearly visible within a few months' time, and the money invested comes back after a few months. After the farmer has obtained favorable results with fertilizers, he is usually more willing to adopt additional improvements. The results might require successive estimates of yields at advancing levels of technology every few years.

In a soil survey report for an area in northeastern U.S.A., it is pointed out that yield is the result of the combination of interactions among seven different factors of soil, water, and crop management (21). The factors are climate, soil properties, crop characteristics, soil management and water-management practices, management skill, and weather this year. Because of the interdependence of the factors, it is impossible to discuss one of them without reference to the others. Estimates of yields are useful in predicting the performance of different soils when the kind of crop is stated and specific combinations and levels of the management practices and management skill are assumed and stated. Then the estimates give a measure of performance of the soils of a particular kind in their climatic environment but are subject to the variations that arise from differences in weather from year to year.

Three suggested levels of management are described in the section: Procedures for Estimating Yields by Kinds of Soil. The common level and the superior level need to be defined for each set of soil survey interpretations. The third (optimum) level probably should be defined as a basis for reference, especially if experimental results at that level need to be considered.

Sources of Data for Yield Estimates

Data for the estimation of yields can be derived from several sources.

Field observations: the soil survey party in a cultivated area has many opportunities to observe growth of crops on different soils and under different sets of management practices. Such observations are of great aid in arranging the kinds of soil from the highest to the lowest in expected yields of each important crop. Orderly notes are needed so the information can be sorted and assembled.

Problems are greater in an area currently not in crops. If some of the soils have been cultivated, remains of drainage ditches or other evidence may show where crops have been grown, and may suggest some of the cultural methods. Most of the data for estimating yields in such an area, however, must come from other sources.

Experimental results: data on yields from experimental plots have accessory value for predictions of yields, provided the plots are fair representatives of the soil mapping units. A soil map of the plots is needed if one has not already been made. The varieties of crops, kind of management, and level of management need to be ascertained and recorded. Practices may differ from those that cultivators are following now or can be expected to follow. Some experiments cover a range of varieties, cropping systems, and management practices. As a rule the analyses and summaries already made by the research workers are useful. However, the soil scientist needs to make sure that the soils are comparable.

Field trials: short term trials can be made to measure performance of selected crops during one or two seasons on soils and under management for which data are needed most.

Field samples: useful data can be obtained by harvesting and recording yields on small measured plots within cultivators' fields, selected to obtain plots of representative soils on which a good history of the treatment can be obtained.

Cultivators' experience: much of the necessary data on yields must be gathered from the experience of cultivators. Records of yields and practices by fields would be very useful, so that fields can be selected that consist mostly or wholly of a single kind of soil. Results based on records of course are preferred over those recalled from memory. Few cultivators anywhere, however, keep the kinds of records that would be most useful. The yields that they recall are likely to be biased. Some remember best the good years and tend to forget the failures. Furthermore, any cultivator is likely to adjust his yields downward if he thinks his taxes might be increased, or upward if he owns the land and thinks he might have an opportunity to sell it. Often, a questionnaire gives the cultivators time to think about the matter, and leads to data somewhat more reliable than those obtained in an on-the-spot interview.

Other estimates: any available data on yields from a census, survey or other source should be obtained and studied. The data may be of some use, but are not likely to be of much direct help in predicting the performance of particular kinds of soils.

Procedure for Estimating Yields by Kinds of Soil

The soil survey party, on the basis of the observations and data described, can list the kinds of soil in order of their productivity for each of the major crops.

The next step is to fill in actual yields, wherever data are available, in standard units of weight or measure per hectare, acre, or other surface unit. Since the data probably reflect different degrees of management, estimates should next be made according to a few selected combinations and levels of management. These should be levels that large numbers of cultivators are following now, or can be expected to follow, or both. Some of the available yields from experimental plots of course may represent a higher level of management than either of those just named.

The third step is to fill in estimates of yields of the important crops, at one, two, or, more rarely, three levels of management, on all the kinds of soil for which the crop is suited. This is done through judgments based on the actual yield data available for the key soils, along with judgments based on comparisons of characteristics of the soils and basic knowledge of plant requirements. The soil scientists should assemble the first draft of this table, but should have their estimates reviewed critically by other research workers; in particular, by specialists in crops and in soil fertility, and by others who have had experience with the crops and soils.

Levels of management: estimates of yields at three levels of management have been suggested (28). Generally, estimates are always useful at level one in the list that follows, usually at levels one and two, and occasionally at all three.

Level one consists of the most common combinations of management that are followed by the majority of successful cultivators on the named kind of soil.

Level two consists of the superior combinations of management practices followed by leading cultivators who take the recommendations of their experiment stations and extension service. The proportion of cultivators following this level of management might range from 1 or 2 percent to as many as 25 percent.

Level three consists of the optimum combinations of management practices; the best that can be done, on a practical farming scale, in the present state of the agricultural arts. Such cultivators are likely to plant superior varieties of crops that fit their soil and climate. They control pests and diseases; and follow a planned cropping system and superior cultural methods. They have the soils tested regularly, and apply fertilizers and soil amendments to fit the soil, the crop, the history of the field, and the yield that they expect.

Variations in yields from year to year need to be noted in assembling all the data, and should be stated as precisely as possible when the estimates are finally made. Variations caused by weather vary greatly from place to place. Yields of wheat on a productive soil in a semi-arid region might range from zero in a dry year to double the average in a year when rain is adequate. In a humid region the range caused by variations in weather is likely to be much less; perhaps no more than plus or minus 30 percent of the average.

Procedures for estimating yields of crops on different kinds of soil are discussed in considerable detail in the U.S. Soil Survey Manual (28), pages 365-395.

Edelman (10), suggested two methods of obtaining data for relative ratings of performance of soils. Both methods are useful in places where agriculture is well developed. One, the best holdings method, consists of detailed studies of soils and the plants growing on them in well-managed holdings. He quotes studies of root systems, above-ground parts of plants, yields, and revenues, mostly for horticultural crops, some in greenhouse culture. The data of course are assembled by kinds of soil.

The other method is called the poor patches method. Since a crop in one field is rarely uniform, the growth on different soil units under identical management can be compared. This method is open to criticism, since the management of a field is likely to be that which gives best results on the good soils, and the poor spots might perform better under management especially suited to the soils in them.

Example of Estimated Yields

There are many methods for presenting estimates of expected yields, and the following example in one such method (21). Predictions of average acre yields of principal crops under two levels of dryland management are given. The figures in A column are predictions of yields under ordinary management; and those in the B columns are predictions of yields under improved management but are not assumed to represent the maximum obtainable.

The improved management used to obtain the yields given in B columns includes the following measures:

1. Consistent use of soil improving crops, cover crops, and high residue crops in rotation.
2. Proper management of crop residues.
3. Conservation of moisture by means of such practices as terracing and contour farming.
4. Timely application of fertilizer in amounts determined by soil and crop needs.
5. Timely seeding, tillage, and harvesting.
6. Timely measures for control of weeds, insects, and plant diseases.
7. Selection of proven better varieties of crops.

Estimated yields of 4 crops, at A and B levels of management on 7 mapping units, are given in Table 3.

Yields of maize (corn) and wheat are given in bushels per acre. A bushel of maize is 56 pounds (shelled), of wheat 60 pounds.

TABLE 3 - PREDICTED AVERAGE ACRE YIELDS OF THE PRINCIPAL CROPS UNDER TWO LEVELS OF MANAGEMENT (DRYLAND). (Yields in A columns are those obtained under ordinary management; those in B columns are yields to be expected under improved management)

SOIL	COTTON		CORN		GRAIN SORGHUM		WHEAT	
	A Lb. of lint	B Lb. of lint	A Bu.	B Bu.	A Lb.	B Lb.	A Bu.	B Bu.
Austin silty clay, 1 to 3 percent slopes	200	300	22	36	1,800	3,000	14	26
Duval fine sandy loam, 3 to 5 percent slopes	175	230	16	25	1,300	2,300	13	21
Houston Black clay, 1 to 3 percent slopes	275	350	26	38	2,200	3,700	23	36
Houston Black gravelly clay, 5 to 8 percent slopes	235	300	21	32	1,800	3,200	17	29
Lewisville silty clay, 3 to 5 percent slopes	200	275	20	34	1,600	2,800	13	24
San Antonio clay loam, 3 to 5 percent slopes, eroded	185	230	20	30	1,600	2,600	12	26
Venus loam, 0 to 1 percent slopes	220	300	22	36	1,800	3,000	15	26

SOIL FERTILITY AND SOIL SURVEY AND CLASSIFICATION

Soil surveys can provide much information which is helpful in soil fertility studies and experimentation, as soil survey data are useful to soil fertility specialists in planning and interpreting field fertilizer trials. Delineating the different soil areas is necessary to ensure the proper distribution of the experimental fields which are representative of those areas. However, in areas where no soil surveys have been conducted, it is not practicable to delay field fertilizer experimentation until such surveys are completed. In such cases the major soil areas could be delineated by reconnaissance methods, making use of all available local agricultural knowledge and experience.

Field further experimentation is recognized as the surest means for ascertaining fertilizer requirements; thus it is important that experimental fields be located on sites representative of the soil area to be studied. Unfortunately in some countries experimental farms and stations are established without reference to the soils; other considerations predominating, such as proximity to a town or a good highway, good farm buildings, or low cost of the land.

There are a number of items of information gathered by a soil survey which can be particularly helpful to those engaged in raising the levels of soil fertility. For convenience these are listed below:

1. Topography and drainage (internal and external). These are important factors that not only affect land use, but also soil fertility and productivity. In the undrained state, the yield potential of poorly drained soils is low and the risk in cultivating these is high. Therefore, fertilizer applications tend to be low. After drainage, the economic levels of fertilizer use are higher and returns are more certain.

2. Soil reaction. The pH of the soil greatly affects the nutrient elements and their uptake by the crops. It also indicates the need for soil amendments such as lime, gypsum and sulphur and gives an idea of what are the more suitable crops to grow.

3. Soil depth and impermeable soil layers. In shallow soils, such as those having layers impermeable to plant roots, the soil volume which the plants can exploit is restricted. Even if these soils were not of lower inherent fertility they would decline in fertility more rapidly because the nutrients cannot be absorbed below the impermeable layer. Where these soils are not well supplied with surface water during the growing season they are in a high risk category. Under these conditions the tendency would be to use less fertilizer than might be used on a comparable soil with a deep permeable solum thoroughly wetted. However, if these soils are well supplied with water the fertilizer requirements are high because of the restricted soil volume. A unique use of soils with impermeable layers is made in paddy culture which produces high yields of food per unit area.

4. Soil texture. Soils of coarse texture usually have lower levels of available nutrients than those of finer textures. On sandy soils in humid areas it is often necessary to apply nitrogen and potassium fertilizers more than once during a season to make the most efficient use of them. The coarser textured soils are poorly buffered. Therefore liming has to be done with considerably more care than on finer texture soils. The consequences of over-liming are usually more serious on coarse textured soils because they generally have lower levels of both major and minor nutrient elements present; and any slight decrease in availability will have greater effects on crop growth. Water-holding capacity and water permeability are directly related to soil texture. The effect that this has on fertilizer use is complex because fertility is also a function of texture; and the quantity, distribution and intensity of rainfall are also involved. In regions of permanently dry subsoils with rainfall of high intensity and short duration, sandy soils give higher yields of wheat and are often fertilized, while heavy soils do not yield so well and are not fertilized. In areas of permenently wet subsoils and infrequent rains of moderate to low intensity, fertilization would be higher on heavy soils because the yield potential is higher. With frequent rains the reverse would be true. The above examples are given to illustrate the complexities of the textural effect.

5. Soil parent material. Parent material of soils influence soil formation as well as crop production. Tropical and sub-tropical soils reflect strongly the influence of the mineralogical composition of parent rocks. Such soils as the dark red or dark brown fertile soils of the tropics and sub-tropics are usually developed from volcanic ash, basalts, andesites, and other basic igneous rocks; or from rocks with appreciable proportions of ferro-magnesium minerals in their composition. Soils developed from

quartz sandstones, or from muscovite granites and gneisses, are usually pale yellow, pale red or yellow red in color and of very low fertility. The mineralogical composition of the rocks and their plant nutrient content influence the farmer of the tropics. He prefers to cultivate the crops on the slopes; not only because drainage is better, but because the soils are shallower and the plant nutrients are therefore more within reach of the plant roots.

6. Soil nutrients. Although on the basis of small scale soil surveys it is not possible to prescribe the fertilizer dressings for individual fields or for individual farms, it is possible to provide general information on the fertilizer requirements by drawing on the broad knowledge of the soils even though in a high order of classification. For instance, many Latosols are very deficient in phosphorus and nitrogen; and Chernozems are highly fertile at the start, but under continuous grain cropping phosphorus and possibly some nitrogen may be needed. In countries where detailed soil surveys have been made and experience has been gained in managing the soils of the different soil units, more precise ideas on the possible need of fertilizer on particular parcels of land are possible.

GROUPS OF SOILS FOR RANGE MANAGEMENT

In areas of extensive grazing, production of forage per acre or hectare usually is low, and soil surveys as a rule must be made at medium or low intensity. Mapping units are likely to be complexes rather than single soils. To make useful soil survey interpretations it is generally necessary to put the soil mapping units, or sometimes the kinds of soil, into groups. Each group should have a characteristic pattern of soils and other features of the environment, especially topography, water supply, and temperature regime.

Range specialists define and map range sites in terms of soil and other ecological factors. A range site is an area of range land that produces a characteristic kind and amount of vegetation under a given intensity of use. Its environment is nearly homogenous. The climax vegetation is a combination of plants that is relatively stable with time, and represents the most advanced stage of development of the vegetation within a given climate. On many ranges, although not on all, the natural climax is the most productive combination of forage plants; and good range management is often directed toward the re-establishment of the climax vegetation. On a particular site, soils play a dominant role in setting the potential of the vegetation in terms of both composition and production. Interpretations of soil surveys for management and improvement of ranges are therefore facilitated by grouping the soils into range sites.

Range sites are given local descriptive names derived from characteristics of the soil, topography, geology, or local climate. The names are not correlated on a regional or continental basis. Examples of names are loamy upland, sandy plains, or saline sub-irrigated.

Soil mapping units that are complexes of contrasting soils usually are also complexes of range sites. Considerable jusgement is required to observe the soils and other features of the environment, synthesize practicable soil mapping units, and group them into significant range sites. Unless this synthesis is done, the interpretations for range use are likely to be either too general to account for important differences among the soils, or too detailed to be applied in a practical way.

After a range site has been identified and named, a description of the site can be prepared and used as a technical guide. One arrangement follows:

1. <u>RANGE SITE NAME</u>: plus the precipitation zone, if it is needed to identify the site.

2. <u>LOCATION</u>: geographic location of the site; also give the specific type location of a typical example of the range site.

3. <u>CLIMATE</u>: the pertinent features of the climate, including the amount and distribution of precipitation and the season when the dominant forage plants make their maximum growth.

4. <u>TOPOGRAPHY AND ELEVATION</u>: the approximate elevation and a brief description of the topography.

5. <u>SOILS</u>: the mapping units in the range site and a brief description of their characteristics that directly influence the growth of range plants.

6. <u>CLIMAX VEGETATION</u>: a brief description of the climax plant community for the site, naming the more important increasers and decreasers.

7. <u>YIELD</u>: the approximate yield of the site in excellent condition expressed as unit measure - e.g. kgs/ha - in favorable and in less favorable years.

A modified description of range site and an estimate of forage produced on it is illustrated by the example which follows (24). The yield estimate is for amounts of forage produced per year on a range in excellent condition, and under average rainfall.

<u>Limy Upland Site</u>:

<u>Topography</u>:	Gently sloping and sloping soils of the uplands.
<u>Soil</u>:	Surface soil and sub-soil of calcareous loam, silt loam, or clay loam. They are permeable, well drained, and have a high moisture holding capacity.
<u>Climax Vegetation</u>:	Mixture of little blue stem, side-oats grama, blue grama, buffalo grass, and other grasses.
<u>Dominant Decreasers</u>:	Little blue stem, side-oats grama.
<u>Dominant Increasers</u>:	Buffalo grass, broom snake weed, and other grasses which form mats.
<u>Common Invaders</u>:	Little barley and three-awn.
<u>Estimated Forage Yield</u>:	1,500-2,250 pounds per acre (air-dry weight).

Since yields and quality of forage depend greatly on range conditions, as well as on the soil and other characteristics that determine the range site and vary from season to season, the rate of stocking must be adjusted accordingly. To do this, the rancher needs supplies of reserve feed to carry his animals through drought or other periods of low production, and should be prepared also sharply to cull and sell stock rather than overcrowd the range in a poor season.

Good range management favors growth and reproduction of species which occur in the natural climax vegetation or a productive vegetation that may be less sensitive to grazing pressure. Under too heavy grazing, the most palatable plants tend to decrease (decreasers) in number and vigor, and less desirable plants tend to increase (increasers). Production goes down. If heavy grazing is continued, hardy, undesirable plants which were not part of the original vegetation may invade the range (invaders). Range technicians recognize range condition classes of excellent, good, fair, and poor, depending on the percentage of climax vegetation that remains and the relative numbers and vigor of the decreasers, increasers, and invaders. Other factors such as erosion and litter cover are also taken into consideration. The four range condition classes are shown as follows:

Condition Class	Percentage of Climax Vegetation on the Site
Excellent	76 - 100
Good	51 - 75
Fair	26 - 50
Poor	0 - 25

Practices for improvement of ranges are those that favor growth and reproduction of good forage plants. Except in the more favored environments, where reseeding or fertilizing can be profitable, the adjustments must be made through proper range use to allow vigorous growth and reproduction of the good plants; deferred grazing, by resting the range to allow plants to mature and form seed; and seasonal rotation grazing, a variation of deferred grazing, in which each pasture is rested at different times in successive years.

Special practices to improve the range and control livestock include seeding of native or improved plants in suitable locations; water development, so that livestock will graze different parts of the range; changes from time to time in salting places to improve distribution of grazing; fencing, to separate the ranges that are used in different seasons and control of weeds and brush, by chemicals or machines, to improve the forage. Location and extent of the different range sites affect all these practices.

GROUPS OF SOILS FOR WOODLAND MANAGEMENT

Soil maps and interpretations provide basic data for management and establishment of forests. In the past, however, many soil surveys were not designed to meet well the needs of forest managers. Some soil surveyors recognized too many mapping units, and thereby made it difficult for map users to sort out major soil differences that affect the growth and harvesting of trees. Others tended to map arable soils in detail, but to generalize the mapping of non-arable soils. As a result, soils having different capabilities for forests were often mapped together in such mapping units as Rough stony land or Rough mountainous land. However, today soil scientists and foresters are working together to design, carry out, and interpret soil surveys of forested soils or of potential forest land.

The work involves the definition of soil mapping units and groupings of soil mapping units with reference to soil characteristics that are significant in forestry. Information about vegetation and climate is needed along with soil and related information.

Much forest land is suited for more than one kind of use. Multiple uses include various combinations of forestry, grazing, recreation, and the conservation, collection or storage of water. If grazing is a significant use and can be permitted without damage to the trees, the soils can be grouped into range sites as well as into the groups most useful for forestry. Groupings of soils for some recreational uses need to give special emphasis to production of food and shelter for wildlife, and to soil and topographic factors that affect construction and use of roads and trails. For watershed uses, factors that affect surface runoff and the intake and storage of water in soils are of special importance.

In Germany, a method of forest site surveying has been evolved in North Rhine-Westphalia (4). A soil survey of forest sites is carried out by the State Geological Department to produce a soil-texture map and a map of genetic soil types. Parallel to the soil mapping, a survey of the vegetation units of forest sites is carried out by a special institute. The maps, with necessary explanations, are turned over to a specially trained forest locationer who evaluates them for forest planning. He works in close contact in the field with the other experts. His task is to convert all the surveys into a forest-site map by supplying information on climatic conditions, forest history, orography, and so on. The site types are classified according to the most suitable species of trees or suitable mixtures. The sites are defined as beech, spruce, oak, or alder sites, and are mapped on a scale of 1:10,000.

In the United States, soils are grouped according to their potential productivity and kinds of limitations for woodland use. The grouping has been described by Lemmon (19) and has been applied in many of the soil survey reports published recently in the United States. Each soil mapping unit, or each important component of a soil complex, is rated for a number of soil-related items that affect growth, management, and harvest of trees. The ratings are studied, and the information is synthesized into a manageable number of groups of soils that are called woodland suitability groups. The following soil-related items are most commonly rated.

1. Productivity. In forestry, as in any other kind of plant production, it is important to know the yield that can be expected from different soils under specified management. In the ratings mentioned, productivity is measured by the site index for important kinds of trees on each named or described kind of soil. Site index is the average height of dominant and co-dominant trees in well-stocked stands at a specified age which varies with the species. Research data available for many species show the relation of average site index to potential yield under designated management. Site index ratings are obtained by measuring samples of existing forest stands growing on the kinds of soil that are to be rated; or they may sometimes be inferred from published research after a field check to make sure that the soils were consistently identified. The site index for a given species generally can be measured on only a few kinds of soil, and must be estimated for the others.

2. Species suitability. Although trees of several commercial species usually grow on one kind of soil, they may grow at different rates. Also, trees that have about the same rate of growth may differ in quality or in value. Some are more difficult than others to establish. Kinds of trees differ in their susceptibility to diseases or insects, and in the risk of breakage from ice, snow, or wind. Suitable planting stock may differ in abundance and cost. Ratings represent the combined judgment and opinions of local foresters, soil scientists, woodland owners, economists, and others regarding suitability of the soils for producing trees that can be marketed. Present and possible future markets and values affect use of the ratings, although not the ratings themselves.

Usually two lists of suitable species are made for each kind of soil. One is a list of the species suitable for planting. The other is a list of species to be favored in managing existing forest stands. Priority among the species suitable for each kind of soil, and eventually for the groups of soils, is often indicated either for single species or for groups.

3. Plant competition (or brush encroachment). Invasion and growth of plants not wanted in a forest stand are influenced by the kind of soil. Some invading plants may compete severely with the desirable trees, especially in a new planting or a young stand. Even under a full forest canopy of trees ready for harvest, serious plant competitors may be present in the understory on some soils, ready to take over and prevent adequate regeneration. Some soils are unusually susceptible to invasion of potential plant competitors from nearby sources. Practices to remove undesirable plants by cutting, spraying, girdling, or other treatment are practicable at some levels of forest management.

Criteria are developed locally to rate the risk of plant competition on each kind of soil as slight, moderate, or severe. A rating of slight is made if expected competition will not prevent adequate natural regeneration and early growth, or will not interfere with good growth of planted seedlings. The rating is moderate if competition is likely to delay or restrict natural or artificial regeneration, but will not prevent eventual development of a fully-stocked normal stand. A rating of severe means that plant competition is expected to prevent adequate natural regeneration; and artificial regeneration is needed, along with intensive site preparation and maintenance treatments such as weeding.

4. Seedling mortality. Potential mortality of naturally occuring or planted tree seedlings, as influenced by kinds of soil or topographic conditions (when plant competition is not a limiting factor), is rated as slight, moderate, or severe. Seedling mortality is likely to be moderate or severe on soils that have low water-holding capacity.

5. Erosion hazard. The degree of potential soil erosion when the soil is used as woodland is rated as slight, moderate, or severe. The ratings assume the kind of forest cover that can normally be maintained on the soil.

6. Windthrow hazard. Soil characteristics that affect development of tree roots, and hence the risk of having trees blown over by normally expected wind, are evaluated. Ratings of the hazard are slight, moderate, or severe.

7. Hazard of pests and diseases. If information about soil-related pests or diseases is at hand, and is important to a forest manager, the hazard is rated as slight, moderate, or severe. Subdivisions may be made; that is, the hazards of specific pests or diseases, or of groups, are rated separately if they are significant.

8. Equipment limitations (or trafficability). The degree of restriction in kinds of equipment, methods of operation, or season of use, imposed by soil or topography, is rated as slight, moderate, or severe.

9. Suitability for special or secondary products. Soils differ in their suitability for special or secondary products such as cascara bark, various nuts, Christmas trees, decorative branches or foliage, and products such as latex, turpentine, or maple syrup, when they are harvested from naturally occurring stands. Little soil information is available in many places for such ratings, and the criteria need to be developed locally. The ratings should reflect significant soil relationships, and need not be made unless some can be discovered. Ratings for specified products are expressed as well suited, moderately well suited, or poorly suited.

In many areas some of the ratings, especially those of factors that are affected by soil moisture, need to be made separately for upper, middle, and lower positions on slopes; and according to aspect, which is the direction of exposure. In middle northern latitudes, northern and eastern slopes generally have less evaporation and a better supply of moisture than southern and western slopes.

Ratings of the kinds of soil for the various items are studied and compared, and the soils are arranged in a workable number of woodland suitability groups. As in every grouping, some precision is lost in the process. Soils in each group should have about the same productivity, and should have about the same rating for most of the items. General ratings are then compiled for each group of soils, and some non-conforming items may need to be covered by explanations.

The following table shows woodland suitability groups, potential productivity, and ratings of major limitations and hazards affecting management (6).

TABLE 4 - WOODLAND SUITABILITY GROUPS, POTENTIAL PRODUCTIVITY A

(Estimates of productivity and ratings of site factors based on Soil Surve

Woodland suitability group	Estimated potential productivity		
	Commercial trees	Site index 1/	Annual growth 2/
Group 1: Deep, well-drained soil with medium textured to fine textured subsoil; on uplands, terraces, and toe slopes	Loblolly pine	79	1.3
	Shortleaf pine	67	.9
	Virginia pine	77	1.3
	White pine	96	1.8
	White oak	70	.6
	Red oak	80	.7
Group 2: Deep, well-drained, severely eroded, medium textured to fine textured soils on uplands, terraces, and toe slopes.	Loblolly pine	80	1.3
	Shortleaf pine	81	1.6
	Virginia pine	81	1.3
	White pine	100	2.0
	Red oak	80	.7
Group 3: Moderately deep, well drained and moderately well drained, medium textured soils on uplands, toe slopes, and terraces.	Loblolly pine	81	1.3
	Shortleaf pine	66	1.3
	Virginia pine	78	1.3
	Red oak	80	.7
Group 4: Moderately deep, well drained and moderately well drained, moderately fine textured and fine textured soils on uplands.	Virginia pine	67	1.2
	Loblolly pine	64	1.0
	Shortleaf pine	60	1.1
	Red oak	70	.6
Group 5: Moderately deep to shallow, well drained stony soils on uplands and toe slopes.	White pine	90	1.7
	Virginia pine	77	1.3
	Loblolly pine	76	1.2
	Shortleaf pine	66	1.3
Group 6: Deep, well drained, chiefly medium textured soils on toe slopes, in depressions, and on flood plains.	Yellow-poplar	120	2.0
	White oak	80	.7
	White ash	80	1.1
	Green ash	80	1.1
	White pine	100	2.0
	Loblolly pine	90	1.5
Group 7: Moderately deep, moderately well drained and somewhat poorly drained, medium textured and moderately fine textured soils on stream terraces, flood plain, and toe slopes.	Virginia pine	85	1.4
	Loblolly pine	76	1.2
	Shortleaf pine	64	1.3
Group 8: Deep, poorly drained, medium textured to fine textured soils on flood plains and low stream terraces.	Sycamore	90	1.6
	Sweetgum	90	1.7
	Green ash	80	1.1
Group 9: Deep to shallow, somewhat poorly drained and moderately well drained, medium textured to fine textured soils on uplands and low stream terraces.	Loblolly pine	77	1.3
	Shortleaf pine	76	1.5
Group 10: Well drained, medium textured to fine textured soils with shallow root zone; on uplands.	Virginia pine	70	1.2
	Loblolly pine	68	1.1
	Shortleaf pine	56	1.0

1/ Average height in feet of dominant and codominant trees at 50 years of age.

2/ In fully stocked stands without intensive management. Units are cords per acre.

RATINGS OF MAJOR LIMITATIONS AND HAZARDS AFFECTING MANAGEMENT

Interpretations for Woodland Conservation, Georgia Progress Report 1961)

Other soil-related site factors					Preferred species	
Plant competition	Equipment limitation	Seedling mortality	Erosion hazard	Windthrow hazard	Native trees	Planted trees
Moderate	Slight to moderate	Slight	Slight to moderate	Slight	Pine and oak	Loblolly pine shortleaf pine Virginia pine
Slight	Slight to moderate	Modorate	Severe	Moderate to severe	Pine (pure stands)	Loblolly pine shortleaf pine Virginia pine
Moderate	Moderate to severe	Moderate	Moderate	Slight	Pine (pure stands)	Loblolly pine Virginia pine white pine
Slight	Moderate to severe	Moderate	Severe	Moderate to severe	Pine (pure stands)	Virginia pine loblolly pine
Moderate to severe	Moderate to severe	Slight to Moderate	Moderate to severe	Moderate to severe	Pine (pure stands)	Virginia pine shortleaf pine
Severe	Slight	Slight	Slight	Slight	Yellow-poplar white pine loblolly pine	Yellow-poplar loblolly pine white pine
Severe	Moderate	Slight	Slight	Slight	Virginia pine loblolly pine yellow-poplar	Yellow-poplar loblolly-pine white pine
Severe	Severe	Moderate	Slight	Slight	Sycamore, sweet-gum, green ash	Sycamore sweet-gum
Moderate	Moderate	Moderate	Moderate	Moderate	Loblolly pine shortleaf pine	Loblolly pine shortleaf pine
Moderate	Moderate to severe	Moderate to severe	Severe	Moderate to severe	Virginia pine loblolly pine shortleaf pine	Shortleaf pine loblolly pine

ENGINEERING USES OF SOIL MAPS AND REPORTS

The soil properties that influence plant growth also affect engineering uses and many other non-farm uses of soil (25). The content of clay and the amount that it shrinks or swells, the permeability to water, the electrical conductivity, the wetness at different seasons, and the depth to rock are examples of properties that affect both kinds of uses.

A slowly permeable soil horizon restricts roots, limits use of a soil for septic tanks, and makes a poor subgrade for a highway. A soil rich in montmorillonite clay shrinks and swells with charges in moisture content, and will break roots of plants, pipelines, and even reinforced concrete foundations for buildings. The changes in volume will also tilt fence posts, trees in an orchard, or poles of a power line. Salts that cause high conductivity in a soil can stunt growth of plants, and can corrode a pipe-line in just a few years. A well-drained flood plain soil that is covered with water for a few hours or days nearly every year may produce good crops but would be a poor location for a dwelling or a factory.

A soil map accompanied by good descriptions and interpretations provides data or inferences about the textural class, permeability, water-holding capacity, soil drainage, reaction, and other properties of each mapping unit. Engineering tests of major horizons in a few selected soils permit estimates of the properties of soils similar to those sampled. Descriptions of the soils contain information about nature of the substratum, depth to bedrock, and kind of bedrock, especially if the soil survey has been designed with engineering uses in mind.

Soil maps and accompanying descriptions furnish important data for planning water control measures on farms, such as drainage systems, ponds, irrigation systems, and terraces; for preliminary studies of locations for roads, airports, pipe lines or cables; for studies to aid in selecting and developing sites for residential, industrial, or recreational uses; for estimates of the suitability of soil mapping units for cross-country movement of vehicles and construction equipment; for the first stage of a search for sources of sand, gravel, or other construction material; and for preparation of special purpose maps or reports that have to do with construction or other engineering projects.

It must be emphasized that a soil map cannot eliminate the need for sampling and testing soils at the site of specific engineering works; in particular, works that involve heavy loads, or excavations deeper than the layers described in the soil report. In these situations the soil map is useful in early appraisal of alternate sites or routes, in planning more detailed field studies, and in suggesting the kinds of problems that can be expected.

Engineers and builders need to remember that a soil mapping unit named for one kind of soil is likely to contain minor inclusions of other kinds. Some of the inclusions are readily apparent to persons not trained in soil science. A well-draind soil may contain wet spots, for example, or a mapping unit of a deep soil might have within it gravelly spots or shallow spots or shallow spots too small to be shown. Other important inclusions may be much less apparent. A small area of slowly permeable soil might be discovered only by boring, and would be of great significance to a home builder who plans to install a septic tank for disposal of sewage.

It is essential to have engineers take part in developing engineering interpretations of a soil survey. A soil scientist should begin by assembling the soil symbols and names, descriptions of the soils, and available data; but few if any soil scientists are familiar enough with engineering uses of soils, and with terms used by engineers in describing soils, to complete the work.

Usage of terms deserves special mention. Many technical terms common in soil science are used by engineers with different meanings. Examples of soil science terms that have different meaning in engineering or other fields are soil, sand, silt, clay, gravel, loam, topsoil, subsoil, and granular. Engineers' terms, such as well graded, might not be understood by a soil scientist without special explanation. It is suggested that the usage of soil science should be followed where applicable, since exact expressions might be difficult otherwise; but any terms that might not be understood should be defined, either in text of the interpretations or in a separate glossary.

Beckel (4) described the use of soil surveys in Germany for town and land settlement. In some places a detailed geological and pedological survey is made, and the soil map shows, by means of colors, patterns, and symbols, important characteristics and properties of the soils. The geological situation and the predominating genetic soil types are described.

A water and building-lot planning map is made as a special map, based on the geological and pedological survey. According to regional requirements the map shows suitability of the various sites for 2-story and 3-story buildings. The necessary precautions to be taken in basement and cellar construction, and with respect to frost danger, are outlined. Additional information concerns ground water, load-bearing capacity of the soils, and occurence of building materials such as gravel, sand, or clay.

A procedure for making engineering interpretations of soil maps has been followed in the United States since 1958, and was outlined in a memorandum of the Soil Conservation Service in 1961 (27). The procedure calls for standard engineering tests of samples from the major horizons of a few representative soils in a soil survey area; compilation of estimated engineering properties of major horizons of all the mapping units; and compilation of an interpretative table, usually with the soils listed by soils series, that gives the suitability as a source of topsoil, sand, and road fill, and summarizes the chief soil features affecting several kinds of engineering works, such as highway location, dikes or levees, farm ponds, agricultural drainage, irrigation, terraces and diversions, waterways, limitations for sewage-disposal fields, and other interpretations if they are applicable. At an early stage in the work on most soil surveys, but not before the kinds of soil have been studied in enough detail to permit selection of representative profiles, samples of the major horizons in a few important soils are taken for standard tests in an engineering soils laboratory.

The first step in assembling engineering interpretations is to list the soil symbols and names of soil mapping units, and to study the descriptions of soils, engineering test data, and other available data on the physical and chemical table or tables. Each soil horizon for which tests were made is classified according to two of the systems for engineering classification of soil materials (1, 31).

A large table is prepared that contains symbols and names of the soil mapping units, a brief description of the soil and site features likely to be of interest (as a rule, generalized for the mapping units in each soil series), and estimates of the important properties of major horizons in the soils of each series.

Tables 5 and 6 show the mapping units, a brief description, interpretation, and the estimated physical properties significant to engineering for certain soils (3).

TABLE 5 - BRIEF DESCRIPTION OF THE SOILS AND THEIR

Soil Name	Description of soil and site	Depth from surface	USDA Texture
Dunbar fine sandy loam, 0 to 2 percent slopes.	About 1½ feet of fine sandy loam over about 1½ feet of sandy clay, underlain, in turn, by 1½ feet or more of clay; somewhat poorly drained soils on low knolls, and ridges; depth to seasonally high water table approximately 1 foot.	0–15 15–30 30–40	Fine sandy loam Sandy clay Clay
Grady loam.	About 1½ feet of loam over ½ foot of sandy loam to sandy clay loam, underlain, in turn, by 1 foot to 5 feet or more of clay; poorly drained soil in small, rounded depressions; water stands on the surface during wet season.	0–5 5–13 13–44	Loam Sandy loam to sandy clay loam Clay
Leon sand.	About 3 to 6 feet of sand underlain by sandy clay loam somewhat poorly drained and poorly drained soil on low sand ridges; 16- to 20-inch layer is a hardpan of organic matter cemented with sand; seasonally high water table near the surface.	0–16 16–20 20–40	Sand Sand Sand
Susquehanna loamy sand, shallow, 2 to 8 percent slopes.	About ½ foot of loamy sand over ½ foot of sandy clay, underlain, in turn, by about 1 foot of clay that rests on sandstone bedrock in many places; somewhat poorly drained soil on uplands; about 1 foot to seasonally high water table.	0–16 10–16 16–24	Loamy sand Sandy clay Clay
Wahee fine sandy loam.	About 1½ feet of fine sandy loam over 3 feet or more of sandy clay; moderately well drained and somewhat poorly drained soil on low stream terraces that are flooded periodically.		Fine sandy loam Sandy clay

1/ Less than 0.05 inches per hour.

ESTIMATED PHYSICAL PROPERTIES SIGNIFICANT TO ENGINEERING

Classification		Percentage passing sieve			Permeability	Available water capacity	Shrink-swell potential
Unified	AASHO	No.4 (4.7 mm)	No.10 (2.0 mm)	No.200 (0.074 mm)	Inches per hour	Inches per inch of soil	
SM or ML	A-4	100	100	40-65	0.8-2.5	.10	Low
CL	A-6	100	100	50-65	0.2-0.8	.10	Moderate
CL or CH	A-6, A-7	100	100	65-75	0.05-0.2	.10	High
SM	A-2	100	100	35-45	0.8-2.5	.12	Low
SC	A-2, A-4	100	100	30-45	0.8-2.5	.12	Moderate
CL	A-7	100	100	55-70	1/	.13	Moderate to high
SP-SM, SM	A-3, A-2	100	100	10-20	5.0-10.0	.05	Low
SM	A-2	100	100	15-25	2.5-5.0	.05	Low
SP-SM, SM	A-3, A-2	100	100	10-20	5-0-10.0	.05	Low
SM	A-2	100	100	20-25	2.5-5.0	.08	Low
CL	A-6	100	100	50-65	0.2-0.8	.11	Moderate
CH	CH or MH	100	100	70-85	0.05-0.2	.12	High
SM or ML	A-4	100	100	40-55	0.8-2.5	.09	Low
CL	A-6	100	100	50-65	0.2.-0.8	.11	Moderate

Soil series	Suitability as source of-				Soil features affecting-	
					Farm ponds	
	Top-soil	Sand	Road fill	Highway location	Reservoir area	Embankment
Lakeland	Fair	Fair to good; poorly graded.1/	Fair to good	Unstable slopes	Rapid permeability and excessive seepage in shallow soils; moderate permeability and moderate seepage below 30 inches	Low strength and stability
Leon sand	Poor	Fair	Fair to good	Unstable slopes	Rapid permeability and excessive seepage	Very low strength and stability
Lynchburg	Good	Poor to fair; poorly graded.1/	Fair to good	Unstable slopes	Moderate permeability and seepage	Moderate permeability and moderate shrink-swell potential
St. Johns	Fair	Poor	Poor; good if confined	Seasonal high water table; low strength and stability	Moderately rapid to rapid permeability and excessive seepage	Moderately rapid to rapid permeability and low strength and stability
Sunsweet	Poor	Unsuitable	Fair to good	Unstable slopes; moderate stability	Slow permeability; seepage at toe slopes	Slow permeability and moderate strength and stability
Susquehanna	Poor	Unsuitable	Fair to a depth of 24 inches	Seasonal high water table; rock generally at 24 inches	Rock at a depth of 24 inches	Slow permeability
Tifton	Good	Poor to fair; poorly graded.1/	Fair to good	High strength and stability	Moderate permeability and slow seepage	Moderate permeability and high strength and stability

1/ Large percent of sand grains of equal size.

ENGINEERING PROPERTIES OF SOILS

Soil features affecting- (continued)						
Agricultural drainage	Irrigation	Pits excavated for irrigation	Terraces and diversions	Waterways	Land levelling	Filter fields for septic tanks
Not needed	Low water holding capacity; rapid intake rate	Rapid permeability; low strength and stability	Rapid intake rate; little or no runoff	Low water-holding capacity	Not generally needed, but soil properties favorable	Soil properties favorable
Rapid permeability; seasonal high water table	Low water-holding capacity; rapid intake	Rapid permeability; low strength and stability	Not generally cultivated	Not generally cultivated	Not generally cultivated	Seasonal high water table
Seasonal high water table; surface drainage needed	Moderately high water-holding capacity; moderate intake rate	Moderate permeability in underlying layers; high strength and stability	Soil properties favorable	Soil properties favorable	Soil properties favorable	Seasonal high water table
Seasonal high water table; surface drainage needed; outlets scarce	Wet soil; not generally cultivated	Moderately rapid to rapid permeability	Wet, level soil	Wet, level soil	Wet, level soil	Seasonal high water table
Not needed	Poor agricultural soil; irrigation may not be practical	Steep slopes; not suitable	Not needed; because of steep slopes	Not needed; because of steep slopes	Poor agricultural soils; shallow root zone	Slopes range from 5 to 17%; soil material changes within short distances
Seasonal high water table; surface drainage needed; rock at 24"	Poor agricultural soil; irrigation may not be practical	Rock at 24 inches; not suitable	Slopes range from 2 to 8% rock at 24"	Rock at 24 inches	Shallow root zone; rock at 24 inches.	Seasonal high water table; rock at 24 inches
Not needed	Moderately high water-holding capacity; moderately high intake rate	Moderate permeability in sub-soil; high strength and stability	Soil properties favorable	Soil properties favorable	Soil properties favorable	Moderately rapid permeability in surface layer and moderate to moderately slow permeability in subsoil

Edelman listed the soil information that should be provided by special soil maps for drainage or for irrigation projects (10). Such maps and related interpretations should cover, in greater geographical detail and in a more quantitative way, several of the items listed in the tables of engineering interpretations that have been mentioned. Such special soil maps would be made at a large scale and could cover only areas selected for drainage or irrigation projects or for special investigations.

The information suggested for a drainage project includes:

Hydro-geological characteristics of the area.

Permeability of the various soil layers to a depth of some meters.

Location of the layer below drain depth to be considered as relatively impermeable for the drainage scheme.

Winter and summer water tables. If the survey is carried out during summer, the winter water tables have to be estimated from the profile characteristics.

Amount of water available for plant growth, calculated for the whole profile, but without the contribution of ground water.

Drainable pore space.

Need for drainage in relation to the water table, climate (rainfall, evaporation), crop, and water storage capacity of the soil.

For an irrigation project the items are:

Infiltration rate, under dry and wet conditions.

Permeability, especially of the subsoil.

Water-retaining capacity of the soil profile (field capacity, wilting point, and readily available water).

Tilth and stability of the surface soils after being wetted.

Chemical composition; fertility level, pH, and organic matter content.

Salinity, and the risk of salinization or waterlogging.

The example in Table 7 shows how three soils in eastern United States were rated for several engineering and other non-farming uses (20). Limitations are rated as slight, moderate, or severe for each of the specified uses. Ratings of moderate or severe are followed by a descriptive term that names one or more characteristics chiefly responsible for the rating.

TABLE 7 - RATINGS OF THREE SOILS IN MARYLAND, U.S. FOR SEVERAL NON-FARMING USES

Name of Soil:	Matapeake fine sandy loam, 0 to 2% slopes, well drained.	Matapeake fine sandy loam, 5 to 10% slopes, well drained.	Keyport fine sandy loam, 0 to 2% slopes, (slowly permeable sub-soil).
Degree and kind of limitation for:			
Disposal of sewage:	slight	moderate, because of slope	severe: slow permeability and seasonally high water table
Sewage lagoons:	slight	severe, because of slope	slight
Foundations of homes, two stories or less:	slight	slight	moderate: seasonally high water table
Landscaping and earth moving:	slight	slight	moderate: seasonally high water table
Streets and parking lots:	slight	moderate, because of slope	moderate: seasonally high water table
Athletic fields:	slight	moderate, because of slope	severe: slow permeability and seasonally high water table
Parks and extensive play areas:	slight	slight	moderate: seasonally high water table
Fill for sanitary uses:	slight	slight	severe: sticky material, seasonally high water table
Cemeteries:	slight	slight	severe: slow permeability, seasonally high water table
Home gardens:	slight	severe, because of slope	moderate: seasonally high water table

Soils that contain allophane clay present special engineering problems. In Chile it was observed, after the earthquake of 1960, that catastrophic landslides occured on steep slopes covered with volcanic ash (31). Several settlements and their inhabitants were overwhelmed. Many bridges were made unserviceable by collapse of their earth ramps made from allophane clay fill. These materials when slightly dry appear to be highly suited as filling material; but they are exceedingly treacherous when moist and cannot carry a heavy load. Under the impact of seismic waves, the clays appear to have exuded moisture in sufficient quantities to make them almost liquid. Many buildings actually slid along on surfaces lubricated by allophane.

SOIL MAPS FOR TOWN AND COUNTRY PLANNING

Planning agencies, local governments, and health officials are making use of soil surveys to guide expansion of towns and and suburbs, to aid in locating parks and providing for other open spaces, and to aid in the expansion of highways and other services required by growing communities.

In Europe the purpose is partly to keep the most productive soils in farming (4, 10). Loss of good farm land concerns soil scientists and public officials in many countries outside Europe. In the United States a more pressing problem at present is to avoid building houses that are unsafe because of unfavorable soil or site factors.

Interpretations of soils for town and country planning are closely related to those discussed under engineering, and also to the section on general soil maps. The section on engineering deals chiefly with appraisal and interpretation of the characteristics of soils at particular sites, and with properties of soils as materials for earth structures. A planning official must study soil characteristics and preferably a soil map over a wider area than that of an individual site or small project.

Planning officials or consultants need to consider soil characteristics, geology, slopes and landforms, ground water, patterns of surface drainage and runoff (including effects of proposed developments), and the present vegetation or land use. They need to weigh the composite effects of these factors, for single sites and for larger areas, in relation to the needs for land developments and the alternative uses that can be made of the areas available. Large-scale maps of some of the factors, especially of soils, provide part of the data needed. The soil map should show streams and water courses in considerable detail, as well as the kind of soil, and should show the boundaries of flood-plain soils with good precision.

Some planners also prepare large scale maps of present land use. Maps based on single characteristics or interpretations, such as slope classes, soil texture, natural soil drainage, or capability classes and subclasses for farm crops and pastures, are often useful so long as they are regarded as steps in the planning process and no single map is taken as a basis for decisions. Other single-factor maps in some areas might show the depth to bedrock, the hazard of corrosion of pipe lines, or the soils that have high shrink-swell potential. Some of these maps are most useful at a scale smaller than that of the soil map.

In many planning projects it is worthwhile to develop further maps that are in fact general soil maps, but designed for this one purpose. The scale should be suited to the size and nature of the project. Considerable study is needed to synthesize and map significant areas, for the detailed maps from which they are derived often show a mass of detail. Emphasis may need to be placed on engineering characteristics of the soils, stability of hillside soils, and other items that affect development of communities and their services. It is unlikely that a general soil map made with a bias toward agricultural interpretations will be best for the planner, even if the scale and degree of detail are suitable. If general maps are made, the planners must continually remind non-technical users that the maps show patterns, that each mapping unit almost always embraces an association of contrasting soils or other features, and that reference to the detailed maps and direct field examination must be made to be sure of the soil and other characteristics at any one site.

Interpretative maps might show such things as areas well suited for developments of houses or small apartments; areas well suited for light or for heavy industries; areas not suited for homes or for industries because of floods, wet soils, ponding, or some comparable reason; areas of slowly permeable soils suited for homes served by sewage lines but not for those that depend on septic tanks; areas of shallow or stony soils that can be used for homes or industries but make poor farm land; flood plains that are inundated only occasionally and can be used for many recreational purposes; flood plains on which soils are wet and recreational uses are limited; or steep soils that will erode and produce floods and sediment if they are not protected by good vegetation. These are only suggestions, since the physical charateristics and the needs of each planning project are unique.

Housing development on soils of low permeability require sewage lines, since the effluent from individual septic tanks will not flow rapidly enough into the subsoil. Lots in such a community must be small enough to keep the cost of sewage lines within reason. Septic tanks will function on permeable, well-drained soils, and there the lots must be large enough to provide for the necessary absorption fields. If the soil and substratum are too permeable, however, there is danger that underground water will be polluted. The largest lots for homes are needed on soils of moderately slow permeability in places not served by sewage lines. Disposals fields on such soils must be large, and some owners need more space if their first system fails. Areas that flood are not suitable for dwellings, and a high water table even part of the time prevents functioning of a septic tank.

Soils that have high shrink-swell potential are likely to move enough to crack foundations and walls, tilt trees and utility poles, and even to break pipe-lines. A break in a sewer line is a dangerous health hazard. A soil map shows the places where trouble is likely to occur. The preferred remedy is choice of a new site, but if no other site is available good design might help prevent some of the likely damage.

Disposal of runoff and control of erosion are especially important in developments where homes and roads are built. Control of water needs to be planned by watersheds, not by individual sites. Controlled channels should be provided, if possible in the natural waterways; diversions may be needed to protect individual homes or other buildings. It usually is difficult for a single owner to dispose of runoff that flows across his lot from a higher source. Streets and roadways need to be planned with regard for their effects on flow of water. Erosion and runoff during construction of a multi-home project can cause serious damage on the project itself, and destructive sedimentation on lower areas and in streams.

Unstable soils on hillsides, subject to soil creep, landslides, or saturated flow, cause damage to buildings, highways, railroads, and other works. A soil map usually suggests problem locations; a geological study may be needed to define the extent and degree of the problems. Houses and apartments on hillside benches of poorly drained soils have shifted and cracked so much as to make them worthless. Filled sites in ravines or lowlands can be troublesome, and need to be investigated in detail. Catastrophic landslides have occurred in soils developed in volcanic ash (33).

Highways through hilly terrain on some kinds of clay or shaly soils are subject to slides in wet weather. Sometimes, although not always, some of the most troublesome sites can be avoided if a soil map is available before the route is laid out. If a highway must be built through an area of unstable soils, the need for extra maintenance should be anticipated. Highway and railway engineers sometimes can use soil maps to help avoid peat bogs, other swampy soils, and places where cuts must be made through hard rock. Utility companies sometimes can avoid placing lines of wooden poles through shallow soils underlain by rock. An airport might be built more economically on well drained soil than on poorly or somewhat poorly drained soils, even if more grading is required. All of these uses have been made of soil maps even though the maps had been made mostly for agricultural purposes.

SOIL MAPS FOR APPRAISAL OF LAND

Soil maps can be useful in appraisal of rural land for taxes or for loans. Specific interpretations or groupings of soils for this purpose are needed; it is not likely that a general soil map, or an interpretative soil map made for another purpose, can be used without adjustment. Other information besides that about soils is also needed. Appraisals are made of social land units, mainly farms, and those units are evaluated in terms of potential production within the institutional and legal environment (28).

Estimated yields of crops on different kinds of soil under defined management, and estimates of range or forest productivity by kinds of groups of soils, provide a basis for estimating potential productivity of a farm or other tract. The soils can be arranged in a convenient number of productivity classes; often 5 or 10 classes are enough, although the number can be greater if more precision is required and data are on hand to make the evaluations. In places where the farms produce mainly a single crop, such as wheat, rice, cotton, or maize, ratings based on that one crop may be desirable. In most places a general productivity rating is likely to be more suitable.

The ratings and groupings of soils will need to be readjusted from time to time. Changes in systems of soil management are certain to occur. More production of some crops and perhaps less of others will be needed. Cheaper fertilizer and increasing numbers or new types of machines will affect farming practices and yields. If the soil mapping units are well conceived and area accurately mapped and described, the ratings and groupings can be adjusted easily; when revisions can be made in the appraisals of specific tracts without additional soil mapping.

Appraisals take into account factors other than productivity of the soils. Location, size of tracts, water supply, productivity of nearby farms, distance to markets, and quality of roads are some of the factors. Laws and customs vary widely regarding the taxing of improvements such as fences or buildings, and the weight to be given to potential versus present production. Almost without exception, the contribution of the soil scientists should be limited to the comparative ratings of kinds of soil, within a framework that will be useful; local officials should decide on the relative values and make the appraisals.

Appraisals for loans generally can begin with the same ratings of soils, regarding crop potentialities and estimated yields, that are useful in tax assessments. The lending agency needs to be concerned with long-time effects of alternate systems of management, and with actual or potential limiting factors such as growth of noxious weeds or potential waterlogging of irrigated soils. Water supply, improvements, location factors, and other items of course are evaluated. The loan appraiser also must assess in one way or another the tenure and skill of the prospective manager, in relation to both the economic setting and the potentialities and limitations of the soils.

INTERPRETATIONS OF GENERAL SOIL MAPS

General soil maps are made at a scale smaller than that required to show the significant mapping units on single farms or ranches. Mapping units are associations of soils; often associations of phases of soil series, of great soil groups, or of suborders or other groups in the new soil classification. Scale varies according to the data available and probable uses of the map. Some general soil maps which are published along with detailed maps are printed mostly at a scale between 1:100,000 and 1:350,000; a few are as small as 1:500,000. General soil maps of an entire province or country are necessarily smaller and the mapping units are more broadly defined. Soil associations in a large country can generally be presented at a scale between 1:500,000 and 1:20,000,000. A useful, although highly schematic, soil map of the world has been reproduced at a scale of approximately 1:200,000,000 (13).

General soil maps of several continents or parts of continents have been prepared in the project: Soil Map of the World of FAO and Unesco. The soil map of Africa (prepared by C.C.T.A.) has been published; the Soil Map of South America is being finalized; second drafts of the Soil Map of the Near East and the Soil Map of Southeast Asia have been prepared; and the Soil Map of North America is in preparation.

Readers can make broad interpretations of a general soil map most easily if the number of mapping units in the legend is not greater than ten. Many good maps of course have a larger number of units; if the map is to be comprehended as a whole, however, the units should be grouped under about ten main divisions. Colors or paterns help the reader to see relations of the units to one another. If the main units are subdivided, the number of subdivisions in each should also be not more than ten, preferably fewer. Readers generally do not try to comprehend divisions at the second level for a map as a whole. They are more likely to study variations within one of the main divisions, or to look at the mapping units within one state, province, or other small part of the map. A map that has more than about ten divisions at the highest level can convey much useful information, but a reader must study it in small sections rather than as a whole.

A general soil map can be made by direct investigation (reconnaissance) or by genralizing from maps of larger scale. Whichever way it is made, a general soil map is the result of synthesis designed to emphazize selected kinds of soil patterns. The user can see quickly the location and extent of each mapping unit over a considerable area. He should be supplied also with a written text which describes the mapping units, especially the kinds and the pattern of soils and related features of the environment. A detailed soil map, in contrast, is generally too large and too complicated to reveal easily the soil patterns in an area larger than perhaps 100 square centimeters of the map surface. A detailed soil survey, even one of low intensity in which mapping units are soil associations, is designed to provide a record of soil conditions which can be consulted for many uses. The user reads the particular map symbol or symbols, looks up the descriptions and available interpretations, preferably examines the soils to see features that are important to him and proceeds to make his own further interpretations or management decisions. A great deal of synthesis, of course, goes into construction of the legend for a good soil map at any level of intensity.

Legends for General Soil Maps

The choice of map symbols and wording of the legend for a general soil map offer opportunities to make the information easily available to readers. Descriptive facts can sometimes be stated without using the specialized terms of soil science. If the need for accuracy and the limitations of space require use of technical soil terms without explanation (for example, names of great soil groups), use of the map by readers not acquainted with those terms is greatly restricted.

On a general soil map of intermediate scale, from about 1:100,000 to perhaps 1:500,000, mapping units are often associations of soil series or of phases of series. They can be named conveniently by using names of one, two, or not more than three of the dominant series in each association. Examples are the Montevallo association and the Montevallo-Klinesville-Rarden association (6). Such names convey no descriptive facts, even to a soil scientist, unless he knows characteristics of the named soils. Addition of descriptive but relatively non-techncial statements make the legend more useful to a large number of possible readers. For example, the Montevallo association is described as steep and very steep, shallow soils on mountains; and the Montevallo-Klinesville-Rarden association as shallow, well-drained soils of the rolling and hilly shale ridges (6).

Numbers make convenient map symbols, especially if the number of mapping units is not more than 10 or 12. Mapping units can be arranged according to their physiographic position or by some other grouping, then numbered consecutively. Map symbols can also be derived from initial letters of the soil names, such as M and MKR for the two associations just mentioned. If that is done, however, any logical grouping of symbols in the legend is almost certain to place them out of alphabetical order. A reader must then look through the entire list to find one symbol.

With any kind of map symbols, a distinctive color tint for each kind of mapping unit makes the map attractive and easy to read.

A general soil map of a large region, country, or continent may require a legend of more than ten items. Mapping units generally are associations of great soil groups or of other groups at a high categoric level; or of phases of such groups. The Soil Map of Europe has 34 kinds of mapping units arranged in 3 general groups. The Soil Map of South America has approximately 400 kinds of mapping units, grouped under some 76 headings. Symbols on the latter map consist of two numbers. The first number is keyed to a broad soil association of one or more great soil groups. The second number indicates more precisely the climate, the kinds of soils in the association, and sometimes the physiographic position, kind of parent rock, or important soil profile characteristics. For example, number 61 in the legend designates a group of associations dominated by Red-Yellow Podzolic soils. Mapping unit 61/1 is an association of Red-Yellow Podzolic soils, intergrading to Red-Brown Mediterranean soils of the subhumid temperate regions with winter rainfall (Chile).

An experimental general soil map of the United States, at a scale of 1:20,000,000 was prepared in 1964 (26). It has 38 mapping units, named at the level of suborders or phases of suborders in the new soil classification. Symbols are combinations of letters and numbers. The first letter is the initial one of the soil order, unless names of two orders begin with the same letter. Mapping units are arranged by orders and brief descriptions are given for the orders and for each of the mapping units.

Uses of General Soil Maps

Several uses of general soil maps can be suggested. A general soil map is an inventory of important resources, and so belongs in almost any treatise or study that deals with development of agriculture, in books of geography, and in many kinds of documents and publications. It is a record of basic knowledge for many kinds of agricultural or economic planning.

Some of the uses include selection of new land to be occupied and developed; planning of roads and other services for new or existing communities; location of potential production areas for selected crops and planning of program to introduce or distribute farm machines.

Scientists and professional workers (not just soil scientists) use general soil maps in the correlation and exchange of scientific data; not only data about the soils, but interrelations among soils, geology, landforms, climate, vegetation and use of land; and in economic studies that deal with soil and water as means of production.

Teachers at all levels, and authors of textbooks and other books, can make use of general soil maps and supporting information.

Planners interested in economic development need information about soils in the form of general maps. Location of major soil associations affects the choice of routes for roads, railways, and other means of transport and communication; and the location of reservoirs for water power, domestic water, or water for irrigation.

It must be emphasized again that a general soil map is good for general uses only. It shows patterns of soils and related factors, but cannot show in detail the soil information that is needed for locating and planning specific projects. An irrigation project, or any project that leads to important changes in land use, should be preceded by a soil survey at the scale and intensity required to depict the necessary facts.

Soil survey work in a developing country generally begins with reconnaissance surveys which produce general soil maps. As part of the reconnaissance soil survey, representative soils are examined, described, and sampled. Detailed or semi-detailed mapping of sample blocks is extremely useful. Data on the climate, vegetation, geology, landforms, and related items are essential. The resulting general soil maps are valuable in planning further soil mapping and other soil research, and in making general land use recommendations or decisions that cannot wait for more detailed information.

Soil interpretations begin as soon as representative soils can be studied. In fact, pressure is often brought on a soil scientist to predict the performance of soils even before he has an opportunity to map sample areas, study the laboratory data, and observe the responses of major kinds of soil. To the extent that he can make valid inferences from the nature of the soils and observations of the soils and crops, backed by knowledge of the performance of similar soils elsewhere, his predictions are useful. The quick opinion of an expert, however, is no substitute for a solid body of soil facts and systematic observations which must be accumulated over a period of years.

Interpretations of general soil maps to show suitabilities of soils and environment for agricultural production have been made by FAO. Work in Nigeria utilized a method for numerical rating of soil characteristics and qualities, and produced interpretative maps showing soil productivity under present management and soil potentialities under improved management (12).

In East Africa, a general map of available information on soils, topography, and climatic regions was prepared at a scale of 1:2,500,000 (5). Climatic phases provide the first basis for selection of suitable crops, while topographic subphases have been used for the separation of areas which are predominantly unsuitable for mechanization. Soil units of the map have been interpreted in terms of natural fertility, internal drainage, and erosion susceptibility. The map has then been interpreted in terms of suitabilities for production of crops at the actual (traditional) management level (called productivity), and at a modern management level (potentiality).

At the traditional level of management, it is likely that little or no capital, except hand labour and animal traction, is used. Implements are the most simple hand tools. Simple drainage works may be installed. Clearing of vegetation is done mostly by burning, and roots are not removed. No fertilizers are applied; and irrigation is used only for a few crops, notably for paddy. Erosion control measures are taken only in exceptional cases. Since farming depends on natural fertility, the land is abandoned when production stops or yields become too low. At the traditional level of management, classes of high, medium, and low productivity have been defined.

At the modern level of management, intensive use is made of capital, and the level of technology is high. Management practices are carried out with the help of power-operated machinery. The practices include intensive drainage where necessary, elaborate anti-erosion measures, and intensive fertilizing where profitable responses are obtained. Irrigation is a special practice; necessary in dry climates for production, and profitable in some places to supplement the natural rainfall in producing crops that have high value. At the modern level of management, classes of potential production have been defined as very high, medium, and low. Sub-classes in places where irrigation is practised can indicate potentialities without irrigation, with supplementary irrigation, and with intensive irrigation; or a separate classification of irrigated soils might be advisable.

Maps have been prepared to show suitability of the soils and environmental factors for specific crops or groups of crops. Reliability of such general maps depends on 1) correct correlation between soil characteristics and crop requirements; 2) reliability of the soil map, and the skill exercised in making the generalizations; 3) reliability of the climate map; and 4) correct percentual estimates of the components of soil associations.

The value of crop suitability maps on a small scale, based on maps which are compiled mostly from other sources (geology, topography, and vegetation) rather than from proper surveys, lies more in the geographical location of suitable areas than in exact quantitative expression of available land. The same statement needs to be repeated for any interpretations made from schematic maps or from general maps of soil associations.

Dewan and Famouri made interpretations for use and management of soil in the associations shown on their general soil map of Iran (9). The general soil map, on a scale of 1:2,500,000, contains 27 mapping units. The mapping units are grouped in the legend under four major physiographic areas: Soils of the Plains and Valleys, Soils of the Plateaux, Soils of the Caspian Piedmont, and Soils of the Dissected Slopes and Mountains. Each of the 27 mapping units is an association of soils named at the level of great soil groups. Slope phases of many of the great groups are described in the text but are not shown on the map.

An interpretative map, also at 1:2,500,000, shows soil potentiality in terms of five major classes based on degrees of limitations. They range from Class 1, soils with no limitations or slight limitations, to Class 5, soils with almost no potentiality. Sub-classes in classes 2, 3, 4, and 5 are described in terms of dominant kinds of limitations to make a total of ten kinds of mapping units. The authors emphasize that any increase in the agricultural area of Iran should be on those soils which have great potentiality.

Soils in the 27 kinds of associations have been grouped into 11 soil management groups (10 numbered groups, but group 2 is divided into two significant sub-groups on the basis of slope phases). In the descriptions of soils in the groups, slope phases of many of the great soil groups have been recognized. The grouping is in fact one of phases of great soil groups, not of soil associations.

Although the soil management groups at this country-wide level must be broadly defined, many useful interpretations of soils in each of the groups can be made. Estimates are given of the total area of soils in each management group, the area under cultivation, and the total area suited to cultivation.

EXAMPLE OF A DETAILED SOIL MAP INTERPRETED FOR A CONSERVATION FARM PLAN

An example from southern United States shows how the detailed soil map of a farm, at medium intensity, is interpreted in terms of capability classes, sub-classes and units; and is used by the farmer and the soil conservationist in planning use and management of the land (33).

Figure 1, adapted from the field soil map made on an aerial photograph, shows the outline of the farm, the soil mapping units, and the capability units.

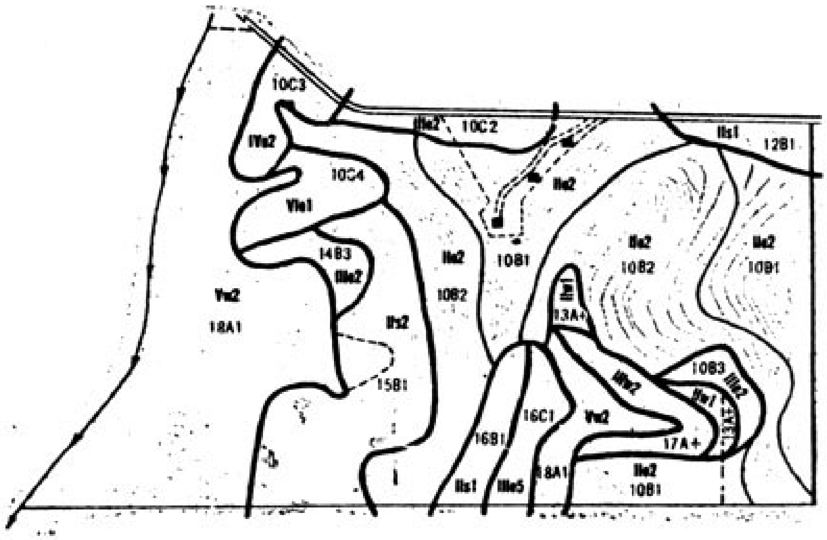

Fig. 1 - A map of the soil and its capability. The symbols pertain to various aspects of soil and topography. For example: 10B1 refers to the kind of soil; the number 10 refers to the soil type; the letter B to steepness of slope and number 1 to degree of erosion. The symbol IIe2 refers to the land capability unit; II designates the land capability class; e indicates the subclass; and 2 indicates the unit. Heavy lines on map indicate boundaries of a capability unit.

Class II soils have some limitations that reduce the choice of use, or require some conservation practices to keep them productive. They can be used for crops, pasture, woodland, or wildlife land.

Soils in IIe2 are gently sloping, deep, and are slightly or moderately eroded. They are well drained and water moves through them easily. Soil erosion and soil fertility are the main soil problems to overcome. These soils are suitable for growing all crops commonly grown in the area.

Soils in IIs1 are deep, sandy, and droughty. Their permeability is moderately rapid, and maintenance of soil fertility is difficult.

Units IIs2 contain sandy, droughty, rapidly permeable soils, on which crops often are limited by lack of moisture and fertility.

Unit IIw1 consists of soils in draws or depressions and are moderately well drained. Water from adjacent higher land often runs on them. If properly protected from overflow and seep water, they are suitable for growing many different crops.

Class III soils have more natural features that restrict their use, and when cultivated require more careful management than soils of Class II.

Soils in IIIe2 are steeper or more eroded than the soils in IIe. Erosion hazard and fertility are the major soil limitations. These soils require careful management to deal with the limitations, but can be used for all the crops commonly grown in the area.

Unit IIIe5 consists of well-drained sloping soils that are subject to some erosion and are somewhat droughty. They require careful management for cultivation without damage. Most crops adapted to the area can be grown successfully.

Soils of IIIw2 are level and often moderately wet. Water moves through them slowly; when undrained, they are best suited to trees or grass. Some clean-tilled crops may be grown if the soils are properly drained.

Soils of class IV have very severe limitations that restrict the choice of plants, require very careful management, or both. With suitable precautions and practices, they can be used for crops, pasture, woodland, or wildlife land.

Unit IVe2 contains well-drained, sloping, severely eroded soils. They are steeper or more severely eroded than the soils in unit IIIe2. These soils are suited for grass or trees and can be used for cultivated crops if the soil management practices are good.

Soils of class V have little or no erosion hazard, but have natural features that generally restrict their use to pasture, woodland, or wildlife land. Their limitations restrict the kinds of plants that can be grown and prevent normal tillage of cultivated crops.

The soils of unit Vw2 are wet and nearly level. They are generally best suited to woodland but, if drained and fertilized, are good for pasture.

Soils of class VI have severe limitations which make them generally unsuited to cultivation and limit their use largely to pasture, woodland, or wildlife land.

Unit VIe2 has soils which are sandy, sloping, and very severely eroded. They are too steep or eroded for safe cultivation, and are best used for grass or trees. Pastures usually can be renovated to improve the forage.

This farm does not have any soils in capability class VII or class VIII.

Slope phases of the soils in this farm are A, very gently sloping, 0 to 2 percent; B, gently sloping, 2 to 5 percent; and C, sloping, 5 to 8 percent.

Main provisions in the plan for use and treatment of soils in this farm are shown in Figure 2 and are set forth in the list that follows. The farmer was able to locate all his cultivated crops on soils of capability Class II.

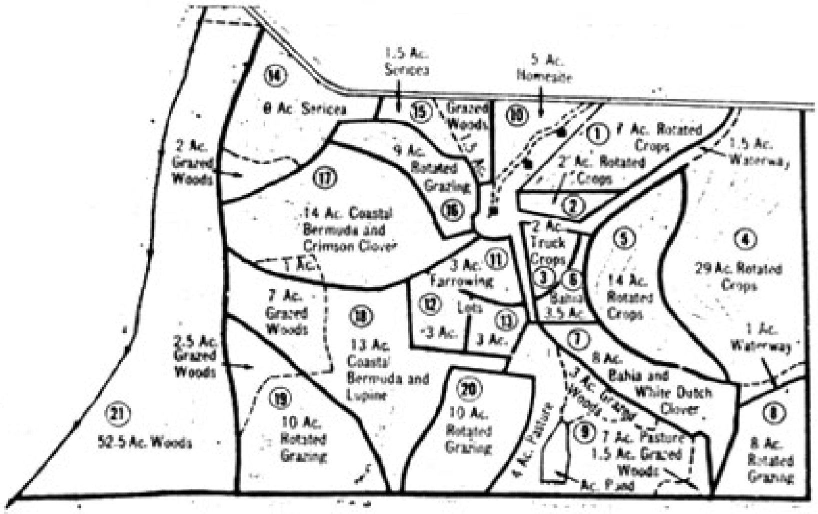

Fig. 2 - A conservation plan map. The decisions made by the farmer concerning the use and management of his land, together with the field unit arrangement, are recorded on this map. These decisions were based on the soil and capability map. Needs of the farmer relative to his farm enterprise were also considered.

PLAN FOR USE AND TREATMENT OF THE FARM

CROPLAND

Field No.	Capability unit	Conservation Plan
1 and 5 (rotated crops; 21 acres)	IIe2	Contour cultivation with terraces. 3-year rotation: 7 acres tobacco (crotalaria); 7 acres corn; 7 acres oats.
2 and 4 (rotated crops; 31 acres)	IIc2	Contour cultivation with terraces. 3-year rotation: 11 acres peanuts or cotton (lupine); 10 acres lupine for seed (Milo); 10 acres corn.
16 and 19 (rotated grazing; 19 acres)	IIe2 IIs2	Contour cultivation with terraces. 2-year rotation; 9 acres oats (lupine); 10 acres corn. For hog grazing.
8 and 20 (rotated grazing; 18 acres)	IIe2 IIs1	Contour cultivation with terraces. 2-year rotation: 8 acres corn; 10 acres oats, ryegrass, and crimson clover. To be grazed off.
11, 12, and 13 (rotated grazing; 9 acres).	IIe2	Crimson clover, oats, and ryegrass followed by millet each year. Farrowing lots.

PLAN FOR USE AND TREATMENT OF THE FARM (cont'd)

GRAZING - WOODLAND

Field No.	Capability unit	Conservation Plan
6, 7 and 9 (22½ acres)	IIe2 IIs2 IIw1 IIIw2	Bahiagrass and giant whiteclover. Fertilizer and manage pond for fish production.
17 (14 acres)	IIe2 IIs2 IIIe2 VIe1	Coastal Bermuda-grass and crimson clover.
18 (13 acres)	IIe2 IIs2 Vw2	Coastal Bermuda-grass and lupine or crimson clover.
14 and 15 (10½ acres)	IIe2 IIIe2 IVe2	Sericea. Add rescue or ryegrass after sericea is well established. Crimson clover may be added. Plant multiflora rose along south border of field 14.
9, 18, and 19 (14 acres)	IIe2 Vw2	Grazed woodland. Harvest trees as they mature. Keep enough trees for shade.
21 (52½ acres)	Vw2	Woodland. Protect from fire. Harvest mature trees. Make stand improvement cuts.

NOTE: - All grazing land should be limed and fertilized as needed. Mow to control weeds. Topdress annually and rotate grazing.

THE STORIE INDEX FOR RATING

An index for numerical rating of soils was developed by R.E. Storie (7, 29). The Storie index expresses numerically the relative degree of suitability, or value, of a soil for general intensive agriculture. The rating is based on soil characteristics only and is obtained by evaluating such factors as depth, texture of the surface soil, density of sub-soils, drainage, salts and alkali, and relief. Other factors, such as availability of water for irrigation, climate, and distance from markets, that might determine the desirability of growing certain plants in a given locality, are not considered. Therefore, in itself the index cannot be considered as an index of land value.

Four general factors are considered in the index rating. These factors are (A) the characteristics of the soil profile and soil depth; (B) the texture of the surface soil; (E) slope; and (X) other factors, such as drainage, salts and alkali, and erosion. Each of these four general factors is evaluated on the basis of 100 percent. A rating of 100 percent expresses the most favorable, or ideal, condition, and lower percentage ratings are given for conditions that are less favorable for crop production.

The index rating for a soil is obtained by multiplying the four factors, A, B, C, and X; thus, any one factor may dominate or control the final rating. For example, a soil may have an excellent profile justifying a rating of 100 percent for factor A, excellent texture of the surface soil justifying 100 percent for factor B (a smooth nearly level surface justifying 100 percent for factor C;) but a high accumulation of salts or alkali that would give a rating of 10 percent for factor X. Multiplying these four ratings (i.e. 1.0 x 1.0 x 1.0 x 0.10 = .1 or 10%) gives an index rating of 10 for this soil. The high accumulation of salts or alkali would dominate the quality of the soil, render it unproductive for crops, and justify the low index rating of 10.

Soils are placed in grades according to their suitability for general intensive agriculture as shown by their Storie index ratings. The six grades and their range in index ratings are:

	Index rating
Grade 1	80 to 100
Grade 2	60 to 80
Grade 3	40 to 60
Grade 4	20 to 40
Grade 5	10 to 20
Grade 6	less than 10

Soils of grade 1 are excellent, or well suited to general intensive agriculture. Grade 2 soils are good and are also well suited to agriculture, although they are not so desirable as soils of grade 1. Grade 3 soils are only fairly well suited; grade 4 soils are poorly suited; and grade 5 soils are very poorly suited. Grade 6 consists of soils and land types that are not suited to agriculture.

SOIL RATINGS AND INTERPRETATIVE MAPS DERIVED FROM A GENERAL SOIL MAP OF NIGERIA

Work done in Nigeria illustrates a method of appraising soil capabilities by assigning numerical values to major soil characteristics and qualities that affect productivity (12). The method was applied for interpretation of a general soil map.

This map, at a scale of 1:5,000,000, was compiled from existing soil maps and recent field studies. There are 29 kinds of mapping units, which are broad associations named at the level of great soil groups. Some of the mapping units are divided into savannah and forest phases. Map symbols consist of letters, such as Cb for semi-arid Brown and Reddish Brown soils, and BdVc for Lithosols (undifferentiated) on crystalline acid rocks.

Nine soil characteristics or qualities (soil moisture content H, drainage D, effective soil depth P, texture and structure T, base status N, soluble salt content S, organic matter O, mineral exchange capacity A, reserves or alterable minerals M) were given index values, assuming present technology, on the basis of an index of 100 for the ideal soil. A value Pa for present productivity (productivity based on natural fertility of soil and on the use of traditional agricultural practices) of each important kind of soil was obtained by multiplying the values of the nine indexes. The advantage of a multiplying formula is that the most limiting factor overrules the others. An index of zero for any one factor gives a productivity rating of zero for that soil when the numbers are multiplied. For example: Pa (present productivity)=

$$X_5 x D_3 x P_5 x T_{ca} x N_4 x S_1 x O_2 x A_2 x M_{2c} =$$

$$100x85x100x80x80x100x90x95x100 = 465$$

(Class High Productivity)

Class of present productivity were established with the following ranges: Very high, 65 to 100; high, 34 to 64; medium, 20 to 34; low 8 to 19; and very low, 0 to 7. A map of the present productivity of the soils, also at 1:5,000,000, shows the dominant class or classes in each mapping unit of the general soil map. Under present technology the best soils are in class 2, high productivity. Color tints emphasize the relative productivity classes, ranging from brown for class 2 to light yellow for class 5. Long symbols, taken from the list that follows, are placed along with class numbers on the map and are keyed to show ratings of seven most important soil characteristics.

The second interpretative map shows soil potentialities (soil productivity with adequate soil management practices) of the mapping units on the general soil map. The scale is the same as that of the other two maps, 1:5,000,000. Indexes at a high but attainable level of management were assigned to the five soil factors that can be corrected by management, namely moisture content, drainage, base status, soluble salt content, and organic matter content. Table V shows how indexes are changed with modern management. Moisture deficiency can be corrected only by irrigation, and it was assumed that up to 10 percent of each of the areas can be irrigated in one way or another. Soils were graded in five classes of soil potentiality; at this level of management some of the soils are in Class 1. The map shows for each mapping unit the dominant class or classes of potentiality. Symbols along with the class number for each mapping unit are keyed to the practices envisaged for the development of soil resources. Color tints, ranging from dark brown for Class 1 to light yellow for class 5, make the general significance easy to grasp.

The following list shows the soil characteristics and qualities that were rated, and the classes that were established.

H, Soil Moisture Content

H_1 Soil extremely dry, below wilting point all year round.

H_2 Soil dry, below wilting point for 9-11 months of the year.

H_3 Soil dry, below wilting point for 6-8 months of the year.

H_4 Soil dry, below wilting point for 3-5 months and wet below field capacity for more than 6 months.

H_5 Soil wet above wilting point and below field capacity during most of the year.

H_6 Soil waterlogged for long periods, almost always above field capacity (see drainage).

D, Drainage

D_{1a} Waterlogging, water table almost reaches the surface all year round (Hydromorphic surface horizon at a depth of 30 cm or less).

D_{1b} Waterlogging for periods of 2-4 months.

D_{2a} Water table sufficiently close to the surface to harm deep rooting plants (Hydromorphic surface horizon at a depth of 30-60 cm).

D_{2b} Waterlogging for periods from 8 days to 2 months.

D_{3a} Good drainage, water table sufficiently low not to impede crop growing (Hydromorphic horizon more than 60 cm below the surface).

D_{3b} Possible waterlogging for brief periods (flooding) less than 8 days each time.

D_4 Soil well drained, deep water table (Hydromorphic horizon lacking or more than 120 cm below the surface), no waterlogging in the profile (see H).

P, Effective Soil Depth

P_1 Soil thickness nil or soil pockets with rock outcroppings.

P_2 Soil thickness less than 30 cm.

P_3 Soil thickness from 30 to 60 cm.

P_4 Moderately deep soil; soil thickness 60 to 90 cm.

P_5 Deep soil, soil thickness 90 to 120 cm.

P_6 Very deep soil; more than 120 cm.

T, Texture and Structure of the A Horizon

T_1 Pebbly, rocky, or gravelly.

T_{1a} Pebbly, stony, or gravelly, coarse fragments more than 60 percent by weight.

T_{1b} Pebbly, stony or gravelly, coarse fragments 40 to 60 percent by weight.

T_{1c} Clay texture, stones 20 to 40 percent by weight.

T_2 Very coarse textured soil.

T_{2a} Pure sand.

T_{2b} Very coarse textured soil, up to 45 percent coarse sand.

T_{2c} Soil with non-decomposed "raw" humus.

T_3 Dispersed clay of unstable structure, or swelling, sticky and impermeable clay.

T_4 Light textured soil, fine sand, loamy sand, or coarse sand and silt.

T_{4a} Unstable structure.

T_{4b} Stable structure.

T_5 Heavy textured soil; clay or silty clay.

T_{5a} Massive to prismatic structure.

T_{5b} Angular to crumb structure (or massive but porous, e.g. soils with high sesquioxide content).

T_6 Medium heavy soil; sandy clay, clay loam, or silty clay loam.

T_{6a} Massive to prismatic structure.

T_{6b} Angular to crumb structure (or massive but porous).

T_7 Medium, balanced texture; loam, sandy loam, or sandy clay loam.

<u>N, Base Status</u> (Based on degree of saturation, $V - \frac{S}{T}$)

N_1 Very strongly leached soil, V - less than 15 percent.

N_2 Strongly leached soil, V - 15 to 35 percent.

N_3 Moderately leached soil, V - 35 to 50 percent.

N_4 Slightly leached soil, V - 50 to 75 percent.

N_5 Very slightly leached soil, V - 75 percent or more.

N_6 Soil saturated with calcium ions (calcareous soil) V - 100 percent.

<u>S, Soluble Salt Content</u>

S_1 Total soluble salts less than 0.2 percent.

S_2 Total soluble salts between 0.2 and 0.4 percent.

S_3 Total soluble salts between 0.4 and 0.6 percent.

S_4 Total soluble salts between 0.6 and 0.8 percent.

S_5 Total soluble salts between 0.8 and 1.0 percent.

S_6 Total soluble salts 1.0 percent or more; alkaline soil if sodium carbonate is present.

S_7 Alkaline soil; total soluble salts, including sodium carbonate, between 0.1 and 0.3 percent.

S_8 Alkaline soil; total soluble salts including sodium carbonate, between 0.3 and 0.6 percent.

S_9 Alkaline soil; total soluble salts, including sodium carbonate, between 0.6 and 1.0 percent.

<u>O, Organic Matter of the A Horizon</u>

O_1 Very little organic matter, less than 1 percent.

O_2 Little organic matter, 1-2 percent.

O_3 Average organic matter, 2-5 percent.

O_4 Fair organic matter, over 5 percent.

O_5 Very high organic matter, but C/N ratio over 25 percent.

<u>A, Mineral Exchange Capacity of Soils and Nature of Clay</u>

A_1 Capacity for cation exchange less than 20 meq/100 g (probably kaolin and sesquioxides).

A_2 Capacity for cation exchange 20-40 meq/100 g (probably a mixture of clays or hydrous micas, illite).

A_3 Capacity for cation exchange over 40 meq/100 g (probably montmorillonite or allophane).

<u>M, Reserves or Alterable Minerals in the B Horizon</u>

M_1 Reserves very low to nil.

M_2 Reserves fair.

M_{2a} Minerals derived from sands, sandy materials, or ironstone.

M_{2b} Minerals derived from acid rocks.

M_{2c} Minerals derived from basic or calcareous rocks.

M_3 Reserves great.

M_{3a} Minerals derived from acid rocks.

M_{3b} Minerals derived from basic or calcareous rocks.

The next list shows how numerical ratings were applied to the various factors. Some of the ratings depend, as indicated, on the kind of crop, moisture regime, position with respect to slope, or other soil factors.

H. Soil Moisture Content

For field crops:

H_1	5
H_2	11 months dry, 10; 10 months dry, 20; 9 months dry, 40.
H_3	8 months dry, 50; 7 months dry, 60; 6 months dry, 70.
H_4	5 months dry, 80; 4 months dry, 90; 3 months dry, 100.
H_5	100

For tree crops:

H_1	5
H_2	10
H_3	8 months dry, 10; 7 months dry, 20; 6 months dry, 40.
H_4	5 months dry, 70; 4 months dry, 90; 3 months dry, 100.
H_5	100

D. Drainage

For field crops, provided moisture is H_2, H_3, H_4, or H_5:

D_1	10–40
D_2	40–80
D_3	80–90
D_4	100

For tree crops:

D_1	5
D_2	10
D_3	40
D_4	100

P. Effective Soil Depth

	Field crops on lower slopes	Field crops on slopes or plateaux	Tree crops
P_1	5	5	5
P_2	20	20	5
P_3	50	30–40	20
P_4	80	50–70	60
P_5	100	100	80
P_6	100	100	100

T, Texture of the A Horizon, Modified by Structure

T_{1a}	10		
T_{1b}	30		
T_{1c}	60		
For:	H_4, H_5, H_6, or irrigated	For: H_3	For: H_1 or H_2
T_{2a}	10	10	10
T_{2b}	30	20	10
T_{2c}	30	30	30
T_3	30	20	10
T_{4a}	40	30	30
T_{4b}	50	40	40
T_{5a}	60	70	20
T_{5b}	80	80	60
T_{6a}	80	80	60
T_{6b}	90	90	90
T_7	100	100	100

N, Base Status

N_1	40
N_2	50
N_3	60
N_4	80
N_5	100
N_6	80

S, Soluble Salt Content

For crops,	For: T_1, T_2, T_4; T_5, T_6, or T_7
S_1	100 - 100
S_2	70 - 90
S_3	50 - 80
S_4	25 - 40
S_5	15 - 25

S_6	5 - 15
S_7	60 - 90
S_8	15 - 60
S_9	5 - 15

O, Organic Matter Content

For:	H_1, H_2, H_3, D_3, D_4	For: H_4, H_5, D_1, D_2, or irrigated
O_1	85	70
O_2	90	80
O_3	100	100
O_4	100	90
O_4	70	70

A, Cation Exchange Capacity

A_1	90
A_2	95
A_3	100

M, Reserves of Alterable Minerals

For:	H_1, H_2, or H_3	For: H_4, H_5, or irrigated
M_1	85	85
M_{2a}	85	90
M_{2b}	90	95
M_{2c}	95	100
M_{3a}	90	95
M_{3b}	95	100
M_{3c}	100	100

The unit of capability: In this study the unit of capability (UC) was defined as "one hectare of soil with a rating of 10C." One hectare with a rating or 50 thus amounts to 0.50 capability unit. In dealing with small scale maps, the hectounit of 100 UC or the kilounit of 1000 UC are more suitable. This concept is useful in comparing the productivity of regions or of different soil associations. The unit of capability (UC) was used in assessing present productivity and future potentialities of the soils of Nigeria. In that study it was estimated that soils below 0.20 UC per hectare are not generally suited for agricultural production, and soils of very high quality have UC values generally above 0.64.

The practices envisaged for development of soil resources, and needed for the assumed high level of management, are indicated along with the numeral expressing soil potentiality class on the interpretative map of soil potentialities. They are:

A Irrigation essential and drainage usually necessary.

B Supplementary irrigation:
- B_1 by sprinkling
- B_2 by flood or furrow irrigation.

C Elimination of excess water: reclamation, drainage or flood protection.

D Ridging, deep plowing, or breaking up of the crust.

E Improvement of soil structure and texture:
- E_1 by stone or rock removal.
- E_2 by mechanical working of soil, difficult and costly, requiring heavy machinery.
- E_3 by improvement of organic soil.

F Fertilizers, including trace elements, and soil amendments.

G Reclamation of saline soils:
- G_1 irrigation and drainage.
- G_2 irrigation and drainage application of gypsum to eliminate sodium salts.

H Improvement of organic matter content by manuring, fodder crops, mulching, and rotations.

J Wind erosion control measures.

K Intensive water erosion control measures, including benching and terracing.

L Light water erosion control measures: contour farming, strip-cropping, and and others.

M Large scale land clearing.

The present productivity and potentiality of soils in Nigeria (912,000 sq.km) were estimated, with the following results:

Soil Classes	Present Productivity percent	Potentiality percent
1	NONE	3.4
2	5.5	45.5
3	31.7	30.3
4	46.5	9.7
5	16.3	11.1
Total:	100.0	100.0

Improvement of soil characteristics or properties by management

Management practices	A	B_1B_2	C	D	E_1	E_2	E_3	F(with A_1 or A_2)*	F(with A_3)*	G_1	G_2	H	J	KL	M
Initial soil properties	H_1H_2	H_3H_4	D_1D_2	$P_1P_2P_3$	T_1bc	T_5aT_6a	T_2	$N_1N_2N_3$	$N_1N_2N_3N_4$	S_3S_4	S_9	$O_1O_2O_5$	H_1H_2 $T_1^+T_2T_4$		
Improved soil properties	H_5	H_5	D_3	$P_2P_3P_4$	T of fine soil materials	T_5bT_6b	T of subsoil	N_4	N_5	S_1S_2 For T_6 and T_7. For T_2, improvement of 4 soil classes rated according to salinity. For T_5, improvement of a single soil class rated according to salinity.	S_7	Add 10% to final index	Add 10% to final index	Add 20% to final index (10% if amendments have already been made; 10% for H.)	0%

* NOTE: A_1, A_2 and A_3 refer to cec data.

LAND CAPABILITY CLASSES

This appendix presents eight land capability classes (18) ranging from the best and most easily farmed land (Class I) to land which has no value for cultivation, grazing, or forestry, but may be useful for recreation, wildlife, water supply, or water-shed (Class VIII). They all fall into two groups: land suitable for cultivation and land not suitable for cultivation.

Land Suited to Cultivation and Other Sources

Class I - Soils in Class I have few limitations that restrict their use.

Soils in this class are suited to a wide range of plants and may be used safely for cultivated crops, pasture, range, woodland, and wildlife. The soils are nearly level 1/ and erosion hazard (wind or water) is low. They are deep, generally well drained, and easily worked. They hold water well and are either fairly well supplied with plant nutrients or highly responsive to inputs of fertilizer.

The soils in Class I are not subject to damaging overflow. They are productive and suited to intensive cropping. The local climate must be favorable for growing many of the common field crops.

In irrigated areas, soils may be placed in Class I if the limitation of the arid climate has been removed by relatively permanent irrigation works. Such irrigated soils (or soils potentially useful under irrigation) are nearly level, have deep rooting zones, have favorable permeability and water-holding capacity, and are easily maintained in good tilth. Some of the soils may require initial conditioning including leveling to the desired grade, leaching of a slight accumulation of soluble salts, or lowering of the seasonal water table. Where limitations due to salts, water table, overflow, or erosion are likely to recur, the soils are regarded as subject to permanent natural limitations and are not included in Class I.

Soils that are wet and have slowly permeable subsoils are not placed in class I. Some kinds of soil in Class I may be drained as an improvement measure for increased production and ease of operation.

Soils in Class I that are used for crops need ordinary management practices to maintain productivity - both soil fertility and soil structure. Such practices may include the use of one or more of the following: fertilizers and lime, cover and green-manure crops, conservation of crop residues and animal manures, and sequences of adapted crops.

Class II - Soils in Class II have some limitations that reduce the choice of plants or require moderate conservation practices.

Soils in Class II require careful soil management, including conservation practices, to prevent deterioration or to improve air and water relations when the soils are cultivated. The limitations are few and the practices are easy to apply. The soils may be used for cultivated crops, pasture, range, woodland, or wildlife food and cover.

1/ Some rapidly permeable soils in Class I may have gentle slopes.

Limitations of soils in Class II may include single or in combination the effects of 1) gentle slopes, 2) moderate susceptibility to wind or water erosion or moderate adverse effects of past erosion, 3) less than ideal soil depth, 4) somewhat unfavorable soil structure and workability, 5) slight to moderate salinity or sodium easily corrected but likely to recur, 6) occasional damaging overflow, 7) wetness correctable by drainage but existing permanently as a moderate limitation, and 8) slight climatic limitations on soil use and management.

The soils in this class provide the farm operator less latitude in the choice of either crops or management practices than soils in Class I. They may also require special soil-conserving cropping systems, soil conservation practices, water-control devices, or tillage methods when used for cultivated crops. For example, deep soils of this class with gentle slopes subject to moderate erosion when cultivated may need one of the following practices or some combination of two or more: terracing, stripcropping, contour tillage, crop rotations that include grasses and legumes, vegetated water-disposal areas, cover or green-manure crops, stubble mulching, fertilizers, manure, and lime. The exact combinations of practices vary from place to place, depending on the characteristics of the soil, the local climate, and the farming system.

Class III - Soils in Class III have severe limitations that reduce the choice of plants or require special conservation practices, or both.

Soils in Class III have more restrictions than those in Class II and when used for cultivated crops the conservation practices are usually more difficult to apply and maintain. They may be used for cultivated crops, pasture, woodland, range, or wildlife food and cover.

Limitations of soils in Class III restrict the amount of clean cultivation; timing of planting, tillage, and harvesting; choice of crops; or some combination of these limitations. The limitations may result from the effects of one or more of the following: 1) moderately steep slopes, 2) high susceptibility to water or wind erosion or severe adverse effects of past erosion, 3) frequent overflow accompanied by some crop damage, 4) very slow permeability of the subsoil, 5) wetness or some continuing waterlogging after drainage, 6) shallow depths to bedrock, hardpan, fragipan or claypan that limit the rooting zone and the water storage, 7) low moisture-holding capacity, 8) low fertility not easily corrected, 9) moderate salinity or sodium, or 10) moderate climatic limitations.

When cultivated, many of the wet, slowly permeable but nearly level soils in Class III require drainage and a cropping system that maintains or improves the structure and tilth of the soil. To prevent puddling and to improve permeability it is commonly necessary to apply organic material to such soils and to avoid working them when they are wet. In some irrigated areas, part of the soils in Class III have limited use because of high water table, slow permeability, and the hazard of salt or sodic accumulation. Each distinctive kind of soil in Class III has one or more alternative combinations of use and practices required for safe use, but the number of practical alternatives for average farmers is less than that for soils in class II.

Class IV - Soils in Class IV have very severe limitations that restrict the choice of plants, require very careful management, or both.

The restrictions in use for soils in Class IV are greater than those in Class III and the choice of plants is more limited. When these soils are cultivated, more careful management is required and conservation practices are more difficult to apply and maintain. Soils in Class IV may be used for crops, pasture, woodland, range, or wildlife food and cover.

Soils in Class IV may be well suited to only two or three of the common crops or the harvest produced may be low in relation to inputs over a long period of time. Use for cultivated crops is limited as a result of the effects of one or more permanent features such as 1) steep slopes, 2) severe susceptibility to water or wind erosion, 3) severe effects of past erosion, 4) shallow soils, 5) low moisture-holding capacity, 6) frequent overflows accompanied by severe crop damage, 7) excessive wetness with continuing hazard of waterlogging after drainage, 8) severe salinity or sodium, or 9) moderately adverse climate.

Many sloping soils in Class IV in humid areas are suited to occasional but not regular cultivation. Some of the poorly drained, nearly level soils placed in Class IV are not subject to erosion but are poorly suited to intertilled crops because of the time required for the soil to dry out in the spring and because of low productivity for cultivated crops. Some soils in Class IV are well suited to one or more of the special crops, such as fruits and ornamental trees and shrubs, but this suitability itself is not sufficient to place a soil in Class IV.

In sub-humid and semi-arid areas, soils in Class IV may produce good yields of adapted cultivated crops during years of above average rainfall; low yields during years of average rainfall; and failures during years of below average rainfall. During the low rainfall years the soil must be protected even though there can be little or no expectancy of a marketable crop. Special treatments and practices to prevent soil blowing, conserve moisture, and maintain soil productivity are required. Sometimes crops must be planted or emergency tillage used for the primary purpose of maintaining the soil during years of low rainfall. These treatments must be applied more frequently or more intensively than on soils in Class III.

Land Limited in Use - Generally Not Suited to Cultivation 2/

Class V - Soils in Class V have little or no erosion hazard but have other limitations impractical to remove that limit their use largely to pasture, range, woodland, or wildlife food and cover.

Soils in Class V have limitations that restrict the kind of plants that can be grown and that prevent normal tillage of cultivated crops. They are nearly level but some are wet, are frequently overflowed by streams, are stony, have climatic limitations, or have some combination of these limitations. Examples of Class V are 1) soils of the bottom lands subject to frequent overflow that prevents the normal production of cultivated crops, 2) nearly level soils with a growing season that prevents the normal production of cultivated crops, 3) level or nearly level stony or rocky soils, and 4) ponded areas where drainage for cultivated crops is not feasible but where soils are suitable for grasses or trees. Because of these limitations, cultivation of the common crops is not feasible but pastures can be improved and benefits from proper management can be expected.

Class VI - Soils in Class VI have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food and cover.

Physical conditions of soils placed in Class VI are such that it is practical to apply range or pasture improvements, if needed, such as seeding, liming, fertilizing, and water control with contour furrows, drainage ditches, diversions, or water spreaders.

2/ Certain soils grouped into Classes V, VI, VII and VIII may be made fit for use for crops with major earthmoving or other costly reclamation.

Soils in Class VI have continuing limitations that cannot be corrected, such as 1) steep slope, 2) severe erosion hazard, 3) effects of past erosion, 4) stoniness, 5) shallow rooting zone, 6) excessive wetness or overflow, 7) low-moisture capacity, 8) salinity or sodium or 9) severe climate. Because of one or more of these limitations these soils are not generally suited to cultivated crops. But they may be used for pasture, range, woodland, or wildlife cover or for some combination of these.

Some soils in Class VI can be safely used for the common crops provided unusually intensive management is used. Some of the soils in this class are also adapted to special crops such as sodded orchards, blueberries, or the like, requiring soil conditions unlike those demanded by the common crops. Depending upon soil features and local climate the soils may be well or poorly suited to woodlands.

Class VII - Soils in Class VII have very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, woodland, or wildlife.

Physical conditions of soils in Class VII are such that it is impractical to apply such pasture or range improvements as seeding, liming, fertilizing, and water control with contour furrows, ditches, diversions, or water spreaders. Soil restrictions are more severe than those in Class VI because of one or more continuing limitations that cannot be corrected, such as 1) very steep slopes, 2) erosion, 3) shallow soil, 4) stones, 5) wet soil, 6) salts or sodium, 7) unfavorable climate, or 8) other limitations that make them unsuited to common cultivated crops. They can be used safely for grazing or woodland or wildlife food and cover or for some combination of these under proper management.

Depending upon the soil characteristics and local climate, soils in this class may be well or poorly suited to woodland. They are not suited to any of the common cultivated crops; in unusual instances, some soils in this class may be used for special crops under unusual management practices. Some areas of Class VII may need seeding or planting to protect the soil and to prevent damage to adjoining areas.

Class VIII - Soils and landforms in Class VIII have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, or water supply or to esthetic purposes.

Soils and landforms in Class VIII cannot be expected to return significant on-site benefits from management for crops, grasses, or trees, although benefits from wildlife use, watershed protection, or recreation may be possible.

Limitations that cannot be corrected may result from the effects of one or more of the following: 1) Erosion or erosion hazard, 2) severe climate, 3) wet soil, 4) stones, 5) low-moisture capacity, and 6) salinity or sodium.

Badlands, rock outcrop, sandy beaches, river wash, mine tailings, and other nearly barren lands are included in Class VIII. It may be necessary to give protection and management for plant growth to soils and landforms in Class VIII in order to protect other more valuable soils, to control water, or for wildlife or esthetic reasons.

LAND CLASSES FOR IRRIGATED LAND USE

Appendix 5 presents the basic land classes for irrigated land as used by the Bureau of Reclamation, United States Department of Interior (34).

These land classes are based on the economics of production and land development within specific ecologic areas. Hence, the production and repayment potentials will differ significantly between such areas. Although all classes will be found in any given ecologic area, they will not necessarily be found in a given project area. Four basic classes are used in the Bureau system to identify the arable lands according to their suitability for irrigation agriculture, one provisional class, and one class to identify the nonarable lands. The first three classes represent lands with progressively less ability to repay project construction costs. The excessive deficiency-restricted utility subclasses of Class 4 may have repayment ability ranging from less than that of Class 3 to more than that of Class 1 depending upon the particular utility involved. The number of classes mapped in a particular investigation depends upon the diversity of the land conditons encountered and other requirements as dictated by the objectives of the particular investigation.

Class 1 - Arable: Lands that are highly suitable for irrigation farming, being capable of producing sustained and relatively high yields of a wide range of climatically adapted crops at reasonable cost. They are smooth lying with gentle slopes. The soils are deep and of medium to fairly fine texture with mellow, open structure allowing easy penetration of roots, air, and water and having free drainage yet good available moisture capacity. These soils are free from harmful accumulations of soluble salts or can be readily reclaimed. Both soil and topographic conditions are such that no specific farm drainage requirements are anticipated, minimum erosion will result from irrigation and land development can be accomplished at relatively low cost. These lands potentially have a relatively high payment capacity.

Class 2 - Arable: This class comprises lands of moderate suitability for irrigation farming, being measurably lower than Class 1 in productive capacity, adapted to somewhat narrower range of crops, more expensive to prepare for irrigation or more costly to farm. They are not so desirable nor of such value as lands of Class 1 because of certain correctible or noncorrectible limitations. They may have a lower available moisture capacity, as indicated by coarse texture or limited soil depth; they may be only slowly permeable to water because of clay layers or compaction in the subsoil; or they also may be moderately saline which may limit productivity or involve moderate costs for leaching. Topographic limitations include uneven surface requiring moderate costs for leveling, short slopes requiring shorter length of runs, or steeper slopes necessitating special care and greater costs to irrigate and prevent erosion. Farm drainage may be required at a moderate cost or loose rock or woody vegetation may have to be removed from the surface. Any one of the limitations may be sufficient to reduce the lands from Class 1 to Class 2 but frequently a combination of two or more of them is operating. The Class 2 lands have intermediate payment capacity.

Class 3 - Arable: Lands that are suitable for irrigation development but are approaching marginality for irrigation and are of distinctly restricted suitability because of more extreme deficiencies in the soil, topographic, or drainage characteristics than described for Class 2 lands. They may have good topography, but because of inferior soils have restricted crop adaptability, require larger amounts of irrigation water or special irrigation practices, and demand greater fertilization or more intensive soil improvement practices. They may have uneven topography, moderate to high concentration of salines, or restricted drainage, susceptible of correction but only at relatively high costs. Generally, greater risk may be involved in farming Class 3 lands than the better classes of land, but under proper management they are expected to have adequate payment capacity.

Class 4 - Limited Arable or Special Use: Lands are included in this class only after special economic and engineering studies have shown them to be arable. They may have an excessive, specific deficiency or deficiencies susceptible of correction at high cost, but are suitable for irrigation because of existing or contemplated intensive cropping such as for truck and fruits; or, they may have one or more excessive, noncorrectible deficiencies thereby limiting their utility to meadow, pasture, orchard, or other relatively permanent crops, but are capable of supporting a farm family and meeting water charges if operated in units of adequate size or in association with better lands. The deficiency may be inadequate drainage, excessive salt content requiring extensive leaching, unfavorable position allowing periodic flooding or making water distribution and removal very difficult, rough topography, excessive quantities of loose rock on the surface or in the plow zone, or cover such as timber. The magnitude of the correctible deficiency is sufficient to require outlays of capital for land development in excess of those permissible for Class 3 but in amounts shown to be feasible because of the specific utility anticipated. Sub-classes other than those devoted to special crop use may be included in this class, such as those for sub-irrigation, and sprinkler irrigation which meet general arability requirements. Also recognized in Class 4 are suburban lands which do not meet general arability requirements. Such lands can pay water charges as a result of income derived either from the suburban land and other sources or from other sources alone. The Class 4 lands may have a range in payment capacity greater than that for the associated arable lands.

Class 5 - Nonarable: Lands in this class are nonarable under existing conditions, but have potential value sufficient to warrant tentative segregation for special study prior to completion of the classification, or they are lands in existing projects whose arability is dependent upon additional scheduled project construction or land improvements. They may have a specific soil deficiency such as excessive salinity, very uneven topography, inadequate drainage, or excessive rock or tree cover. In the first instance, the deficiency or deficiencies of the land are of such nature and magnitude that special agronomic, economic or engineering studies are required to provide adequate information, such as extent and location of farm and project drains, or probable payment capacity under the anticipated land use, in order to complete the classification of the lands. The designation of Class 5 is tentative and must be changed to the proper arable class or Class 6 prior to completion of the land classification. In the second instances, the effect of the deficiency or the outlay necessary for improvement is known, but the lands are suspended from an arable class until the scheduled date of completion of project facilities and land development such as project and farm drains. In all instances, Class 5 lands are segregated only when the conditions existing in the area require consideration of such lands for competent appraisal of the project possibilities, such as when an abundant supply of water or shortage of better lands exists, or when problems related to land development, rehabilitation and resettlement are involved.

Class 6 - Nonarable: Lands in this class include those considered non-arable under the existing project or the project plan because of failure to meet the minimum requirements for the other classes of land, arable areas definitely not susceptible to delivery of irrigation water or to provision of project drainage, and Classes 4 and 5 land when the extent of such lands or the detail of the particular investigation does not warrant their segregation. Class 6 irrigated land with water rights encountered in the classification will be delineated and designated Class 6 W. Generally, Class 6 comprises: steep, rough, broken, or badly eroded lands; lands with soils of very coarse or fine texture, or shallow soils over gravel, shale, sandstone, or hardpan; and lands that have inadequate drainage and high concentrations of soluble salts or sodium. Excluding the position sub-classes, the Class 6 lands do not have sufficient payment capacity to warrant consideration for irrigation.

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