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9. ABSTRACT

International efforts to improve agricultural productivity in developing countries have long been hampered by the lack of a single international taxonomic system for surveying and recording the properties or resources of existing soils. These proceedings contain the papers and summaries of discussions of a workshop conducted in April, 1977, to obtain a review of a soil resource inventory program now being conducted at Cornell University. The purpose of the program is to develop a classification system for soil surveys that will provide mutually exclusive classes of soils defined by properties which can be recognized by non-soil scientists, independent of soil classification systems. The 30 papers, addresses, and discussion summaries in these proceedings cover eight topics: types and categories of soil surveys, evaluation of soil surveys and maps, case studies of soil survey methodology, soil survey techniques, methods of evaluating map characteristics, soil properties important for given land uses, presentations of soil resource data, and the role of soil surveys in the decision-making process for developmental planning.

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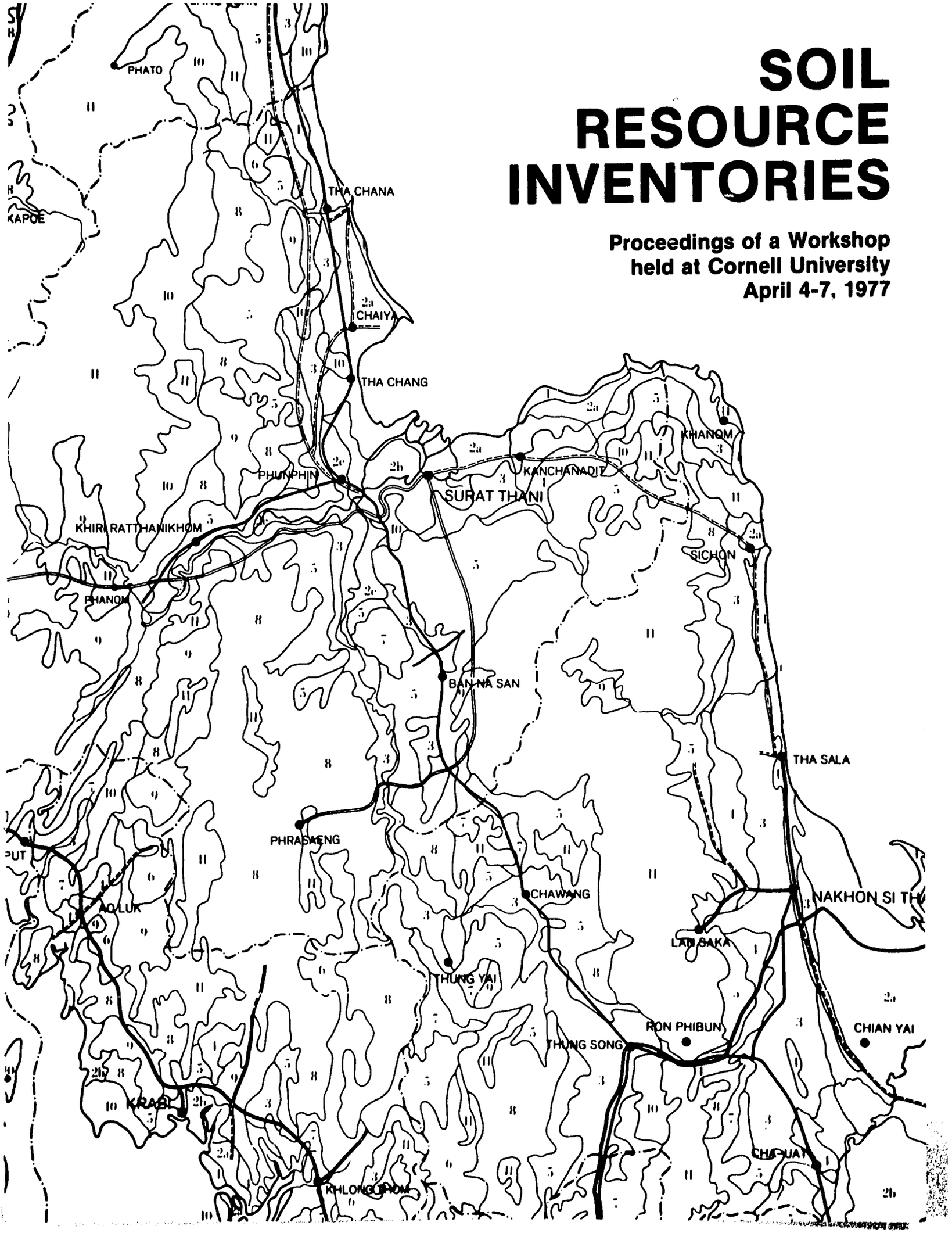

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April 4-7, 1977

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OPENING ADDRESS

R. W. Arnold [1]

We are extremely pleased that each of you has been able to come here for several days. Just as spring is arriving and flowers and buds are utilizing stored energy to confirm and renew hope eternal in a world facing difficult decisions, so this workshop will draw upon your storehouse of knowledge to reassure the world that pedology offers strength and hope as a part of the solution to land use problems. The dynamic processes of springtime integrate many aspects of an environment and only through their interactions do we see the brilliant transformations. As a working group we can only concentrate on several components of land use; however, a consensus concerning the role of soil resource inventories will contribute to meaningful expressions of renewed hope for our fellow human beings.

Our longer range objective is to assist others in developing feasible soil survey strategies to meet planning objectives that affect land use, primarily in developing countries. Thus we are concerned with the items or aspects that improve the effectiveness of soil resource inventories.

The U. S. Agency for International Development has a long history of concern for the "small farmer" and the improvement of his status in his economic, social, and political environment. Because of his small parcels of land, it is often not possible to provide information adequate for improved performance of these individual tracts of land. However, most users of land throughout the world respond to policies and land use decisions made by various government agencies. These policies may include project development, price supports, forms of credit, production goals, marketing procedures, infrastructure, industrial growth, and balance of payment schemes. These are the constraint systems within which all farmers operate. It seemed reasonable to us that better decisions and policies should result from better communication and interchange between pedologists and land use decision makers.

Two-stage Program

1. The first stage is to gain a better understanding of properties and qualities of soil maps and soil surveys. What are the characteristics associated with these aspects? This consequently provides pedologists and others with the knowledge of constraints, limitations, and potentials related to providing soils information.

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2. The second stage will involve working with planners who make different kinds of decisions that affect land. We hope to match their ideas, needs, and constraints with the potentials of soil resource inventories so they can decide on the alternatives that improve the cost-effectiveness of soil survey effort. The purpose of this workshop is to focus more on the first stage -- that is, what do we know about soil maps and what additionally do we need to know? A portion of the workshop will discuss the use of soil survey in the planning process -- mainly as viewed by pedologists. A later workshop will concentrate more on planning as viewed by non-pedologists.

The Task Ahead

We have invited each of you because of your interest and expertise in pedology. We are asking for your help in sharing thoughts in this endeavor. Each of us has more expertise in some areas of concern than others, and by teaming up we hope to strengthen all of our viewpoints and bring to light a more solid understanding or comprehension of problems and solutions in evaluating soil resource inventories.

Underlying the unique vantage point that each of you has is the knowledge of repeating and consistent aspects of soil inventories which are shared in common. These underlying concepts and principles are the ones that must be given attention in designing and evaluating soil surveys.

It is exactly these concepts that we hope to bring out and try to unify during our few days together because we want to be able to provide information on alternative solutions and provide guidance to the agencies of less developed countries in their endeavors to develop and strengthen their own programs of soil and land resource inventories. We do not envision our role as telling others what to do -- rather we want to bring together information that will make their tasks easier and hopefully not repeat the costlier mistakes of our own experiences.

How well we succeed likely depends on our abilities to provide proper information, training materials, self-help guidelines, and ideas that are logical, reasonable, and useful in evaluating available data and in designing more effective soil resource inventories in the years ahead.

Experts in pedology are truly exceptional people. You are not possessive of your ideas and concepts; you are dedicated to understanding the environment; you are humanitarians with a genuine concern for the world community. You are unselfish with your time and talents, and you certainly aren't afraid of hard work. We are grateful that each of you has become one of these experts. In addition to doodling on pads of paper we want you to jot down concerns and comments about each subject area of our discussion groups because Wednesday morning we will ask for your recommendations about where we are and where we ought to be going.

The approach of the Cornell group up till now has been directed to some problems of appraising the utility of soil maps. There are, of course, many ways to conceptualize the problems and many places to begin. We started with soil maps because they are often the most conspicuous product presented for obtaining information about an area. Actual decisions are most commonly based on other maps whose information is derived from the soil map; consequently we felt it was imperative to know about soil maps.

Professor Cline has been instrumental in guiding our recent thinking; that explains why we sent you a copy of his ideas. His article is also the first under the Cornell contributions. In essence there are two leading questions:

1. What does one need to know to appraise the soil itself for use and management?

2. To what degree does a soil map and associated materials provide the things we need to know?

Each of these is really a generator of sets of related questions for which we are seeking guidance, judgments, advice, and consensus of expert opinion. We are painfully aware that most aspects are inter-related and can seldom be adequately considered out-of-context. Nevertheless it appears that the big picture can only be handled by focussing attention on specific parts long enough to bring out the principles needed to abstract the essence of the smaller parts.

Workshop Format

The main emphasis of this workshop is to identify those items necessary to evaluate soil resource inventories. On one hand we have some maps and reports already available -- many of which defy classification by current concepts -- and on the other hand are those items needed to produce soil information in the years ahead that will be used to advantage in policy making and land use decisions.

This workshop will consist of eight areas of concern. Each session will begin with two or three presentations of about 15 minutes each, highlighting the subject and providing us with ideas for the discussion groups. We are together here as specialists in pedology; we don't have to impress others of the significance of our work -- we already know this. Consequently I charge each of you to remember that each person here is generally familiar with your subject matter and some of your personal contributions to pedology. Believe me, we are impressed, and that is exactly why you are here. The presentation sessions are the prelude to the time when each of us must give our best effort in evaluating what needs to be known and approaches for obtaining this information. The discussion group periods do not last very long but they are the heart of this workshop.

Unfortunately we must try to maintain a fairly rigid timetable. There are happily no such schedules in the evenings and we hope you take that time to discuss further or follow up on the hundreds of ideas you have about pedology.

The eight formal sessions are given in your outline. They are:

1. Orders of soil surveys -- kinds, objectives and interpretations of different types or kinds of soil surveys.

2. Evaluation of soil surveys and maps -- what attributes need evaluating, what is quality and effectiveness, and what about map unit accuracy.

3. Soil survey methodology -- case studies.

4. Soil survey methodology -- techniques: using Landsat, designing survey legends, airphoto and other remote sensing techniques.

5. Review of methodology of evaluating soil map characteristics -- some results of the Cornell group.

6. Soil properties important for given land uses -- soil and land qualities, trace elements, and other considerations.

7. Soil data presentation -- what can we do to help different users understand and take advantage of soil information.

8. The role of soil surveys in the decision-making process for development planning -- the effects of scales and legends, and the role of soil surveys.

You will hear more about Session 9 later. It will be a time to draw together the many ideas into recommendations and guidelines for proceeding further with soil resource inventory evaluations. You will need to consult your own notes as we try collectively to be of assistance in looking at where we are and how to move ahead.

There is a chairman for each presentation session. Following each session we will break up into three discussion groups. These are all listed -- with the discussion leader, secretary and participants. Our group assignments were picked at random; there was no bias toward any of us. Our sincere thanks to each of you for being here to assist in our deliberations.

SESSION I

Monday morning, April 4, 1977

ORDERS OF SOIL SURVEYS

Chairman: R. W. Arnold

Speakers

G. Aubert	-	Soil Survey: Different Types and Categories
A. C. Orvedal	-	Comments on Interpretation Potentials in Relation to Soil Survey Orders
A. J. Smyth	-	The Objectives of Soil Surveys of Various Intensities

SOIL SURVEY: DIFFERENT TYPES AND CATEGORIES[1]

G. Aubert[2]

Soil is a natural object, and as such, it is an indispensable object of study, both as an entity itself and to understand the action of its formative factors in order to determine its genesis and evolution, its place in a natural and rational classification, and its global distribution.

Since soil is one of the fundamental components of terrestrial ecosystems, we must therefore attempt to ascertain how soil interacts with them. These ecosystems are often transformed directly or indirectly by man into agro-ecosystems which furnish food, fiber, and other products such as textiles, wood, oil, etc. The study of soil types must therefore be performed with the goal of determining their possible adaptation to these utilizations.

Soil survey, the field and subsequent laboratory study of soils, is based on grouping individual elements into classes to determine the characteristics, properties, and evolution of soils -- elements which permit the expression of the specificity of soils, the role they play in ecosystems, and their possibilities for utilization. Mapping is performed to show the spatial distribution of these defined units.

OBJECTIVES AND TYPES OF SOIL CLASSIFICATION FOR USE IN SOIL SURVEY AND MAPPING

As mentioned, the fundamental objective of soil survey is to define map units by classifying grouped elements that are a function of soil characteristics, their relationship with the environment and their evolution. These map units may be ultimately expressed as a distribution on a rational map.

Soil Surveying and Mapping on a Pedological Level

Classification. The various categories of soils do not always correspond to natural classification units, which for practicality must not be extremely complex; consequently, they do not always represent the range of natural variability. Frequently

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a classification system is the basis of a soil legend: this legend can include *intergrades* or *taxadjuncts*, units related genetically to the *pure* units which form the real framework of the survey site.

The representation of complexes on soil maps is a difficult problem to resolve. Whatever may be the legend and scale of the soil map, there are varying numbers of areas containing such numerous and intricate soil units that it is impossible to accurately represent the exact position or area of each of the units, regardless of whether the survey was sufficiently detailed to locate them with precision.

Several solutions to this problem are possible, and their applicability depends on the scale of the map and its objective. In the case of interpretive pedological maps with scale ranges of 1:500,000 to 1:5,000,000, one could try to represent the most characteristic soils, even at the risk of exaggerating certain points and not representing others. For medium scale maps, (1:50,000 to 1:200,000, and occasionally 1:500,000), which are suitable as a regional planning base, the method utilized is entirely different. Here, cartographic units correspond to soil associations. Sometimes it is possible to replace these simple, most utilized soil complexes with toposequences, or successions of toposequences, or even catenas of soils. This last method is the most satisfactory, especially for determining more explicit applications for regional planning. First, it is necessary to show the existence and extent of these catenas. Already the utilization of toposequences in areas where they are developed greatly improves the cartographic representation of the soil survey results, and allows the faster production of more informative maps. In large scale maps, the same complex units are employed, but their proportion with respect to "pure" units is normally more limited, if the survey was sufficiently precise and detailed.

Factors of formation. In surveying, the relationships between the kinds of soil and their various factors of formation and evolution assume great importance. Often it is essential to make these characteristics a component of the system, especially for intermediate map scales. In the French classification system the characteristics of parent material are included at the family level. Vegetation and geomorphology parameters are not incorporated in the definition of soil, except for their occasional use at the series level (where judgments based on the criteria of soil depth are more effective). However, the cartographic regrouping of soil units can be accomplished based on the consideration of these two factors, which are themselves consequences of soil genesis. As did Tricart (1974), Kilian (1974) defines cartographic units on the basis of *geomorphology*. Under this premise, it seems preferable to regroup soils into *landscapes* in which their distribution and relationships are more precisely shown in detailed maps (Eschenbrenner and Badarello, 1975).

Pouget (1977) has integrated the study and representation of vegetative groupings and soils, in surveying soils of the steppe areas of Algeria; this permits him to create for a medium scale of 1:100,000 a more complete map illustrating the potential uses of landscapes.

Another procedure is to include on each page of the map itself, small scale schematic diagrams showing the general distribution of the genetic factors: geomorphology, vegetation, climate, etc. This has been done with the French soil maps at the 1:100,000 scale and the New Hebrides soil maps.

Soil Surveying and Map-making for Utilization

The knowledge of soils and their properties, process of formation, and distribution is generally required only for formulating plans for soil utilization. Usually this utilization is agricultural development, although at times it is for public works or urbanization (including recreational areas), for the preservation of the ecosystem and its integral complexity, or for environmental goals (to create reserves, national parks, etc.). It is very certain that if the evaluation of suitabilities or limitations of a soil with respect to a certain type of use depends initially on the soil itself, its characteristics and properties, and often its process of formation and evolution, this evolution must also place particular importance on diverse factors (geomorphological and topographic conditions, vegetation, etc.) and consider certain of its environmental elements, and even general or local conditions that are exterior to the soil itself (for example, technical or socio-economic conditions) (Brinkman and Smyth, 1973). These last factors have great temporal variability and consequently the possibilities of integrating them into maps are limited because with the time and cost considerations involved, the results should be representative for as long as possible.

Diverse methods have been proposed to accomplish the transition from surveying to graphic representation of the soils' possible use.

1. *Synthesized.* The interpretation of the accumulated knowledge of soils and their environments, in the context of the latest agronomic techniques and local ecological conditions, can be expressed in a synthesized manner. In certain cases this can be represented as explanatory paragraphs on the fertility and utilization of each soil unit, or as a summarizing chapter in the text of the soil survey report. This has been frequently effected during the O.R.S.T.O.M. studies in tropical Africa and in Maghreb (Maignien, 1969 and Segalen, 1970).

Usually however, it seems most effective to report the results obtained on a map called *optimum utilization* (a term previously used by Aubert and Fournier, 1954; Riquier, 1954; etc.) or *cultivation potential of the land.* These are qualitative agronomic

terms that express the data of a pedological map either generally or as a function of local soil-based recommendations for crop groupings or land use types. In effect, the level of fertility of a parcel may be very different, as may be its cultivation or use potential, depending on its assignment to annual crops, tree crops, pasture, or forest. Besides the agricultural categories, recommendations could be made for the assignment of a certain field to recreational or industrial installation areas.

In arid regions, the development should be considered with and without the presence of irrigation. Aside from the soil map or cultivation potential map, a map of potential productivity indicating cropping possibilities following improvements such as drainage, removal of calcareous crust or other activities could be compiled (Vieillefon, 1967; Riquier, Bramao, and Cornet, 1970). This kind of interpretation must consider not only soil characteristics, but also environmental ones: slope, degree, danger of erosion, and even vegetative cover. Maps which depict these factors must be based on studies made with a very large scale, or marginally with a medium scale.

2. *Analytical.* The interpretation of soil maps for agronomic planning or for more general area land use planning must be analytical. The method may be parametric, given the utilization of complex indices with weighted parameters based on ecological zones, principal crops, and envisaged uses (Riquier, 1974).

More commonly, the method is simply analytical, or essentially based on values obtained for relevant soil characteristics (such as depth, texture, pH, etc.), environmental characteristics (for example slope), or for a combination of charactistics (perhaps erodibility), which are judged to have primordial importance for agricultural development or generalized land uses. These characteristics and especially the limiting values, or thresholds, vary as a function of local climatic conditions.

Such factors can be depicted in the format of analytical maps (of texture, hydrodynamic properties, permeability, etc.) (Lévêque, 1975), *cultural constraint maps* or as *soil resource maps* (Boulet, 1976 and Fauck, 1977).

3. *Interpretative.* Interpretation, irrespective of whether it is interpretative or analytic, may also be thematic or designed for a particular type of use, especially cultivation. This form of interpretation is often of transitory value due to the tremendous control external factors such as economics, problems of location, etc. have on the possible use of the land. For example, the suitability of land for banana production typically depends on the proximity of a shipping port or marketplace. With the inherent risks involved in this type of land evaluation, the technique is becoming progressively less utilized,

despite persistent demands for it by economists. Rather this strategy has been replaced by the intermediate interpretative type of approach, either thematic or analytical (Boyer, 1974).

TYPES OF MAPS AND LEGENDS

As indicated in the preceding discussion, in most cases the results of both soil surveys and studies derived from them are expressed in the form of maps indicating the distribution of different recognized units and their relationships. Pedological and non-pedological soil maps include a vast variety of forms, but these can be distinguished by the density and precision of their detail, their scale, and their legend (Aubert and Tavernier, 1972).

Different Kinds of Maps as a Function of the Density and Precision of Detail Contained in their Information

In those regions, now globally rare, where essentially no valuable surveys of terrestrial resources exist, maps of the "probable" distribution of principal soil types expected as a function of existing information on soil formative factors (geologic deposits, climate, topography, and even vegetation), can be compiled. These maps do not have definite significance except at the scale of synthesis (1:1,000,000 to 1:5,000,000), or at medium scales (1:200,000 to 1:500,000).

Habitually, three levels of cartography are distinguished on the basis of precision, as the above-mentioned type of map is rarely encountered:

1. *Reconnaissance maps.* These are based on observations and results obtained from traverses conducted throughout the study region and on known elements of factors of formation, as well as relationships which have been established during the course of the investigation between the observed soils and those diverse factors . . . in particular, at the end of the study of the toposequences formed over the principal parent rocks of the area. The soil map of France at the scale of 1:1,000,000 conforms to this definition, at least for the majority of the country.

2. *Semi-detailed maps.* Such surveys are carried out using traditional procedures, but the precision of observation, at least theoretically, corresponds to one observation per cm^2 of the map.

3. *Detailed maps.* These maps are the result of very precise, detailed studies. The level of precision necessary for this category is minimally four observations for each cm^2 of the map.

Such limits of precision are very theoretical, and are hard to apply to practical situations since calculations of the

gain in precision are difficult (the coefficient by which it would be necessary to divide the preceding recommendations or multiply the envisaged surfaces for a known point) due to the use of aerial photography and additional satellite imagery.

Although the use of these modern techniques permits greater rapidity and more detail in establishing the limits between the map units, it certainly needs to be supported by numerous traverses and observations of the soils.

Different Kinds of Maps as a Function of Scale

Another common habit is the classification of soil maps as a function of their field scale. However, it should be remembered that field work is often undertaken at a scale that is at least double, and preferably quadruple to, that at which the map is published. (For example, in France the field scale is 1:25,000 for a 1:100,000 published map). Classification on this basis has different potential possibilities and significance for the use of these documents.

1. *Small-scale maps.* Maps at the scale of 1:1,000,000 or smaller permit general interpretations. As such they are of great didactic value since they permit the performance of interesting geographical studies of soils in either diverse regions or on several continents, and allow useful extrapolations about the consequences of land use, in particular agronomic use. According to our conception with respect to the French classification system, the legends of such maps can include classification levels as low as subgroups with their associated phases, and can even distinguish those families which have particular importance.

2. *Medium-scale maps.* Scales of 1:50,000 or 1:100,000 are correlated with maps designed for regional planning. These in effect serve as a base for prospective work. In France, those at 1:100,000 have been retained simply because of the time and effort invested; those at 1:50,000 are more interesting in terms of their applications. In tropical countries a scale of 1:200,000 as in the soil map of Bossangoa (Boulvert, 1974) or 1:500,000 in the map of Upper Volta (Fauck, 1977), is more commonly utilized. Of course with the last scale, the document clearly represents an intermediate stage with respect to the preceding case.

In the legend of these maps the soil families as distinguished by the lithographic nature of the parent material can be indicated, even as can be soil series that generally correspond to significant gradations of soil depth for the land use, especially if it is principally agricultural.

3. *Large-scale maps.* At scales larger than 1:50,000, the soil map permits practical applications for local development planning and area development. Soil series, and even phases

of those characterized by different erosion intensities or internal drainage conditions, are distinguished on the legends of these maps.

Even if these two general methods of soil map classification are clearly different, their results nevertheless partially overlap. For example, maps at a scale of 1:1,000,000 or at smaller scale are in general types of reconnaissance maps if they are not really derived from a synthesis of more detailed maps, such as those at the 1:200,000 or 1:100,000 scales. Similarly, maps at larger scales are not always reconnaissance maps; rather they are more often detailed maps.

Different Kinds of Maps as a Function of their Objectives

This subject has been briefly considered in the first part of the report and specific recommendations have been given in the preceding paragraphs of the second part.

1. *Pedological maps.* Theoretically, for pedological maps, the kinds of maps and legends follow the rules of the precision and level of information, as a function of their scale as given in the beginning of the second part of this paper. The legend is linked as narrowly as possible to a soil classification system, as for example, the morphogenetic (soils map of France) or morphological (soil map of the U.S.) classification systems.

2. *Regional planning maps.* In the last several years, it has become increasingly more apparent that representation of the milieu at a medium scale (1:100,000 or 1:200,000) is insufficient as a basis for regional planning. The global characterization of the evolution of diverse soil types, their distribution, and even their relationships with various factors will not suffice for a general description of the milieu for expressing the general possibility of its use. Thus various authors have attempted to accomplish the objective at this level by presenting maps that are both pedological and morphogenetic.

Without remaining at the initial stage of French soil maps where geomorphological descriptions do not appear except in the form of accessory maps at a smaller scale, nor proceeding to the morphogenetic maps (such as those prepared by Tricart and Kilian) in which soil characteristics appear only in a secondary form, the methodology of Beaudou and Chatelin (1976) can be followed: A description of the pedological regions, followed by pedological soil landscapes, and finally functional segments or elements of toposequences and catenas of soils. Eschenbrenner and Badarello (1975) used schematic drawings to describe and explain morphogenetic landscapes of the northern Ivory Coast (Odienne region).

In this method, the landscapes are defined by the presence of characteristic morphological elements: inselbergs, residual relief, buttes (which are generally cupped with ironstone), the

remains of plateaus, derived forms more or less flattened or convex with an appearance of the slopes of lower bottoms, and nick-point values. Landscapes are also defined by the relative importance of soils at the level of the subgroup and their associated phases, and even of the families.

Maps of grouped morphopedological landscapes have been constructed at the scale of 1:200,000; but each of them is supplemented by a pedological detailed map, at the scale of 1:50,000, which is representative of a typical landscape, and by corresponding airphotos.

3. *Maps of agronomic application.* As has been previously stated, maps of agronomic applications can be very different, both in their detail and scale, but they must be based on a soils map established on an identical or larger scale.

a. *Maps of soil resources* are established at smaller scales (such as the 1:500,000 map of Upper Volta), and they are analytical in nature. They include delineation of agro-climatic zones and emphasize texture, primarily that of the surface horizon, but also that of the lower horizon to the extent that it affects plant performance. Taxonomic units are indicated with respect to the principal kinds of improvements proposed for various characteristic features: drainage conditions, actual water consumption, organic matter content, exchangeable bases, physical properties (particularly unfavorable ones), and the presence of toxic elements.

Some subunits are defined by the association of different component units in a zone or "spot" of the soils map, as this has been indicated in the units of the pedological map.

In northern climatic zones, cultivatable lands have been separated into areas suitable for dryland and irrigated agriculture and rangelands. On the map itself, a table was compiled that indicated the order of the units and subunits as assembled on the pedological map, and these units were given values characteristic of the various land uses for each of the retained fertility factors.

b. At medium and detailed scales (1:100,000) or larger, synthesized maps of *optimum agricultural utilization* or *suitability for cultivation* are assembled. The legend includes units of "universal agricultural value" and the principal possible uses as a function of the soil characteristics themselves (their type of evolution, parent material, depth, etc.) and also as a function of their environment, slope, degree of erosion, etc.

The most interesting system (such as the one utilized by Roederer in Tunisia), as previously mentioned, indicates

for each unit of land the relative fertility for each of the principal kinds of use or possible cultivation groupings, and the principal forseen improvements. It is of course indispensable that these documents be prepared with collaboration of an agronomist.

An example is given by the *management maps* compiled for the high-plateau steppes of Algeria which were prepared by Pouget (1977) in collaboration with geomorphologists, botanists, and agronomists. The maps include recommendations and forseen management and the potential yield of forages.

c. Maps of *cultivation constraints* have been rarely established by French pedologists, as many of the previous map types include in their taxonomic descriptions constraints such as "utilizable depth" or various other unfavorable physical properties.

However, maps have been made for the northern Cameroons by P. Brabant that analyze depth, texture, profile differentiation, insufficiency or excess of available water, and degree and danger of erosion. They have also been made in France by the "Organization for the Management of the Hills of Gascogne." The limiting factors are primarily the slope and the depth of usable land, and extreme textures, the excess of calcareous materials and any fertility or chemical insufficiencies.

d. In France, purely *thematic* maps are also established at very detailed scales with regard to drainage operations (various working groups of INRA), or for particular irrigated cultivations (Organization for the Management of Lower-Rhône Languedoc). The maps compiled at very small scales (1:1,000,000 or 1:5,000,000) concerning the dangers of desert formation and the degradation of soils [R. Pontanier (1976) in Tunisia] and the salinity of soils [Aubert (1977) for Africa] can also be included.

CONCLUSION

I would like to point out some of the main fundamental problems that keep soil survey from better achieving its objectives.

1. We need an improved soil classification as a basis for the map legends, especially for the small-scale general soil maps.

2. For medium-scale soil maps we have to work on a better use of the geomorphological soil characteristics of the landscapes for the definition of the soil complex units.

3. For detailed soil maps at the large scale level we have to give more regular definition of the soil series and their phases, to get an easier interpretation for land utilization.

4. For agricultural use interpretation we need a more precise study of the relations between soil properties -- mostly physical properties and the yields of main crops of various ecological zones.

5. For general land use, we need to work on the most important soil conditions for every type of non-agricultural use.

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COMMENTS ON INTERPRETATION POTENTIALS IN RELATION TO SOIL SURVEY ORDERS

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The value of soil surveys as resource inventories depends on what interpretations can be made from the soil maps and supporting documents.

In my discussion I shall refer to the recent classification of orders (classes) of soil surveys developed by the U. S. National Cooperative Soil Survey (Chapter 2 of the new draft of the *Soil Survey Manual*, revision dated 4-75). These orders, of which there are five, are unavoidably broad and each order encompasses a rather wide range in kinds and intensities of surveys. Yet, this classification is the best we have, at least in the United States. It is a big improvement over what we have had before.

ORDER 1

It is rather obvious that the greatest number of potential interpretations and the highest reliability of interpretations reside with soil surveys of order 1. This is the order with the largest map scales and therefore is potentially the most precise geographically. In this order, the soils are classified according to phases of series -- the most precise classes in the U. S. soil survey system.

Of all the categories in the U. S. *Soil Taxonomy* , (U. S. D. A., SCS, 1975) the soil series names connote the most information and have the narrowest ranges in soil properties. Nevertheless, at the level of soil survey order 1, most soil series permit ranges too wide in some characteristics for the objectives for which order 1 soil surveys are made. To overcome this shortcoming, liberal use is made of soil phasing -- subdividing the soil series for purely pragmatic purposes -- so as to attain the specificity needed to meet the objectives.

In the United States, not many soil surveys qualify as order 1; most of them are order 2. Order 1 soil surveys are made for purposes that require appraisal of soil resources as small as experimental plots and building sites.

ORDER 2

Soil surveys of order 2 portray the soil geography on maps with scales between 1:12,000 and 1:31,680. In the United States the most common map scale today is 1:20,000 (3.17 inches to the mile) with 1:15,840 (4 inches to the mile) ranking second. In

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the spectrum of soil map scales from the largest to the smallest, these scales are considered large. They permit areas as small as 1.0 to 1.6 hectares to be shown on maps. They permit more than one kind of soil to be shown on most farmers' fields. The scales are large enough to permit reorganization of field layouts on most farms so as to adjust soil use and management to kinds of soils.

Let us look at the soil survey of Lexington County, South Carolina (Lawrence et al., 1976), a modern survey of order 2. The soil map is at the scale of 1:20,000. Most of the soil map units are consociations of phases of soil series. Most of the phases are texture and slope phases, indicating that the soil series names connote the other information needed for the objectives of this survey. This survey shows three consociations of the Cecil series. All carry the texture designation of fine sandy loam; but the three consociations differ in slope, and these differences in slope are highly relevant to the use and management of Cecil soils in Lexington County.

The soil survey of this county carries ratings of the soils for 25 kinds of uses covering the principal kinds of crops grown there, an important pasture grass, elements of wildlife habitat, certain engineering uses, and land uses relevant to town and country planning. In addition, it points out key soil features relevant to seven engineering soil uses for which ratings are not given, and it also classifies every soil in the U. S. land capability classification system (Klingebiel and Montgomery, 1961). The interpretation potential, as demonstrated by the soil survey of Lexington County, obviously is high, and it provides a great deal of information about the soil resources of that county.

If the soil survey of Lexington County had been order 1 rather than order 2, how much more resource information would have been provided? There probably would have been some refinement in phase designations. The main gain, however, would have been in greater geographic precision of the delineations and greater purity of the map units. Some delineations smaller than 1 hectare may have been shown.

ORDERS 3 - 5

If the soil survey of Lexington County had been a 3rd order survey, how much information would have been sacrificed? There probably would have been fewer consociations and more associations. The same array of interpretive ratings probably would have been made, but some geographic precision about areas to which the interpretive ratings apply would have been sacrificed. The survey nevertheless would have had a high utilitarian value.

Let us now skip to a 5th order soil survey. In fact, this particular survey probably would be beyond the upper limit of a 5th order survey if it had an upper limit. I am referring to

a soil map made by the Brazilians for the vast interior of Brazil (Ministério da Agricultura, 1966). The scale is 1:5,000,000 and hence the smallest delineation is about 100,000 hectares, which is equal to the size of some of the smaller counties in the United States. The Brazilians qualify this map as being both schematic and a first approximation to guard themselves against users putting too much confidence in it.

Nevertheless, this map is highly informative. By making liberal and skillful use of phases, the Brazilians have a map, even at this small scale, good enough to serve as a base for technical land classification maps. They have made three, all at the scale of 1:5,000,000, showing the general suitability of the soils for the production of annual cultivated crops and perennial tree crops under assumptions of three broad management systems. One map portrays the soil suitability assuming "primitive" management, another "semi-developed, without irrigation," and the third, "developed, without irrigation."

This Brazilian experience demonstrates that soil maps at small scales can be informative and useful if the maps are well designed. Even though no more than general interpretations are possible, such interpretations nevertheless are useful in agricultural planning for large regions.

TERMINOLOGY

We have a problem with terms for expressing interpretive ratings. In the United States, we express nearly all ratings in qualitative terms: for suitabilities -- good, fair, poor, and unsuited; for limitations -- slight, moderate, severe, and very severe. We have found that our soil survey users find a 3-class or 4-class rating system adequate for their purposes, and they probably would look askance at a 7- or 8-class rating system.

We do not have, at least not yet, a hierarchic set of rating terms. To have such a set would be useful. For the small-scale soil maps we depend on admonishing the users of the fact that exceptions to a rating, or ratings, given for the soils within a delineation is to be expected; and we hope that users will exercise appropriate caution.

LIFE OF INTERPRETATIONS

For how long are interpretations valid? All or nearly all interpretations are ephermeral; but the length of time different interpretations remain valid varies greatly. In the United States, perhaps the first interpretation to become somewhat obsolete was the only one that is routinely expressed quantitatively, i.e., the yield estimates of wheat, corn and other crops. As new varieties are introduced and better ways of managing the soils evolve, the yields tend to increase.

Also, as new management systems evolve, some soils now considered unsuitable for cropping may become suitable. Let us look again at the soil survey of Lexington County, South Carolina. In it there is a soil suitability scale of 1 to 4 for cropping. Class 1 is the best; 4 is the poorest. Cecil fine sandy loam, 10 to 15 percent slope, is rated as 4. Under the prevailing soil management systems used today in Lexington County, this rating of 4 means that this strongly sloping phase of Cecil soil should not be used for cropping, and estimates of corn and wheat yields are not provided. If and when the no-till management system becomes common in Lexington County, will this strongly sloping Cecil soil command a better rating than 4? Probably it will.

The fact that soil survey interpretations eventually become obsolete, however, is not particularly serious for two reasons. One is that most interpretations are valid for at least several years, many of them for many years. The second reason is that if they are based on a good soil survey in the first place, old interpretations can be updated and new ones made without making a new soil survey, although some revisions in the mapping may be necessary. We might add a third reason, which is hidden in the vagueness of the rating terms. Whether a soil is rated good, fair or poor for a given use depends at least in part on judgment interpretations for which the rating criteria are as quantitative as we can write them. If the advancement in soil management applies about equally to all soils, a soil rated as moderately suitable yesterday may still rate the same tomorrow because all the rating terms will have been upgraded and the relative position of the soil in question probably remains the same.

RELIABILITY

There are two aspects to reliability of interpretations. One pertains to the soundness of the soil map itself and the supporting documents. Obviously, geographically reliable interpretations are not possible if the map itself is inaccurate or lacks sufficient documentation.

The second aspect has to do with knowledge of the use for which an interpretation is made. In order to evaluate a soil for the production of wheat, for example, the soil scientist needs to know what the soil requirements of wheat are, and what the farming system is under which wheat is to be grown. To evaluate a soil for septic tank filter fields, the soil scientist needs to know which soil characteristics limit such use and which do not. In the United States, help from agronomists, foresters, engineers, and others has been necessary to set forth the soil criteria for the interpretations that are now made, and usually the associated scientists help soil scientists make the interpretations too.

We might mention a third aspect, and that is the degree of specificity with which an interpretation is expressed. If it is expressed in broad, non-specific terms, the reliability may be said to be high although the soil map may be less useful than it would have been if the interpretation had been expressed with greater specificity.

EFFECTIVENESS

The effectiveness of a soil survey depends on how much it is used as a source of information for making decisions about soil use and management. Several factors relate to effectiveness; I shall deal with only one.

In my experience, maps that are difficult to use simply are not used. Not only must delineations and symbols be legible, the legend must be well organized too, especially if the number of map units is large. The organization should be such that any map user can quickly and easily find in the legend the symbol in which he is interested. This usually means that the symbols should be alphabetically or numerically arranged. Anyone who has used the soil survey of Puerto Rico published in 1942 or the soil association map of the United States published in the 1938 USDA Yearbook of Agriculture will know what I'm talking about; the symbols on these maps are not arranged alphabetically. As elementary and obvious as this legend-organization rule is, I am still surprised to find many maps on which it is not followed.

CONCLUSION

As a generalization, we inevitably sacrifice information and geographic precision as we go from 1st order soil surveys to the 5th. How much we sacrifice depends on the complexity of the soil pattern in nature and on the skill of the scientists making the soil surveys and the interpretations. How damaging these incremental losses are, depends on the purpose or purposes for which the soil surveys are made in the first place.

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THE OBJECTIVES OF SOIL SURVEYS OF VARIOUS INTENSITIES

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No attempt is made here to review the extensive literature related to this subject nor is the treatment intended to be comprehensive. The viewpoint is essentially personal and, hopefully, provocative.

In general, it may be stated that the objective of soil survey is to obtain a better understanding of spatial changes in the characteristics of the soil continuum so that soils may be used more efficiently for the benefit of mankind. The information obtained by soil surveys contributes to comparisons of environmental situations so that experience may be exchanged. It is also used directly as a guide in planning land use for agriculture, and increasingly, for engineering purposes.

Soil survey data has long been regarded as providing a foundation on which land development can be constructed. This paper ends by suggesting that it is more realistic to see soil data as a part of the physical ceiling beyond which present technology does not allow us to pursue objectives generated by social, economic, and political pressures.

TERMINOLOGY

Experience suggests that discussion of different "kinds" or "orders" of soil survey is often hampered by misunderstanding arising from different interpretations of the terminology.

Table 1 presents a system of terminology developed within FAO specifically to assist international discussion of this topic (FAO, 1969). Table 2 presents additional information that places this terminology in clearer perspective.

It will be noted that the terminology is based on intensity of observation. Terms such as "detailed," "semi-detailed," and "reconnaissance" are avoided because they carry a wide variety of connotations. Furthermore, the detail and to a large extent the scale of soil survey maps are matters of convenience within constraints of accuracy determined by the intensity of observation.

A terminology based on observation intensity is equally appropriate whether the soil survey data is presented in mapped

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Table 1. Terminology of soil survey intensity in relation to final mapping scale and kind of mapping unit (based on FAO, 1969).

Kind of Survey	Range of Scales	Kind of Mapping Unit
Very High Intensity	Larger than 1:10,000	Phases of soil series; soil series; occasionally soil complexes
High Intensity	1:10,000 to 1:25,000	Phases of soil series; soil complexes
Medium Intensity	1:25,000 to 1:100,000	Associations of soil series; physiographic units (enclosing identified soil series)
Low Intensity	1:100,000 to 1:250,000	Associations of Great Soil Groups; occasionally individual Great Groups; phases of Great Groups. Alternatively, land units of various kinds enclosing identified Great Soil Groups)
Exploratory	1:250,000 to 1:1,000,000	Land units of various kinds (preferably enclosing identified Great Soil Groups)
Syntheses	Smaller than 1:1,000,000	Great Soil Groups and phases of Great Groups (having essentially taxonomic significance)

Table 2. Additional information on soil surveys of various scales (FAO, personal communication).

Kinds of Survey	Scale	Area Represented by 1 cm^2 of map	Density of Observations† (0.5 obs./cm^2 of map)	Approx. Average Rate of Progress‡ (per 2-day month)	Accuracy of Boundaries
Very High Intensity	1:5,000	0.25 ha	1/0.5 ha	500 ha	Position of all boundaries checked throughout length on the ground
	1:10,000	1.0 ha	1/2 ha	800 ha	
High Intensity	1:20,000	4.0 ha	1/8 ha	1,250 ha	Position of almost all boundaries checked throughout length on the ground
	1:25,000	6.25 ha	1/12.5 ha	1,500 ha	
Medium Intensity	1:50,000	25.0 ha	1/50 ha	75 km^2	Some boundary checking--most inferred
Low Intensity	1:100,000	1 km^2	1/2 km^2	200 km^2	Almost all boundaries inferred

†Density of observations: figures represent the density of all soil observations averaged over the entire area of the map (acceptable density usually ranges between 0.25 and 1.0 observations/cm^2 of map on this basis).

‡Rate of progress: figures given represent an approximate average from the wide range of progress rates experienced in actual surveys.

or tabular form.

Such terminology is not inherently meaningful, however, as a guide to the objectives which a soil survey will serve. Clearly, the exact density of observation required for a certain interpretation will vary from one environment to another particularly in relation to the complexity and degree of contrast of the soil pattern. There is also wide variety in the possible nature of observations, which can include:

1. Observations to characterize soil units, involving detailed study of morphology and sampling for physical and chemical examination (usually soil pits);

2. Routine observations to establish kinds of soils and to check on homogeneity within identified units (usually auger borings);

3. Rapid bores to check boundary locations; and

4. Special observations including deep boring in irrigation/drainage areas, infiltration tests, conductivity measurements, neutron probing, etc.

Thus, the specifications of a soil survey should describe the nature as well as the density of observations.

BASIC RELATIONSHIPS BETWEEN OBJECTIVES/INTENSITY/SCALE IN SOIL SURVEY

The practical applications of soil surveys of various intensities have been described in many publications and, in general terms, are well known. A detailed general account is given by Stobbs (1970) and Bie and Beckett (1970) have reviewed soil survey practice in many countries.

In the context of developing countries the purposes of the kinds of survey distinguished in Table 2 can be summarized as follows:

Syntheses. Final mapping scale usually less than 1:1 million; promoting public awareness (teaching, conservation campaigns, etc.); some direct practical value at global and international levels of planning.

Exploratory studies. Final mapping scales usually between 1:1 million and 1:250,000 but occasionally much larger; preliminary identification of areas having high development potential or serious development problems; occasionally for testing soil classifications.

Low intensity soil survey. Final mapping scales usually between 1:250,000 and 1:100,000; national level solutions to the problems "WHAT TO DO" and "WHERE ELSE TO DO IT" in agricultural

development; assessment of possibilities and priorities in use of limited manpower and facilities.

Medium intensity soil survey. Final mapping scale usually about 1:50,000; regional solutions to the question "HOW?" in agricultural development; adequate for implementation of less intensive forms of land use (e.g., some forms of forestry and grazing) and for planning broad agriculture/urban zonation.

High intensity soil survey. Final mapping scales usually between 1:25,000 and 1:10,000; precise local solutions to the questions "WHERE" and "HOW" in the context of rain-fed arable development; may be an adequate basis for implementing irrigation and even for some engineering decisions in uncomplicated situations.

Very high intensity soil survey. Final mapping scales less than 1:10,000; suitable as a basis for planning implementation of sophisticated agricultural schemes, including irrigation, and to assist engineering decisions in areas where soil pattern is complex and soil differences significant.

An excess of observations is not only needlessly expensive but it also complicates data storage and analysis. There is a real danger that superfluous data will obscure information of special interpretative value. This is perhaps especially true of excessively detailed descriptions of soil morphology and squirrel-like accumulations of soil chemical data. Whether the computer can lead us back out of the maze which our enthusiasm sometimes creates remains unproven.

To the author's knowledge all aid agencies recommend to less developed countries that they should undertake soil studies in a systematic sequence of surveys of increasing intensity. The logic of this approach, as a means of ensuring that limited specialized manpower and facilities are concentrated in the most promising areas, requires no elaboration. It is interesting to note, however, how few of the "developed" countries have adopted this approach systematically themselves. Several are suffering the consequences; having mapped substantial areas in detail they find themselves constipated with data, unable to see the panorama for the pedons.

If low intensity studies show that the pattern of soils is complex and that the soil differences are significant in relation to the likely development objectives then the need for soil surveys of high intensity is established. How intensive should they be?

The answer to this question is inextricably related to the choice of final mapping scale, for a mapped presentation of data relevant to detailed planning problems is nearly always required. Many extraneous factors such as the scale of available air photography or of base maps or the mere availability of cartographic facilities often have a crucial bearing on

the choice of mapping scale but, in an ideal world, this author thinks that two factors deserve special consideration: (1) the required precision of soil boundary placement, and (2) the likely minimum area of planning interest.

The first factor reflects the relationship between soil characteristics and development objectives. In a prospective irrigation scheme, for example, knowledge of the distribution of marked contrast in the hydraulic characteristics of soils needs to be precise if it is to assist the design of canals and drains. In other contexts, the precise position of soil changes will usually be much less significant. It is worth noting that the value of precise mapping of soil boundaries is qualified by the likely accuracy with which these boundaries will be relocated on the ground when the map is put to use.

The minimum area of planning interest can be defined as the area within which practical considerations of management dictate that farming practice (or, more broadly, *land use*) must be uniform. In practical terms, which allow for some exceptions, this is the smallest area of land that can be usefully differentiated on an interpretative soil map. It should not occupy less than 1 to 2 square centimeters of the map, if the map is to be used conveniently. This means, for example, that a planner interested in soil units as small as one hectare requires maps of 1:10,000 scale or larger.

Not all of the information needed to determine the minimum area of planning interest will be available in advance of a soil survey, but an educated guess can usually be made in consultation with agricultural economists and other specialists. A great many physical, social, and even political factors of the environment are involved in this assessment.

A CLOSER LOOK AT THE OBJECTIVES OF SOIL SURVEY

Beckett (1971) in a paper on the cost-effectiveness of soil survey defined the aim of a soil map and its memoir as:

> "to equip the user to make more precise or more accurate statements about the soil conditions at any site of interest, or to make statements with less expense or trouble, than would have been possible without such map and memoir."

As Beckett and his colleagues have demonstrated in a series of valuable papers, a definition of soil survey objectives in terms of discrete statements provides a basis for quantitative comparison of the effectiveness of different methods and intensities of soil survey. These papers have emphasized the assessment of purity of the mapped soil unit as a quantitative measure of the accuracy and reliability with which statements about the soil and its properties/potential can be made (see Bie and Ulph,

1972, and its attached list of references). No less important, however, than the reliability of a statement is its practical significance, particularly in relation to other statements that might need to be made about site environment. The range of possible significance of different statements about soils is very great especially in the context of surveys of differing intensity.

A major difficulty for users of soil information is to separate the statements that are significant to their problem from those that are not. The solution of this difficulty should be amongst the objectives of soil survey.

The extent to which soil conditions are likely to influence agricultural development planning depends on the level of generalization at which decisions have to be made. Normally at national level (low intensity studies) the controlling environmental influences on decision making are firstly climate and secondly, landform. In medium intensity studies (say 1:50,000 mapping) landform often remains predominant and even in very localized investigations surface slope, rather than internal soil characteristics, may largely determine the distribution of agricultural possibilities. The boundaries on soil maps, especially small scale soil maps, often represent a synthesis of detectable information on climate, landform, and vegetation as well as actual observed data on soils. In labelling such maps "soil maps" the surveyor should consider his objectives carefully to ensure that he is not chauvinistically obscuring the most directly valuable information.

From the late fifties onward soil surveyors have grown increasingly conscious that their work should serve immediate practical objectives as well as contribute to basic scientific knowledge. They recognized that amongst other things this called for improved communication with potential users of soil maps and memoirs and the surveyors devised ways of synthesizing their statements about soils in terms of land capability and suitability classifications.

A TREND TOWARDS MORE DYNAMIC LAND CLASSIFICATION?

In the seventies growing recognition of the urgency of development needs in the Third World seems to have outpaced growth in development activities. By creating a demand (sometimes unbalanced) for action rather than further studies, this situation has placed an emphasis on immediate practical objectives that amounts, in some countries, to disillusion with the long-term soil survey objectives of the past.

Concurrently, development attention has focused perforce on the agriculturally marginal areas of the world. Economic production in these areas often depends upon effecting change in the land resources themselves. Frequently it is change in

the fertility, salinity, drainage, or droughtiness of the soils that is feasible. Thus, the capacity of a soil to be changed becomes a major consideration of soil survey interpretation; indeed the main focus changes from the static and the long term to the dynamic and the short term. Hopefully, soil surveys can be adjusted to meet both short- and long-term objectives, for soil surveying is too expensive to be repeated at short intervals.

Figures 1 and 2 simulate dynamic and static approaches to land classification, respectively. In Figure 1 feasible land use alternatives (shown by asterisks) lie within a "field" determined by three main constraints: physical constraints (or land qualities), socio-economic constraints, and socio-political aspirations (the desires, or objectives of the people).

None of the constraining corners of the "field" is fixed; all can be changed. As the arrow simulates, investigation starts by establishing the desired objectives which are examined in relation to physical constraints of the land, including those of the soil. The physical constraints can be changed, however, by inputs that involve a change in the socio-economic constraints. The path of the investigation, therefore, curves in the socio-economic direction (in practice it would proceed through a series of zig-zags). To establish an acceptable compromise (a feasible alternative of land use) the originally desired objective may also have to be modified. This anticipation of change is the essence of the dynamic approach.

The principles of a dynamic approach to land classification have been outlined in the FAO *Framework for Land Evaluation* (FAO, 1976) and are presently being tested in various parts of the world.

In contrast, Figure 2 simulates the static approach typified by the Land Capability Classification of the U. S. Soil Conservation Service (Klingebiel and Montgomery, 1961) and its imitators. Here the corners of the investigative field are fixed. The socio-economic constraints are frozen by assumption. Similarly, those aspects of the total reality of land that are investigated (mainly soil characteristics and climate) are considered temporarily immutable. The investigation examines the chosen land characteristics in the light of various assumptions and proceeds directly to the recommendations - an equally fixed point that substitutes for the objectives in Figure 1.

A dynamic view of land appraisal problems calls for considerable change in the objectives of soil survey interpretation. In the first place soil survey will be asked to provide only a contribution to what is essentially a multidisciplinary study. Elements of information will be needed from a range of disciplines to build up the overall appraisal. The more these elements are discrete and independent the more easily they can be rearranged as the terms of reference of the appraisal change. Land capability classes based on soil survey are altogether too complex to serve this purpose.

Figure 1

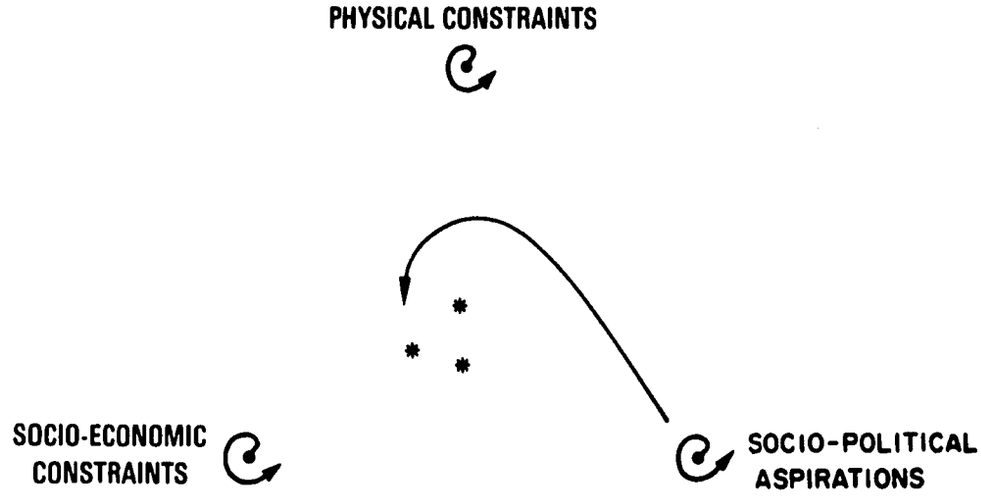
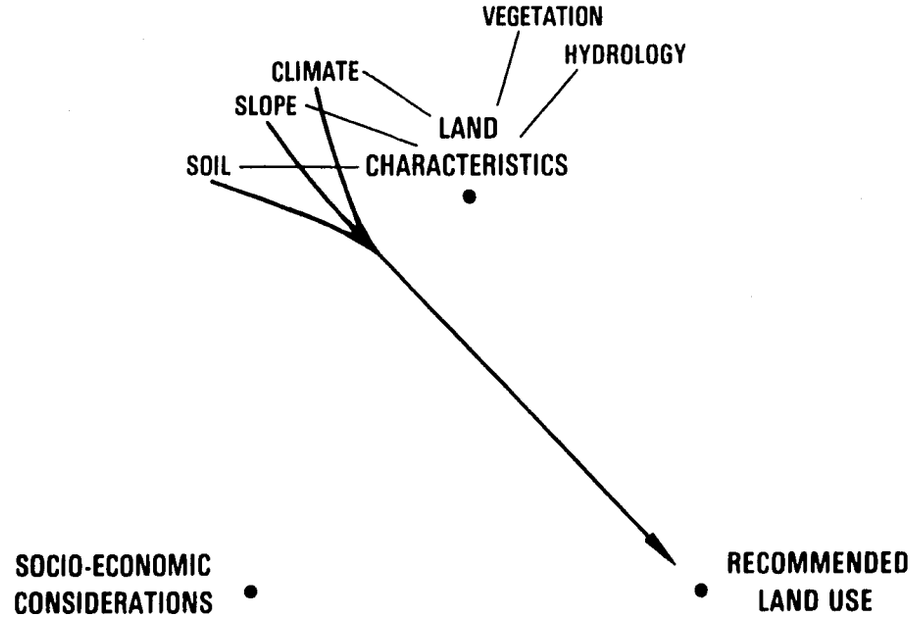


Figure 2



Secondly, instead of concentrating on solving the question "WHAT TO DO?" in terms of choice of crops or forms of land use, which used to be the main preoccupation of soil surveys in developing countries, attention will be focused more and more on "HOW?" to achieve an aim that is determined largely by human interests, perhaps despite the physical environment. Understanding of soil has special importance in this context for of all the many aspects of land, soil is the most amenable to change by man, for better or for worse.

By changing the soil through labour and economic inputs new uses may be made possible or the level of production from existing uses may be raised. Above a certain level improvement will no longer be economically feasible. This is the ceiling, adjustable with time, beyond which it will usually be pointless to proceed. Contributions to a knowledge of these ceilings and of the means by which they may be approached for a range of relevant land uses can be regarded as the main short-term objective of soil survey. The long-term objective, as always, is knowledge itself.

Presented 4/4/77.

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SESSION II

Monday afternoon, April 4, 1977

EVALUATION OF SOIL SURVEYS AND MAPS

Chairman: A. C. Orvedal

Speakers

T. R. Forbes	-	Soil Map Parameters and Classification (Authors: H. Eswaran, T. R. Forbes, and M. C. Laker)
R. Webster	-	Soil Survey: Its Quality and Effectiveness
B. F. Hajek	-	Evaluation of Map Unit Composition by the Random Transect Method

SOIL MAP PARAMETERS AND CLASSIFICATION

H. Eswaran, T. R. Forbes, and M. C. Laker[1]

The concept of soil map evaluation implies to most people an assessment of (1) the accuracy and thoroughness with which different soils areas are indicated, and (2) how useful the map is for planning and decision-making purposes. However, many users of soil maps may not be able to check the accuracy of the map (ground truth). They may be quite familiar with other physical attributes of the area in question such as the climate, geology, relief, etc., but not necessarily familiar with the distribution of soils of the area. Such a user may gain much information simply by examining the "information content" of a soil map. By "information content" is meant the relationships found in the number, size, shape, frequency, and pattern of soil areas or delineations outlined on a soil map; soil variability; and map legend characteristics.

This section discusses measures which have been developed to appraise the characteristics of the soil map itself. Such attributes as the number, size, shape, and pattern of soil areas outlined on soil maps are dealt with. These affect legibility and are indicators of the amount of detail mappers have shown in relation to map scale. They do not pertain directly to the accuracy of the information presented. Several concepts have been developed concerning the attributes of delineations on maps and these will be set forth here. These concepts of map attributes form the basis of a methodology of map evaluation and map classification.

CHARACTERISTICS USED FOR SOIL MAP EVALUATION AND CLASSIFICATION

Map Legibility

Legibility refers to the ease with which a map user can read the information recorded on a soil map. A legible map presents information in a direct, clear, concise, and perhaps pleasing or artistic manner. Several factors influence the legibility or readability of a map:

1. the number of outlined soil areas, called delineations, per unit area of the map (i.e. the sizes of delineations).

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2. the choice of colors or patterns to represent delineations.

3. ground control (cultural and natural features shown to allow readers to locate soil areas on the ground) or amount of non-soils features (vegetation or land use) included in the map.

4. quality of map presentation.

Too many delineations crowded into a small area make a map illegible or difficult to use. Delineations which are too small to be easily identified detract from legibility.

In colored maps, choice of colors is critical. The "Scottish-plaid" maps, where cross-hatching with different colors is employed, are unsightly and may be confusing. Colors which are too dark may obliterate a lot of ground control detail or important non-soil features.

Indications of ground control features are essential to locate soil areas. An insufficient amount of ground control may make a map unusable. A map crammed with ground control and overloaded with non-soil information obscures soil information.

Finally, legibility is also a function of the printing quality, i.e. quality of the paper, quality of the print, lay-out, and many other factors which make for good, clear graphic representation.

Study of the factors affecting legibility led to the development of a number of measures which proved to be useful in the description and evaluation of a large and varied sample of soil maps. They should be useful for evaluation of most soil maps. These are discussed and, where appropriate, examples are given.

Minimum-Size Delineation

The "minimum-size delineation" is a term found in the existing literature on soil maps (USDA, 1975). The minimum-size delineation appears to be equivalent to Vink's (1963) "basic mapping unit." Vink described it as "the smallest area that still can be indicated on a map" (Vink, 1963). It might be helpful to add to Vink's definition "the smallest area that still can be *legibly* indicated on a map." In this respect the minimum-size delineation is purely a cartographic parameter.

According to the USDA (1977) and Smyth (1970) the legibility of a map decreases greatly if a large number of map symbols must be placed outside small delineations and keyed into them by arrows. In this regard a minimum-size delineation can be defined as the smallest delineation in which a simple map symbol (consisting of no more than two or three digits) can still be

printed legibly. In this regard the shape of a delineation is important, i.e. a long, thin delineation must be relatively large, as compared to a round or square delineation, before it is possible to print a symbol in it. The criterion of being able to print a simple map symbol in a delineation requires a larger minimum-size delineation than the criterion of simply being able to demarcate a soil boundary.

Obviously the smallest legible delineation is, within certain size limits, quite an arbitrary or subjective concept. The minimum-size delineation then has the following attributes:

1. It is the smallest delineation inside which a simple map unit symbol can be printed legibly, or

2. It is the smallest area which can be easily discerned by a user of a map, and

3. It is actually determined by which one of (1) or (2) is the larger one.

The minimum-size delineation is a "constant" for the determination of a suitable published scale and also is a constant for the comparison of the other map parameters which are discussed henceforth. For purposes of uniformity it was decided to assign an arbitrary value of 0.4 cm^2 for the area of the minimum-size delineation. This area seems to fall in the range of areas which for the most people delimit the boundary of legibility of the most frequently occurring smallest areas on soil maps. The USDA (1975) considers the minimum-size delineation to have an area of 1/4 x 1/4 inch or 1/16 $inch^2$ or 0.403 cm^2. Vink (1963) indicates his "basic mapping unit" by 0.5 cm x 0.5 cm or 0.25 cm^2. Figure 1 illustrates minimum-size delineations which, when the original scale of the map is reduced, become illegible and inaccurate.

The actual land area which is equivalent to 0.4 cm^2 on a map is a function of the map scale. The values for a series of map scales are given in Table 1.

Least-size Delineation

On examination of many soil maps one will often find that there are some delineations smaller than 0.4 cm^2. These have been named least-size delineations and are defined as the smallest areas which are actually delineated on a specific map by a soil surveyor. If only a few of these very small delineations are found on a map, then they do not decrease legibility of the entire map under examination.

The least-size delineation may be an indication of the amount of detail the surveyor attempted to include in parts of the map or may be an indication of the variability of the soils of the area or it may be just a purely incidental observation. The latter is especially true for small scale maps.

Figure 1. The arrow indicates a minimum-size delineation which becomes less legible as the original map (A) is successively reduced (B-D).

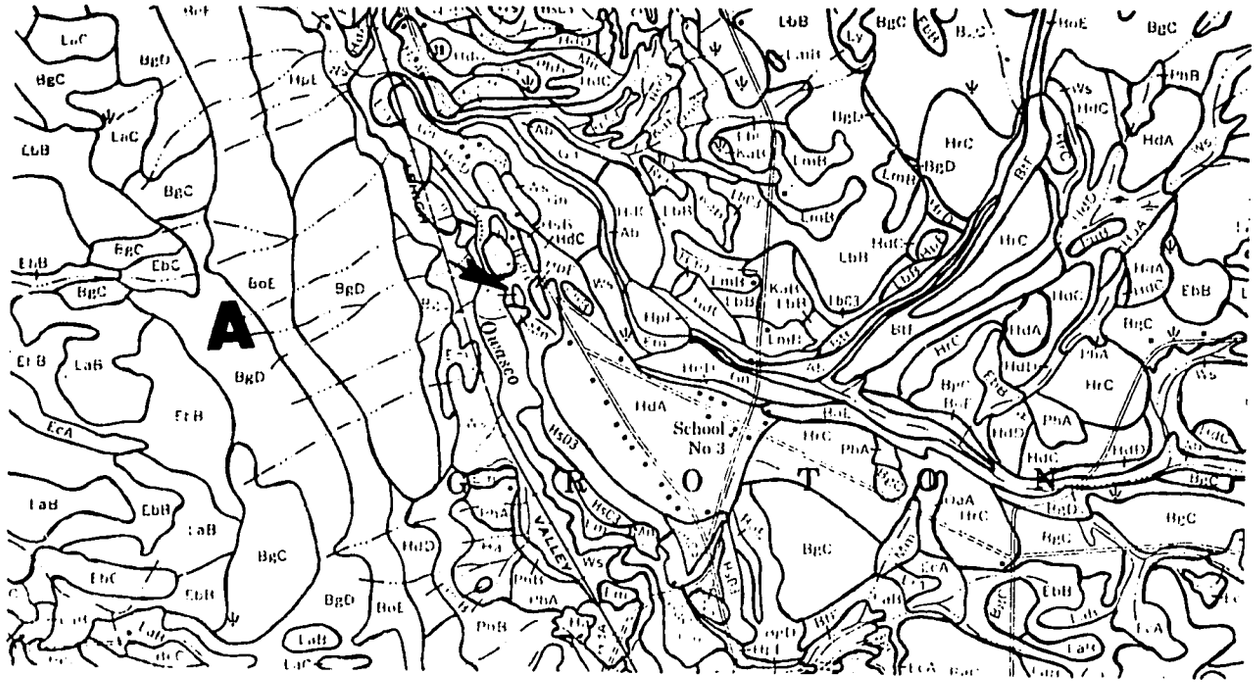
Table 1. Minimum-size delineation values on actual ground scale for a number of map scales (minimum-size delineations for all published maps being 0.4 cm^2)

Map Scale	Minimum-size delineations on ground scale (ha)
1:5,000,000	100,750
1:1,000,000	4,030
1: 500,000	1,008
1: 250,000	252
1: 200,000	161
1: 100,000	40.3
1: 50,000	10.1
1: 25,000	2.52
1: 20,000	1.61
1: 10,000	0.40

It was observed that least-size delineations are normally smaller than the theoretical minimum-size delineations, are usually oval in shape, and are usually found as small "islands" within larger delineations. Least-size delineations are particularly significant in large scale maps, since this would seem to imply highly contrasting small areas that are not just incidental observations. Figure 2 shows some examples of selected map areas with least-size delineations. Note that the areas do not meet the requirements of legibility as do the minimum-size delineations.

Average-Size Delineations

The size of delineations on a soil map is determined by the complexity of the soil pattern, the way in which mapping units are defined, and the map scale. The attributes of complexity of soil patterns can be assessed through soil contrast and variability. The efficiency of the surveyor and design of the legend will determine whether or not the necessary attributes of contrast and variability are sufficiently defined on the map by the delineations for the specified purpose(s). If then contrast and variability are optimally represented, the size of delineations should reflect these aspects and therefore this size of delineations is an important attribute of soil maps.



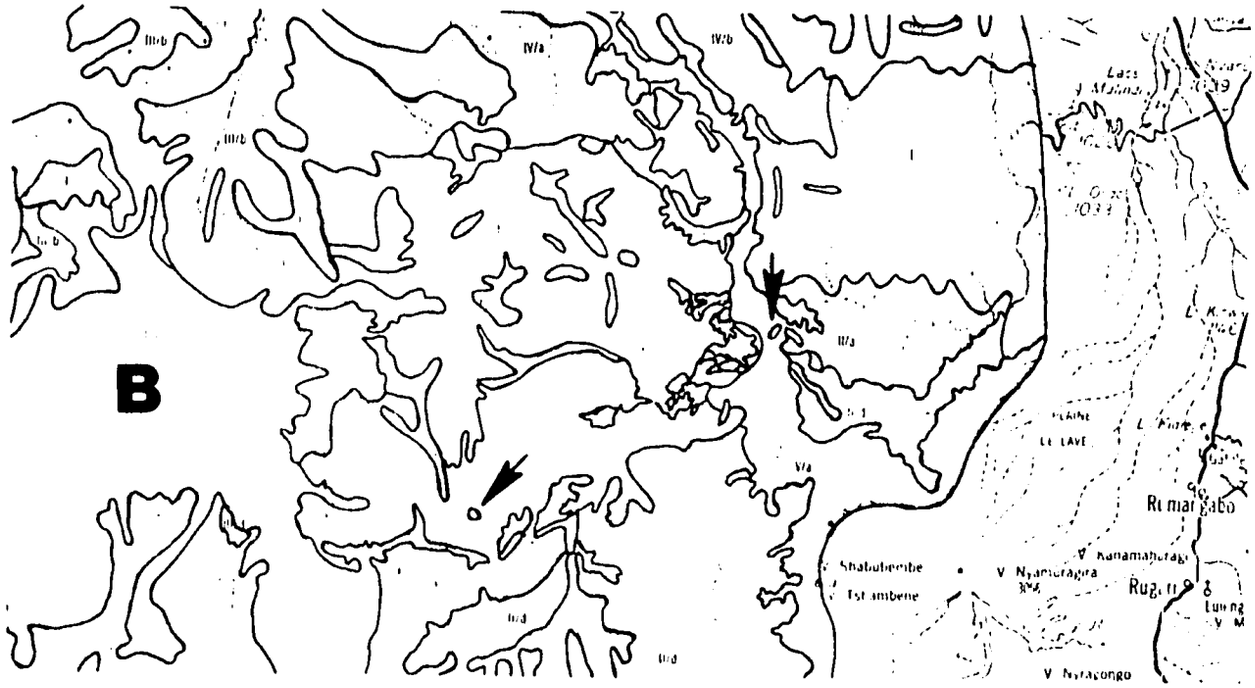


Figure 2. The arrows indicate least-size delineations on a large-scale map (A) and a small-scale map (B).

The average size of the delineations on a soil map is termed the "average-size delineation." The average-size delineation can be expressed in terms of the average number of delineations per unit area on the map. The average-size delineations can be converted to some appropriate unit (e.g., ha or km^2) on actual ground scale.

Mapping Intensity

Some parts of soil survey project areas may be mapped more intensively than others. As a result some parts of the soil map have more delineations per unit area than others (see Figure 3). The larger delineations of the less intensively surveyed area may correctly represent associations or higher levels of generalization. The more intensively surveyed areas may be represented by map units of lower taxonomic classes. The reasons for mapping at two or more intensities in different parts of a survey area include the following:

Objectives of the survey. For surveys with specific objectives the areas where the objectives are feasible (or are likely to be feasible) may be mapped at greater intensities, for example:

1. When the objective is to locate soils for wet-land padi, adjacent hilly areas may receive less attention.

2. When national laws prohibit cultivation above certain elevations, these areas may not be traversed at all.

Physical limitations, such as accessibility. Jungle and swamps are commonly not mapped at the same intensity as adjoining cleared areas, unless specific objectives require them and warrant the extra cost.

Soil heterogeneity. When all other factors are constant, map intensity is determined by the complexity of the soil patterns. Areas which are characterized by large homogeneous tracts of soil of low contrast and variability have a low map intensity. However, in this case it does not mean that the low intensity areas were mapped less accurately.

Nature of the legend. This should not affect intensity but there is a general tendency to have more subdivisions for soils with aquic soil moisture regimes or those formed over alluvium than for the well-drained upland soils.

Soil maps can be divided into those which have only one intensity over the whole map or are uniform (so-called mono-intensity maps) and those that reflect different intensities on different parts of the map (multi-intensity maps). These intensities are defined purely in terms of complexity of the map. They may or may not indicate different mapping intensities. There are different ways to determine whether a soil map is a mono- or multi-intensity map. The most common are:

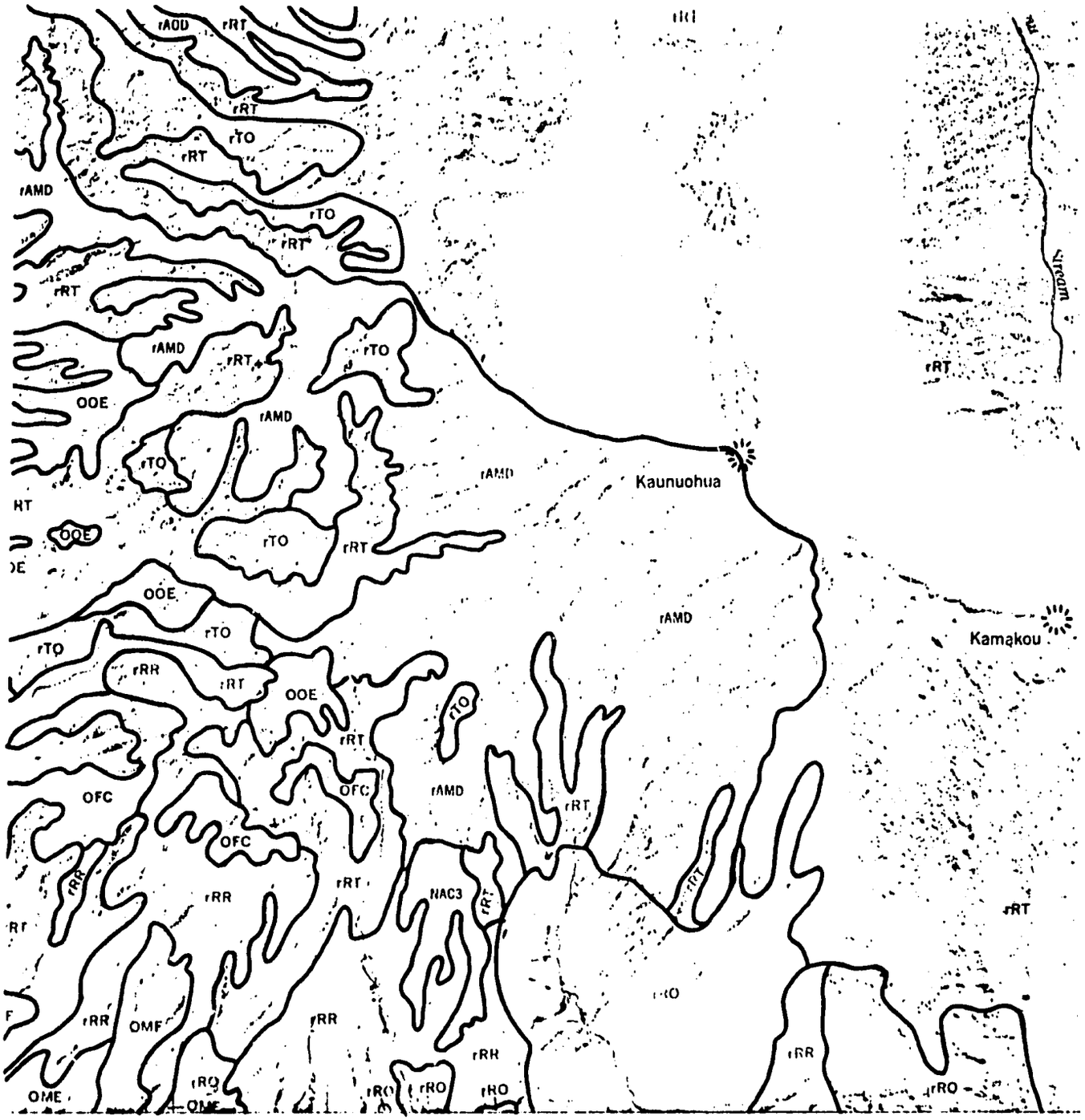


Figure 3. This map reproduction shows two adjacent land areas mapped at different intensities.

1. Indications in the accompanying soil survey report that different areas were mapped at different intensities.

2. *Visual estimation.* A map may be divided into two or more parts by visually estimating the mapping intensities.

3. *Stratified sampling.* This may be used to confirm visual observations and to define boundaries between areas of different intensities.

4. *Random sampling.* This may be used to confirm visual observations in a more general way. Boundaries are not as precise as those defined by stratified sampling or by circle counts. (See "Selection of a Method for Determination of Map Intensities of Soil Maps" by M. C. Laker, this volume.)

Map Texture and Map Texture Intensity

Map texture refers to the sizes and distribution of the delineations on a map as a whole or on parts of it, depending on whether it is a mono- or multi-intensity map. In multi-intensity maps, the map textures in the different intensities are described separately.

The maximum possible number of delineations per cm^2 is determined by cartographic limitations and is the reciprocal of the minimum-size delineation. Since the minimum-size delineation has been set at 0.4 cm^2, the maximum number of delineations is 2.5. The map texture intensity is defined as the ratio of the observed number of delineations per cm^2 (n) to 2.5.

$$\text{Map texture intensity} = \frac{n}{2.5}$$

$$\text{Since } n = \frac{1}{\text{average-size delineation}}$$

$$\text{and } 2.5 = \frac{1}{\text{minimum-size delineation}}$$

$$\text{therefore also map texture intensity} = \frac{\text{minimum-size delineation}}{\text{average-size delineation}}$$

The map texture intensity is an index of complexity or simplicity of the map, using the maximum number of delineations as a base. For comparison of portions of a map or of different maps, the map texture intensity is expressed in a percentage by multiplying by 100.

Both map texture and map texture intensity can be used as clues to suggest relative mapping intensities, although they may reflect differences in soil pattern in nature as well. They provide comparative data by means of which mapping intensities within the confines of a specific map scale can be compared.

This is of practical importance, as will be indicated. They also provide the basic data by means of which actual mapping intensities can be calculated.

Map Index of Maximum Reduction

A map becomes illegible if a large proportion of the delineations are very small. If most of the delineations are very large, then the map is of good cartographic quality and highly legible, but this does not mean that it is a "good" map.

The map index of maximum reduction is defined as the degree to which scale of a map can be reduced before the average-size delineations become smaller than the theoretical minimum-size delineations (which are taken as 0.4 cm^2). It is therefore postulated that the scale of a map can only be reduced until the average-size delineations of the reduced map become equal to the minimum-size delineations. The map index of maximum reduction is therefore defined as the square root of the ratio between the average-size delineation and minimum-size delineation of the actual published map.

$$\text{index of maximum reduction} = \sqrt{\frac{\text{average-size delineation}}{\text{minimum-size delineation}}}$$

Thus, map intensity can also be specified by the map index of maximum reduction where the map index of maximum reduction is inversely proportional to the square root of the map texture intensity.

In multi-intensity maps, the map index of maximum reduction, for purposes of classification, is determined by the portion which has the smallest average-size delineations, i.e. by the portion which has the finest texture. The map index of maximum reduction, however, could be determined for all portions of the map.

Minimum Scale of Reduction

The minimum scale of reduction is the smallest scale to which a map can be reduced before the sizes of average-size delineations become smaller than the minimum-size delineation limit. The minimum is the product of the actual published map scale and the map index of maximum reduction:

$$\text{minimum scale of reduction} = \text{actual map scale} \times \text{index of maximum reduction}$$

For example, suppose actual map scale = 50,000 (for a map scale of 1:50,000) and map index of maximum reduction = 2. Then minimum scale of reduction = 50,000 x 2, or 100,000.

The minimum scale of reduction does not indicate a useful map scale. If the average-size delineations are reduced to the

size of minimum-size delineations, it will be clearly seen that a large proportion of the delineations will be so small that the actual utility of a map at this reduced scale will be extremely low.

The map index of maximum reduction and minimum scale of reduction are parameters which could be used to evaluate the quality of a map. If the map index of maximum reduction is low, i.e. 1-2, the map or parts of the map are intensively mapped. On the other hand, if it is 10-20, the delineations are very large. This may indicate: (1) homogeneous soil units in nature, (2) improper scale definition in terms of legend (perhaps an example of this may be the use of soil associations at a scale larger than necessary), or (3) a poor survey. It also implies that the surveyor could have worked with a smaller scale.

Figure 4 relates the actual map scale and max index of maximum reduction to the minimum scale of reduction.

BOUNDARY REPRESENTATION, MAP SCALE, AND SIZES OF DELINEATIONS

To relate delineation boundaries, map scale, and delineation sizes, some background information must first be introduced.

The intensity of survey and map scale influence the reliability of boundary location. At large scales a large number of observations are required for boundary placement and the actual position of the boundary is theoretically more certain than at smaller scales. Also the amount of significant or critical ground control data that aids in the location of soil boundaries decreases rapidly as the scale of the base map decreases.

Arnold (personal communication) states: "The accuracy of map boundaries involves locational tolerances and the width of line relative to scale of map being evaluated. Because many soil boundaries are related to transitional or gradational sets of soil properties that are not easily recognized by external features, there is a zone of acceptable placement of such soil boundaries due to the judgment involved. The width of a pencil line or a standard pen represents different ground widths according to the scale of the map. For instance, a Koh-I-Noor No. 0 pen line is 0.016 inch and represents 34 ground feet at 1:24,000 and about 708 feet at 1:500,000 (Hord and Brooner, 1976)."

Line Thickness

The thickness of the lines which are used on the final map is important. Normally lines that are 0.3 mm or 0.4 mm wide are used, but lines as wide as 1.0 mm have been found, even on published maps. According to Arnold (personal communication), the National Map Accuracy Standard of the U.S. indicates that

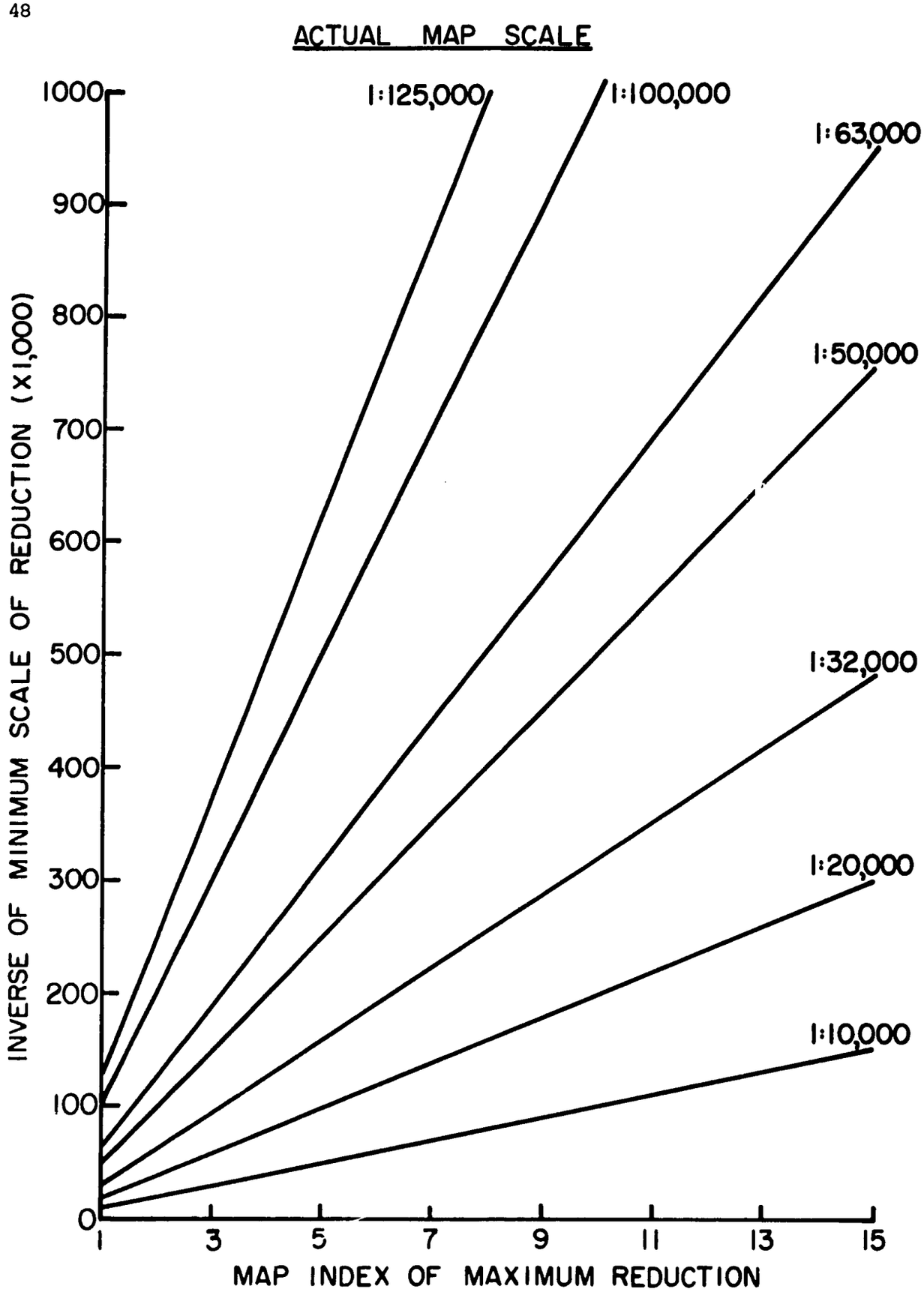


Figure 4. Relationships between actual map scale, map index of maximum reduction, and minimum scale of reduction.

for an accurate map at a scale of 1:20,000 or smaller, not more than 10% of well-defined points shall be in error by more than 1/50 inch (i.e. 0.02 inch or 0.5 mm).

The thickness of map delineation lines therefore can have an effect on the percentage error which the standard delineations, minimum-size and average-size discussed previously, contain. A factor to consider is the magnitude of boundary errors caused by the thickness of map delineation lines. As was indicated by Arnold (personal communication) a line of 0.4 mm represents a ground width of only about 212 meters on a scale of 1:500,000 or a width of about 10 meters on a scale of 1:24,000. The three meters or less which it represents at a scale of 1:6,000 may not at first appear to be significant.

Delineation Purity in Relation to Boundary Error

The magnitudes of these "small" errors relative to the sizes of delineations present a completely different picture, however. Suppose (hypothetically) that all delineations are circles. Suppose there are three delineations with sizes of (a) 0.4 cm^2, (b) 1.131 cm^2, and (c) 19.64 cm^2 respectively. Delineation (a) is the size of the defined minimum-size delineation. The reason for the choice of size (b) will be explained later. Size (c) represents the area of the circle which is used for the determination of the average-size delineations.

Suppose the radii of the circles are (1) either 0.3 mm too small or 0.3 mm too large, or (2) either 1 mm too small or 1 mm too large. The percentage errors for each of the three delineations for each of the two cases are summarized in Table 2, which clearly illustrates how the percentage error increases with decreasing delineation size. This increase is curvilinear, because of the quadratic relationship between area and radius (Figure 5).

Table 2. Magnitudes of error in sizes of delineations if the radii of delineations are in error by different degrees.

Correct Size of delineation (cm^2)	Percentage error in sizes of delineations	
	Radius in error by 0.3 mm	Radius in error by 1 mm
0.400	16.9	56.1
1.131	10.0	33.4
19.64	2.4	8.0

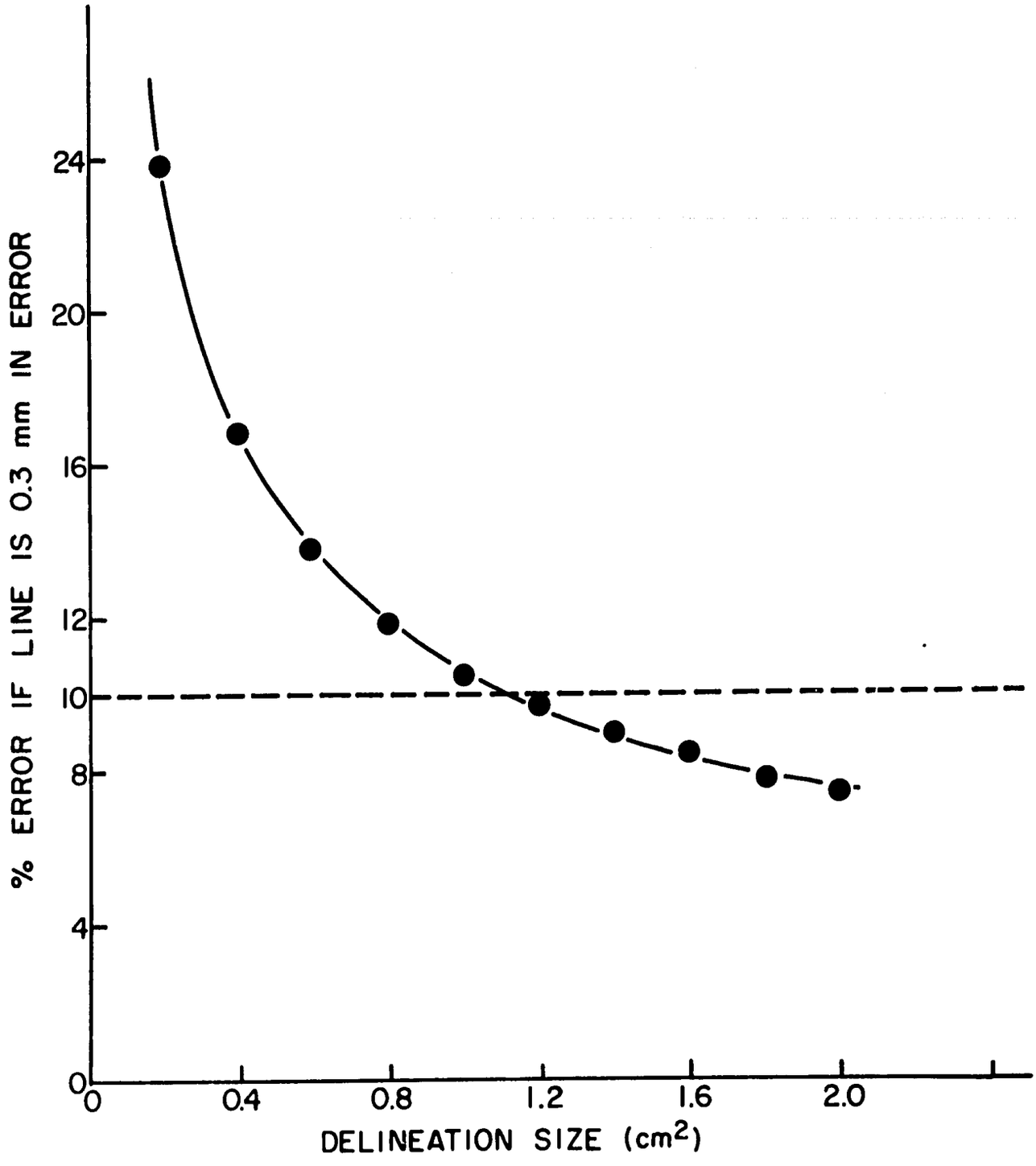


Figure 5. Percent error of delineation content as a function of delineation size.

For shapes other than true circles this relationship between linear error and error in area will follow the same quadratic type of pattern.

Secondly, the percentage error in delineation size increases linearly as the linear boundary placement error increases, for a specific delineation size. The rate of increase in error in delineation size with increasing boundary error is much larger for small delineations than for larger delineations (Figure 6). This means that relatively small increases in boundary error have much more serious consequences in the case of small delineations than in the case of larger delineations.

Useful Delineation Sizes

Overall there is a great degree of parallelism between the degree of boundary precision that is required for different levels of planning detail and the degree of boundary precision that can be attained at corresponding map scales. It may therefore be logical to have a constant, basic delineation size for each range of map scales that are encountered. These delineation sizes must be large enough so that errors due to incorrect boundary placement are small enough to be acceptable. The U.S.D.A. (1977) indicates that an absolute maximum of 10 percent of a limiting inclusion is the most that can be tolerated in a mapping unit of an ultra-detailed soil map.

One can then relate this criterion to boundary errors and their effect on percent limiting inclusions. If we accept that a boundary can be in error by 0.3 mm on a detailed soil map, then it is found that a delineation may not be smaller than 1.131 cm^2 to be in error by no more than 10 percent (Table 2). It can actually be expected that boundary errors are larger than this. This would require an even larger delineation to be acceptable. A round figure of 1.2 cm^2 can be used to indicate the minimum reliable delineation size. For a boundary error of 0.3 mm, a delineation size of 1.20 cm^2 not only approaches the critical acceptable level of 10 percent error, but also represents an important turning point on the curve (Figure 5) relating percentage error to delineation size. For delineation sizes above 1.20 cm^2 the decrease in error relative to increase in delineation size

$$\left(- \frac{\Delta E}{\Delta S} \right)$$

becomes low. In other words, gains in accuracy by having larger delineations become low above this value. Below this value drastic losses in reliability with decreasing delineation size is operative, however.

This delineation area is a cartographic property, much as the minimum-size delineation was, and is 1.2 cm^2 no matter what the actual map scale.

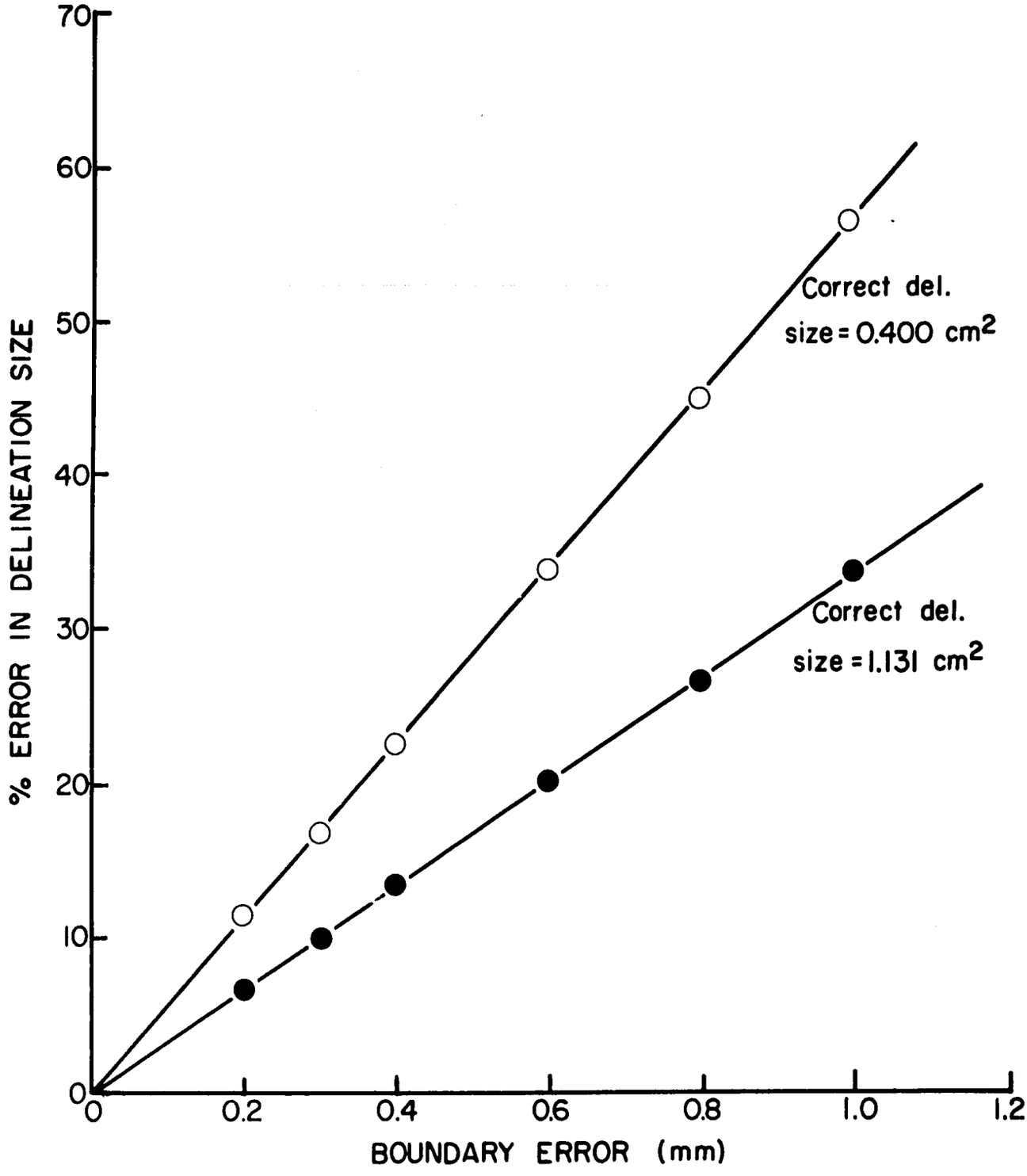


Figure 6. Percent error in delineation content as a function of boundary error.

A decision about map scale can then be made according to the following criteria:

1. For what purpose is the survey to be used?

2. With what degree of precision can boundaries normally be expected to be located on maps of the scale range which is normally used for that purpose?

3. What maximum percentage of delineation error is permissible?

4. What is the minimum-size delineation that will still have an acceptable small error at the degree of boundary precision which is expected?

5. At what map scale will the minimum area of interest to planners be equal to this minimum acceptable delineation size?

It is logical that for a map to be useful the average-size delineations should not be smaller than the minimum acceptable delineation size. Even if the average-size delineations are equal to the minimum acceptable delineation size the map will have too many small delineations to be useful for the originally intended purpose.

CLASSIFICATION OF MAPS BASED ON MAP CHARACTERISTICS

Several map characteristics may be used to classify maps. The most convenient of these is the actual scale of the map. Map scales are expected to give an indication of the possible uses of the map, the level of detail incorporated in it, and the kinds of interpretations that could be made. Unfortunately, map scales are not sufficiently informative apart from allowing a map user to convert map areas to land areas. Soil surveys differ in their philosophy, methodology, and manner of presentation of data and all these factors make it difficult to judge the quality of maps or to use the scale alone for classifying maps.

Density of Observations

Vink (1963), developing on an earlier suggestion of Buringh, introduced the concept of the "basic mapping unit." He suggested that each map should carry a square or rectangle representing an area of 0.25 cm^2 on the map. The square or rectangle represents at least one observation and if the number of observations varied, the size of the square or rectangle was changed proportionately. Steur (1961), Vink (1963), and Boulaine (1966) all believe that the density of observations provide a better measure of detail than map scale. It is partly for this reason that Vink (1963) wished to have some indication of density

of observation on soil maps. The actual map scale together with the density of observations provide some measure of the reliability of the map. This measure could then be employed as a parameter in the classification of maps. However, the proposal is not tenable as it only applies for grid surveys (as defined by Steur, 1961). In addition, many soil survey reports do not give information on the density of observation and so this parameter cannot be used to classify maps.

However, Boulaine (1966) and Burrough, Beckett, and Jarvis (1971) employ the density of observations to define their "virtual scale" (the scale of the map recalculated to give five observations per cm^2). They indicate that this is only applicable to grid surveys. In developing the concept of the virtual scale, they imply that the actual scale of the map must be accompanied by some other parameter which defines the survey methodology or results, in order for maps to be compared or classified.

For convenience, and in the absence of other universal parameters, the actual map scales are employed to develop classes in the *Soil Survey Manual* (U.S.D.A., Soil Conservation Service, 1977, in preparation). Six classes are recognized, but the class limits proposed do not include the map scales most frequently used within a class. Therefore some changes are needed. In Table 3, the class limits of the *Soil Survey Manual* and the modified limits are given. The modifications are based on a proposal by Cline (1977, this volume).

Classes	Map scales	Modified map scales
A. Ultradetailed	>1:7,920	>1:13,000
B. Mesodetailed	1: 7,920-1: 24,000	1: 13,000-1: 26,000
C. Macrodetailed	1: 24,000-1: 62,500	1: 26,000-1: 65,000
D. Meso-reconnaissance	1: 62,500-1: 250,000	1: 65,000-1: 130,000
E. Macro-reconn.	1:250,000-1: 500,000	1:130,000-1: 650,000
F. Exploratory	1:500,000-1:2,500,000	1:650,000-1:2,500,000
F_1 Generalized	<1:1,000,000	<1:1,000,000
F_2 Schematic	<1:1,000,000	<1:1,000,000

Table 3. Map classes as a function of map scales.

In the following proposal for classification of maps, the limits of the modified map scales in Table 1 will be used; the class names will be retained.

Map Index of Maximum Reduction and Minimum Scale of Reduction

The objective here is to select a parameter based on the map attributes discussed in the earlier part of this paper. The intention is to produce mutually exclusive classes based on characteristics which reflect the soil survey itself. The number and distribution of delineations indicate this best; therefore related attributes are employed.

The map index of maximum reduction is a useful parameter to classify maps for two reasons.

1. As defined, the map index of maximum reduction indicates the reduction necessary to bring the average-size delineation to the minimum-size delineation. This is a function of the texture of the map and indicates not only the effort made to produce the map but also the complexity of the landscape or the soil pattern.

2. The map at the minimum scale of reduction serves as a basis for comparison. It was pointed out earlier that the methodology of the survey is not indicated in the actual map scale and in only some cases when the virtual scale is used. The methodology is taken into consideration when the minimum scale of reduction is used.

The map index of maximum reduction (IMR) is grouped into five classes, and as it is related to map texture, map texture terms are employed to name these classes. The following table gives the class names and limits.

Class	Map index of maximum reduction
a. Very fine textured	$1 \leq IMR < 2$
b. Fine textured	$2 \leq IMR < 4$
c. Medium textured	$4 \leq IMR < 6$
d. Coarse textured	$6 \leq IMR < 10$
e. Very coarse textured	$10 > IMR$

Portions of a map may have finer textures than others for various reasons including landscape features, accessibility, and objectives of the survey. This texture variation in fact is an important characteristic of a map and should be indicated in any classification of maps.

From a practical point of view, it is not normally necessary to recognize more than three areas of different intensities. Depending on the number of intensities present, maps may be termed as mono-, bi- or tri-intensity maps.

Classification System

In this classification system, the three characteristics -- map scale, map index of maximum reduction, and map intensity -- are used. The following examples illustrate the scheme.

Case I. Mono-intensity maps. These are classified simply by combining the class for map scale and that for map index of maximum reduction.

Map Code	Map name
aA	Very fine textured, ultradetailed map
cD	Medium textured, meso-reconnaissance map
dF_1	Coarse textured, generalized map

Case II. Multi-intensity maps. In such maps there are two or more areas with different map textures. The map index of maximum reduction only considers the finest textured area. However, it is useful to indicate that areas with other textures are present.

In the following nomenclature, the finest texture (on which the map index of maximum reduction is based) is indicated last. The percentage of the area occupied by the most frequent textural class, if different, is also indicated in brackets.

Map code	Map name
$a_{60}B$	Very fine (60%) textured, mesodetailed map
$e_{60}aC$	Very coarse (60%), very fine textured, macrodetailed map

$a_{60}B$ indicates that the most frequent is also the finest textured.

$e_{60}aC$ indicates that the most frequent is very coarse and the finest textured is very fine.

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SOIL SURVEY: ITS QUALITY AND EFFECTIVENESS

R. Webster [1]

THE PURPOSE OF INFORMATION

Soil survey is a general procedure whereby information is obtained about the soil of areas of land. The information can be about particular attributes of the soil, for example, the presence or absence of calcium carbonate, boulders or rock near the surface, soil horizons and their sequences. It can consist of measured values of soil properties such as depth, strength, permeability, salinity, cation exchange capacity, or nitrogen content. Or the survey might record only the kinds of soil present. The information can be gained by visual inspection or measurement in the field, laboratory analysis, or microscopic examination.

The purpose of soil survey is sometimes to aid understanding of current land use or soil formation, or to serve as the basis of tax assessment. In the developing countries it is more often done because some change in land use is envisaged: e.g. land settlement, agricultural development, road or airfield construction. The soil properties recorded will relate to the activities envisaged, and the people making the survey may well record their judgments on the suitability or otherwise of soil for such activities. We may regard judgments of this sort as information if we like, but we must distinguish them clearly from inferences about the soil at places not actually visited.

Soil is continuous, but most information about soil, certainly that concerning its intrinsic properties, derives from observations at discrete places, often no more than a few centimetres or few tens of centimetres across, more or less widely separated from one another. We cannot record what the soil is like everywhere. Yet those who commission soil surveys often want to know just that. They want to be able to infer, or predict in a spatial sense, the nature of the soil at many unvisited or unrecorded places from relatively few observations made elsewhere. So, although the essential business of soil survey is the collection of information, the way in which the information is obtained, organized, and used is a substantial and almost ever-present problem. Much of the mystique of soil survey concerns this problem; so do many of the misunderstandings of soil survey and the arguments that follow from them. The fact is that the precise nature of the problem varies from country to country, and often from district to district within a country. It depends on the

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purpose for which information is wanted, the size of area involved, and the staff and other resources available for survey. There is therefore no universal solution, but many more or less different ones tailored to particular circumstances.

SOIL MAPS

Mapping is usually a part of survey procedure. Indeed it has become so much a part of soil survey procedure that soil survey and soil mapping are thought to be the same thing by many people. As we shall see, they are not. Maps are nevertheless important visual aids, and provided we recognize the distinction between survey and map, we shall find it convenient to think in terms of the maps that are or could be produced.

The type of map produced in most soil surveys is familiar enough. It shows the land surface divided into parcels, within any one of which the soil is considered to be of the same kind or of a few kinds that can be listed and described. Parcels of a similar nature are grouped into classes, which constitute the legend of the map - the soil classification for that map. The parcels on the map are disjoint but contiguous, and the whole of an area surveyed falls into one or another parcel. Coverage is complete. Maps that partition an area in this way are known generally as *choropleth* maps. We can take the term into our vocabulary of soil science, as we shall need it to distinguish between these and other kinds of soil maps.

In many instances the choropleth map represents the surveyor's attempt to show the extent of certain classes of soil profile. But as we now know it is not very successful. We can expect no more than about 60 percent of the soil in any one mapping unit to belong to the class of profile it purports to show. Such maps do not display data. Instead their main function is to serve as indexes to data. On output from a soil survey a choropleth map shows the limits, as soil boundaries, within which data can be safely used for prediction.

Similar maps are often made at an early stage in a survey. The boundaries are drawn on evidence of land form, changes in vegetation or land use, appearance on air photographs, and prior knowledge of the geology. The fundamental assumption is the same, namely, that the soil within any one class is sufficiently similar or definable to allow useful prediction. But its function is to allow economy of sampling. It can be used to ensure that every important extent of soil is adequately covered while avoiding undue replication on any one kind. On completion of the survey the map may be published with little or no alteration, again serving as an index to the available data. And both this and maps of the former type can serve as sampling frameworks for later investigators gathering their own information.

Choropleth maps are quite the most familiar soil maps, but they are not the only ones. We should be aware of at least two other types.

Point Symbol Maps

In these the condition of the soil is shown by symbols placed at points corresponding to the positions where the observations were made. The symbolism can be more or less complex. It can show simply presence or absence of some character; it can show by means of a grey or colour scale several levels of a variable; it can combine two or more characters. But in all cases point symbol maps are displays of actual data. Any inference about the soil at intermediate points, by interpolation for example, is made by the user of the map, not by the map maker. Perhaps the leading proponent of point symbol soil maps is C. C. Rudeforth in Great Britain. He has developed several techniques for displaying sample data in this way, and prepared numerous maps. See for example Rudeforth (1975), Rudeforth and Bradley (1972), and Rudeforth and Webster (1973).

Isarithm or Contour Maps

A continuous variable, e.g. thickness of soil or hydraulic conductivity, can be mapped by means of isarithms, lines of equal value. The data values are assumed to lie on a continuous surface of varying shape, and to be sufficiently close that they are spatially dependent, i.e., near points are more likely to be similar than distant points. Mapping consists of constructing the surface from the data and then displaying the result. Such maps can look very like topographic contour maps. Indeed, they are often called "contour" maps, and the procedure by which they are made is often termed "contouring." The terms should be used with caution, however, because there is an important difference between topographic contour lines and isometric lines representing a soil variable. The former are drawn to join points of known equal value; the latter, even where they pass through observed values, join points of inferred equal value. It is, of course, quite impossible to identify actual isometric lines for any property of the soil.

Isarithm maps are sometimes used in detailed planning work, and are likely to become more familiar now that they can be made automatically from sample data.

Neither point symbol nor isarithm maps are as closely integrated with data collection as are choropleth maps. They are essentially adjuncts. Once data have been collected, and nowadays stored in a computer, maps can be made from them as and when required.

Finally in this section, we should recognize that for some purposes maps are not needed at all. A planner, for example, might ask how much soil there is in area suitable for some enterprise. He could be answered by a surveyor's first mapping soil types in the conventional way and then measuring each parcel of soil judged to be suitable. However, since the planner

is not asking where all the suitable soil is the answe ould be provided at much less cost by a statistically sound sampling procedure, from which the proportion of the total area, and hence how much land is suitable, can be estimated.

PURPOSE OF SURVEY

As above, soil survey is not an end in itself: it is done for a purpose. In some instances the purpose is very specific, for example the identification of areas in which zinc or chromium is so concentrated in the soil that it is likely to poison plants growing there, or the design of foundations for a new airfield. Such surveys are special purpose surveys. In other instances survey is carried out to provide an inventory of the soil as a resource. The use made of the survey depends on what is found. These surveys are general purpose surveys, and usually involve recording many properties of the soil.

SURVEY INTENSITY AND APPLICATIONS

The actual soil information obtained by survey derives from the sampling points. The sampling intensity can vary from very dense, say more than 100 points per ha for foundation design, to less than one point per km^2 in rapid surveys of large areas. Sampling intensity is often linked to the scale of map that can be constructed and published with reasonable confidence. This is very roughly five observations per cm^2 of map. The connection is necessarily rough because, for choropleth mapping at least, it takes no account of the judicious use of other information. Some quite satisfactory maps are based on a much less dense sampling than 5 points/cm^2 of map. Allowance must also be made for the user who will tolerate imprecise soil information but must have a large scale map that shows detail of other sorts. For example, in laying gas supply pipes it is more important to have accurate cadastral information that it is to know precisely where the soil changes from one type to another (unless that change is unusually abrupt).

With these qualifications in mind we can divide the range of survey intensity into a few groups. The following, based on F.A.O. practice, will serve.

Descriptive term	Scale range		
Intensive	1:10,000	to	1:2,500 or more
Detailed	1:25,000	to	1:10,000
Semi-detailed	1:100,000	to	1:25,000
Reconnaissance	1:500,000	to	1:100,000

The denominators of the division points are of course convenient round numbers. Some organizations find it equally

convenient to publish their soil maps at these same scales, making it difficult for us to decide which class of survey intensity would be most appropriate for them. This is not serious; it simply shows that the precise division points are quite arbitrary.

Intensive Surveys

These are required to plan enterprises on small areas (a few ha to a few hundred ha) in detail, for example, buildings, irrigation layouts, and intensive farm and plantation management, especially in the context of problem solving. Information from vegetation, land form, and air photographs does not usually lead to economy of effort, and almost all information must be obtained by intensive sampling. That in turn is expensive and is only justified for costly enterprises.

Intensive surveys are almost always special purpose ones, and properties are measured only if they have a direct bearing on the purpose. For example, a fruit grower planting an orchard might wish to know the depth and drainage characters of the soil; a construction engineer would want measurements of bearing strength, Atterberg limits and shrinkage, before designing foundations. The data are usually well suited for isarithmic mapping, and this is often done.

Detailed Surveys

These too are carried out for specific projects though over somewhat larger areas, for example, agricultural development including irrigation works. More soil properties might be of concern here than in the previous group. In many instances information derives largely from sampling, but in others use may be made of surface features to distinguish soil types. No one procedure dominates, and the group represents a gradation between the intensive and semi-detailed groups.

Semi-detailed Survey

Soil surveys in this group are made for a variety of purposes. Some are special purposes, in which particular soil properties are of interest, for example, geochemical survey. Others have specific ends that depend on several soil properties. Examples include location of new settlement and assessment of potential for agricultural development. The systematic surveys carried out in Western Europe and North America also fall into this group. They are general purpose, principally resource inventories, with choropleth maps as integral parts of the procedure. In most instances the classes represented, soil series and the like, are homogeneous types; that is, each can be regarded as uniform for many practical purposes, and any local variation is small enough to be ignored. Some mapping units are defined as mixtures, complexes, etc., but these are the exception rather than the rule.

Reconnaissance Survey

The surveys in this group are almost always of large areas--national territories or large regions within them. The term *reconnaissance* is applied because the surveys are often carried out rapidly or with few staff or with limited access or some combination of these, and information is a good deal sparser than either those making the survey or their clients would wish. Those who make reconnaissance surveys often do so on the understanding that the survey is a preliminary to more detailed work, if resources allow, of the whole area, or of those parts that seem the most suitable for some specific purpose. Surveys at this scale are carried out to provide resource inventories of large areas. For strategic planning the main aim is to obtain sufficient, and reasonably uniform, coverage of information for the whole country or region. Though the scale of survey brings it into this group it is not properly reconnaissance.

The small-scale maps from such surveys are almost always choropleth maps. But the kinds of mapping units differ greatly from map to map, and in some instances from unit to unit on the one map. Some maps purport to show individual classes of soil, usually at some coarse level of classification, e.g. great soil groups or some such. Others more honestly show dominant soil types. Yet others show soil associations -- groups of more or less different types of soil that occur, and usually recur, in association with one another in the areas bounded.

An extension of this is the land system map. Land systems as such were first mapped in the North of Australia to help assess the agricultural and pastoral potential of that country (Christian and Stewart, 1953). A land system is akin to a soil association in that it is a pattern of recurring elements of land, but differs from a soil association by embracing more than just soil; land form, surface geology, water regime, and often natural vegetation are additional attributes of it. Its advantages, even from a soil surveyor's point of view, are that both it and its component parts, which we can call *land facets*, are much more readily recognized and mapped than are soil types or associations. Land systems can be distinguished on air photographs with confidence. Land system survey is now a valuable tool for remote areas and has been carried out to advantage in many countries for both agricultural and engineering purposes.

In reconnaissance surveys soil data are not only sparse but also do not usually relate to any one whole mapping unit. In fact, it is not immediately obvious how generalization or prediction of any kind can be made from the data, since the parcel in which any data point lies can contain areas of very different soil. Data from a point can sensibly be extrapolated only to other parts of the same type of soil, say soil series or land facet, that is within a class than can be treated as

uniform. A land system or soil association map is not itself a sufficient index or guide. There must also be means for identifying the type of soil or land facet at both sampling points and at other points for which predictions are wanted. These must be provided in an explanatory document accompanying the map. The map will then tell the user which mapping unit is relevant, and the description of the mapping unit will enable him to decide which soil or land type occurs at any point of interest. It is a distinct two-stage process. The British Royal Engineers contributed substantially to this aspect of land survey in the 1960s, and the results are reviewed by Beckett et al. (1972).

RELIABILITY OF SURVEY

Records made by novices in the field and data from ill-equipped laboratories and poorly maintained instruments cannot be relied on. Information obtained by experienced staff using sound equipment will be reliable, in the sense that it faithfully describes the condition of the soil at the sampling points. But to be useful or effective such data must also represent the soil of some area well and so allow worthwhile prediction and generalization.

To be properly representative sampling points should be chosen without bias. This is best done in such a way that every point in the area to be represented has an equal, or at least known, chance of being chosen. In detailed and intensive surveys this can be achieved fairly easily. In semi-detailed and reconnaissance surveys it is less easy or uneconomical, and is very unusual in practice. Instead representative sites are chosen intuitively by surveyors. The practice depends on having surveyors with experience and sound judgment; otherwise the risk of bias, which is always present, becomes serious.

UTILITY OF DATA

Sample data may be required for either generalization about the soil of areas or for prediction or both.

Generalization

Taking generalization first, it is clearly helpful for a farmer to know the average phosphate content of his soil, since from this information he can judge how much phosphate fertilizer to buy. Similarly a mining company might wish to know how much aluminium the soil contains; that information would enable the company to judge whether to invest capital to strip the area for bauxite. In these instances the mean value is of interest. Its estimate can be improved simply by increased sampling. The precision is proportionate to the square root of the sample size.

Prediction

Prediction is different. A plantation manager might wish to know the depth of soil at many places on his plantation; a military tactician will be concerned with the bearing strength of the soil along a continuous tract of country. If they lack other information they might use the mean values of depth or strength as predictors. But the confidence that they place in the prediction depends on the variance of the property concerned. The more variable the soil is the more in error prediction is likely to be. Increased sampling does not of itself reduce this error.

Classification

There are two ways of improving prediction from sample data. The first, and most familiar to soil surveyors, is to link the data to a soil classification (or choropleth map) of the area. Prediction for any point is then based on data from the soil class (mapping unit) to which the point belongs. The variance within the class is likely to be less than in the area as a whole, and hence the confidence interval for prediction should be narrower. The prospect is attractive: reality is less so. Our experience suggests that the variance of a soil property within classes at series level is unlikely to be less than half that in the larger landscape or survey area. For some properties in some areas a particular classification may bring about no reduction in variance, and in one instance that was examined exhaustively general purpose classification brought about no worthwhile decrease in the variance of any property of interest (Webster and Butler, 1976). The user of a soil classification should expect modest improvements in prediction rather than spectacular ones, and should always be prepared for the situation where a soil classification is unprofitable. The method also demands a reasonable sample for each class recognized, otherwise the class means themselves will be subject to substantial error. One of the tasks of survey is to judge the best compromise between creating many classes to diminish within-class variance and increasing the sampling effort needed to describe those classes adequately.

Interpolation

The other and less familiar method of improving prediction is numerical interpolation, in which the value of a variable is based on the values at previously sampled points and on their distance away. Now with machines to take on the heavy computing involved there is renewed interest in interpolation.

A number of methods have been proposed for interpolation. Each is an attempt to be intuitively reasonable, to make the best of machine resources (program, data, and intermediate results must fit into the computer and jobs run to completion in the time allotted), and to work empirically. Of these, the method known

as *Kriging* (Matheron, 1965) seems the most promising for soil survey, but has not yet been applied. It provides unbiased estimates of the true values; the estimation variances are minimal and in this sense the method is optimal, and the error of estimate is known.

For any kind of interpolation to be worthwhile the sample points on which it is based must be closer than the limit or range of spatial dependence. The range can be determined by measuring the autocorrelations between points different distances apart. Webster and Cuanalo (1975) show how it can be done in soil survey. In general the sample spacing should be half the range at most, and with this proviso the more intense the sample survey the better interpolation will be.

With these ideas in mind we can see why different procedures are needed to make use of information at different levels of intensity. In intensive and detailed surveys a sampling interval of 20 m to 100 m is usually well within the range of spatial dependence, which might be an order of magnitude larger. Interpolation then makes the best use of the data. If there are obvious sharp changes these can be taken into account. At the semi-detailed level the interval at which observations are made and the range of spatial dependence are of the same order of magnitude, and are often about the same. Interpolation is unprofitable, but simple classification is an economic alternative. At the reconnaissance level simple classification is also unprofitable, and we need two-stage indexing for our information. The effectiveness of a two-stage reconnaissance map therefore depends on (1) the homogeneity, or within-class variance, of the soil types or land facets listed, and (2) the quality of the identification aids to the soil types and facets, in addition to accurate delineation of the mapping units.

The above represent the limiting conditions for interpolation and classification. We should also recognize that there are practical limits to the refinement that we can hope to achieve. As above, roughly half the total variance of a soil physical property in an area of say 100 km^2 can be accounted for by a soil series or land facet classification. Of the remainder we should expect to find again about half present within 100 m^2, or even 1 m^2. We cannot generalize quite so readily for chemical properties. Some are apparently unrelated to any formal or obvious soil classification; others are related. But all still show very considerable variation within a 10 m distance. This variation will remain present as noise in most sampling schemes or classification, since in practice we cannot sample closely enough nor create enough mapping classes and delineate them to take account of it.

CLASS PURITY

The foregoing discussion on reliability and utility of survey data is presented in terms of continuous variables --

quantities like zinc content, bearing strength, lime requirement--that are or can be measured. In many surveys the characters of interest are attributes. If the attribute is strictly binary (e.g. present or absent) then it can be treated as above, though it might be better to apply Shannon's information statistics.

One line of study in particular needs mention. It is that concerning the purity of soil mapping units. In this approach it is assumed that soil mapping attempts to partition an area into parcels such that each parcel contains one and only one class of soil profile. The classes of profile are disjoint, and may be defined prior to survey. Soil being what it is the attempt is never wholly successful, and the mapping units always contain some proportion of soil other than the classes they were intended to bound. They are always more or less impure, and the several studies carried to assess impurity show it to be anything from 25 to 65 per cent. The results are depressing if taken seriously.

However, I believe that purity of this kind is largely irrelevant. For practical purposes the map provides the definitive classification to which useful data are indexed by virtue of their location. The soil profile class is not information that the user wants. The information he does want is about individual soil properties or about the suitability of soil for particular purposes. Provided the survey produces a map showing homogeneous areas, each mapping unit should be substantially pure with respect to its suitability. If there is any doubt about this for a specific purpose then the suitability of the soil should be assessed at a number of places on the map to establish the facts. A few results from this kind of investigation are available and show that the mapping units can be treated as uniform, just as the surveyors intended. The following example from Beckett et al. (1972) is an illustration, and enables us to end on an optimistic note. The Oxford district of England, covering some 2,400 km^2, had been mapped into land facets (homogeneous classes of land) by a combination of air photo analysis and field work. Twenty-nine test sites were then chosen at random on six of the facets and visited by engineers who assessed the suitability of the sites for the construction of airfields. The results, given in Table 1, show a very strong association between the land classification and suitability for airfield construction.

SUMMARY

Soil survey is a procedure for obtaining information about the soil of areas, from which to generalize and predict. Soil mapping is usually part of the procedure. Choropleth maps (area partitions) are the commonest type of soil map, and show the limits within which point data can safely be extrapolated. With automation isarithm maps are a reasonable alternative. They display statistical surfaces interpolated from point information.

Table 1. Contingency table showing the number of test sites in the Oxford district in each facet and airfield suitability class.

	Land facet					
Airfield suitability class in rank order	13	1	10	3	4	5
1	5					
2		5				
3			4	1		
4					3	2
5				3	3	3

The utility of a survey depends on competent staff recording relevant soil properties at enough representative sites. The utility of the data obtained is more or less enhanced by interpolation in intensive surveys, by map classification in semi-detailed surveys, and by a combination of classification and descriptive guides to class identification in reconnaissance work. There are nevertheless practical limits to the extent to which these enhance prediction. There is always substantial short-range variation unaccounted for.

Choropleth maps of soil can be used to predict suitability classes of land for various purposes, and are generally successful. The estimation of purity with respect to a formal classification is unprofitable, and unnecessary for this purpose.

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EVALUATION OF MAP UNIT COMPOSITION BY THE RANDOM TRANSECT METHOD

B.F. Hajek[1]

Accurate composition of individual soil delineations can be obtained from closely placed transect data (Bartelli and DeMent, 1968; McCormack and Wilding, 1969; Powell and Springer, 1965; Johnson, W. M. 1961. Transect method for determination of the composition of soil mapping units. Soil Survey Technical Notes. U.S.D.A., S.C.S.; Mokma, D. L., and E. P. Whiteside. Point-transect method for determining mapping unit composition or legend accuracy. 1974. Annual Report. MC-109 Project, Michigan State Univ., East Lansing, MI.) However, in dissected, heavily wooded areas a soil scientist often can spend more time gathering transect data than he spends mapping the soil by conventional means. In these areas soil scientists also have problems in adequately defining inclusions and determining what is typical for a mapping unit. The major difficulty is statistical problems such as the number of samples required, bias, systemic sampling procedures, and the definition of computable soil populations (White, 1966; Protz, et al., 1968).

A procedure for random sampling of mapping units and a statistical method for analyzing field data has been evaluated in five Alabama soil surveys. Taxonomic composition, consistency of delineations, and minimum number of transects needed for mapping unit characterization were determined by routine field examination, random transect investigation, and statistical analysis of field data.

METHODS

This random transect method is designed primarily for use in wooded areas, areas of complex terrain of limited accessibility, or other areas where need of average-size delineations is in excess of 120 ha. In the past many of these mapping units would have been called complexes, associations, undifferentiated units, or land types (Soil Survey Staff, 1951).

The design was made with the idea of use in mapping order 2 and 3 soil surveys, previously designated as reconnaissance surveys. However, as a means of quality control, its use could be expanded to the sampling of soil populations at any intensity of soil survey.

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The soil individuals that make up a population are difficult to define (Knox, 1965). As an aid in defining the soil population to be sampled, the following "target" population terms were used (Griffiths, 1967, p. 14-15): hypothetical, existent, available, and random. To utilize most of the desirable bias that the soil scientist has acquired from his field studies and soil observations and to minimize sampling bias, the population terminology has been altered to connote soil populations as follows:

Hypothetical population: that portion of the earth's surface which at one time existed or could have existed in soil pedons. It is not represented in any set of samples because of bias, erosion, or misinterpretation of soil-forming processes.

Existent population: that portion of the earth's surface which presently exists in soil pedons. This population is real but cannot be sampled in its entirety because of inaccessibility and time limitations. This is the true or target population for soil investigation but it cannot be sampled as all individuals of the soil population may be present but are not equally likely to be encountered in a sampling program.

Available population: that population which is readily accessible for point investigation along a line traverse. This population should be investigated and properly sampled. It should be investigated to the extent that the sampler knows that the sample area represents the existent population.

Random population: that population actually sampled. It should represent and typify the available population.

The random transect method for soil survey was developed by use of the entire available population of transets obtained during the course of a soil survey in Talladega County, Alabama (Cotton et al., 1974; Steers and Hajek. 1974. Agronomy Abstracts. Am. Soc. of Agron., Madison, WI). In addition, randomly selected transects from reconnaissance mapping units in Geneva, Mobile, Clarke, and Cleburne Counties (Alabama) were used.

The method used involved the following steps:

1. Soils were mapped and investigated in the field by conventional means. An adequate amount of time was devoted to soil series identification and landscape evaluation so that key soil association patterns for mapping units were established. After mapping units were designed, areas were traversed and delineated on field sheets. All delineations were investigated to some extent and projections were checked by on-site soil investigation.

2. As a part of field mapping and investigation, available transects were located which in the soil scientist's judgment

represented specific delineations and typified existent populations. These available transects were distributed evenly throughout the mapping unit delineations as they existed in the survey areas and characterized areas equal to the expected average management size plots. Alabama has used a ratio of 1 transect for every 120 to 240 ha in reconnaissance surveys for woodland planning. This ratio will vary with area and needs. Each delineation, no matter how large or small, included a minimum of 1 available transect. Transects were commonly located at right angles to drainage patterns, included as much of the complete range in elevation as possible, and represented the typical landscape for the area delineated.

3. A record of each available transect was maintained. After a sufficient area of a particular mapping unit was mapped (about 20% of its expected occurrence) transects were selected by use of a random numbers table. Total number of transects for initial sampling varied with extent of the unit, number of delineations, and complexity of soil patterns.

4. Random transects were sampled by the point intercept method. Transects included between 10 and 20 observations. Intervals between observations varied from 30 to 90 m depending on length of transects. Data were recorded in terms of percent composition of various included soils.

5. Statistical analysis included a simple one-way analysis of variance (Steel and Torrie, 1960) that provided estimates of variance and gave the following useful parameters:

a. arithmetic mean for each specific soil component,
b. number of traverses (n) needed to determine soil components at a specific confidence (80%), and
c. confidence interval (of a mean) at a specific level of confidence (80%).

6. The statistical data were used by party leaders in writing their mapping unit descriptions. This data became the basis for land use planning and interpretations before completion of the survey. A few mapping units were inconsistent in soil composition at the first sampling. Further study of these mapping units revealed that some delineations were mapped too broadly for the original mapping unit standards. In these few instances, a reinvestigation of questionable delineations was performed and an additional mapping unit was designed and evaluated by the same random transect procedures. Such inconsistencies showed up at the time transects were completed and before statistical analysis.

7. After 80-100 percent of field mapping is completed another random sampling is made. A guide for the number of transects (sample size) needed is determined by considering data from the initial sample. In determining the number of transects for final sampling, we used "n" values that gave

the transects needed to characterize about 80 percent of soil occurrence. Populations for final random sampling include the complete available transect population and each has an equal possibility of being selected. These data are analyzed in the same manner as the initial sample, summarized, recorded, and used in preparation of the soil survey manuscripts.

This procedure has shown that many mapping units in a survey area can be characterized with less than 10 transects at 80% confidence. In some cases it may be necessary to group soil series into similar interpretive units to reduce transect numbers and to present data that can be used.

Examples 1-4 show the field data form used, summarized data, a statistical worksheet, and an example of a calculator print-out for the Esto series in the Eustis-Troup association in Mobile County, Alabama. The number of transects needed to characterize this unit would be based on the largest "n" value calculated from the series that make up 80 percent of the mapping unit, that is, Eustis, Esto, Troup, and Norfolk.

Example 5 shows data for two associations each in five Alabama counties. These data are from the initial sampling after about 20 percent of the expected occurrence had been mapped. Recently, after 95 percent of mapping was completed, a final sampling using the calculated n-value confirmed these results.

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 EXAMPLE 1

AL-95 (5-67)
AUBURN, ALABAMA

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SOIL TRANSECT DATA SHEET

Page No. _____

County | Soil Mapping Unit

Transect No. | Direction | Boring Interval | Length

Starting Location

Date | Photo | By

Remarks

Profile No. _____

Percent Slope | Aspect | Erosion

Position on Slope

Horizon	Depth	Color	Tex-ture	Struc-ture	Consis-tence	Mottles	Frag-ments	Clay Films	pH

Additional Notes

Series

Classification

Profile No. _____

Percent Slope | Aspect | Erosion

Position on Slope

Horizon	Depth	Color	Tex-ture	Struc ture	Consis-tence	Mottles	Frag-ments	Clay Films	pH

Additional Notes

Series

Classification

Profile No. _____

Percent Slope | Aspect | Erosion

Position on Slope

Horizon	Depth	Color	Tex-ture	Struc-ture	Consis-tence	Mottles	Frag-ments	Clay Films	pH

Additional Notes

Series

Classification

Mobile County, Alabama
by M.G.M. and E.H.M.

EXAMPLE 2

ASSOCIATION Eustis - Troup
(Association; Hilly)

Soil Series	Transect Numbers														
	26	32	33	34	36	37	38	42	43	44	46	47	48	49	50
	%														
Eustis	37	25	29	37		13	13	8			8	25	9	36	
Dorovan	9	8			7		6				21	16			
Esto	18	17	14	10	28	13	13	15	45	18	35		17		17
Osier	9	8	7	9	7	8	6	8				25	8	19	
Troup	18	25	36		43	33	31		19	8	14	17		36	34
Bibb	9		7	9				8	9	8	8		17		8
Norfolk		17	7	18	15	33	31	61	27	58	14	17	41	9	41
Goldsboro				18						8			8		

ASSOCIATION Eustis - Troup

EXAMPLE 3

STATISTICAL ANALYSIS

	Soils							
	Eustis	Dorovan	Esto	Osier	Troup	Bibb	Norfolk	Goldsboro
ΣX	240	67	260	114	314	83	389	34
$\bar{X} = \frac{\Sigma X}{n}$	16	4.5	17.3	7.6	20.9	5.5	25.9	2.2
$\Sigma(X^2)$	6672	927	6408	1538	9506	837	14679	452
$(\Sigma X)^2$	57600	4489	67600	12996	98596	7744	151321	1156
$\Sigma(X - \bar{X})^2 = \Sigma(X^2) - \frac{(\Sigma X)^2}{n}$	2832.06	627.20	1901.20	672.00	2933.00	378.00	4590.60	3752.0
$s^2 = \frac{\Sigma(X - \bar{X})^2}{n - 1}$	202.29	44.8	135.8	48.0	209.5	27.0	327.9	26.8
$s_{\bar{X}}^2 = \frac{s^2}{n}$	13.47	2.99	9.05	3.20	13.97	1.80	21.86	1.79
$s_{\bar{X}}$	3.67	1.73	3.00	1.79	3.74	1.34	4.68	1.34
confidence interval ($\pm$%)	4.94	2.33	4.04	2.41	5.03	1.80	6.29	1.80
sample size $n = \frac{t_1^2 s^2}{d^2}$	16	41	9	16	10	17	10	103

$t_{0.8}$; $d = \bar{X}(0.3)$

EXAMPLE 4

Monroe Calculator Print-Out

Esto

	%	
	18.000	Σ '
	17.000	Σ '
	14.000	Σ '
	10.000	Σ '
	28.000	Σ '
	13.000	Σ '
	13.000	Σ '
	15.000	Σ '
	45.000	Σ '
	18.000	Σ '
	35.000	Σ '
	0.000	Σ '
	17.000	Σ '
	0.000	Σ '
	17.000	Σ '
$\bar{x}$	17.333	
n	9.086	A
	13.286	A
confidence interval at 80%	21.380	A

EXAMPLE 5

Alabama County	Association Name	Major Soil Series & Groups	Arithmetic Mean	Confidence Interval	Number of Transects Needed
			%	±%	
Clark	Lucedale assoc., nearly level	Lucedale	88	2	2
	Cravens-Sawyer-Angie assoc., nearly level	Cravens	27	6	2
		2w8	73	7	2
Cleburne	Madison assoc., hilly	Madison	78	7	2
	Madison-Louisa assoc. steep	Madison	43	9	2
Geneva	Chastain and Bibb soils	Chastain	45	23	9
		2w9	70	14	2
	Bigbee-Kalmia-Eunola assoc.	Kalmia	27	9	7
Mobile	Smithton assoc., undulating	Smithton	44	8	3
		wet soils	72	4	2
		2w9-Smithton	58	6	2
	Troup assoc. hilly	Troup	21	5	9
		3s2-Troup	37	7	6
Talladega	Tallapoosa-Tatum complex, 6 to 15% slope	Tallapoosa	43	7	2
	Tallapoosa-Tatum assoc., hilly	Tallapoosa	54	5	2

SESSION III

Monday afternoon, April 4, 1977

SOIL SURVEY METHODOLOGY: CASE STUDIES

Chairman: G. Aubert

Speakers

E. W. Presant - Soil Survey Methodology in Tanzania

R. Guerrero - Interpretations of Soil Surveys for Agricultural Purposes in Colombia

SOIL SURVEY METHODOLOGY IN TANZANIA

E. W. Presant[1]

The surveys described in this paper were conducted in Tanzania between 1971 and 1973 for an agronomic research project, jointly funded by Canada and Tanzania. The main purpose of this project was to explore ways of increasing wheat production in Tanzania. A high priority for this project was soil survey of land areas that showed promise for wheat production. Two surveys were done in the northern highlands region of Tanzania. One survey was done of the Basotu state farm of about 25,000 acres and published on a 1:50,000 base (Presant, 1975b); the other survey covered about 200,000 acres in the Arusha area, and was published on a 1:250,000 base (Presant, 1975a).

MATERIALS AND METHODS

Basic Data--Remote-Sensing Information

The only air photographs available were black and white photos taken between 1958 and 1962 at 1:40,000 scale. These were extremely important mapping aids, in spite of their age. They were carefully examined by stereoscope, and tentative soil map unit boundaries were outlined. Then traverses and sampling sites were set up to give the best coverage of the map units in the limited time that was available.

As additional aids for constructing the legends, plotting traverses and locating sampling points, 1:50,000 topographic maps were used for most of the survey areas. There were also some surficial geology maps available for portions of the surveyed areas, and some very generalized soils information from the *Atlas of Tanzania* (1967) and older reports.

Data Collecting Techniques

Field observations. The limitations of time and manpower were the main factors that determined the number and pattern of field observations. The differences in the purposes of the two surveys and the scales of the published maps were additional factors.

The main purpose for the survey of the Basotu state farm was to determine the nature of the soils where wheat was already

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growing, as well as that of the uncultivated portions of the farm, with the idea of expanding the wheat acreage quickly on the best soils for wheat. This required a fairly systematic, semi-grid type of survey, with observation sites wherever major soil differences had been indicated by airphoto interpretation. The intensity of field checking was about one site for each 140 acres.

The survey of the Arusha-Monduli area was a schematic survey published on a 1:250,000 base. Its purpose was to obtain general inventory of the soils and an indication of the location and extent of promising soil areas where more detailed soil surveys, state farms, etc., should be located. To expedite this survey, field traverses were minimal and observation sites were chosen wherever possible near accessible roads and trails. Again, major soil differences as indicated by airphoto interpretation were the most important determinants of observation sites, within the constraints of the road and trail network. The intensity of field site observations was about one site for each 1000-2000 acres.

At each observation site, soil information was collected from auger holes, pits, road cuts, or stream cuts. Observations were made on land characteristics such as surface vegetation, slope, and stoniness. Soil properties such as texture, structure, colour, mottling, horizonation, depth to carbonates, depth to bedrock, and concretions were noted. Additional, more detailed information on properties such as consistence, pores and cracks, etc. were taken from pits or cuts selected as modal sites.

Lab analyses. Grab samples (for particle-size analyses and pH determinations) were periodically collected during the field mapping to assist with field texturing and classification.

At all modal sites, large bag samples were collected of all horizons for lab analyses. There were nine such sites chosen for the Basotu project, and 16 for the Arusha-Monduli survey. Each site represented a major soil group or subgroup.

The following analyses were done by our Tanzanian lab on all modal horizon samples: pH, organic carbon, available P, nitrate N, and exchangeable Ca, Mg, Na, and K. Particle-size analyses and conductivity measurements were made on selected horizons of certain profiles. Clay mineralogy analyses were done on all Basotu samples by a Soil Research Institute lab in Ottawa.

Mapping Legend

Delineations and mapping units. The main delineations and mapping units used in both surveys were soil associations of subgroups. These subgroups are defined in the legend of D'Hoore's *Soil Map of Africa* (1964). In this legend the equivalent of the North American great group is the major soil group, two examples of which are Vertisols and Calcimorphic soils. Major soil groups

are broken down into subgroups which specify landscape position and/or parent materials of the major soil groups; e.g. a Vertisol subgroup is Vertisols of topographic depressions; another is Vertisols on calcareous rocks, etc.

Each soil association consists of two or more map units which are designated as dominant units, associated units, or inclusions. Each map unit consists of a subgroup separable from other units of the same subgroup by differences of texture, slope, or depth over bedrock.

Associated map units are estimated to occupy at least 20% of the soil association; inclusions are important map units occupying less than 20% of the soil association.

Naming of mapping units. The name of the soil association was dependent on the subgroup of the dominant map unit in the association. In the following examples, the dominant subgroups in the associations are Eutrophic Brown soils on volcanic and alluvial sediments. Thus the associations are designated as 1H, 2H, etc.

H-Eutrophic Brown Soils on Volcanic and Alluvial Sediments

Soil Association Number	Dominant Soil Map Unit	Associated Soil Map Units	Inclusions
1H	He2s	Hd2s, BAel	Cd2s, AAel
2H	Hd2	Hc2	Hd3, Cc2

The following example indicates the convention of symbolization used in the dominant map unit of soil association 1H:

Subgroup (Eutrophic Brown soil on volcanic and alluvial sediments)

Soil texture (medium)

H e 2 s

Slope (>15%)

Shallow over bedrock (30-75 cm)

Strategies in Soil Survey Operations

Time. This was our greatest limiting factor. It was important in determining the scale, location, and extent of the surveys that we did. We attempted to conduct our surveys in areas where they would have the greatest impact on the wheat program in as short a time as possible. In order to do this, and to finish the field work during our two-year period in Tanzania, our largest survey had to be of a broad-scale schematic nature.

We had also hoped to have the maps and reports published and available immediately after the field survey. Unfortunately,

they were not published until two years after completion of the field mapping.

Human resources. Although we were supposed to train Tanzanian counterparts to take over the soil survey work when we left, none were available or assigned to me or my Canadian successors.

Field assistants were always available. Most of these men had some training in various aspects of experimental plot work. Although they had virtually no soils training, they could have been trained to measure soil properties such as texture, structure, colour, etc. Unfortunately, a different assistant was assigned to me almost every survey trip, so it was difficult to train anyone adequately.

Economics. Survey costs were not a constraint. There were delays in acquiring vehicles and equipment and in setting up the lab, but these were mostly due to non-economic problems.

Economics was an important consideration in the selection of the survey areas in the Arusha-Monduli region. Areas were selected as much for their nearness and accessibility to roads, storage, and marketing facilities, as for favourable soil, topographic, and climatic conditions.

In the long run, it would probably be cheaper, and certainly provide more continuity and better correlation, for Tanzania to have a soil survey unit on a permanent basis.

Accessibility. Both surveyed areas were relatively accessible to 4-wheel drive vehicles during most of the year. There was a good road and trail network through the Arusha-Monduli area, with some asphalt roads. During the rainy season, though, some roads, especially in the Basotu area, were almost impossible to traverse. Thus, most field mapping was done during the dry season when conditions for both road travel and field traversing were better.

SUMMARY

Probably the most important consideration in determining the scale, number of observations and mapping techniques, was that all the field work, and most of the other work, be completed before leaving Tanzania. This was so that the reports could be published and made available as soon as possible.

Because the costs of transportation, storage, and marketing are factors that are just as limiting to successful wheat production as those of soil, climate, and topography, areas were chosen for broad reconnaissance surveys near the roads, elevators, and railways of the Arusha-Monduli region.

Received 5/15/77.

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INTERPRETATIONS OF SOIL SURVEYS FOR AGRICULTURAL PURPOSES IN COLOMBIA

Ramiro Guerrero M.[1]

Soil surveys have been carried out in Colombia for about 25 years under the responsibility of the Instituto Geográfico de Colombia "Agustín Codazzi." In general, the methodology followed that proposed by the Soil Conservation Service (U. S. D. A., 1965), but was modified according to the nature of the country and selected criteria.

There appear to be some gaps in gathering the information and giving recommendations for regional planning or for specific farms. Apparently, agronomists and farmers are unable to find the information they need and/or apply the practical recommendations to particular situations. Therefore, the present paper intends to show briefly how the soil survey is made and used for agricultural purposes and to point out some of the problems which should be considered in order to make the soil survey more useful for land utilization purposes. The paper includes information on the procedures of data collection and the way the data are used to make recommendations. A general evaluation on the application and usefulness of soil surveys for land use and soil management purposes is also presented.

THE SOIL SURVEY

Depending upon the importance of the area and the purposes of the study, the field work is performed with little or much detail (Mosquera, 1972). For the sake of brevity and for the purpose of the paper, we will only consider the "detailed" soil survey for more developed, flat areas (roughly equivalent to the 2nd order), and the "general" for undulating and non-developed areas (roughly equivalent to 4th order).

Mapping Units

In detailed soil surveys, soil consociations, soil series, and soil complexes are used and in general soil surveys, soil associations.

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Kinds of Components

Detailed soil survey maps show phases and types of the soil series (slope, erosion, effective depth, salinity, etc.). In general surveys, soil "families" (but not in its present sense of *Soil Taxonomy*) have been employed.

Soil Cartography

In detailed soil surveys, scale is an average of 1:10,000 or less, with little or no photo-interpretation support. The mapping units include about 15% inclusions of other taxonomic units.

In general soil surveys, scale of the maps ranges from 1:60,000 to 250,000, with considerable photo-interpretation support. Soil units are delineated as associations of the predominant soil series.

Soil Correlation

The correlation work is done by a team of soil scientists; it includes both local and national correlation. The local correlation is performed at the end of the field work in order to make inspections and observations of the soil profiles, to check some mapping units, and to establish definite taxonomic units, descriptions of the soil units, and their range, legend, and final cartography. The subgroup is also indicated.

The national correlation is done after the soil samples are analyzed and during the preparation of the soil survey report. Discussions on the soil descriptions plus laboratory data will show how the soils of the area correlate with other ones of the same or different areas. The final draft of the soil map is adjusted, definitive legends are checked, soil classification following *Soil Taxonomy* at levels higher than soil series is proposed, and a final soil map is elaborated.

For detailed soil surveys, a map showing different classes of land for irrigation purposes is prepared. In general and detailed soil surveys, a land capability map (U. S. D. A. system with modifications) is prepared, retaining the original boundaries of the mapping units.

The Soil Survey Report

The report includes some general characteristics of the area (geology, geomorphology, climate, vegetation, land uses, etc.); descriptions of the soil profiles (two or more of the same soil series in detailed surveys); the general description of the soils series and their ranges of variation, phases, and legends; laboratory analysis of the profiles described (two or more for detailed soil surveys); and

interpretation of the soil analysis. Lately, chapters on soil genesis, taxonomy of the soils at higher categories, and recommendations on land use and soil management have been included.

USE OF SOIL PROPERTIES FOR RECOMMENDATIONS ON LAND USE AND SOIL MANAGEMENT

On the basis of the information on soil properties provided by field and laboratory studies, detailed soil surveys include a special chapter dealing with land use and soil management. This material is prepared by a team of soil scientists with training in different disciplines (such as soil chemistry, soil fertility, soil physics, soil conservation, beef cattle, dairy, crop production, ecology and soil taxonomy, and of course, soil survey). The report also includes information or data obtained by other agencies on these subjects. It follows the purposes, scope, procedures, and recommendations outlined below.

Objectives

To evaluate the general conditions of the area and the soil properties in order to give proper recommendations on the best use and management of the land, both for better soil conservation and maximum crop yields under various levels of inputs.

Scope

The appraisals and recommendations of the report are focused toward governmental agencies, agricultural enterprises, and small farmers, either for regional planning or for individual farms.

Procedures to Make Evaluations of Soil Properties and Recommendations

The evaluation of soil properties to make specific recommendations on land use takes into consideration:

1. The external or general conditions of the area, such as: infra-structure, marketing, economics, tradition, water sources, and some soil properties like relief and micro-relief, soil moisture regimes, and soil temperature regimes. This type of pre-evaluation will suggest the general suitability of the area for specific land use, e.g. annual crops, plantations, fruit trees, beef cattle, dairy, forestry, or irrigation districts.

2. The internal soil conditions, such as morphological, physical, chemical, mineralogical, and biological soil properties. Evaluation and/or information from other agencies

on these subjects will suggest the particular conditions of the soil, workability and tillage, plant variety, root growth, nutrient status, amounts, methods and frequency of fertilizer application, liming and micronutrient problems, rotation of crops, weed control, etc.

The Colombian Agricultural Institute (I. C. A.) has had as its responsibility for almost 25 years research on agriculture for the whole country. This investigation has been carried out at 17 experimental stations located at rather representative places in the Andean valleys, the coastal plains, and the highlands of the cordilleras of the western and more developed parts of the country, and to a lesser extent in the low non-developed tropical areas. Soil scientists have conducted research on soil physics, chemistry, fertility, classification, microbiology, irrigation, and drainage and management practices, both at the stations and in regional trials with the farmers. Experimental stations have detailed or ultradetailed soil surveys (1st or 2nd order); trials outside of the stations have been located on representative soil series of the area. Results obtained at both areas have been statistically analyzed and correlated in order to establish the soil response to the treatments under different conditions. Likewise, these studies have been supported by the information brought by specialists from other disciplines. Most of ICA's investigations on soils have been oriented toward levels, sources, and frequency of fertilizer application for the main crops of the country and also toward laboratory and greenhouse studies on calibration of the methods of soil test analyses. Results have suggested specific recommendations on N, P, K, lime, and micronutrient application on different crops in several areas. Other soil studies have been conducted on tillage, irrigation, drainage, salification, manure, green crops, plant population, and economics of fertilization. Many results obtained have been published and are currently used by people of the National Soil Survey Program (Cortés, 1976), farmers, other agencies, and agronomists assessing crop production.

INTERPRETATION AND EVALUATION OF SOIL CHARACTERISTICS

The following are some examples showing the criteria and the applications of selected soil properties for land use and soil management in Colombia. (These are only simplifications and/or generalizations, not for specific situations. Considerations are restricted to some outstanding points.) Table 1 summarizes the information presented in this section.

Appraisal of Some Morphological Characteristics

Mottling. For many soils, low chroma mottles are associated with excess of water, restriction of internal drainage,

Table 1. Selected examples of the use of soil properties in making recommendations on land use and soil management (simplification).

Soil Property	Condition Affected	Implication
Morphological		
Mottling	Internal drainage, water content, aeration	Drainage practices or selected crops
Effective depth	Root growth, drainage	Type of crop, limited use
B-cementation	Root growth, drainage	Type of crop, drainage
Physical		
Coarse textured soils	Fertility, water management	Productivity, irrigation
Medium textures o/fine	Water content and management	Selection of crop, suitab. for rice
High clay content	Tillage, drainage	Physical problems, conserv. practices
High water infiltration	Content and retention of water	Type of crops, frequency of irrigation
Chemical		
Organic matter content	Nitrogen content	N-responses, management of org. matter
Available phosphorus	Fertility, plant growth	P-fertilization, crop selection, economics
Salinity/sodicity	Plant growth, yields	Land reclamation, select. crops, economics
Mineralogical		
Dominance 1:1 clays	Tillage, drainage, fertility	Fertilization, select. crop, planning
Dominance 2:1 clays	CEC, fertility, physical conditions	Tillage, drainage, productivity
Dominance of allophane	Availability of P, fertility	Select. of crops, fertilization, economics
Climatic		
Soil moisture regimes	Plant growth, weed control, soil mgmt.	Selection of crops, potential, planning
Soil temp. regime	Plant growth, type of crop	Select. of crop, limited use, planning

and limitations for root growth.

For other soils, restricted drainage influences, but does not necessarily exclude some crops. Therefore, mottled soils could be selectively used for some crops while for others a drainage system must be foreseen.

Effective depth. Root growth, internal drainage and, eventually, tillage may be limited by factors affecting the effective depth. Crops with a less-developed root system could be suitable for soils of this nature.

B-cementation. The presence of a cemented or indurated layer in the B horizon near the surface limits the natural drainage and the root growth and favors low infiltration rates. Conditions of this nature may be an advantage for irrigation purposes but a disadvantage for dry-land crops.

Appraisal of Some Physical Properties

Coarse textured soils. Generally, fertility is lower and, depending upon the moisture regime, irrigation is required. As a consequence, coarse textures affect the water management and the soil productivity.

Medium textures over fine textures. The presence of medium textures over fine textures in flat areas decreases the infiltration rate and favors water retention. This could determine the suitability of the land for rice under irrigation.

Very high clay content. For soils having 2:1 clays, this indicates tillage problems and drainage limitations. Consequently, depending upon the amount and distribution of rainfall and the economics, one should consider a drainage system, or alter the date of soil preparation and/or land use.

Appraisal of Some Chemical Characteristics

Organic matter content. Usually N-response is well correlated with organic matter content. Depending on the crop, the altitude, and nature of the organic matter, there will be N-responses if the organic matter content is low, especially on graminae.

Phosphorus problems. For many soils, the P deficiencies seriously limit crop production and are closely associated with high acidity. In such a case, a P-fertilization program is required. In Colombia, ICA has found some reasonable recommendations on P fertilization, mainly as basic slag (Escorias Thomas). For most soils, P problems also require a liming program. Therefore, if P is deficient, land use and economics of soil management must be considered.

Salinity-sodicity problems. The presence of saline and sodium compounds causes limited productivity of the land and restricts the range of crops. Land utilization and soil management must consider tolerant crops, soil reclamation practices, and regional drainage systems.

Appraisal of Some Mineralogical Properties

Dominance of 1:1 clays. Most of the soils in which 1:1 clays are predominant have low fertility status but good physical conditions. This favors tillage but affects fertility and potential productivity for specific crops or regional planning.

Dominance of 2:1 clays. Opposite to the 1:1 situation, soils in which 2:1 clays are dominant generally have a high fertility but represent poor tillage conditions. Use of these lands and soil management practices must include considerations on the use of machinery, drainage, and productivity.

Dominance of allophane. It has been observed that P-fixation is significantly higher in soils in which allophane content is high. Since Andosols are quite common in Colombia, the use of these lands and soil management practices considers heavy P fertilization, light N applications, and some liming. Small farmers are getting reasonable yields utilizing their plots with intermixed crops.

Appraisal of Climatic Characteristics

Soil moisture regimes. Deficiencies or excesses of moisture content in the soils produce strong limitations on the yields of most crops. Plant growth and soil management are closely related to the amount and distribution of the rainfall. Therefore, land use and soil management consider soil moisture regime when recommending particular crops or pastures for a given area.

Soil temperature regimes. The same type of considerations exist for temperature regimes. The presence of frost and temperatures below freezing at high altitudes, mainly during the dry season, are quite important for plant growth, especially for broad leaf crops.

In summary, the chapter on land use and soil management of the soil survey report presents: in detailed surveys, special recommendations on suitability for land use (annual crops, livestock, irrigation districts, etc.) and soil management and cultural practices (drainage, irrigation, liming, tillage, fertilizers, weed control, etc.). The general soil survey report includes a general pre-evaluation of the lands for broad state-wide and regional preliminary plans, colonization projects, beef cattle, etc. It also includes some general remarks on suitability for crops, nutrient status, physical problems, and fertilizer needs.

EVALUATION OF THE COLOMBIAN SOIL SURVEY AND RECOMMENDATIONS

In general, it appears that the Colombian soil survey is presenting reliable and practical information for specific areas of the country, in regard to suitability of the lands for different purposes (crops, livestock, forestry, etc.), according to the general conditions of each area; the nature of the soils; and their physical, chemical, and climatic characteristics. The survey emphasizes their advantages and serious limitations for specific uses, land capability, and suitability for particular crops and mentions some necessary management practices. At present, directors of the program are introducing some changes in the field work, report, and cartography in order to improve the quality and usefulness of the work for potential and actual users.

However, there seem to be particular situations which are limiting the usefulness of the studies. Some of these are mentioned in the following paragraphs.

Logistic Limitations

1. Insufficient up-to-date air photos and related cartographic material.

2. Insufficient budget, personnel, and facilities.

3. Delay in the publications: writing of the manuscripts, editing the report, and publishing colored maps.

4. Insufficient soil correlation at the local and/or national level.

Evaluation of the Recommendations

Most of the recommendations on land use and soil management are done for large areas shown on the maps, but the user is looking for specific recommendations for individual farms. In the future, Colombian soil survey could consider the following aspects:

Inclusions. Since inclusions are not presented in the soil map, there may be some errors generated by applying the same recommendations to the inclusions as to the soil series, especially in small farms in which the mappable size areas are out of the scale.

Soil "families." Until a few years ago, soil families as presented in the soil map were within the old, obsolete concept of this category (that is, by grouping soil series having rather similar characteristics). The recommendations presented for such soil series should be revised.

Fertility recommendations. The interpretation of the soil analysis and subsequent recommendations on application of fertilizers for the soil series, on basis of the samples taken at one or two pedons, may lead to wrong conclusions. As a matter of fact, the range of variation of the soil fertility of the surface layer of a particular soil phase may show great differences from place to place in the same area and even within the same farm, depending upon the land use and soil management in the past, and to some extent on natural variation in the range of the original properties.

Another point in relation to fertility appraisal of specific land units is that the original recommendations were made on a particular date and at the present time they are not up-to-date. However, they become of rather permanent character, not taking into account early and late uses and management practices of the different plots in the field. Actually, recommendations for fertilizer applications by ICA were obtained on particular soil series and some have been generalized for the whole area or farms.

Land capability classes. The map of land capability classes (adapted from the U. S. D. A. system) represents to some extent qualitative rather than quantitative appraisals. Therefore, decisions on specific situations become highly subjective and subject to different evaluation from person to person.

Map scale. In areas on which small farms are predominant, the scales of the maps do not permit exact identification of individual farms for specific recommendations.

"Overlapping" of the orders of soil surveys. In some cases, the information given in "detailed" (2nd order ?) soil surveys is rather generalized, and vice versa; data contained in "reconnaissance" soil surveys is rather specific.

"Ceiling" of recommendations. The recommendations on land use and soil management should not have more specificity or scope than that given by the "type" or order of the soil survey.

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SESSION IV

Tuesday morning, April 5, 1977

SOIL SURVEY METHODOLOGY: TECHNIQUES

Chairman: R. Webster

Speakers

A. A. Klingebiel - Use of Landsat for Determining Soil Potential

J. D. Rourke - Legend Design for Various Kinds of Soil Surveys

W. R. Philipson - The Use of Airphoto Interpretation and Remote Sensing in Soil Resources Inventories - with Special Reference to Less-developed Countries (Authors: T. Liang and W. R. Philipson)

SOIL SURVEY METHODOLOGY-
USE OF LANDSAT FOR DETERMINING SOIL POTENTIAL

A. A. Klingebiel[1]

People making estimates of food potential for the world and in developing countries are making decisions from very limited data. In most developing countries it is not known how many hectares of land are under cultivation, or how many hectares are being irrigated. They do not know the location or size of areas that have good potential for increasing food production.

It is important to know the location and area of these soils that have good potential for producing food and fiber, the kinds of crops best adapted to the soils, and the kind of management or reclamation required to achieve full potential. With this information at hand, the economic feasibility of carrying out needed soil improvement such as drainage, irrigation, flood control, fertilization, and related practices can be determined.

When an inventory of soil and water resources is available for a country (soil maps and interpretations), accurate predictions can be made about the potential to produce food and fiber under different levels of management. When an inventory is needed and not on hand, it can be obtained within a reasonably short time by supplementing available maps and data through the use of Landsat imagery and with reconnaissance field studies.

It is important to determine what soil and related resource data are available and to gather additional data as needed for the area being evaluated. Assemble these materials in an orderly manner for easy reference and use for people making decisions on land planning and development.

Soil maps of one kind or another are available for some or all parts of most countries. Most of these maps have been made at different times by people using different classification systems and various map scales. The objectives of the different surveys often vary, resulting in vast differences in the kind and amount of interpretations that can be made from the maps. In order to use these maps it is necessary to convert them to one legend and one map scale. To do this it is necessary to utilize the soil maps and soil descriptions together with other available resource data such as climate (seasonal variations and amount), topography and landform, geology, hydrology, native vegetation, present land use, recorded yield data under

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different levels of management and related information.

Improved basic resource data useful in determining soil potential for food and fiber production can be made available in a relatively short time for regional and country planning decisions. Information about soil potential, soil limitations, and yield estimates of selected crops can be greatly improved through the utilization of data and methodology presently available.

METHODS

The methods and procedures that were developed by Klingebiel and Myers (1974 and Myers, Klingebiel et al., 1975, p. 1760-1764) to evaluate the soil resources of Mexico were designed to locate those areas that have good, fair, and poor soil potential to produce food and fiber. The information was designed for use in regional and national planning. The following is a brief summary of the steps followed in developing soil potential maps in Mexico and more recently in the Sudan, Africa.

1. Obtain Landsat imagery for both wet and dry season.

2. Prepare overlays on clear plastic and resource maps (soils, geology, topography, climate, vegetation, land use, infrastructure, etc.) at map scale to be used.

3. Prepare photo interpretation keys to interpret tonal differences observed on imagery.

4. Synthesize (presently) available data and maps and prepare a new soil map for use in aerial reconnaissance and field study.

5. Assemble yield and related data by kinds of soil (and/or by location) for making soil interpretations.

6. Develop criteria and assumptions to use in making soil interpretations.

7. Use a small aircraft to fly at low altitudes over entire area to observe, record and relate tonal differences on imagery to actual aerial observations.

8. Reconnaissance ground check by car and on foot to describe dominant soils and observe soil behavior under different uses and management.

9. Reconstruct preliminary soil map (prepared in the office) using information obtained in aerial and ground reconnaissance.

10. Describe mapping units and major components of units.

11. Record in tabular form selected soil properties for each of the major soil components, including factors limiting use.

12. Prepare a table of yield estimates for selected crops under defined levels of management for major kinds of soil.

13. Prepare interpretive maps from soil maps and interpretations.

14. Prepare recommendations regarding actions needed to achieve soil potential.

Imagery Used

Landsat imagery used consisted of 9 inch transparencies at a scale of 1:1,000,000. From this transparency three kinds of images were prepared: CIR color composite transparencies from bands 4, 5, and 7 at 1:1,000,000 scale; color prints and band 5 black and white prints, both at scales of 1:1,000,000 and 1:500,000. In some cases two sets of CIR transparencies were prepared, one representing the wet season and the other the dry season. Multispectral Scanner band 5 prints were produced since that portion of the spectrum often provides information on soils and landscape differences that is not as obvious on other bands or on CIR composite imagery.

Office Procedures

Overlays were made on transparent material at a scale of 1:1,000,000 from each of the following resource maps: geology, soils (FAO classification), topography, precipitation, present land use and cultural features. These overlays were prepared for each Landsat image. Imagery and overlays were then mosaicked for the areas to be studied.

A tabulation was made of selected soil properties and basic soil interpretations such as yields of important crops, pasture-carrying capacity, etc., for each of the principal kinds of soil in the area. This information was used in making the first draft of a soil map and for making predictions about soil behavior under a moderately high level of technology for each of the major kinds of soil in the area.

Photo interpretation keys were prepared for use in synthesizing the basic resource data and in interpreting the differences observed on the imagery. The task was to relate color tones, tonal characteristics, and geometric patterns to specific and consistent differences on the ground. Landform, vegetation, drainage patterns, geology, and soil color are all clues used to relate the differences observed on the imagery. These observations were recorded for later use in making interpretations from imagery.

Finally a new soil map for use in the aerial reconnaissance and field studies was developed utilizing all of the materials

prepared and information obtained in the other preparatory steps. This required careful study and evaluation of all the resource data, relating it to differences observed on the imagery. Each different delineation on the map was given a symbol and the soil units classified and described.

Field Procedures

Field studies and reconnaissance aircraft flights are essential parts of satellite interpretation procedure, the classification of soils and the establishment of photo interpretation keys. Preferably, the aircraft flight should precede the ground check, since the observations provide a general comprehension of many features that comprise the final product and also dictate many of the ground check points that require attention on the field study trip.

A small aircraft, flying at an altitude of about 1,000 meters above the ground surface, and at a speed of about 120 nautical miles per hour, provides a very suitable platform for the purpose. CIR Landsat imagery at 1:500,000 scale is ideal for making both the aerial and ground study. Some people however prefer the 1:1,000,000 scale imagery for the aerial observation because that is the scale of the navigation charts used to locate roads, streams, towns, and other cultural features. The two maps are used simultaneously during the aerial flights. The soil map used in flight is on a clear mylar overlay placed over the Landsat imagery. In this way one can make notations and changes on the clear overlay map without defacing the imagery. Observations can be recorded directly on the clear overlay and keyed to the different tonal patterns shown on the imagery. Photographs (35mm) are also taken to show the relationship of the landscape with the other features observed on the imagery. Infrared film is used as well as high speed Kodachrome film.

A subsequent ground check is an essential part of the photo interpretation procedure. This consists of traversing the area so that representative soils within each delineation can be studied. The dominant soils are classified and observations made of the vegetation, terrain, and other features important in the use and management of the soil. Soil interpretation and photo interpretation techniques are integrated to determine the most useful utilization of land resources.

The product of the aerial observations and field studies is a final soil map resulting from synthesizing the background material with all of the observations and data obtained in the air and on the ground. Final descriptions of each map unit are prepared and soil and soil properties and soil interpretation tables completed to conform with the mapping units shown on the final soil map.

Interpretation maps are produced from the final soil map. Predictions can be made about the soil potential for range use, land capability, erosion hazard, soil wetness, soil depth, soil slope, suitability for irrigation, suitability for growing specific kinds of crops and many other uses. With these interpretive maps, decision makers can weigh the alternatives for using the soils in different ways.

SUMMARY

The soil maps with accompanying interpretations are intended to give a broad picture of the potential soil resources of a region or country. They can be used to provide a guide for more detailed study of those areas that have good or fair potential for development. If specific works of improvement are planned such as drainage or irrigation, more detailed soil studies are needed. These soil maps will focus the efforts for future development on those areas that have the greatest potential for development and improvement. They will also pinpoint the kinds of soil limitations that need to be overcome if the area is to be developed or improved.

The data obtained from these kinds of studies will provide decision makers with more reliable information about the soil potential of a region or country to produce food and fiber. The method described here can be employed at a reasonable cost and completed for an area in a relatively short time. These methods have been used successfully in several countries.

Presented 4/5/77.

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LEGEND DESIGN
FOR
VARIOUS KINDS OF SOIL SURVEYS

J. D. Rourke[1]

Soil surveys are made to furnish adequate information for land use decision makers. The kinds of decisions these individuals will be making should be, and I maintain must be, made before soil survey commences. The specificity of their needs, and this includes the size of their management units, will determine the field procedures to be used in the soil survey and the scale of the base maps necessary to depict the required detail.

LEGEND DESIGN

Legend design, or the kinds of mapping units, for a given kind of soil survey is determined by: (1) the nature and complexity of the soil pattern, (2) the field procedures used to examine the soils and to plot their boundaries, and (3) the purpose of the soil survey.

The soil classification system defined in *Soil Taxonomy* is the basic reference used in the National Cooperative Soil Survey of the United States to classify soils and interpret soil surveys. It is a multicategoric system with the most specific definitions in the lowest (soil series) category. Each successively higher category is less specificially defined. Classes of the system are used as the references to define and name mapping units of soil surveys. Soil series are the most common reference names used, but classes in other categories are also used.

A mapping unit is a phase of either a named kind of soil, a miscellaneous area, or some combination of the two. The named kind of soil can be at any categoric level in a soil classification system. The purpose of a mapping unit is to provide information significant to use and management. The most specific information can only be provided at the lowest category (soil series) in the classification system. When the purpose of the soil survey is to provide data for operational planning, the information must be specific. When the purpose is to provide data for broad land use planning, the information can be more general in nature or the reference taxa can be named at higher categories in the system.

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ORDERS OF SOIL SURVEY

The concept of orders of soil surveys was developed to provide guidelines by which soil surveys made for different uses could be designated with reasonable consistency. The different kinds of soil surveys are designated as follows: 1st Order Soil Survey, 2nd Order Soil Survey, 3rd Order Soil Survey, 4th Order Soil Survey, and 5th Order Soil Survey.

Soil surveys have four attributes: kind and intensity of field procedures used to identify and map the soils, kinds of mapping units (includes soil taxa used to identify the components), scales for field mapping and publication, and minimum size delineations. These attributes can, and often do, vary in degree independently to satisfy in the most reasonable manner the purposes for which a soil survey is made. This purpose will determine the degree of variability among the five attributes; this was used to distinguish the five orders.

In the following discussion emphasis will be placed firstly on the purpose of the soil survey and secondly on the specificity of the information, the kind and intensity of field procedures, kinds of mapping units, minimum size delineations, and map scales required to satisfy this purpose in a reasonable manner.

1ST ORDER SOIL SURVEY

Purpose of Soil Survey

Provide information for resource conservation planning of highly intensive land uses such as agricultural experimental tracts, high-value commercial agricultural areas, high-density urban areas, and areas planned for intensive development requiring complex, high-cost inputs.

Specificity of needed information. Maximum or near-maximum refinement of soil differences, both categorically and cartographically, that are significant to these very intensive land uses.

Kind and intensity of field procedures. Soils in each delineation are identified by transecting and traversing at closely spaced intervals using direct observation. Mapping unit boundaries are plotted by visual observation throughout this length. Field observations are sufficient to locate and plot areas of dissimilar soil as the minimum size delineation required.

Minimum size delineation. Very intensive land use may require evaluation and decisions about land use and predicting management response for areas of less than 0.6 hectare. The minimum size delineation of dissimilar soils, could, therefore, be 0.6 hectare or smaller.

Mapping scale. The mapping scale must be large enough to accommodate the minimum size delineations of dissimilar soils that

are significant to the purposes of the soil survey. As stated in the preceding paragraph, these could be 0.6 hectare or smaller. Mapping scales of less than 1:12,000 have been suggested when the anticipated land use is very intensive.

Kinds of mapping units. Mapping units will be mainly consociations of phases of soil series with narrow ranges of texture, slope, etc. A consociation is a mapping unit in which only one identified taxon, plus allowable inclusion, occurs in each delineation.

Legend design. Examples of these kinds of mapping units are: Alpha silt loam, 0 to 1 percent slopes, and Alpha silt loam, 1 to 2 percent slopes.

2ND ORDER SOIL SURVEY

Purpose of Soil Survey

Provide information for resource conservation planning for such intensive land uses as high-value general agricultural areas, and urban and industrial areas.

Specificity of needed information. The refinement of the soil information and map detail must be sufficient to determine suitabilities and limitations for all common agricultural and non-agricultural uses and for evaluating management needs.

Kind and intensity of field procedures. Soils in each delineation are identified by transecting and traversing. Mapping unit boundaries are verified at closely spaced intervals and are plotted by direct observation and by some interpretation of remotely sensed data. Field observations are sufficient to locate and plot areas of dissimilar soils as small as the minimum size delineation required.

Minimum size delineation. Resource conservation planning of land use and related management practices where decisions are based on soil resources may be made for areas as small as 0.6 to 4 hectares. The minimum size delineation of dissimilar soils could, therefore, range from 0.6 to 4 hectares.

Mapping scale. The mapping scale must be large enough to accommodate the minimum size delineations of dissimilar soils significant to the purposes of the soil survey. As stated in the preceding paragraph, these could range from 0.6 to 4 hectares. Mapping scales of 1:12,000 to 1:31,680 have been suggested when the anticipated land use is intensive.

Kinds of mapping units. Mapping units are mainly consociations of phases of soil series, and complexes of phases of soil series; some mapping units are undifferentiated groups of soil phases; rarely are mapping units associations of phases of soil series.

A *soil complex* is a mapping unit in which different kinds of soils (or a soil and a miscellaneous area) occur in a geographic pattern which is so intricate that the individual components cannot be delineated separately at scales of about 1:20,000 or larger.

Undifferentiated groups are mapping units in which two or more kinds of soils occur without regularity of pattern and the individual components can be delineated separately at map scales of about 1:20,000. Each delineation has at least one of the major components and may have all of them. The soils may be either similar or dissimilar but same phase criteria such as steepness of slope, stoniness or rockiness, or flooding for extended periods determines the use and management practice for the purposes of the soil survey. Delineating each individual component separately would, therefore, add unnecessary cartographic detail to the maps, reduce the number of mapping units in the legend, and avoid repetition of the same interpretations in a report.

An *association* is a mapping unit in which two or more distinctive kinds of soils (or a soil and a kind of miscellaneous area) occur in a repeating geographic pattern. Unlike a complex mapping unit, the individual components could be delineated separately at map scales of about 1:20,000.

Legend design. Examples of these kinds of mapping units are: (1) Consociations of phases of soil series (Alpha silt loam, 0 to 3 percent slopes and Alpha silt loam, 3 to 8 percent slopes); (2) Complexes of phases of soil series (Alpha-Beta silt loams, 0 to 3 percent slopes and Alpha-Rock outcrop complex, 8 to 10 percent slopes); (3) Undifferentiated groups (Alpha and Beta extremely stony soils, 15 to 45 percent slopes); and (4) Associations of phases of soil series (Alpha-Theta association, 8 to 15 percent slopes).

3RD ORDER SOIL SURVEY

Purpose of Soil Survey

Provide information for (a) resource conservation planning for such extensive land uses as woodland management, wildlife management, and watershed management, and (b) general land use planning, e.g. potential for cropland, pastureland, woodland, urban developments, and rural intensive development.

Specificity of needed information. The information, both categorical and cartographical, need not be as refined as that needed for intensive land use decisions, but it must be sufficient to determine the suitabilities and limitations for general agricultural and nonagricultural uses. General land use planning and resource conservation planning of extensive land uses and related management practices do not require that different kinds of soils, equivalent to the refinement of soil series, be mapped separately.

Kind and intensity of field procedures. The soils in each delineation are identified by transecting and traversing. Mapping unit

boundaries are plotted by observation, and by interpretation of remotely sensed data with some observations. Field observations should be frequent enough to locate and plot areas of dissimilar soils that are significant to the purposes of the survey.

Minimum size delineations. The size of the tracts of concern in resource conservation planning for extensive land use and for general land use planning could range from several 10's to many 100's of hectares. Minimum size delineations of dissimilar soils could range from a few 10's to several 100's of hectares.

Mapping scale. Mapping scales ranging from 1:24,000 to 1:250,000 have been suggested for soil surveys intended for resource conservation planning of extensive land uses and for general land use planning. The scale must be large enough, however, to accommodate the minimum size delineations of dissimilar soils deemed necessary for the purpose of the survey.

Kinds of mapping units. Mapping units are usually designed to separate segments of the landscape that because of the location or other physical factors, will be used in the same or similar manner as recognized for the purposes of the survey. If the soils of the survey area are known, the mapping units should be associations of phases of soil series. Rarely would these be consociations of phases of soil series and if used, the phases would have a wide range. If the soils are not known, the mapping units could be consociations, associations, and some complexes of phases of families, subgroups, and great groups.

Legend design. Examples of these kinds of mapping units are:

(1) Associations of phases of soil series (Alpha-Theta association, 3 to 15 percent slopes, or Alpha-Theta association, undulating to moderately steep);

(2) Consociations of phases of:

  (a) families (Aquic Hapludalfs, fine-loamy, mixed, mesic, 0 to 3 percent slopes),
  (b) subgroups (Aquic Hapludalfs, loamy, mesic, 0 to 3 percent slopes), or
  (c) great groups (Hapludalfs, undulating to moderately steep or Fluvaquents, frequently flooded);

(3) Complexes of phases of:

  (a) great groups (Hapludults-Dystrochrepts complex, undulating to steep), or
  (b) suborders (Aquents-Aquults complex, frequently flooded); and

(4) Associations of phases of:

  (a) great groups (Hapludults-Haplaquents association, nearly level to rolling), or
  (b) suborders (Udults-Aquents association, nearly level to rolling).

4TH ORDER SOIL SURVEY

Purpose of Soil Survey

Provide information for broad land use planning at multi-county, regional, state or provincial level and to identify areas having potential for more intensive development. General accessibility for field soil survey operations may be limited.

Specificity of needed information. The refinement of the information, both categorically and cartographically, can be general in nature. As the land use planning will be broad in nature, the interpretations would be general rather than specific, e.g. for cropland and urban development rather than for maize yields and limitations for on-site sewage disposal.

Kind and intensity of field procedures. The soils of representative landscapes and their pattern of occurrence on these landscapes is determined by transecting. The soils of similar landscapes are verified by some traversing, observations, and by interpretation of remotely sensed data verified by occasional observations. Mapping unit boundaries are plotted by interpretation of remotely sensed data verified by occasional observations.

Minimum size delineations. The size of tracts of concern in broad land use planning could range from 100's to 100,000's of hectares. Minimum size delineations of dissimilar soils could range from several 10's to many 100's of hectares in size.

Mapping scale. Mapping scales ranging from 1:100,000 to 1:300,000 have been suggested for soil surveys intended for broad land use planning. The scale must be large enough, however, to accommodate the minimum size delineations of dissimilar soils deemed necessary for the purposes of the soil survey.

Kinds of mapping units. Mapping units are usually designed to separate landscapes or segments of landscapes that because of location or other physical factors, will be used in the same or similar manner as recognized for the purposes of the survey. Mapping units would rarely be composed of a single kind of soil, even if recognized at the subgroup or great group level. If the soils of the survey are known, the mapping units could be associations of families of soil series. (*Families of soil series* include all soils having similar physical and chemical properties that affect their responses to use and management and manipulation for use. The responses of comparable phases of all soils in a family are nearly enough the same to meet most needs for practical interpretation of such responses. In order to keep the names of the mapping units as short as possible common family names are used. For example, Alpha family would include all those soils that are classified the same as Alpha soils and whose responses to use and management are similar.) If the soils of the survey area are not known, the mapping units could be associations of phases of subgroups or of great groups.

Legend design. Examples of these kinds of mapping units are: (1) Associations of phases of: (a) families (Alpha-Beta families, undulating), (b) subgroups (Typic Hapludalfs - Fluventic Dystrochrepts association, nearly level to hilly), and (c) great groups (Hapludalfs-Dystrochrepts association, nearly level to hilly).

5TH ORDER SOIL SURVEY

Purpose of Soil Survey

Very broad general land use planning at multicounty, regional, state, provincial, or national level. Usually, to determine potential for cropland, pastureland, woodland, urban development, etc., and to identify areas having potential for more intensive development. General accessibility for field soil survey operations is limited.

Specificity of needed information. The refinement of the information, both categorically and cartographically, is general in nature. As the land use planning will be quite broad in nature, the interpretations would be general rather than specific.

Kind and intensity of field procedures. The soils of representative landscapes and their patterns of occurrence on the landscapes are identified and the composition of mapping units determined by mapping selected areas (35 to 50 square kilometers) using the field procedures of 1st or 2nd order soil surveys or alternatively by detailed transects of selected areas. Other areas are mapped by interpretation of remotely sensed data, verified by widely spaced observations.

Minimum size delineations. The size of tracts of concern in very broad land use planning could range from a few million to many millions of hectares. Minimum size delineations of dissimilar soils could range from a few 100's to several 1,000's of hectares in size.

Mapping scale. Mapping scales ranging from 1:250,000 to 1:1,000,000 have been suggested for soil surveys intended for very broad land use planning. The scale must be large enough, however, to accommodate the minimum size delineations of dissimilar soils deemed necessary for the purposes of the soil survey.

Kinds of mapping units. Mapping units are designed to separate landscapes or segments of landscapes that because of location or other physical factors, will be used in the same or similar fashion as recognized for the purposes of the survey. Mapping units would rarely be composed of a single kind of soil, even if recognized at the subgroup or great group level. Mapping units could be associations of phases of subgroups, great groups, suborders, and orders.

Legend design. Examples of these kinds of mapping units are: Associations of phases of: (a) subgroups (Typic Hapludults-Lithic Dystrochrepts association, undulating to steep), (b) great groups (Hapludults-Dystrochrepts association, undulating to steep), (c) suborders (Udults-Ochrepts association, undulating to steep), and (d) orders (Ultisols-Inceptisols associations, undulating to steep). The general purposes of a 5th Order Soil Survey are similar to those of a 4th Order; the difference is mainly in the kind and intensity of field procedures.

SUMMARY

Soil surveys are made to provide data to those individuals who are responsible for making sound land-use decisions that are adequate for their needs. These individuals and the kinds of land-use decisions they will be making are quite varied. The soils data furnished to them should be specific enough for their needs -- no more and no less. If the data is less than they need, the decision made can be quite costly in the end. If the data is more than they need, the decision probably cannot be made until the data has been generalized to the point where it meets their needs. When data is more than is required, valuable resources -- time, funds, and personnel -- have been unwisely used.

The purpose for which a soil survey is being made will determine the kind and intensity of the field procedures necessary to furnish the specificity of the information, both categorically and cartographically, needed for this purpose. Minimum size delineations, map scale, kinds of mapping units, and legend design are, in turn, related to the specificity of the information needed.

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THE USE OF AIRPHOTO INTERPRETATION AND REMOTE SENSING IN SOIL RESOURCES INVENTORIES WITH SPECIAL REFERENCE TO LESS-DEVELOPED COUNTRIES

Ta Liang and Warren R. Philipson[1]

This paper reviews the use of remote sensing[2] methods in soil resources inventories, and discusses the potentials and limitations of their future use in light of current technological developments.

INTRODUCTION

The use of airphotos in soil resources inventories began with their serving as base maps in the field, in the early 1930s, when airphotos first became available. Gradually, more and more techniques were developed to extract soil information from airphotos. By the 1950s there were many mapping programs which depended heavily on airphotos as the major source of soil information. Comparisons of results of airphoto interpretation and field methods were attempted. While the accuracy of photo interpretation depends largely on the scale of photos, level of mapping categories, and competency of the interpreter, it has been also generally recognized that the use of airphotos in soil resources inventories has been more successful than its use in detailed soil surveys. Such soil resources applications have expanded rapidly and extensively during the past twenty years.

Since the mid-1960s, the use of color and color infrared photos has become more common. In addition, more and more spectral data, both in digital and image format, have been acquired. Since the early 1970s, satellite-derived data have been routinely available at increasing frequencies. With the multitude of data, semi-automation and automation in interpretation and presentation are not only desirable but necessary under certain circumstances. Now seems an opportune time to assess the significance of these developments and how best to make use of them effectively.

WHY AIRPHOTOS WERE USED

Historically, airphotos were used because they provide an impartial (or undisturbed) visual record of the land, and in 3-D, when acquired and viewed stereoscopically. Existing photos are generally available in most parts of the world; there are

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[2]Airphoto interpretation is a part of remote sensing, although it often is separated in the literature.

relatively few regions that do not have some type of airphoto coverage, and many have repeated coverages. Thus, they provide an inexpensive and excellent source of soil information.

BASIC APPROACH OF PHOTO INTERPRETATION

A major cornerstone in photo interpretation is the evaluation of landform units. Through stereoscopic study of airphotos, the topographic (slope), drainage, soil erosion, gray or color tone, vegetation and land use characteristics can be assessed; relevant landforms and pertinent soil, rock, and water features can be determined; field study plans can be formulated and subsequent field data interpretation greatly facilitated.

POTENTIALS AND LIMITATIONS OF PHOTO INTERPRETATION

As photo interpretation has been developed primarily with the physiographic approach, it is therefore strong in revealing physical characteristics of soil and rock, including such items as texture, moisture, permeability, and cemented beds, in the profile. For instance, the assessment of landslide and ground water potential, the estimation of depth of soil over bedrock, and the location of construction materials by photo interpretation are well documented (Colwell, 1960 and Reeves, 1975). These are useful to the engineering and geology disciplines as well as to soil science. Hence, photo interpretation has been highly successful if we consider "soil resources" in a broad sense.

However, many limitations should be noted. In addition to the limitation of scale, the quality of airphotos is not only affected by photographic processing but unavoidably by season and time of photography and the associated atmospheric, foliage and ground cover, and moisture conditions. Furthermore, the potential of extracting chemical and biological data from photos is low; such information, if obtainable at all, usually is derived through observation of subtle photo patterns by highly competent interpreters.

It should also be noted that an airphoto is a record of ground conditions at only one point in time. Further, interpreters should be especially aware of the possible influence of an environment, natural or manmade, that he might not be familiar with. These, and the open-ended nature of photo interpretation, are nonetheless limitations that would apply as well to all field investigations.

SPECIAL CONSIDERATIONS IN LDCs

Before leaving the discussion on conventional photography, several factors pertinent to LDC conditions are relevant.

Large Regions, Few Maps

In many LDCs, airphotos served most effectively because there were few alternatives. In recent years, in Australia and many other Commonwealth countries, large regions were mapped into land systems, subsystems, or similar units based on common physiographic, geologic, soil, and vegetative characteristics. Medium scale (1:40,000) airphotos have been used as sources of basic information. Supported by ground checks, maps produced even at such general levels could serve many planning and development purposes. More detailed follow-up studies could be accomplished with larger scale photos.

Tropical Soils

Most of the LDCs are located in the tropical or subtropical regions of the world. There, items such as plinthite, ironstone, termite mounds, black clays (Vertisols), and coral-related materials are significant in agriculture as well as in engineering and economic development. Airphoto patterns of these and others have been reported in the literature (Liang, 1965).

Tropical Vegetation

In the arid and semi-arid tropics, airphotos are most effective because of the cloud-free atmosphere and the fact that there is little vegetative cover to mask the soil and moisture conditions. The opposite is true in the humid to wet tropics. Some of the wettest parts of the world, such as those in Panama, Colombia, Brazil, Philippines, and Indonesia, experience such extreme levels of cloud cover that radar images had to be used.

In many areas, although flying airphotos are possible, heavy forests have hindered ground interpretation. Two opposite approaches have been taken. One is to fly high-level photography (at 1:60,000 scale or smaller) so as to get a large perspective and hopefully to enable the recognition of landforms in spite of the "superficial" forest cover. The other approach is to fly low-level photography (at 1:10,000 scale or larger) to get a close view of the structure and pattern of the forest and then to deduce the ground conditions, considering the prevailing temperature and moisture environment (Holdridge et al., 1971). It is apparent that the former is a simpler solution; the latter requires more specialized personnel, and at present is still very much in the developmental stages (except for some of the well-established species-soil relationships such as mangroves-swamp).

Identification of crops by use of airphotos has been reported (Philipson and Liang, 1975). Future development along this direction would allow the assessment of soil resources through the interpretation of crop status and management practice. At present, photo patterns of major crops are established. More

work is needed for refinements in some lesser crops, mixed crops, and small farms, and in the correlation of crops and soil resources parameters.

SEQUENTIAL AND PLANNED PHOTOGRAPHY

Because one set of existing photography often was not taken at the optimal time to depict foliage, moisture, and other ground conditions, and since one-time photography does not register the short-term and long-term changing conditions, it is often desirable to use sequential photography. This would include photos taken periodically in the past, as well as planned photography in the future.

COLOR AND COLOR INFRARED PHOTOGRAPHY

Since the early 1960s, color and color infrared photos have been more commonly available and used in soil resource projects. Many comparisons of color with panchromatic (black-and-white) airphotos have been made (Colwell, 1960 and Reeves, 1975). The consensus has been that color and color infrared generally add information and that color infrared particularly brings out certain subtle vegetative characteristics[3], and both expedite the interpretation process. The drawback has been the higher cost and demanding facility in photographic reproduction. To counter some of the problems, the use of both color and black-and-white prints from color negatives has been one compromise practice.

The basic consideration might be reduced to whether the incremental information obtained from colors justifies the additional cost and effort. This would vary under differing situations. When the interpretation depends largely on topography (slope), drainage and seepage, panchromatic photography is highly effective and often sufficient; where land use, crops and vegetation have to be interpreted, color photos undoubtedly are superior. One also should consider whether bare soil would be exposed and whether direct observation of soil on photos is possible and essential.

SPECTRAL DATA - IMAGES/TAPES

Since the mid 1960s, applications of spectral data (identified as "tones" in the conventional panchromatic photo inter-

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[3]While this is generally true for crops and many natural vegetated areas, a major experiment in tropical forests has demonstrated that under humid tropic conditions, where growth is luxurious, color is often superior to color infrared (Holdridge et al., 1971).

pretation) in soil resources studies have developed rapidly. With multispectral photographic systems or scanners, ground information is recorded in image or digital form. This information can then be displayed or enhanced and manipulated, in accordance with the spectral characteristics of the various component parts of the ground. This approach has enabled the separation of moist soils from other dark soils on the photos, for instance, and more refined differentiations require experiments to cope with local or regional parameters. The major consideration here is whether the spectral characteristics of surface material are significant. Sometimes this "tone" characteristic is crucial for separating meaningful soil units; other times it could be irrelevant. An extensive experiment in southwestern Pennsylvania in the early 1970s proved that this approach yields remarkable results with bare soils but fails hopelessly when obscured by ground covers (Reeves, 1975).

AUTOMATION AND SEMI-AUTOMATION

A logical development with multispectral data is automation. The practice varies from simple color display and automatic area integration to training computers in differentiating target areas and mapping ground units automatically. Some sort of man-machine interaction is (or should be) required in most procedures. The potentials and limitations here are similar to those discussed under 'spectral data,' but with automation, their order of magnitude is multiplied and the task may easily extend to large area coverages. Compared to traditional interpretation methods, the major bottlenecks facing automation today are: (1) lack of topographic (slope) input and (2) lack of the required sophistication for expressing the reflectance pattern (tonal pattern or texture). Both have been major elements in traditional photo interpretation. Until break-throughs are made in these (and efforts are being made by some groups), progress for automation in soil resources interpretation would be slow.

THERMAL INFRARED, PASSIVE MICROWAVE, RADAR

Only brief comments about these sensors are included to complete our "shopping list". Thermal infrared, not to be confused with photographic infrared, measures temperature-related radiation. Thus, the incremental information it can provide is surface temperature. It would differentiate soil, rock, vegetation types, and moisture regimes only when there are significant temperature or emissivity differences. These differing types often are already observable in photos, which normally provide much better resolution and less distortion than thermal infrared images.

Passive microwave and radar operate in much longer electromagnetic wavelengths. These have the advantage of all-weather

ability, but are greatly limited by the low resolution of available data. Further, the current cost of mobilizing and operating such sensing systems is high and may not be justifiable in most LDCs for soil investigations alone. The advantages, however, of a multiple channel approach should not be overlooked. With further development, such prospects as limited penetration of ground by long wave radar channels seem attractive.

SATELLITE DATA

Since 1972, the series of Earth Resources Technology Satellites (Landsats 1 and 2) have provided four-spectral band data over most of the earth, at 18-day cycles. This is of major importance to all who are concerned with resources inventories (Williams and Carter, 1976).

The major advantages of the Landsat images are:

1. Synoptic views of large areas (185x185 kilometers per image) of nearly all parts of the world.
2. Sequential coverage (every 18 days).
3. Four spectral bands (individually recorded; subject to practically endless manipulation).
4. Available and at nominal costs to any user.

The limitations are:

1. Resolution (now about 80 meters).
2. Lack of 3-D view.

Because of the limiting resolution, the use of Landsat data in detailed soil resources inventories is out of the question. However, in many areas for which general maps are unavailable or poorly done, the Landsat images provide excellent base maps. Then, making full use of the four spectral bands, one may perform visual interpretation through the use of a color additive viewer or similar equipment, or digital analysis with tapes; major physiographic or landform units, various geologic features, and land use patterns can be differentiated.

The outlook for future satellite-derived data appears to be bright. Several countries are planning to install data-receiving facilities in addition to those currently being operated in and by Canada, Brazil, and Italy. Furthermore, Landsat C, which is scheduled to be launched in 1978, is to add a thermal-band sensor; others in the series to follow are being planned to include more spectral bands with better resolution. Advanced sensing devices are also planned for the forthcoming Seasat. Generally, one could look forward to a resolution of 30 meters or better in the near future. Supplementing these, data derived from weather satellites are being used in hydrologic (in addition to weather) studies on a regional basis.

These images provide high frequency sequential data, though with gross resolution (0.5 to 4 kilometers).

EQUIPMENT

The lowly pocket stereoscope is still the most convenient and frequently used piece of equipment for many basic photo interpretation tasks. Depending on the level of sophistication and type and quality of data, more elaborate and high-priced equipment (including stereoscopes, color additive viewer, density slicer, densitometer, and a number of rectifying and enhancing equipment for semi-automation and automation) might be used, not to mention the associated extensive computer systems. Each organization should consider its own needs and acquire the basic equipment, instead of rushing to buy some very costly items that may not necessarily provide much additional information. Such items may also become obsolete in a relatively short time. It is highly commendable that many are suggesting, even in this country, some well-equipped regional centers be established to meet the needs of users in a region. LDCs would be prudent to take this road to conserve resources.

SUMMARY

Photo interpretation/remote sensing plays a major role in data collection for soil resources inventories. This is particularly significant in LDCs where there is a general lack of existing maps or information.

Current techniques in panchromatic airphoto interpretation depend heavily on the landform approach, yielding information that is strong in physical aspects of the land but weak in chemical and biological aspects. This approach, however, may continue for some time, with possibly some refinements in interpreting soil, weathering, crops, and forests in the tropics, thus providing improved inputs to the soil resources inventory.

Color, color infrared photos, and other spectral data provide incremental information over panchromatic photos about soil color, vegetation, and land use. Thermal infrared, passive microwave, and radar -- each has its respective merits, but their resolution, and the limited availability and high cost of the latter two, have greatly hindered their practical uses.

The recent availability of space data (Landsat and others) provides some new and inexpensive sources that one should watch closely, particularly considering the scheduled improvement in resolution and spectral coverage for future satellites.

In summary, for soil resources inventory projects, the multitude of possible photos and images now available as tools

is really a challenge as well as an opportunity for the user. One should assess his regional or national requirements, consider the constraints of each tool and the personnel, equipment, and facilities involved, and formulate the best approach for his program.

Presented 4/5/77.

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SESSION V

Tuesday morning, April 5, 1977

REVIEW OF METHODOLOGY OF MAP CHARACTERISTIC EVALUATION

Chairman: E. G. Knox

Speakers

M. C. Laker - Selection of a Method for Determination of Map Intensities of Soil Maps

H. Eswaran - Examples of Soil Surveys †

† Contents of this presentation are summarized in "Soil Map Parameters and Classification," H. Eswaran, T. R. Forbes, and M. C. Laker, this volume.

SELECTION OF A METHOD FOR DETERMINATION OF MAP INTENSITIES OF SOIL MAPS

M.C. Laker[1]

The intensity of a soil map can be defined as the number of delineations demarcated per unit area. A large number of delineations per unit area indicates a high intensity.

Soil maps are published at different scales. Consequently, the number of delineations per unit area on different maps does not provide a true basis for the comparison of the intensities of different soil surveys. To obtain a true basis for comparison, intensity should be expressed as the number of delineations per unit actual land area (e.g., per ha or km^2).

The only way to determine the number of delineations per unit actual land area is by determining the number of delineations per unit area (e.g., per cm^2) on the published map and then calculating the number of delineations per unit actual land area. This calculation is done by means of a conversion factor, which is a function of the map scale.

The only direct and true way to determine the number of delineations per unit area on the published map would be by counting the total number of delineations in the whole map and dividing this by the total area of the map. This is such an extremely tedious procedure that it is completely impracticable.

The objective of this study was to find a method which provides a reliable measure of the actual number of delineations per unit area on a map and which is at the same time practicable.

PROCEDURE

Twelve map sheets, representative of published soil maps from different countries in Africa and Asia, were selected for the study. These maps were selected to provide examples of the different degrees of map intensity, different types of soil patterns, and different map scales that were encountered during a preliminary study.

A 15 cm x 15 cm square was drawn on transparent tracing paper. This square was fixed in position over one selected

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area of each of the map sheets. The total number of delineations in this 15 cm x 15 cm "mini-map" was then counted. The number of delineations per cm^2 was calculated for each "mini-map." This was the absolute figure for each "mini-map" and was used as the basis against which the different methods were then tested.

Six types of determinations were tested in each "mini-map." Three involved the use of a circle and the other three, the use of linear transects.

A circle with a radius of 2.5 cm (area: 19.64 cm^2, circumference 15.71 cm) was used for the circle counts. Preliminary studies indicated that a circle with a radius of 5 cm is too large and involves a counting procedure that is too tedious. The average number of delineations in a circle with a smaller radius is, on the other hand, considered to be too small to be a reliable measure. This was not tested statistically and was a purely arbitrary decision. Circle determinations were replicated at five different positions within each 15 cm x 15 cm "mini-map."

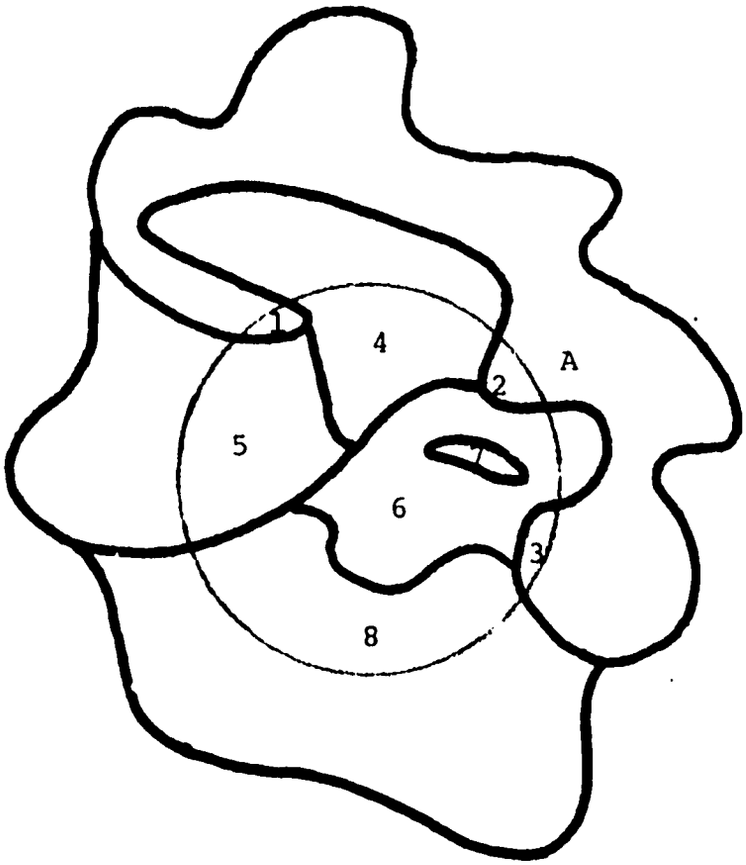

Figure 1. Illustration of the determination of the number of delineations in a 2.5 cm radius circle.

1. The first circle method involved the determination of the number of delineations within the circle. Each area in the circle was counted as a separate delineation. Even where two or more areas actually formed parts of one specific larger delineation which was mainly outside the circle, they were counted as different delineations. This is illustrated in Figure 1. Areas 1, 2, and 3 in the circle all actually form part of the large delineation A. They are counted as three separate delineations, however, and the total number of delineations in the circle is taken as 8.

2. The second circle method also involved the determination of the number of delineations within the circle. However, where two or more areas actually formed parts of one large delineation they were counted as only one delineation. Thus, in the case illustrated in Figure 1, areas 1, 2, and 3 would be counted as only <u>one</u> because they all form part of one common delineation (A).

3. In the third case the number of lines crossing the circumference of the circle were counted. For the example illustrated in Figure 1 this would be 7.

4. The first linear transect determination consisted of counting the number of lines crossing a horizontal transect. Five transects, spaced at 3 cm intervals and spanning the total width of the 15 cm x 15 cm "mini-map," were studied in each case. The transects were spaced as illustrated in Figure 2 to ensure that all five transects were actually inside the "mini-map."

5. The second linear transect determination was similar to that described above, except that vertical transects were used instead of horizontal transects.

6. The third linear transect determination was just a calculation of the average of the horizontal and vertical transects combined.

In order to simplify subsequent tables, figures, and discussions, a set of symols are defined in Table 1 for the different types of determinations.

RESULTS AND DISCUSSION

The average values for each of the types of determination for each of the twelve "mini-maps" are summarized in Table 2. The correlation coefficients for the relationships between the actual intensity (X) or its logarithmic transformation (X_1) or its square root (X_2) and the different methods tested to estimate X (i.e., Y_1 to Y_6) are given in Table 3.

From Table 3 it is clear that all six methods which were tested correlated very well with X or any of the two transformations of X which were used. Theoretically, any one of these

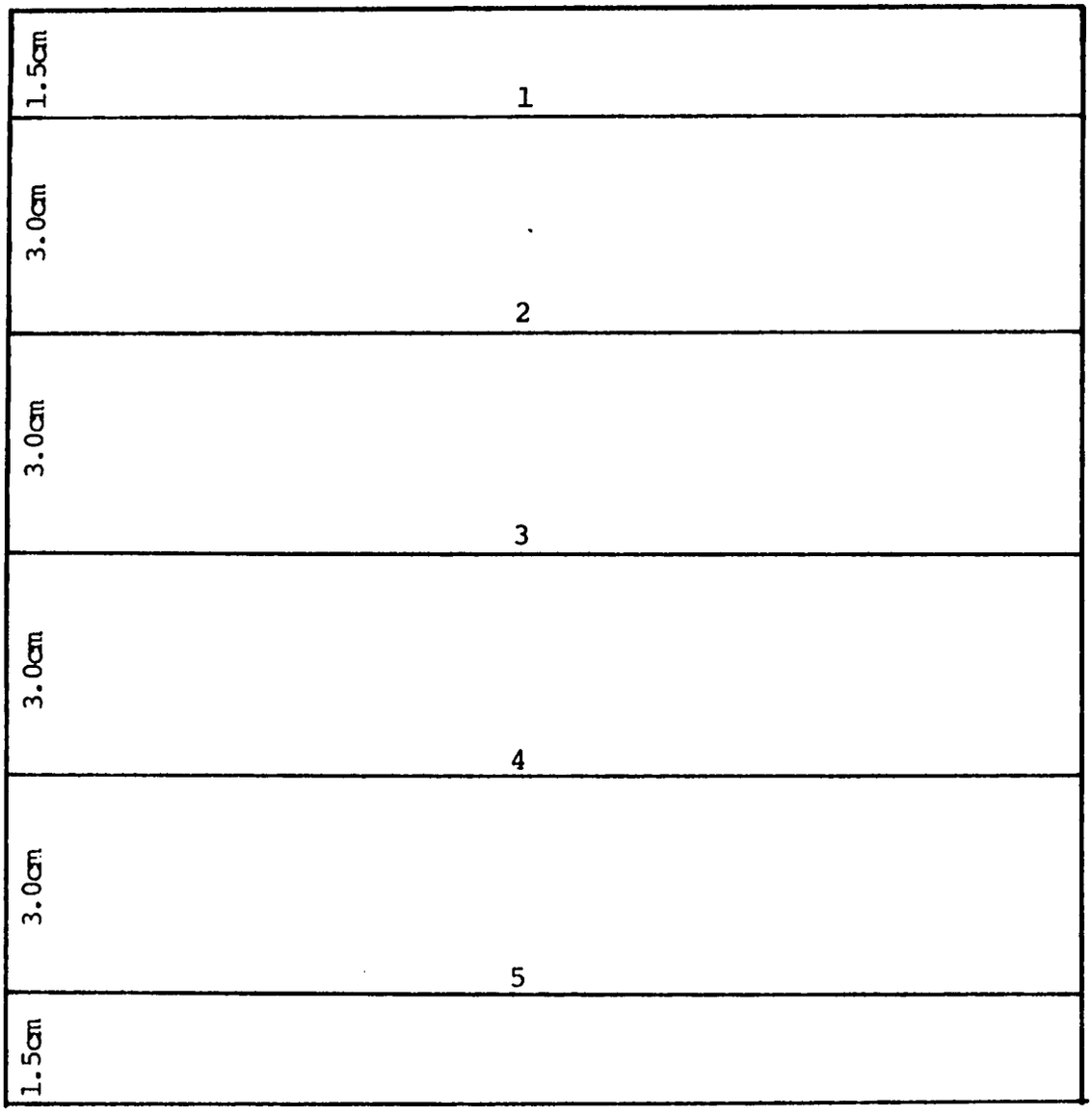

Figure 2. Illustration of positioning of 5 lines in a 15 cm X 15 cm square.

Table 1. List of methods employed to determine number of delineations per unit area.

SYMBOL	PARAMETER
X	Actual number of del/cm^2, determined in a 15 cm X 15 cm "mini-map"
X_1	$\ln X$
X_2	$\sqrt{X}$
Y_1	Representative number of del/cm^2, determined by counting the number of delineations in a 2.5 cm radius circle. Separate parts of the <u>same delineation</u> inside the circle are counted separately.
Y_2	Representative number of del/cm^2, determined by counting the number of delineations in a 2.5 cm radius circle. Separate parts of the <u>same delineation</u> inside the circle are counted together only as one.
Y_3	Number of lines/cm, determined by counting lines crossing the circumference of a 2.5 cm radius circle.
Y_4	Number of lines/cm, determined by counting lines crossing a 15 cm straight horizontal transect.
Y_5	Number of lines/cm, determined by counting lines crossing a 15 cm straight vertical transect.
Y_6	Number of lines/cm, average of Y_4 and Y_5.

Table 2. Results of measurements.

"Mini-Map" No.	PARAMETER						
	X †	Y_1 †	Y_2 †	Y_3 ‡	Y_4 ‡	Y_5 ‡	Y_6 ‡
1	0.040	0.092	0.092	0.076	0.120	0.120	0.120
2	0.093	0.285	0.255	0.484	0.573	0.253	0.413
3	0.147	0.340	0.300	0.599	0.600	0.467	0.534
4	0.151	0.450	0.380	0.790	0.707	0.573	0.640
5	0.160	0.358	0.342	0.525	0.488	0.475	0.483
6	0.173	0.397	0.387	0.509	0.829	0.520	0.673
7	0.240	0.580	0.550	0.870	0.800	0.970	0.890
8	0.258	0.682	0.509	1.044	1.067	1.027	1.047
9	0.306	0.520	0.540	1.010	0.970	1.090	1.030
10	0.570	1.030	0.940	1.450	1.320	1.630	1.480
11	0.609	0.886	0.855	1.057	1.067	0.920	0.993
12	0.902	1.477	1.298	1.668	1.747	1.533	1.640

† Number of del/cm^2

‡ Number of lines/cm

Table 3. Correlation coefficients -- All statistically significant at P = 0.0001; except $X:Y_5$, which is significant at P = 0.0006.

	X	X_1	X_2
Y_1	0.9736	0.9263	0.9719
Y_2	0.9866	0.9434	0.9883
Y_3	0.8970	0.9440	0.9369
Y_4	0.9114	0.9391	0.9403
Y_5	0.8432	0.9070	0.8948
Y_6	0.8930	0.9412	0.9350

six methods can be used to estimate the actual number of delineations per unit area in a soil map.

Some interesting observations can be made, however. Firstly, it is evident that the two methods which measure two-dimensional units (i.e., Y_1 and Y_2) provide an almost perfect method to determine the actual number of delineations per unit area (X). This is logical because the latter is also based on two-dimensional units (areas). The correlation coefficients for the relationships between Y_1 or Y_2 and the square root of X (X_2) are almost identical to the above. This is unexpected because, in this case, a two-dimensional unit is correlated with a linear or one-dimensional unit ($\sqrt{X}$). The graphs illustrating the linear relationships between Y_1 and X and Y_2 and X, respectively, are presented in Figures 3 and 4.

In the case of all the line transect countings, the logarithmic and square root transformations of X quite definitely improved the correlations with the different line countings (Y_3 to Y_6), although the effect was of no statistical significance. These improvements are logical since the one set of parameters (Y_3, Y_4, Y_5, or Y_6) in each determination was a linear function while the other (X) was a quadratic function (area). The direct linear correlations between Y_3, Y_4, Y_5, or Y_6 and X were actually much better than would be expected for the direct correlation between a linear function and a quadratic function.

The graph illustrating the best relationship between the circular line transect determinations (Y_3) and the actual number

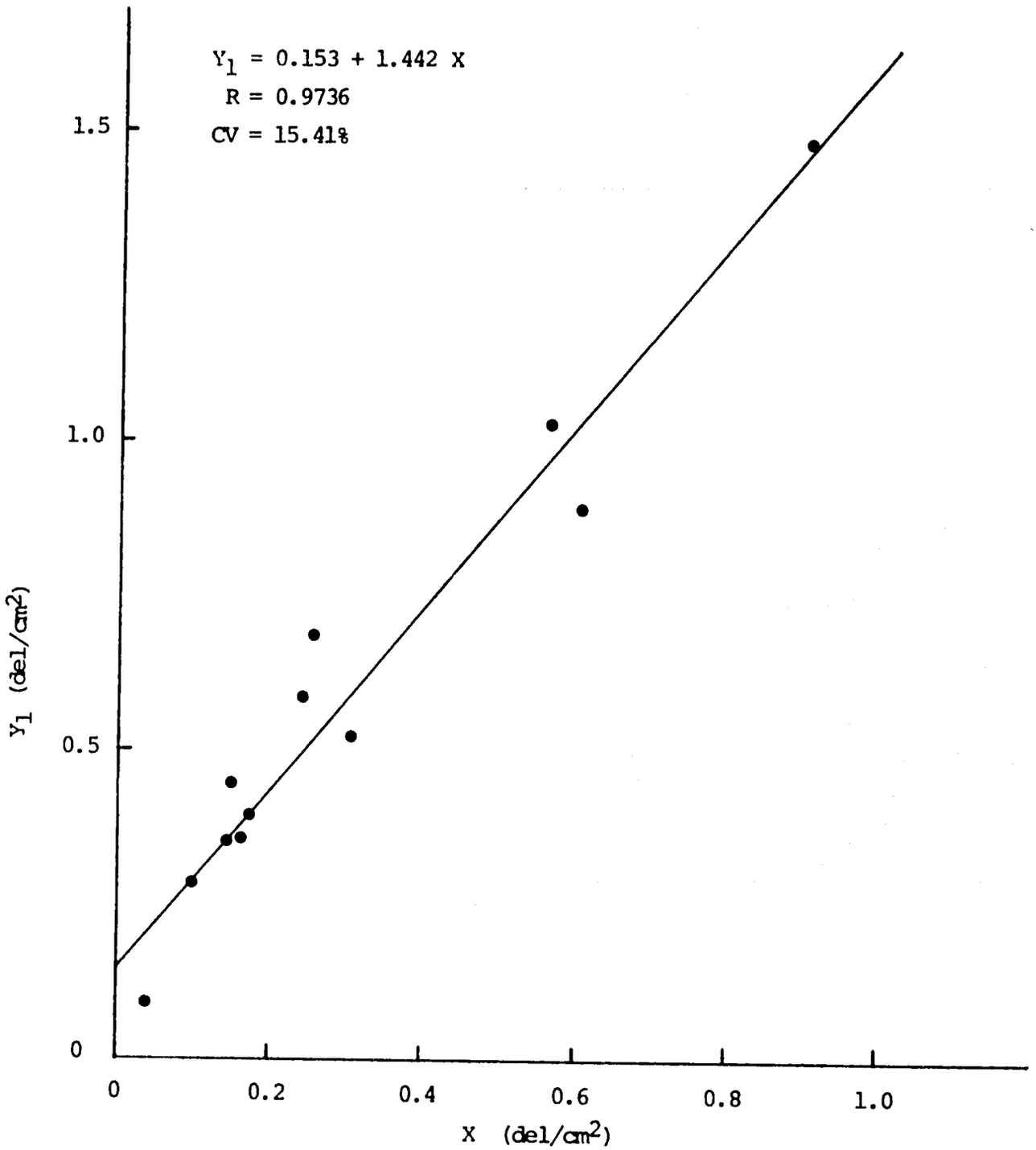

Figure 3. Relationship between X and Y_1.

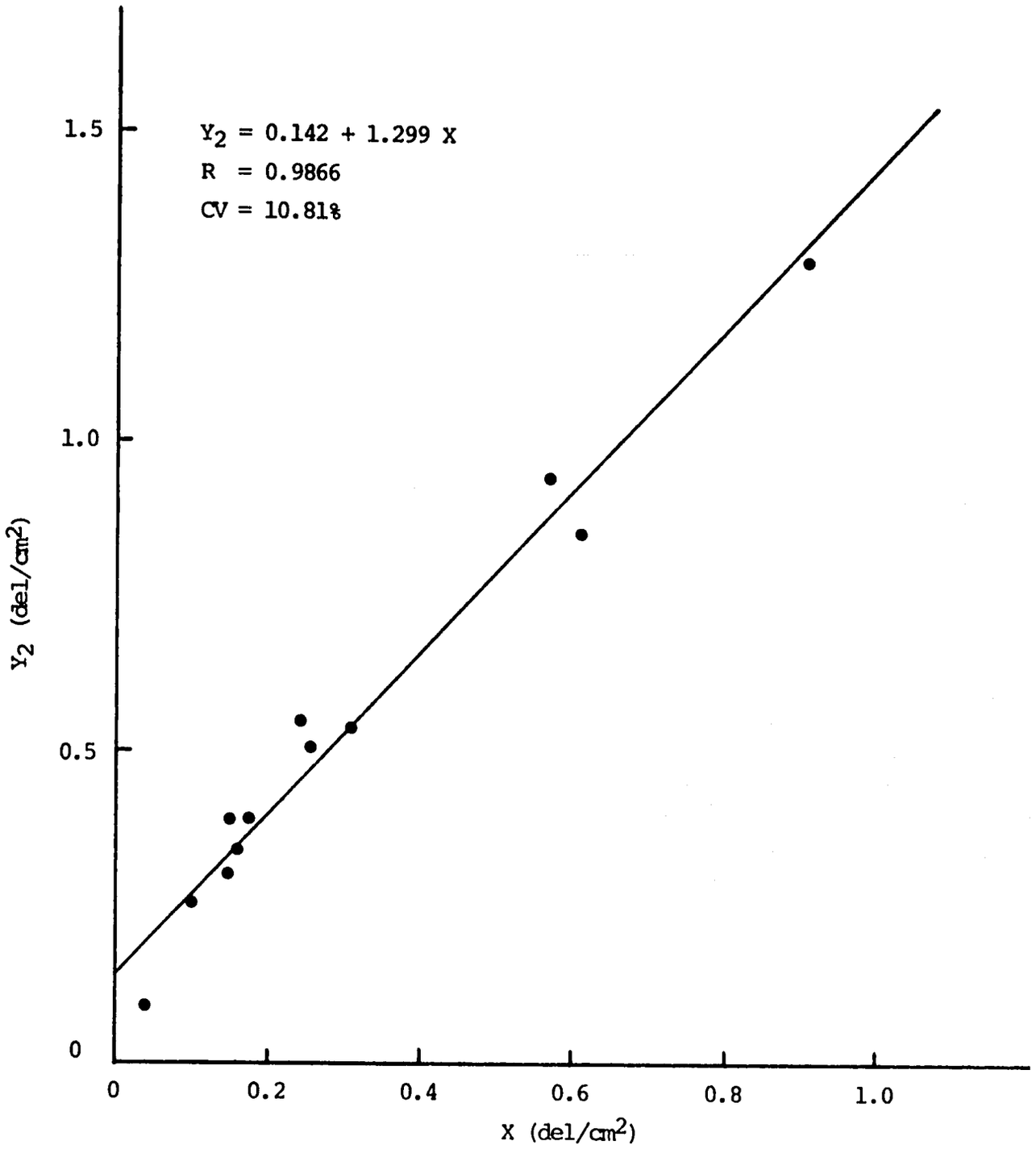

Figure 4. Relationship between X and Y_2.

of delineations per unit area (X) is given in Figure 5. The graph for the average of the straight line transect determinations (Y_6) and X is presented in Figure 6. It is interesting that not only did both Y_3 and Y_6 correlate best with the logarithmic transformation of X, but the most important statistical parameters (the regression equations, R values and coefficients of variation) were also almost identical for the two graphs.

SPECIAL TEST

Five replicates of each of the different types of determinations were made in a 10 cm x 10 cm "mini-map" on a part of a map sheet with an extremely high intensity and a very conspicuous "fibrous" type of soil pattern due to the presence of numerous small rivers. Estimated values for X were calculated using the regression equations given in Figures 3-6. These estimated values of X were also expressed as percentages of the actual directly determined value of X to get an indication of the accuracy of the different methods for this exceptional case. The results are summarized in Table 4. (Note: A 10 cm x 10 cm "mini-map" was used because a 15 cm x 15 cm one could not be fitted into the specific corner of the map sheet.)

Table 4. Relationships between actual map density and estimated map densities for a special type of map.

METHOD	AVERAGE VALUE	Xe † (del/cm^2)	$\frac{Xe}{X}$ x 100
X	1.09 del/cm^2	-	-
Y_1	1.92 del/cm^2	1.225	112.4%
Y_2	1.52 del/cm^2	1.061	97.3%
Y_3	3.56 del/cm	± 60	± 5500%
Y_6	2.86 del/cm	± 15	± 1400%

† Xe = X estimated by means of regression equations

From Table 4 it is evident that the two methods of counting the number of delineations in a circle gave very good estimates of the actual number of delineations per unit area despite these facts: the delineations had such exceptional patterns and a different size "mini-map" was used as reference.

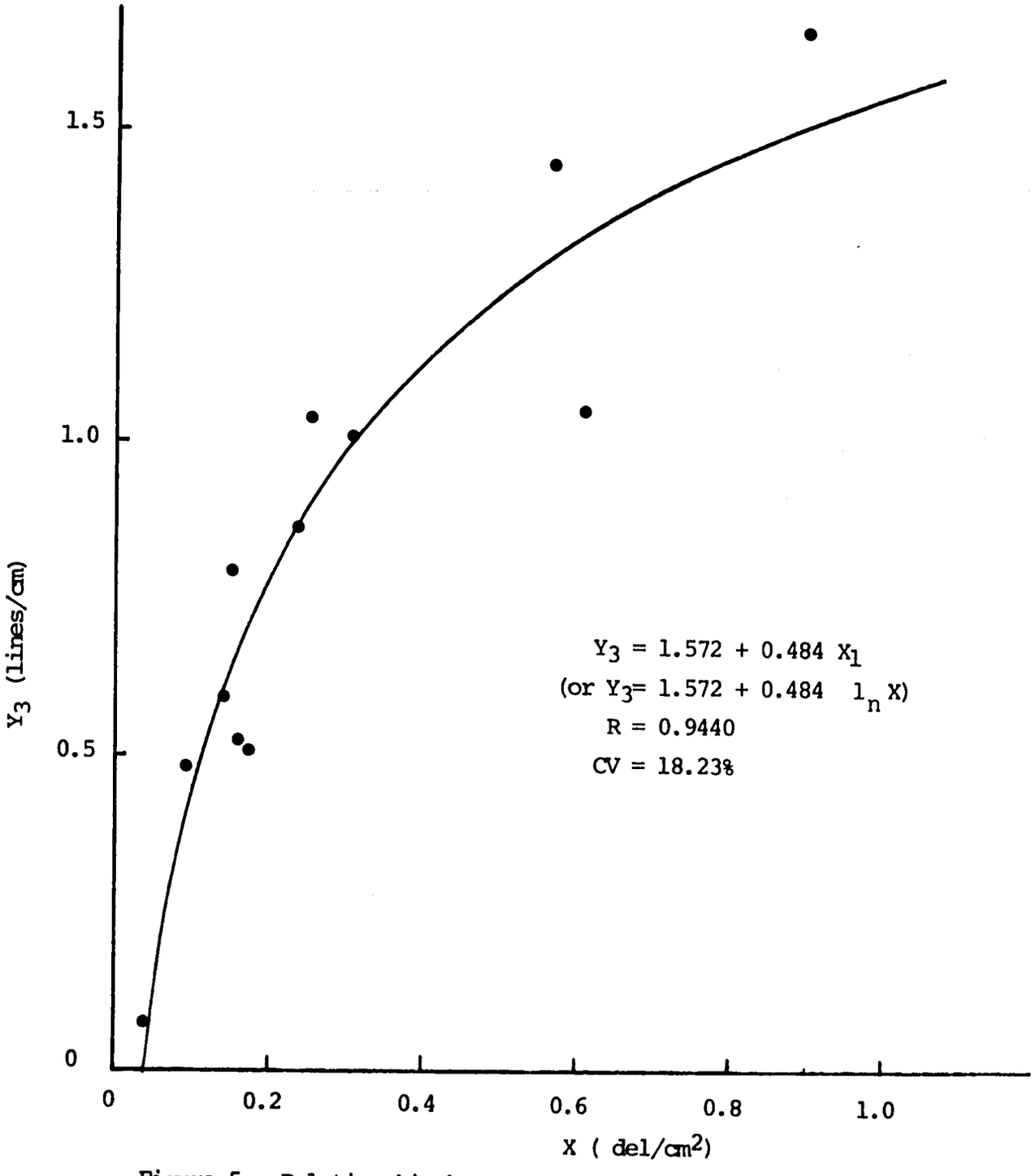

Figure 5. Relationship between X and Y_3.

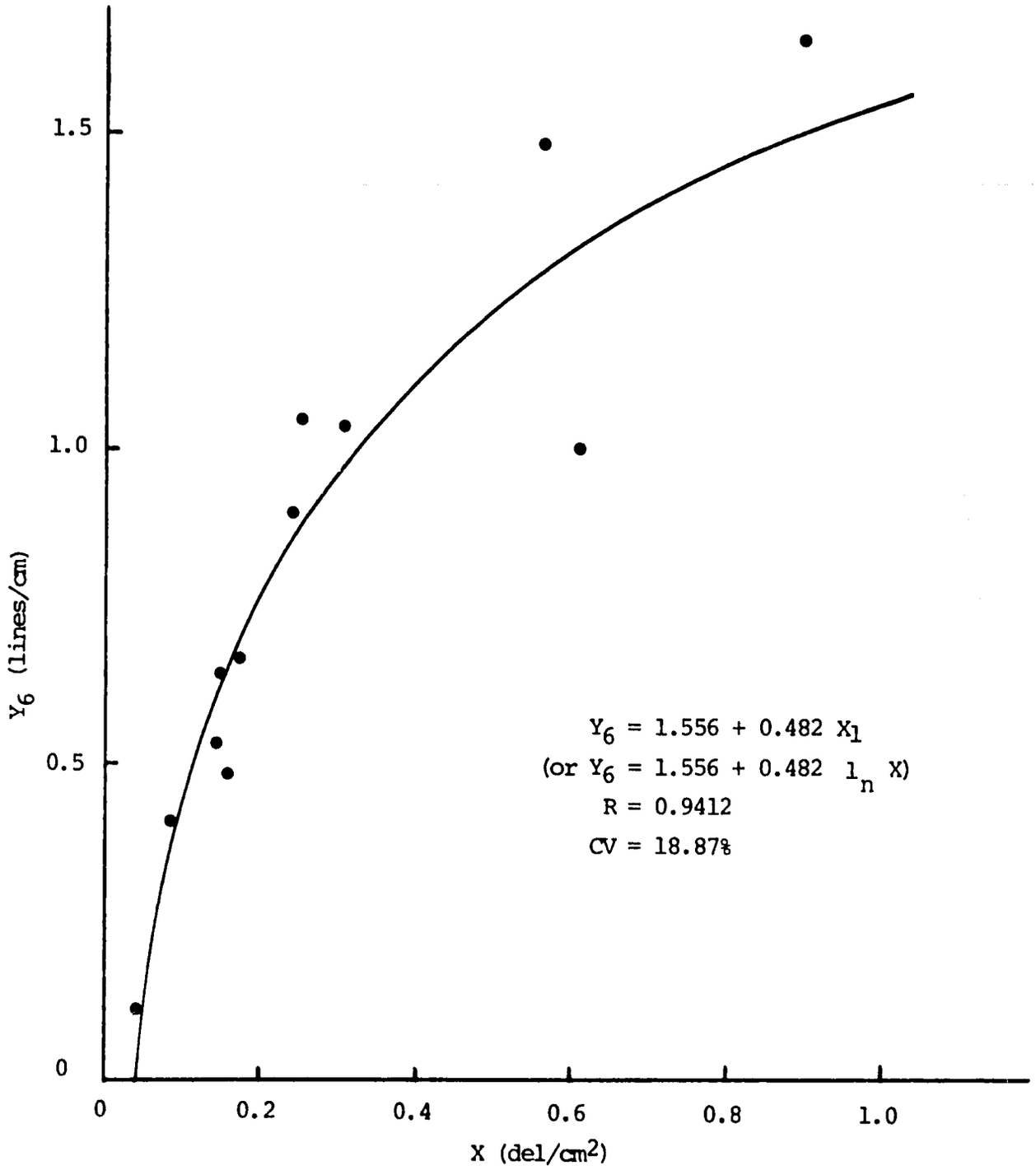

Figure 6. Relationship between X and Y_6.

Neither the circular line transect nor the straight line transect could give any indication of the actual map intensity for this type of map. In this case the linear regressions for these methods would actually give much better predictions for X, overestimating it "only" by 89 percent (Y_3) and 50 percent (Y_6), respectively.

RECOMMENDATIONS

In view of the results obtained for the correlation study, as substantiated by the special test, it is recommended that the number of delineations in a 2.5 cm radius circle are counted to calculate the actual number of delineations per unit area (or map intensity) for a soil map. It was found that it is easier to count every delineation that is encountered in the circle than to count those areas which form parts of the same larger delineation only once. Therefore, it is recommended that all delineations, or parts of delineations, in the circle are counted separately as they are encountered (Method Y_1).

It is recommended that ten random circle counts be made for each map sheet (or each intensity area in the case of multi-intensity maps) and that the average of these counts be used for further computations. To randomize the ten circle positions, the map sheet must be subdivided into a number of blocks of equal size. Useful block sizes range between approximately 100 cm^2 to 150 cm^2. Blocks demarcated by coordinate lines on the map or formed by the folding of the map can be used. These blocks are then numbered and ten blocks are selected randomly.

The circle counts are then made for each selected block in turn. The positioning of the circle in each block is done as follows: The circle (drawn on transparent paper) is held a few cm above the center of the block. It is then lowered onto the map sheet while looking away. The circle must not be shifted after it has been put down. These steps are intended to avoid conscious selection of certain map intensities or types of soil patterns.

The actual number of delineations per cm^2 on the soil map sheet is then calculated by means of Equation (1):

$$n = (0.0353\ AN - 0.106)\ del/cm^2 \qquad (1)$$

Where n = actual number of delineations per cm^2 on the published map sheet, and

AN = average number of delineations per circle.

Equation (1) was derived by combining Equations (2) and (3).

Equation (2) gives the average number of delineations per cm^2 in the circles:

$$y = \frac{AN}{19.64} \text{ del/cm}^2 \qquad (2)$$

Where y = the average number of delineations per cm^2 in the circles,

AN = the average number of delineations per circle, and

19.64 = the area of a circle with a radius of 2.5 cm (in cm^2).

Equation (3) is the regression equation which gives the relationship between the average number of delineations per cm^2 in the circles and the actual average number of delineations per cm^2 on the map:

$$n = (0.693y - 0.106) \text{ del/cm}^2 \qquad (3)$$

Where n and y are as in Equations (1) and (2). (This equation is another form of the equation given in Figure 3.)

Equation (1) is obtained by substitution of Equation (2) into Equation (3):

$$n = (0.693y - 0.106) \text{ del/cm}^2 \qquad (3)$$

$$\text{but } y = \frac{AN}{19.64} \text{ del/cm}^2 \qquad (2)$$

$$\text{therefore, } n = (0.693 \frac{AN}{19.64} - 0.106) \text{ del/cm}^2$$

$$\text{thus } n = (0.0353 \text{ AN} - 0.106) \text{ del/cm}^2 \qquad (1)$$

Piech (personal communication) tested the validity of this method for an actual average size map sheet (instead of a "mini-map," as was used in the development of the method). By counting all the delineations on the whole map sheet, she found an average of 0.424 del/cm^2. By using the recommended circle method and Equation (1) she found an average of 0.448 del/cm^2. This represents a difference of only 5.7 percent.

The average number of delineations per cm^2 in the circle (y) may never be used instead of n as a shortcut, because this will give completely incorrect results. In the example tested by Piech (personal communication) y was 0.80 del/cm^2, which over-estimated the actual number of delineations per cm^2 on the map by almost 89 percent.

Equation (1) can only be used if the following conditions are observed:

1. A circle with a 2.5 cm radius must be used. Circles with other radii will require other equations.

2. The number of delineations must be counted according to method Y_1.

3. Results must be expressed in terms of delineations per cm^2 on the published map.

4. AN must not be lower than 5.75 delineations per circle (y must not be lower than 0.300 del/cm^2). In other words, Equation (1) is not valid for maps with very low map intensities. This is because the size of the circle becomes a limiting factor on maps with such large delineations.

If AN is smaller than 5.75 delineations per circle, then Equation (4) is used to calculate n:

$$n = (0.0299\ AN + 0.164)^2 \qquad (4)$$

Equation (4) is based on the regression equation describing the quadratic relationship between n and y (i.e. the relationship between X_2 and Y_1, see Tables 1 and 3).

In the case of maps with extremely low map intensities, i.e. where AN is smaller than 2.00 delineations per circle (y is smaller than 0.100 del/cm^2), it will be more correct and easy to count the actual number of delineations on the whole map rather than to use the indirect circle method.

Applications of n

All other parameters related to map intensities are calculated using n as the basis. These parameters include (i) average-delineation, (ii) map texture intensity, (iii) map index of maximum reduction, and (iv) minimum scale of reduction. These were discussed by Eswaran, Forbes, and Laker (this volume).

Received 6/23/77.

SESSION VI

Tuesday afternoon, April 5, 1977

SOIL PROPERTIES IMPORTANT FOR GIVEN LAND USES

Chairman: A. J. Smyth

Speakers

K. J. Beek	-	The Selection of Soil Properties and Land Qualities Relevant to Specific Land Uses in Developing Countries
J. Kubota	-	Role of the Soil Survey in Trace Element Studies
R. Protz	-	Soil Properties Important for Various Tropical Crops: Pahang Tenggara Master Planning Study
P. Ph. Antoine	-	Soil Properties and the Use of the U. S. *Soil Taxonomy* in Northern and Western Africa

THE SELECTION OF SOIL PROPERTIES AND LAND QUALITIES RELEVANT TO SPECIFIC LAND USES IN DEVELOPING COUNTRIES

Klaas Jan Beek[1]

Soil information can play an important role in solving land use problems that farmers face in developing countries. To make a significant contribution, data collection, which is necessarily a selective process, has to be problem-oriented. The soil properties that should receive attention will depend on the existing land use problems, the detail of the study, and the criteria for optimal land use. The most common criteria for optimal land use are favourable input-output relationships and conservation of the environment (the latter in terms of sustained production capacity and environmental quality).

In developing countries we usually meet with a technological transformation continuum: modern and traditional land use operate side by side, sometimes linked by land uses characterized by so-called intermediate technologies. If we focus our attention on the more traditional types of land use and the possibilities for their development, we should recognize another, probably overruling criterion for optimal land use: minimal risk.

MINIMAL RISK IN DEVELOPING AGRICULTURE

Traditional agriculture aims at minimizing risks to assure a continuous food supply, often of a low nutritional standard, for the family. Traditional land use represents a (precarious) balance between the productive capacity of the land and the production means of the rural family. It is a closed system, virtually without capital inputs, occasionally shaken by episodic hazards.

Population pressure may upset the balance of these systems. The result is often a degradation of the quality of the land, and social disaster. Soil survey in developing countries is expected to contribute to solving such problems. Sometimes, new areas of suitable land can be identified for settlement, but mostly there will be a need for the introduction of land use changes leading to intensification, based on capital inputs (especially for plant nutrients and water). Properties studied by soil survey should therefore be relevant, not only for an

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assessment of the soils under present management, but also for predicting their response to specific inputs such as fertilizer, irrigation water, new farm equipment, etc. The introduction of such inputs in traditional agriculture has often resulted in disappointment; the traditional dependence of the small farmer on the natural environment is replaced by dependence on the commercial environment, accompanied by new, and sometimes fatal, factors of risk and uncertainty.

Obviously, soil survey has a responsibility to provide the information necessary to minimize the risks of a developing agriculture in its early, most vulnerable stages; the introduction of fertilizers needs an assured minimum effect, and the certainty that the cost can be repaid. The introduction of a more advanced plow should be made in a period when the moisture conditions of the topsoil (its "workability") permit its use. New seeds should be sown when the aeration, moisture, and temperature conditions are ideal for germination.

In developed countries, soil management and engineering can rely on high level research facilities and experience. In the Netherlands, for instance, an analog simulation model of the non-steady unsaturated flow of moisture has been developed to predict the moisture tension of the topsoil during springtime (Wind, 1976), an essential piece of data for the timing of field operations. The model also permits simulation of different tile-drain spacings and depths for optimizing the drainage conditions. Such a model can be most valuable for land use planning, reducing the risk and uncertainty related to the timing of plowing, seed-bed preparation, sowing, etc. It could be applied to land use problems in developing countries if the necessary data were made available: rainfall data for a long enough period, evaporation, runoff, infiltration rate, and moisture characteristics of the soil.

The model is based on the following relationship between soil moisture tension and capillary conductivity: $k = k_o e^{a\Psi}$.

k = capillary conductivity (cm day^{-1})

k_o = capillary conductivity at zero suction

Ψ = moisture suction topsoil (cm) = -300 cm in top 5 cm (workability limit)

a = soil parameter

$k = 2.78e^{0.035\Psi}$ ($\Psi > -300$ cm)

$k = 0.225^{-1.4}$ ($\Psi < -300$ cm)

The nutrient status of the soils of many traditional farmers has probably decreased to the point where additional inputs are essential. But, for continuous croppers, the risk of reducing the acreage under food crops may be too high to compensate for

the mathematically proven advantages of including legumes in their crop rotation. Of course, shifting cultivators will be able to introduce green manures (in addition to the naturally occurring species) in their fallow land, without much additional risk.

PROBLEM-ORIENTED SOIL SURVEY

Data collection in soil survey is guided by standards that traditionally aim in the first place to solve soil classification problems. This paper is more concerned with the solution of land use problems, which requires a more complex body of information of which soil data is an essential part.

Even in reconnaissance soil survey, the main land use problems and development options are recognizable. Instead of standardized data collection for a high category of soil classification, it snould be possible to collect some additional data such as infiltration capacity of sloping land occupied by traditional farmers, hydraulic conductivity of poorly drained bottom lands, pF values, data about aggregate stability, etc. Indeed, reconnaissance soil survey in Brazil includes collecting compound samples for soil fertility analysis. However, few soil survey manuals deal with specific purposes: the draft edition of FAO on soil survey investigations for irrigation is an exception (FAO, 1974).

FAO (1976) recently published a *Framework for Land Evaluation*, which explains the concepts and procedures of land evaluation for specific purposes. The procedures include a preparatory phase of interdisciplinary consultation or problem analysis where the more relevant land use possibilities or land utilization types are identified in terms of produce, technological level, management, scale of operations, capital, and labour intensity. The detail of such definitions will correspond with the intensity of land evaluation. The preparatory phase should also provide us with the already mentioned criteria for land evaluation and optimal land use planning (FAO, 1975).

Supposing that we are able to identify the relevant land utilization types for our target group -- the poor farmer -- then the next step should be to collect the pertinent information. The objectives of land evaluation as defined by FAO obviously refer to a broader information base than soils alone, but this should not discourage us.

Soil Data and Fundamental Land Use Processes

When collecting soil data to solve land use problems of farmers in developing countries we must be fully aware of the farmer's soil-dependent activities. We should be able to concentrate on the fundamental processes and activities of the specific land use system (or land utilization type) and the role of measurable soil properties in these processes.

The question arises whether it will be possible, or realistic, to study soil properties in the light of fundamental land use processes. This depends on our interpretation of the term *fundamental*. For a biologist (de Wit et al., 1974), photosynthesis, respiration, and transpiration are fundamental processes. He may try to simulate, for instance, plant root growth as a function of variables such as soil temperature and soil oxygen, measured hourly or daily. Such precision may be possible in a program of meteorological data collection but not in soil survey. On the other hand, parametric methods which translate a set of measurable soil properties directly into expressions of productivity or suitability, based on correlations found statistically, pay little attention to the fundamental processes that take place. It seems that we should strike a balance between these two extremes.

To achieve this, land use (which is a continuous process) will first need to be subdivided into a number of specific activities for finite time periods, each with its own land demands and therefore possibly limited by one or more soil properties. A kind of check list of activities could be:

land preparation — irrigation
sowing — drainage
fertilization — germination
phytosanitary practices
vegetative development (roots, stems, leaves)
early vegetation growth (roots, stems, leaves)
rapid vegetation growth (roots, stems, leaves)
generative development (sexual: flowering, fruit and seed development, ripening and dissemination of seed; asexual: buds, layering, bulbs, tubers)
harvesting — fallow (rotations)
survival (perennials) — maintenance (e.g. ditch cleaning)
engineering (installation of irrigation and drainage systems, etc.)

Relating these activities to the various environmental regimes (energy, water, gas, biotics, nutrients, hazards, foothold, toxic elements) of the diverse strata of the environment (off ground, near ground, ground surface, soil, deeper sub-strata, or geophysics) should give us a first impression of which environmental regimes need careful examination. A problem, of course, is how to measure the time-variable regimes, and as far as this paper is concerned, the soil regimes. We may have to go to great lengths, by constructing an analog model mentioned earlier, to characterize a non-steady-state regime. Research, in its effort to construct sophisticated analog and computer simulation models, sometimes forgets that some concrete analog models may still be found in nature; the natural vegetation and present land use can reveal much of how hypothetical land use alternatives may be expected to perform. A good example from Brazil is the interpretation of the natural forest vegetation in terms of water availability (Bennema, Beek, and Camargo, 1964). Another example is the use of the natural vegetation as an indicator of soil permeability and soil salinity (Risseeuw, 1972).

The soil surveyor is in the exceptional position of being able to observe and correlate such phenomena to refine the prediction of soil behaviour under specific uses. He will need this ability, because soil surveyors will be increasingly asked to study soils with complex utilization problems; agriculture is now extending into areas of problem soils (e.g. heavy clays, acid sands, acid sulphate soil) that defied cultivation until recently.

Another problem arises when soil of low or medium potential is used in the absence of an alternative. Often the land of poor farmers in the humid tropics is located on steep but fertile slopes which, according to U.S.D.A. standards of land capability, should be reserved for forestry. In such marginal situations imaginative data analysis is needed, because classification in terms of "impossible" or "unsuitable" cannot change the situation. However, last year on two occasions our Institute had no other alternative but to advise against project development: the settlement of poor farmers on acid sands in the Western Province of Zambia, and on aluminum-saturated Ultisols in Indonesia. Decision-makers may not accept the conclusions of soil scientists, as happened with the land settlement on extremely poor kaolinitic Oxisols along the Trans-Amazon Highway in Brazil. However, the cost of a careful determination of soil properties is justified, even if the final conclusion should be negative.

Land Qualities

It is difficult to characterize the soil regimes affecting agricultural processes: water, nutrients, gas, biotics, foothold, toxicities, and mechanical strength. It is also difficult to measure the soil conditions that affect successful management operations and response to physical input. However, for the interpretation of soil information, attempts should be made to synthesize the relevant measurable soil properties into assessment factors that have a specific influence on these processes and activities. Therefore the concept of land quality has been developed.

A *land quality* can be defined as a component regime of the physical land conditions with a specific influence on land use performance. "Each land quality acts in a manner distinct from the actions of other land qualities in influencing the suitability of land for a specified kind of land use" (FAO, 1976). Kellogg introduced the term *soil quality* in 1961 for a similar concept, perhaps more in line with the subject of this workshop.

The following examples (from Beek and Bennema, 1972) illustrate different types of land qualities:

1. *Major land qualities related to plant growth:* availability of water, nutrients, oxygen for root growth, and foothold for roots; conditions for germination (seed bed, etc.); salification and/or alkalinization; soil toxicity or extreme acidity; pests and diseases

related to the land; flooding hazard; temperature regime (including incidence of frosts); radiation energy and photoperiod; wind, storm, hail, snow, and air humidity as affecting plant growth; and drying periods for ripening of crops and at harvest time.

2. *Major land qualities specifically related to animal growth:* hardships due to climate; endemic pests and diseases; nutritive value or toxicity of grazing land; resistance to degradation of vegetation and soil erosion under grazing conditions; availability of drinking water; and accessibility of the terrain.

3. *Major land qualities related to natural products extraction:* presence of valuable wood species, fruits, game for meat and/or hides, medicinal plants and/or other vegetative extraction products; and accessibility of the terrain.

4. *Major land qualities related to practices in plant production, animal production, or extractions:* possibilities of mechanization, resistance to erosion; freedom in the layout of a farm plan or a development scheme, including the freedom to select the shape and size of fields; trafficability from farm to land; and vegetation cover in terms of favorable or unfavorable effects for cropping.

There is still much to be achieved in the quantitative measurement of land qualities. They are usually ranked on an ordinal scale, using threshold values to distinguish different levels. In Brazil, land qualities have been used since the reconnaissance soil survey of São Paulo (Lemos et al., 1960). Even night frost, a hazard to coffee-growing, was considered. Since then a data bank with a highly efficient reporting system has been set up in São Paulo. Although its use for predicting episodic hazards is still limited, the computer can print out maps of the effect of night frost on coffee plantations the day after the frost has occurred.

The concept of land quality is currently in use in FAO projects (Philippines, Indonesia, Sudan, Thailand) and in Netherlands bilateral technical assistance programs (Kenya, Portugal, Colombia). In the Netherlands too, the concept has been recognized and is now being developed for soil survey interpretation (Table 1). Although most of the soil properties that contribute to land quality are measured on a ratio scale, the land qualities themselves are mostly rated on an ordinal scale: high - medium - low - very low. Appendix I includes seven references to literature about land evaluation, which in one way or another incorporate the concept of land quality in their methodology.

The land quality concept represents a component regime or subsystem of the environment and has a known influence on the basic processes that control land use performance. When measuring and rating land qualities it will be useful to distinguish those threshold values of component properties that are pertinent for the use in question, e.g. in soil salinity, soil fertility, erosion hazard. For example, the limit of 300 cm H_2O moisture

Table 1. Land qualities or "site conditions" in the Netherlands soil survey interpretation methodology.

Site conditions	Regarded as relevant for				Levels or gradations		Desired level determined	Refers to		Nature of conditions	
	arable farming and hortic.	pasture production	forestry	recreation	recognized	quantitatively expressed		basic processes	management system	chemical	physical
Drainage status	x	x	x	x	x		x	x			x
Moisture supply	x	x	x	x	x		x	x			x
Workability	x				x		x		x		x
Structural stability	x				x		x		x		x
HCl-reaction/ lime content	x				x	x	x	x		x	x
Bearing capacity		x			x	x	x		x		x
Spring earliness	x	x			x		x		x		x
Nutrient status			x		x		x	x		x	

Source: Gibbons and Haans, 1976, Table 3.

suction in the top 5 cm of the soil during one week is an example of a threshold value for the land quality workability in springtime in the Netherlands (Wind, 1976). The threshold value will depend on the type of land utilization. When recommending sugar beet production, the moisture suction value of the top 5 cm of the seedbed must be known; but for potatoes, the moisture condition of the top 7 cm of soil is required. For grain production, the information is required for only a few centimeters depth, as these seeds require a shallow seedbed.

Land qualities can be described and rated independently to express the status of component regimes of the environment during a particular time period. But the significance of these ratings and of the threshold values of component properties will depend on the knowledge of the specific land requirements of the use in question.

The kind of land use and the objectives of land use determine which land qualities are limiting and to what degree. The constraining effect of such land qualities will need to be assessed first for the already mentioned time-discrete land use processes and activities, and after that, by means of some kind of integration or critical path analysis, for the whole sequence of time-overlapping land use processes.

LAND QUALITIES, LAND IMPROVEMENT, AND LAND EVALUATION

Land qualities can provide a link between land resources inventories and land use planning by identifying the properties that merit observation, measurement, and classification and by suggesting the detail, in terms of number and density of observations, that is required. We measure only the essential qualities of the land so they can be used as independent determinants of the land quality-dependent effects or "outputs" resulting from a specific use of the land in question. Similarly to land qualities, these outputs are also often measured on an ordinal scale: e.g. very high, high, medium, low, or very low yields; high, medium, low, or very low soil erosion losses.

The relationship between certain levels of land qualities and the corresponding outputs to be expected if used for a certain utilization type can be presented in conversion tables (Table 2). These tables must relate each kind of output to land qualities that determine the output. Principal component analysis is useful for analyzing the influence of land qualities on the output (Bastide and Goor, 1970).

Land Quality/Output Relationships

Often, a graphical presentation or "production function" is preferred to present the LQ/Y relationship. For this purpose, the multi-dimensional land quality vector is subdivided into a number of significant trajects according to values representing critical or "threshold" levels for the use in question, e.g. critical levels of soil salinity, nutrient status, or moisture

Table 2. Conversion table to convert land qualities to land suitability.

Y = outputs:

e.g

Y_y = yield

Y_e = soil erosion losses

Y_s = soil salinization

	0–1	1–2	2–3	3–4	4–5	5–6
I					LUT_1	
II				LUT_1		LUT_2
III			LUT_1			
IV	LUT_1 LUT_2	LUT_1 LUT_2	LUT_2	LUT_2		

LQ = Land Quality, e.g.

LQ_e = resistance to soil erosion

LQ_w = water availability

LUT_1 = Land Utilization Type 1

LUT_2 = Land Utilization Type 2

I-II-III-IV = output classes

0-1-2-3-4-5-6 = threshold values of land qualities used for distinguishing output classes

conditions in the topsoil. Sometimes there will be only one critical level; sometimes there will be several, each corresponding with a different level of output. The choice of the number of levels of land qualities is free.

The land demands of the land utilization type determine the curvature of the function expressing the LQ/Y relationship. Thus, the same amount of available water (LQ_w) during a finite time period Δt can be more limiting for the yield Y_y1 of one crop (land utilization type 1) with water requirements a_w1 during that particular period, than for the yield Y_y2 of another crop (land utilization type 2) with water requirements a_w2 during that same period. Similarly, the same erosion susceptibility LQ_e during a finite time period Δt can lead to higher soil erosion losses Y_e1 when used for one crop (land utilization type 1) with erosion resistance demands a_e1 than for another crop Y_e2 (land utilization type 2) with erosion resistance demands a_e2. The values taken by a_w and a_e are parameters of the output/land quality relationships: $Y_{(LUT,LU)} = F(LQ_{(LU)}, a_{(LUT)})$

Land Evaluation

One of the most critical aspects of land evaluation is the availability of information about the specific land demands, i.e. the values of the parameters of the types of land utilization under consideration. Most literature about the land requirements of tropical crops is vague about this.

The LQ values assumed for predicting the outputs Y_y, Y_e, etc. correspond with the levels of land quality resulting from management, improvement and conservation practices applied within the range of possibilities defined for the land utilization type in question.

However, land evaluation is often required to include an explicit assessment of the effects of specific physical input for management, improvement and conservation of the land qualities on land use performance; in other words, to analyze input-output relationships: $Y = F(LQ,I)$ in which

I = physical inputs for the manipulation of LQ

The ultimate goal of analyzing such input-output relationships, first in physical terms and subsequently in economic terms, is to select the optimal levels of output with a specification of the corresponding inputs. The meaning of "optimal" depends on the objectives and derived criteria of land use planning and development.

The land quality concept could be useful as an intermediate variable for analyzing the relationships between physical inputs

for the management, improvement, and conservation of land resources and the effects or "outputs" to be expected from such inputs.

Systems analysis approach. Instead of an empirical site-specific analysis which ignores the underlying processes that control such input-output relations, I have proposed a more fundamental method of analysis, in a report to be published by ILRI in the latter part of 1977. In this study I attempted to introduce systems analysis in a staged multidisciplinary land evaluation procedure (Figure 1).

During the first stage *(problem analysis)* of the procedure the most relevant land use options or land utilization types are selected and provisionally defined. These land utilization types (LUT) have a strong influence on the kind and detail of data to be collected during the second stage (the *descriptive systems analysis*). Basically, two closely related systems are described: the land system and the land use system. In the light of the information produced during the description of the land system, the definitions of the land use systems or land utilization types are refined. Special attention is paid to the exact land demands of the land use during finite time periods in relation to each land use process or activity. The third stage is the stage we are most concerned with in this paper: *operational systems analysis*. Now a specific land use system is superimposed upon a particular land system, and its sequence of activities is simulated in order to predict the combined effects to be expected if this land use system were to act on this particular kind of land.

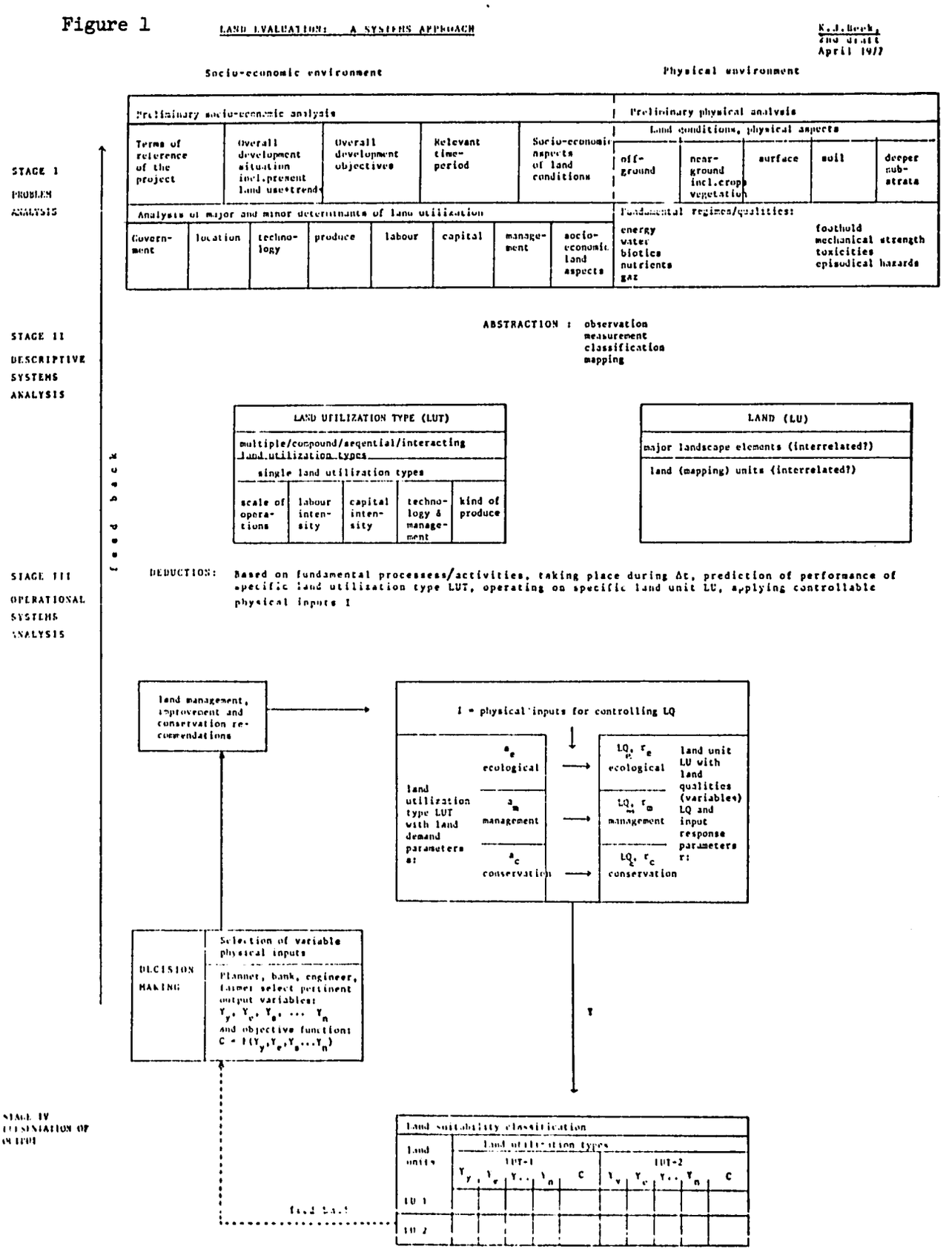
Since the land qualities of the land system comprise all component regimes of the physical environment, including such dynamic components as radiant energy and rainfall, the only additional physical inputs to the system are those applied for management, improvement, and conservation of the land system. These physical inputs represent the operational variables of the data analysis. Their value must be selected in such a way that the outputs take values that are closest to the objectives of the decision-makers (the planners, the bankers, the engineers, the farmers). The essence of stage three, operational data analysis, is the analysis of input-output relations and their optimization, based on fundamental processes taking place during finite time periods. Basically the data-analysis consists of two steps:

(1) land quality/output analysis
(2) input/land quality analysis

By combining (1) and (2) it becomes possible to carry out:

(3) input/output analysis.

Figure 1


LAND EVALUATION: A SYSTEMS APPROACH
K.J.Beek, 2nd draft April 1977
Socio-economic environment
Physical environment
STAGE I
PROBLEM ANALYSIS
Preliminary socio-economic analysis
Terms of reference of the project
Overall development situation incl.present land use+trends
Overall development objectives
Relevant time-period
Socio-economic aspects of land conditions
Preliminary physical analysis
Land conditions, physical aspects
off-ground
near-ground incl.crops vegetation
surface
soil
deeper sub-strata
Analysis of major and minor determinants of land utilization
Government
location
techno-logy
produce
labour
capital
manage-ment
socio-economic land aspects
Fundamental regimes/qualities:
energy
water
biotics
nutrients
gaz
foothold
mechanical strength
toxicities
episodical hazards
STAGE II
DESCRIPTIVE SYSTEMS ANALYSIS
ABSTRACTION : observation
measurement
classification
mapping
LAND UTILIZATION TYPE (LUT)
multiple/compound/sequential/interacting land utilization types
single land utilization types
scale of opera-tions
labour inten-sity
capital inten-sity
techno-logy & manage-ment
kind of produce
LAND (LU)
major landscape elements (interrelated?)
land (mapping) units (interrelated?)
feed back
STAGE III
OPERATIONAL SYSTEMS ANALYSIS
DEDUCTION: Based on fundamental processes/activities, taking place during Δt, prediction of performance of specific land utilization type LUT, operating on specific land unit LU, applying controllable physical inputs I
land management, improvement and conservation re-commendations
I = physical inputs for controlling LQ
land utilization type LUT with land demand parameters a:
a_e ecological
a_m management
a_c conservation
LQ_e, r_e ecological
LQ_m, r_m management
LQ_c, r_c conservation
land unit LU with land qualities (variables) LQ and input response parameters r:
DECISION MAKING
Selection of variable physical inputs
Planner, bank, engineer, farmer select pertinent output variables: Y_y, Y_e, Y_s, ... Y_n and objective function: $C = f(Y_y, Y_e, Y_s ... Y_n)$
Y
STAGE IV
PRESENTATION OF OUTPUT
Land suitability classification
Land units
Land utilization types
LUT-1
LUT-2
Y_y Y_e Y_s ... Y_n C
LU 1
LU 2
feed back

Land Quality/Output Analysis

$$Y_{(LUT,\ LU)}=F\{LQ_{(LU)},a_{(LUT)}\}$$

In a purely physical land suitability classification it would be difficult to bring the multi-dimensional output $\{Y_y, Y_e, Y_s...Y_n\}$ under a common denominator. Therefore, land suitability class distinctions will include criteria for each kind of output: expected yield, acceptable levels of erosion, salification, yield probability, etc. Commensuration of the multi-dimensional output into common (mostly monetary) terms is difficult and requires economic analysis, often based on mathematical optimization techniques and an objective function: $C=F\{Y_y, Y_e, Y_s,...Y_n\}$. The physical inputs (I) will usually be selected in such a way that the objective function (C) takes the most favorable value. But in physical analysis, especially at reconnaissance and semi-detailed levels of land evaluation, simpler methods of analysis would be preferred. A practical way of presentation is by using step-functions; this seems in line with the proposed methodology using land qualities and threshold values for their component properties (Figure 2).

To this end the output vector is subdivided into a number of trajects, to indicate the expected levels or "classes" of output of the land use, depending on the threshold values of the land qualities. Sometimes the planners have specified beforehand the levels of output (the significant production levels for class distinction, the acceptable levels of salinity of drainage water and soils, the acceptable levels of risk of failure or crop damage).

The integral effect of all combined outputs is summarized in a land suitability class. For practical reasons, the number of suitability classes does not usually exceed three or four.

Input/Land Quality Analysis

It will be necessary to distinguish between the levels of the unimproved land qualities: LQ_u, and the levels of the improved land qualities: LQ_i.

$$LQ_{i\ (LU)}=F\{LQ_{u(LU)},\ I,\ r_{(LU)}\} \qquad \text{(see Figure 3)}$$

I = variable physical inputs required for improving the land quality $LQ_u \rightarrow LQ_i$ of land unit LU, if used for a specified land utilization type LUT.

The physical inputs for management and conservation of LQ may also be included here, if a distinction between such inputs for different land units is considered to be relevant for the land suitability classification, e.g. a distinction in fertilizer

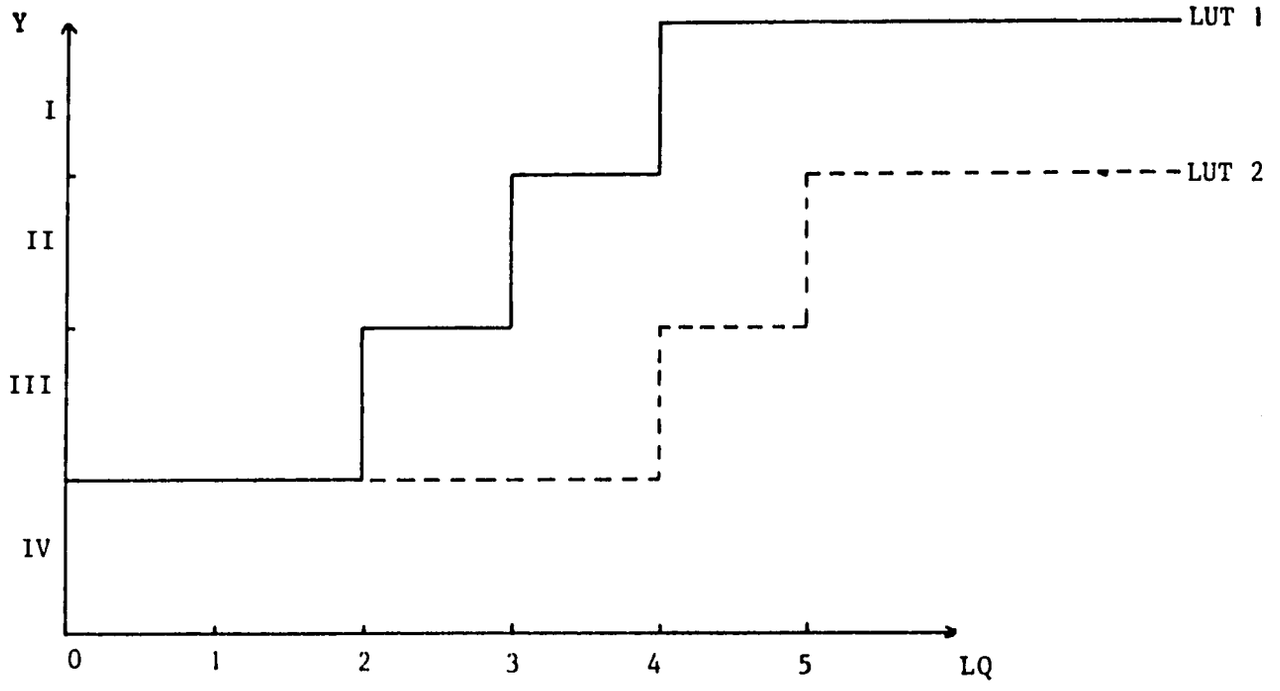


Figure 2. Step functions expressing output-land quality relation of two different land utilization types LUT_1 and LUT_2.

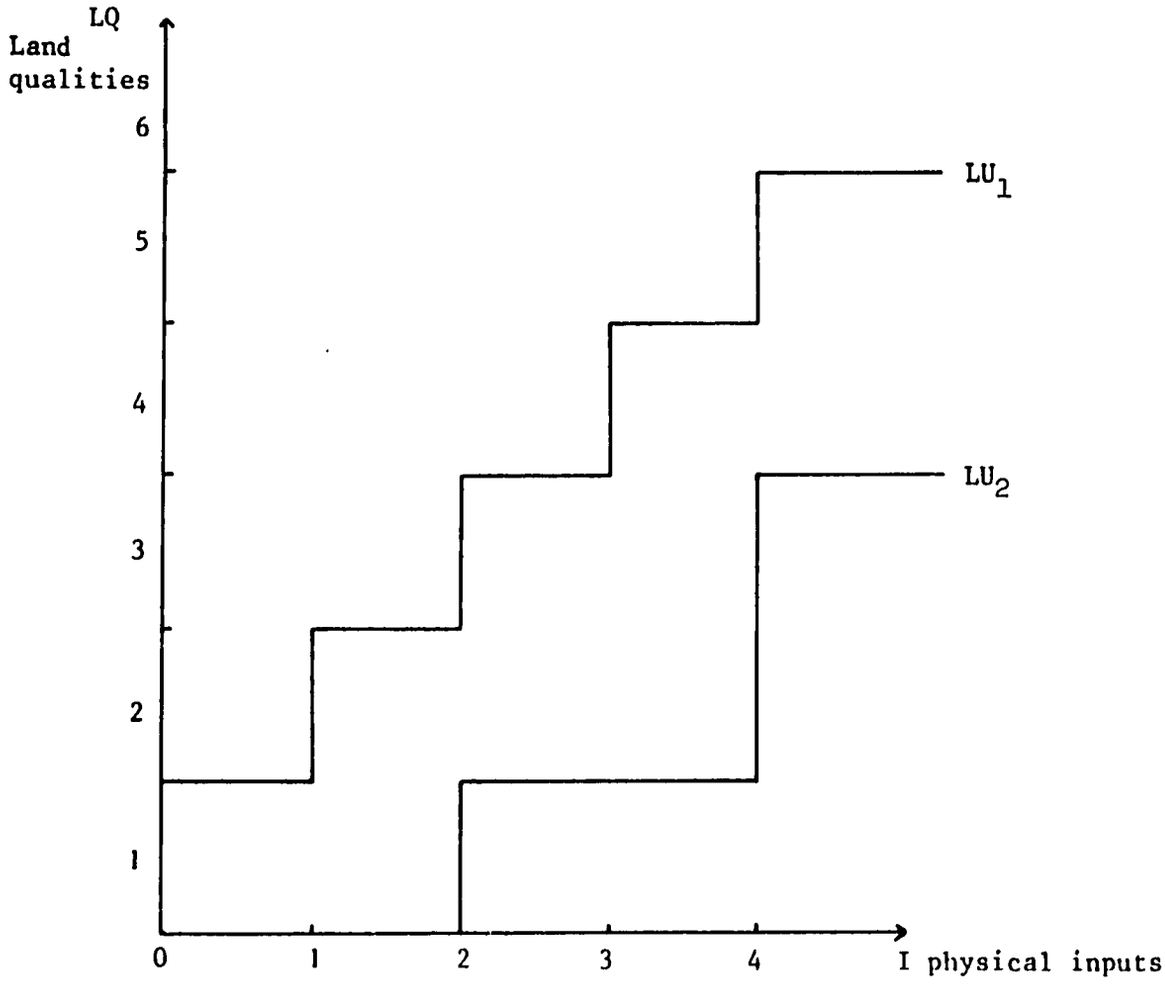


Figure 3. Step function expressing input-land quality relationship of two different land units: LU_1 with input response parameters r_1 and LU_2 with input response parameters r_2.

applications or in physical inputs for soil conservation. This may be pertinent for detailed land evaluation. But in many cases the input/land quality analysis will be restricted to the study of the effects of major land improvements (such as irrigation, drainage, deep plowing) on the levels of the land qualities. $r_{(LU)}$= input response parameters of the land unit in question. One land unit will show a different response to input applications from another; it has different irrigation water efficiency or a different response to fertilizers because of different soil properties (texture, organic matter content, cation exchange capacity).

Such response parameters of the land units have also been named "response land qualities" (Bennema, 1976). Although handled as parameters in this context, because the influencing soil properties may often be difficult to modify, the input-response parameters may be modified if their influence on land use is paramount (e.g. by applying organic waste or soil conditioners).

Input/Output Analysis

By combining the relationships found in (1) and (2) we arrive at the relationships:

$$Y_{(LUT,\ LU)}=F\{I_{(LUT,\ LU)},\ LQ_{u(LU)},\ a_{(LUT)},\ r_{(LU)}\}$$ (Figure 4)

CONCLUSION

Land evaluation should be able to analyze the relationships between the variable land qualities LQ, physical inputs I, and outputs Y on the basis of the underlying fundamental land use processes taking place during finite time periods. If this analysis can use exact information on the values of the input-response parameters of the land $r_{(LU)}$, and the land-demand parameters of the land use $a_{(LUT)}$, land evaluation should be able to make reliable predictions of outputs and corresponding physical inputs for specific types of land use acting upon specified kinds of land. Being based on fundamental land use processes and formal scientific laws, transfer of analogy in agricultural research will be enhanced; this is very important for developing countries.

Soil survey in developing countries needs to be oriented towards analyzing specific land use problems. The fundamental land use processes influenced by soil properties are important. These processes are controlled by simple chemical and physical variables such as N_2, CO_2, O_2, NO_3, and NH_4, which are unfortunately very difficult to predict in terms of measureable soil properties for finite time periods. To help overcome this problem the land quality concept has been introduced. It is "a complex attribute of land, which acts in a manner distinct

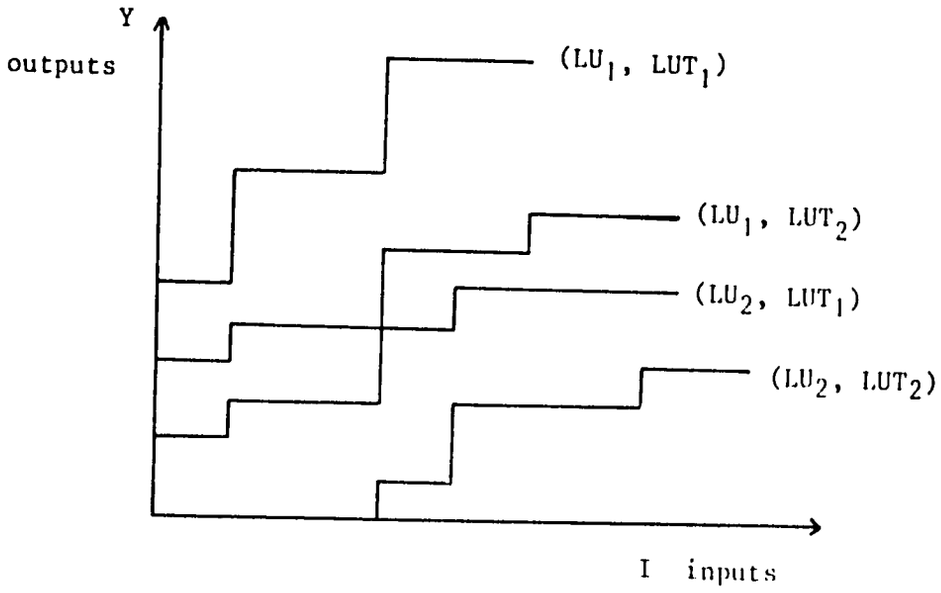


Figure 4. Step function expressing input-output relationship of two different land utilization types LUT_1 and LUT_2, acting on two different land units LU_1 and LU_2.

from the actions of other land qualities in its influence on the suitability of land for a specified kind of use" (FAO, 1976).

The land quality concept is in its early stages of development. If it can be developed successfully, the concept could serve several purposes:

- indication of soil properties deserving priority for study in soil survey;

- systematization of the soil surveyor's capacity to observe and interpret natural phenomena. Levels of some land qualities can be deduced directly from the present land use. Crops and natural vegetation stand model for the optimal land use systems as far as ecological processes and related ecological land qualities are concerned (Bennema, 1976);

- knowledge transfer to areas in developing countries with a poor data base for optimizing land use, because site-specific soil properties are synthesized into land qualities controlling fundamental land use processes; and

- improvement of the predictive value of land suitability classifications and the possibility of their periodical up-dating.

Vink (1975), in a book that gives a thorough treatment of land use in advancing countries and contains many references to soil survey and land evaluation, concludes that "the study of land qualities is an essential factor in the development of more complicated systems of land evaluation." However, a more fundamental approach to land evaluation should not necessarily be more complicated. Simplification will be possible if we succeed in mobilizing the soil surveyor's capacity for observing natural phenomena, by trying to measure (at least on an ordinal scale) some of the land qualities directly in the field. The soil drainage classes of the U. S. soil survey manual are an example. Also, in the Netherlands, soil surveyors have a special skill in the measurement of the soil permeability directly in the field on an ordinal scale, although there is a confirmed risk of discrepancies between ordinal measurements made by different individuals. Such measurements require correlation, calibration, and refinement with additional ratio scale measurements in the field and in the laboratory. Refinement of the techniques of interpretation of soil resources inventory data in general will give rise to critical questions about the accuracy of the data base [for example, concerning the variance in the measured soil properties and the degree of heterogeneity of soil/land (mapping) units]. These (mapping) units for planning purposes will be handled as homogeneous land areas with a homogeneous performance. Soil resources inventory reports need to be very explicit on this subject of variance versus accuracy.

Finally, I would appreciate hearing the opinion of the participants of this workshop regarding the prospects of develop-

ing the land quality concept further than has been achieved so far with the "limitations" of the land capability system, to provide a useful link between soil resources inventory and land use planning.

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ROLE OF THE SOIL SURVEY IN TRACE ELEMENT STUDIES

J. Kubota[1]

To some, giving consideration to trace elements at a Soil Resources Inventory Workshop directed towards developing countries may appear to be an exercise in futility, in view of the magnitude of problems in developing viable programs. Trace element studies portray an image of sophisticated laboratories and work on problems that emerge as management practices are intensified to attain higher yields.

In retrospect, many historically unproductive areas have been made productive as problems of trace element deficiencies or toxicities have been overcome. The best example is Australia. Here, broad expanses of land were considered destined forever as "inherently infertile." The transformation of such areas to productive croplands has been dramatic, often with only a few ounces or pounds of a trace element (Anderson and Underwood, 1959). Applying a few ounces of molybdenum with nitrogen and phosphorus to land earlier vegetated by harsh native scrub plants has created lush pastures. A significant fact was that the potential of lands "inherently infertile" greatly exceeded acreages then in cropland.

In the United States, a historical note is also evident in the case of cobalt deficiency. Early settlers in parts of the New England states lived with a problem of poor livestock production. Before its association with cobalt deficiency, this poor productivity was attributed to a curse placed by Indian chief Chocurua on the white settlers for the death of his son (Keener, Percival, and Morrow, 1954). Similarly, selenium toxicity has been an endemic animal nutrition problem in parts of the U.S. This fatal disease among cavalry horses was first described in 1857 by an Army veterinarian in the Nebraska Territory (Anderson, 1961, p. 2). Earlier yet, it seems likely that Marco Polo encountered the same problem as he led his animal caravan to China. Numerous other examples are cited by Beeson (1941).

Such historical reviews emphasize a need to identify factors associated with poor agricultural productivity. Trace element problems are soil-related and their recognition can lead to productive land use. Recognition of specific soil characteristics associated with specific trace element problems is essential. Information applicable to assessment of potential trace

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element problems is often collected when soils are studied and mapped.

GENERAL CONSIDERATIONS

There are a number of trace elements that affect plant growth and a number that affect animals through the plants they ingest. Some, like An, Cu, Fe, and Mn, are essential to both plants and animals; others like B primarily affect plant growth; still others like Co, I, and Se are essential to animals (with the exception that Co is essential for legumes). Then, there is an element like Mo that is essential to plants but, if present in exceedingly low or high concentrations in forages, also affects the animal. In ruminants, Cu utilization is affected by Mo.

The list of trace elements important to animals and man has increased with the recognition that Cr and Ni are essential to animals. The importance of some like Cd, Pb, and Hg has also become widely recognized because of their detrimental effects on environmental quality.

Soil-plant systems are important because most trace elements move in a food-and-feed chain from soils to plants to animals. Atmospheric pathways are important for some elements like I that are volatile and return to land surfaces in rainwater.

Most trace element problems result from an interaction of soil and plant factors that either enhance or depress trace element absorption by plants. Nutritional problems in animals arise largely because their trace element requirements and tolerances differ from those of the plants. Meeting plant requirements consequently does not necessarily meet the requirements of the animal. A wide range of problems exists and soil survey principles can be applied to their identification as well as to their solution.

ROLE OF SOILS IN NUTRITIONAL PROBLEMS OF ANIMALS

SELECTED EXAMPLES

Some pertinent soil characteristics associated with four trace element problems in animal nutrition are presented (Table 1). Factors that affect the trace element concentration of plants are identified using forages as a common plant.

Cobalt

Cobalt is a trace element essential to ruminant animals for the production of vitamin B_{12}. Without adequate Co, animals suffer from a deficiency of vitamin B_{12}, a wasting disease. A minimum of 0.04 to 0.07 ppm of Co is needed in forage plants to meet animal requirements. Humaquods of sand texture are a common example of soils that produce Co-deficient forages in the

Table 1. Soil characteristics and soil parent material interactions associated with nutritional problem areas for animals in the U.S.

Trace element	Nutritional problem-animals	Significant plant conc.	Principal characteristics	
			Soil	Soil parent material
Cobalt	Deficiency	0.04 to 0.07 ppm or less	Sand texture, acid, poor drainage (Humaquods)	Coastal plain dep.; glacial drift-White Mtn granite
Molybdenum	Toxicity	10 to 20 ppm or more	Poor drainage, neutral to alkaline reaction	Granitic alluvium; alluvium from shale
Selenium	Toxicity	4 to 5 ppm or more	Alkaline reaction, calcareous, good drainage	Seleniferous rocks, Cretaceous shales
	Deficiency	0.05 ppm or less	Acid reaction	Mixed, nonseleniferous deposits.
			Neutral to alkaline	Volcanic ash.
Magnesium	Deficiency	0.15% or less (?)	Mesic soil zone; limited available soil moisture	Mixed, unconsolidated deposits, volcanic ash.
	Adequate	0.20% or more	Mesic soil zone	Dolomitic till; weathered serpentinite
			Thermic soil zone	(except coastal plain)

U.S. Recognition of these soils largely defines the geographic extent of the problem areas. Humaquods on the lower Atlantic coastal plains in particular have small amounts of Co (about 1 ppm total). The low Co content of soils reflects low levels inherited from the sandy coastal plain deposits, which have undergone one or more cycles of weathering prior to their transport and deposition. The consequences of these inherited low Co levels in Humaquods are accentuated by leaching losses.

Molybdenum

In the case of Mo, animals suffer from molybdenosis when Mo exceeds 10 to 20 ppm in forage plants. Supplemental Cu, either through injection or feeding of mineral supplements enriched with Cu, counteracts the effect of excess Mo. Molybdenosis consequently is recognized as cases of Mo-induced Cu deficiencies. Soil wetness, neutral to alkaline soil reactions, and Mo-rich soil parent materials are interrelated factors that enhance the production of Mo-toxic forage plants. Alluvial fans and floodplains of small streams are likely problem areas because they are landscapes where Mo-rich alluvium is deposited essentially undiluted with low Mo materials from other stream sources. Molybdenosis is not a problem on floodplains of major rivers.

Forage crops with exceedingly low Mo and high Cu have been implicated in cases of Cu-induced Mo deficiencies. Naturally occurring areas are recognized in Australia but the problem has not been clearly identified in the U.S.

Selenium

Selenium is implicated in both animal deficiencies and toxicities in the U.S. White Muscle disease in cattle and sheep is a common Se-responsive disease. Deficiencies result when selenium levels in forages fall below 0.05 ppm. The development of acid soils on soil parent material with low to moderate Se levels is a contributing factor in disease incidence.

The Se-toxic areas for animals are nearly always associated with the development of well-drained, neutral to alkaline, calcareous soils formed on Se-rich soil parent materials. Cretaceous shale is often the seleniferous rock associated with Se-toxic areas. The growing of Se-accumulator plants like certain species of *Astragalus* and *Stanleya* on seleniferous soils accentuates the movement of Se from soils to plants and enhances incidences of Se toxicity in animals.

Magnesium

Grass tetany is a conditioned Mg deficiency that is a widespread nutritional disease in cattle in the U.S. and elsewhere. A high incidence in the midlatitude states implicates temperature. With adequate moisture, grasses grown under warm temperature take

up more Mg than grasses grown under cooler temperatures. The role of warm temperature is evident in grasses from the Piedmont region of the southeastern U.S. (thermic soil zone). Soils here are highly leached and have low Mg status (exchangeable soil Mg) but the grasses have as much Mg as they do where grown on soils formed in dolomitic till in Wisconsin, Illinois, Minnesota, and Iowa. A high turnover rate of soil Mg probably is important in the Ultisols, and a large Mg reserve in Alfisols formed in dolomitic till.

The production of forage plants with deficient, adequate, or toxic trace element levels reflects an interplay of several soil factors. Soil parent material is an important component in nearly all cases because it largely establishes the soil capacity for sustained trace element release to plants. Soil weathering largely activates this release and thus serves as an intensity factor. Together they govern the availability status of soil trace elements. The effect of the two components can be measured using plants as a bioassay tool.

Most soils in the U.S. are formed in unconsolidated surficial deposits. An assessment of kinds of surficial deposits is useful. Comparisons of Mo in glacial deposits of the north-central states, for example, indicate that outwash has less Mo and loess and lacustrine deposits more Mo than does glacial till associated with them. Clay soils also have appreciable amounts of Co and plants grown on such soils have adequate Co.

APPLICATION OF SOIL SURVEY

Principles of the soil survey can be selectively applied with principles of soil chemistry and mineral nutrition of plants in the understanding of soil trace element behavior. Essential features from these disciplines can be used to account for the biological activity of trace elements in soils and their absorption by plants. Water-soluble forms of mineral elements are available for plant absorption. In humid regions they are subject to leaching losses; in dry land areas, their role would be dependent on available soil moisture supply.

Planning stage

Conceptual models of soils associated with a trace element problem can be developed through literature review and field observations. The development of a working soil model provides a basis to account for low, adequate, or high trace element concentrations in plants. Poor plant growth is a poor indicator of excesses or deficiencies of trace elements in forage plants fed the animals.

Selection of sites

Careful selection of real soils using models of problem soils greatly enhances the selection of sites to study. The

geographic distribution pattern of problem areas is often obscure in the initial phases of studies and the problem areas may be quite localized, occupying only parts of the landscape. The kinds of soils available for study are almost unlimited (over 12,000 soil series) and judicious selection of sites is essential. In most cases sampling errors override magnitude of analytical errors.

Soil maps when available can be used to locate specific soil sites for study. In areas where soil maps are not available general knowledge of geology, soils, and animal observation can be used to good advantage.

The validity of soil models can be tested with data from a relatively few, carefully selected sites. The model of problem soils can be modified as data become available. A necessary component for such evaluations would be the availability of complete soil descriptions.

Collection of soil profile samples

As a study develops, a need for a better understanding of trace element distribution and behavior in soils through laboratory studies may become evident. Where initial phases of the study are tied closely to soil, they enhance the collection of soil profile samples. For example, a need arose to study the distribution of Co in southeastern coastal plain soils. Cobalt deficiency appeared to be confined principally to areas of Humaquods and its absence from areas of Ultisols was striking. Determinations of acetic acid and dithionite-extractable Co together with total Co showed that much more of the total Co was in extractable form in Ultisols than in Humaquods (Kubota, 1965). While not linear, the larger amounts of extractable Co were reflected in higher Co concentrations in plants.

DISCUSSION

Successful use has been made of soil survey principles in cooperative trace element studies by the Soil Survey Investigations, Soil Conservation Service, and the U.S. Plant, Soil and Nutrition Laboratory, Agric. Research Service. The inclusion of a soil survey in the planning stage provides a means to prepare subsequent maps that depict the geographic distribution of trace element problems. Principles of soil weathering and soil chemistry have many common features and both can be applied in the understanding of trace element behavior in soils.

The study of molybdenum-toxic areas illustrates how soil survey principles were applied, in a series of studies, to solve a trace element problem in the western states. The first study was initiated in Nevada in the late 1950's. Molybdenosis was suspected but the role of soils and factors associated with them

was not defined. Results from relatively few carefully selected sites the first year clearly implicated wet parts of granitic alluvial fans. As much as 400 ppm of molybdenum was found in legumes, well above toxic levels of 10 to 20 ppm. Results of the following year showed that granitic alluvial fans differed widely with respect to molybdenum (Table 2) and only some of them were implicated (Kubota et al., 1961).

An interaction of soil parent material molybdenum and soil wetness was implicated. The role of soil wetness in increasing molybdenum concentration was verified by growing plants under controlled wetness in the greenhouse (Kubota, Lemon, and Allaway, 1963). The excessively drained Mottsville soil (sandy, mixed, mesic Torripsammentic Haploxerolls) and its poorly drained associate, the Ophir soil (sandy, mixed, mesic Typic Haplaquolls) responded similarly when subjected to similar soil wetness conditions (Figure 1).

The model was then tested in Baker Valley, Oregon. Here, narrow floodplains of six tributary streams, all of the Powder River, were investigated (Kubota et al., 1967). As much as 4.3 ppm of molybdenum was found in the wet soil (mostly Aquepts) of Hot Creek compared with 0.6 ppm in morphologically similar soils of Wolf Creek and Spring Creek (Figure 2). The soil molybdenum concentration was reflected in plant concentration (Figure 3). Similar plants from well-drained soils had uniformly small amounts of molybdenum.

Possibilities of molybdenum-toxic areas in other western states were investigated, focusing on livestock production areas where physiography, bedrock, and soils were similar. Several areas previously not associated with molybdenosis were identified (Kubota, 1975) in Washington, Montana, Idaho, Wyoming, and Colorado.

Observations of plant molybdenum concentrations in the western states combined with those of the eastern states (Kubota, 1977) provided the basis to prepare the plant molybdenum map of the U.S. (Figure 4). Effects of soil molybdenum availability are reflected in the decreasing plant molybdenum concentration from west to east.

Principles for sampling soils for trace element studies have been presented (Kubota, 1972) as have their application to study the geographic distribution of trace element problems in the U.S. (Kubota and Allaway, 1972).

Recognition of soil temperature and soil moisture regimes is useful when plant response to trace elements in soils is assessed. Lack of soil moisture may be the limiting factor rather than an absence of available forms of soil trace elements to plants. They also provide a means to account for differences in plant concentrations observed under field conditions and under carefully controlled conditions in a greenhouse or growth chamber study.

Table 2. Molybdenum in legumes from seven granitic alluvial fans - Nevada.

Fan	Molybdenum †	
	Alfalfa	Clover
	ppm	
	Carson Valley	
I	--	16
II	23	76
III	241	315
IV	114	175
	Washoe Valley	
V	14	22
VI	7	11
VII	6	5

†Means of several samples.

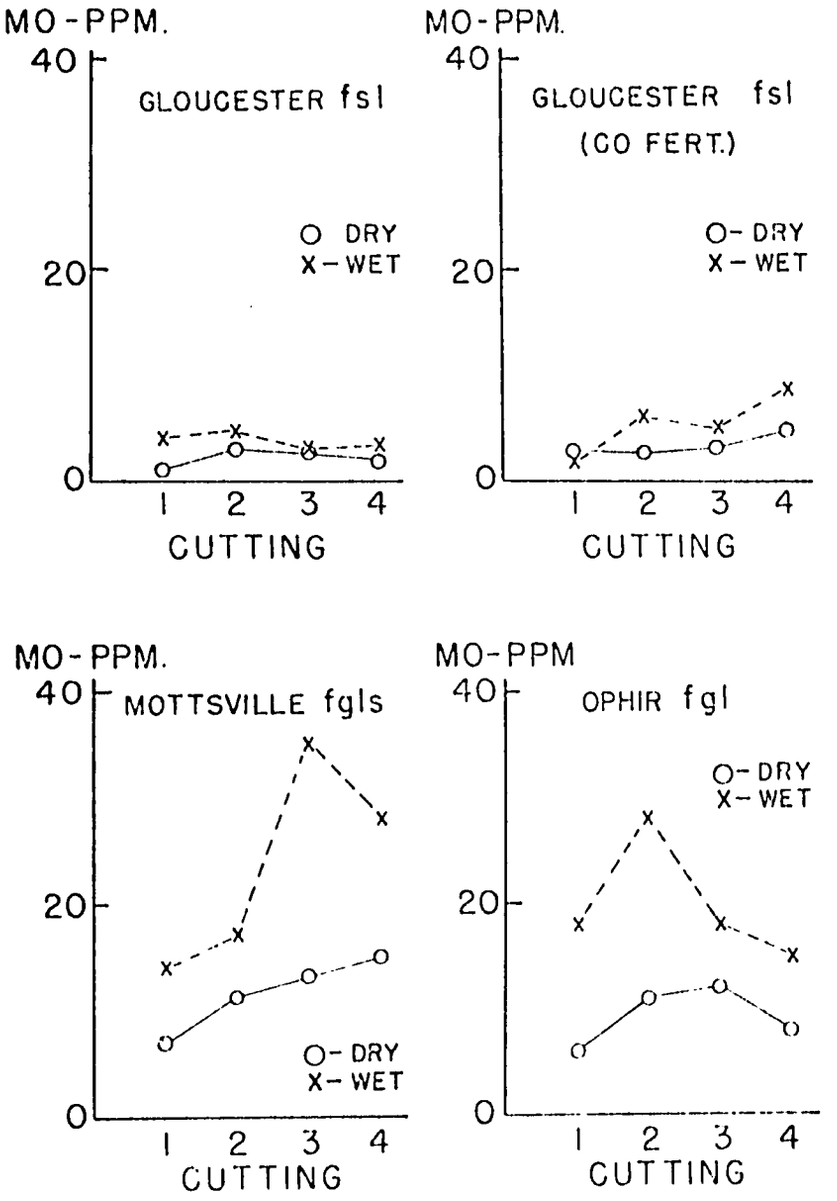


Figure 1. The effect of moisture treatments upon the molybdenum content of alsike clover.

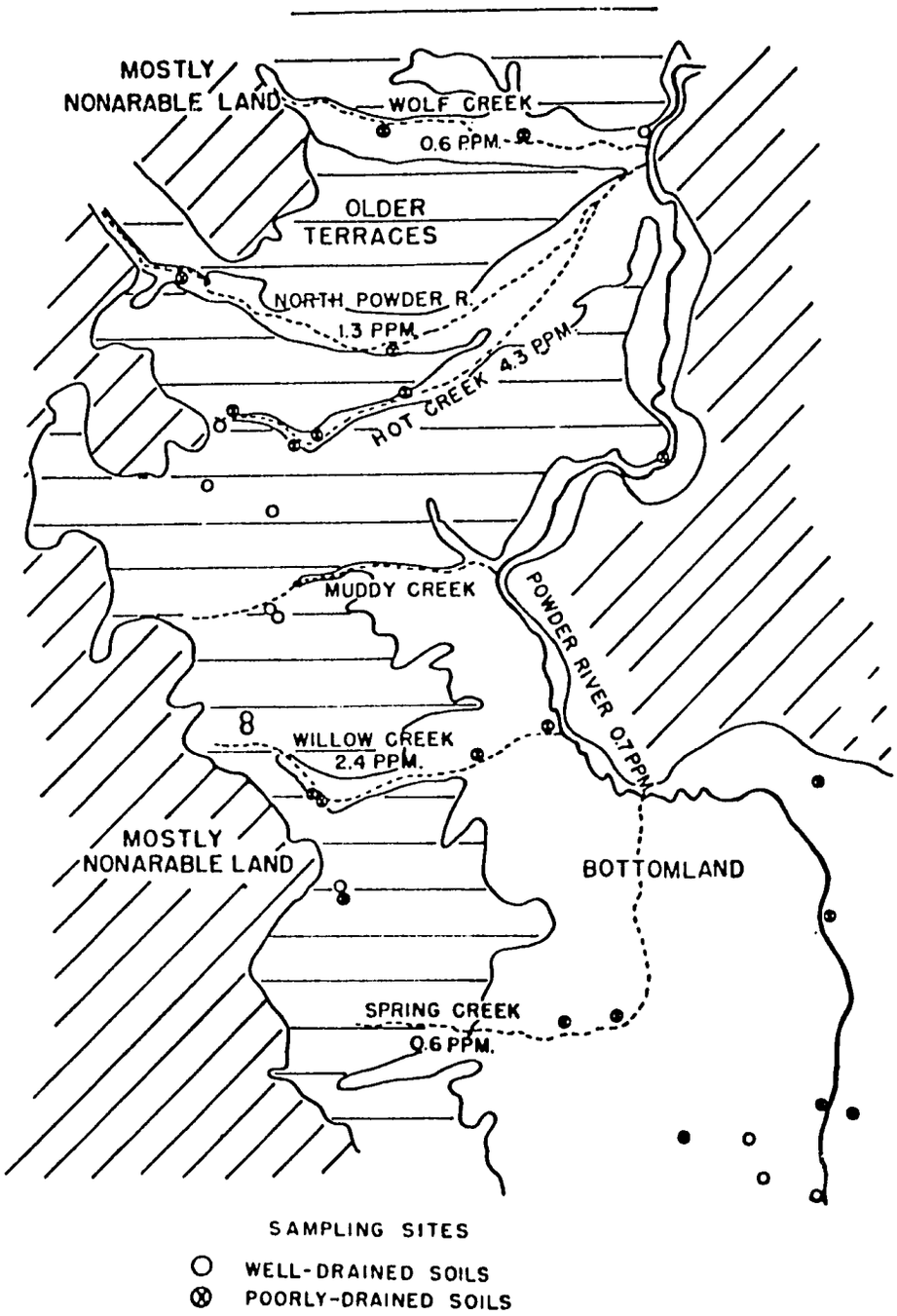


Figure 2. Molybdenum content of soils in Baker Valley, Oregon, in relation to tributary stream sources.

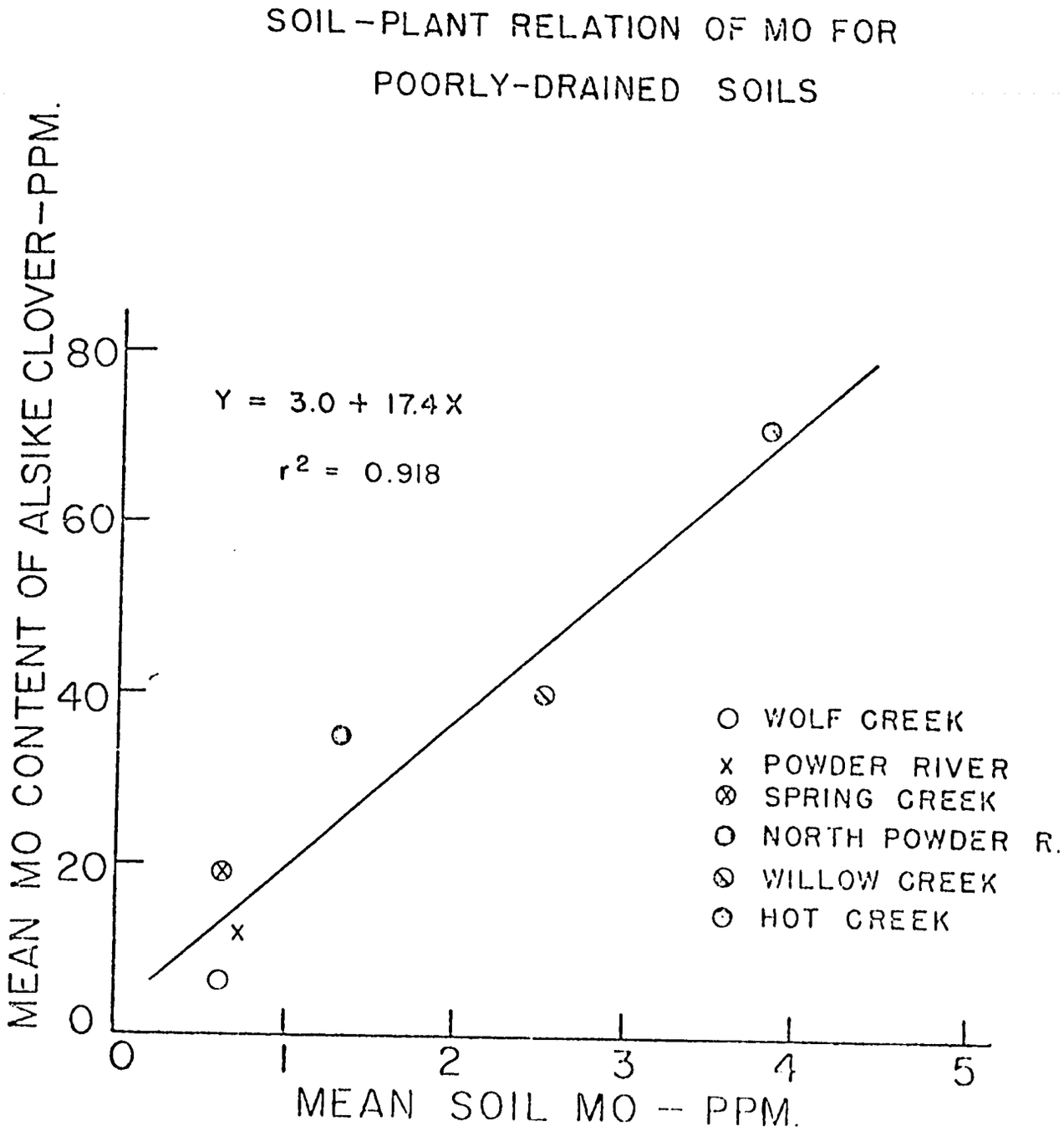
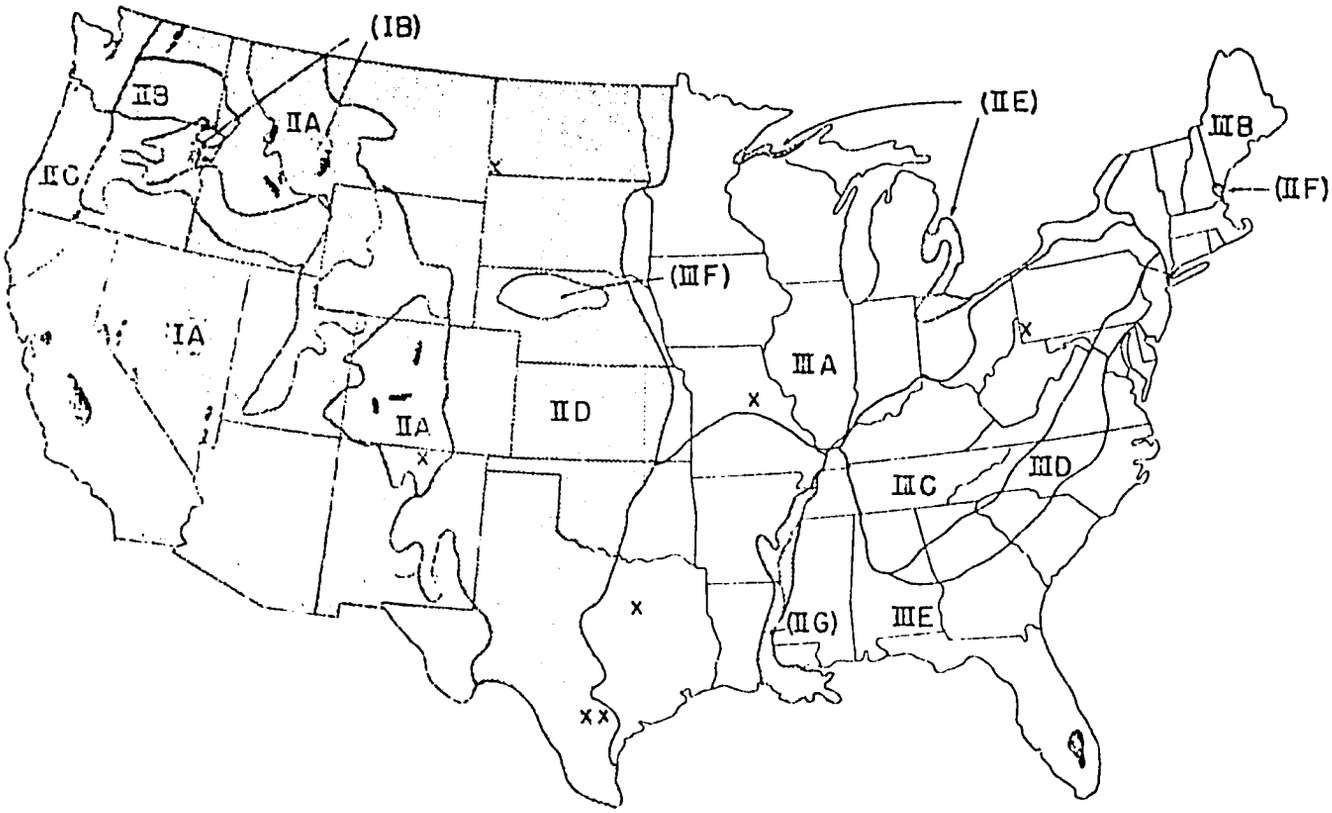


Figure 3. Molybdenum content of legumes in relation to soil molybdenum (total) in Ap horizons of poorly drained soils.



AREA	NUMBER OF SAMPLES	MEDIAN CONC.	FREQUENCY DISTRIBUTION (%) OF SAMPLES WITH Mo CONCENTRATIONS (ppm) OF :					
			<0.1 to 0.5	0.5 to 1	1 to 2	2 to 4	4 to 8	>8
IA	344	6	—	2	9	12	45	32
IB	79	8	0	0	3	19	24	54
II A	174	2	—	14	16	28	29	13
II B	174	3	—	8	14	42	32	4
II C	108	2	—	—	35	26	27	12
II D	34	2.6	6	12	24	26	21	11
II E	64	1.9	2	19	31	39	7	2
II F	10	3.2	0	0	30	50	10	10
II G	17	1.5	0	18	47	24	11	0
III A	201	0.4	54	23	14	7	2	0
III B	78	1.0	22	26	32	18	2	0
III C	37	0.3	74	16	5	5	0	0
III D	26	0.4	73	8	19	0	0	0
III E	41	0.4	51	25	22	2	0	0
III F	8	0.5	50	25	13	12	0	0

GENERAL LOCATION OF NATURALLY OCCURRING MOLYBDENUM-TOXIC AREAS

X GENERAL LOCATION OF INDUSTRIAL MOLYBDENOSIS

Figure 4. Geographic distribution of molybdenum concentration in legumes of the United States.

Sensitive analytical methods are continually being developed or adapted to meet the needs for soil-plant studies of trace elements. With increased, sensitive methods, a greater need arises to better select meaningful samples for laboratory study. Carefully planned studies based on soil surveys have greater predictive value than randomly collected samples.

Potential trace problems in plants and animals and their geographic distribution can be assessed as soil survey inventories are made. Their importance will increase as wider uses are made of soils for varied purposes.

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SOIL PROPERTIES IMPORTANT FOR VARIOUS TROPICAL CROPS: PAHANG TENGGARA MASTER PLANNING STUDY

Richard Protz[1]

The ultimate soil survey would be of a scale such that the rooting area is characterized for each plant. This is impossible to achieve for small crops because the concentration of soil observations during a survey would be so great that the surveyor would literally be creating a new soil. However, for the major tree crops a soil survey for each tree is possible. In areas of the world of very intensive land use, the farmers treat each tree as an individual and know the soil properties in sufficient detail.

In these areas the soil questions are: (1) which soil properties dominate growth, and (2) if the crop is grown on a different soil what changes in yield can be expected. These are two very important questions as people cultivate larger areas of less suitable soils.

OPERATIONAL ASPECTS OF THE PAHANG TENGGARA PROJECT

Soil Survey

The soil science team had to survey 500,000+ acres on a ½ mile rentis interval with eight observations/mile (Pahang Tenggara Regional Master Planning Study, 1972). Each soil mapping unit had to be assessed as to its suitability for the production of any crop that might be grown.

To start with we had the economists and agronomists decide which crops could possibly be profitably grown in Pahang Tengara given known agronomic techniques and world market conditions. They generated a list of approximately 40 crops (Table 1) from which we had the agronomists generate six characteristic rooting patterns. These six rooting patterns were given to the soil surveyors, the purpose being that the surveyors would note additional soil characteristics which would be useful for classifying each mapping unit for specific crops.

Soils Criteria for Crops

The soil management literature was reviewed for specific soil properties affecting each crop. Precious little information

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Table 1. Crops with an economic potential in Pahang Tenggara - clustered into groups with similar growing habits and requiring similar soil properties and soil management.

Crop Group	Crops in Group
A. Rubber Group	- Rubber
B. Oil Palm Group	- Oil Palm
C. Sago Group	- Sago Palm
D. Tapioca Group	- Tapioca, Sweet Potatoes, Soyabeans, Chillies, Vegetables
E. Tea Group	- Lowland Tea
F. Grass Group	- Stylo, Grasses (cut)
G. Citrus Group	- Citrus, Mangosteen, Chiku
H. Papaya Group	- Papaya, Pineapple, Passion Fruit, Guava, Salak
I. Banana Group	- Bananas, Durian, Rambutan, Langsat, Duku, Soursop, Jackfruit, Chempedak, Avocado, Kundangan
J. Cashew Group	- Cashew
K. Cocoa Group	- Cocoa, Coffee
L. Coconut Group	- Coconut
M. Maize Group	- Maize, Sorghum, Groundnuts
N. Rice Group	- Lowland Rice

was available beyond the standard ... this crop grows best on deep, well-drained, friable, highly fertile soil... Obviously, if a decision was to be reached on which crop had the best chance of economic success on the poorer soils, more specific soils criteria were required.

We decided on ten soil properties which were important to crop growth and which were mappable ("uniform" - within soil mapping units). These properties are shown in Table 2. From the literature limits were projected on each of the ten soil properties for each crop. The Malaysian agronomists and soil scientists were consulted and their ideas were incorporated; the criteria are shown in Table 3.

Creation of a Crop Suitability Map

Upon completion of the soil survey map, Soil Capability Performance Groups were tabulated. The Soil Capability Performance Groups are subdivisions of the soil capability subclasses and are collections of soil mapping units, or single mapping units that have comparable potential productivity and need similar management to maintain or improve their level of productivity. On the basis of this concept the soil mapping units were condensed into a shorter list of Soil Performance Groups and each of these were classified for each crop group (Table 4).

From Table 4 and the soil maps a summary of the acreages available for each crop group by each soil capability class was developed (Table 5). Then a crop suitability map was generated. The project economists and planners were given the number of acres and the distribution of those acres for each crop group. Thus the economists and planners could now calculate all possible alternative crop combinations depending upon location and economic criteria.

CONCLUSIONS

The need for the Soil Capability Performance Groups remains a question. It seems we could easily go from the soil mapping units through to the soil capability subclasses directly to the crop suitability tables and maps. Wong (1974) has made this shortcut.

I question if we should spend any more effort on ...deep, well-drained, friable, highly fertile soils... There is a greater need for knowledge on Soil Capability classes III and IV in countries with present low food production.

Presented 4/5/77.

Table 2. List of ten soil properties and reasons for their choice.

Soil Properties	Reason Chosen
1. Slope	- mappable, important from mechanization and conservation viewpoints.
2. Effective soil depth	- mappable, important for root penetration, nutrient and water holding capacity.
3. Soil texture-structure	- mappable, important for water release, workability, aeration and root penetration.
4. Drainage	- mappable, important for mechanization, aeration, water supply.
5. Water release	- mappable from texture and structure, important for crop water uptake.
6. Salinity	- can be approximated for soil series, important for plant growth.
7. pH	- can be approximated for soil series, important in fertility, minor element deficiencies, toxicity effects of certain elements, plant disease resistance and liming requirements.
8. Depth to acid sulfate	- mappable, important due to effects on pH, salt concentration, and root penetration.
9. Thickness of peat	- mappable, important for mechanization, tree crop stands and shrinkage.
10. Workability	- mappable, important for cultivation of annuals and certain tree crops.

Table 3. Major criteria used in assessing the soil suitability for crops.

Crop Group Crop	SOIL CRITERIA									
	Slope	Effective Soil Depth	Soil Texture Structure	Drainage	Water Release	Salinity mmhos/cm at 25°C	pH	Depth to Acid Sulphate	Thickness of Peat(drained)	Workability
A. Rubber										
Rubber	0-20°	>125 cm	Exclude LS or coarser	Exclude poorly drained	All year	<2 mmhos in top 150 cm	4.0-6.0	>150 cm	<50 cm	N. I.*
B. Oil Palm										
Oil Palm	0-15°	>125 cm	Exclude SL or coarser	Some temporarily poorly drained	All year	<2 mmhos in top 150 cm	4.0-6.5	>100 cm	<100 cm	N. I.
C. Sago Palm										
Sago Palm	0-2°	>100 cm	Exclude SL or coarser	Very poorly to poorly only	- -	<2 mmhos in top 150 cm	4.0-6.0	>125 cm	<50 cm	N. I.
D. Tapioca										
Tapioca	0-6°	>50 cm	Exclude clays and poor structures	Exclude poorly drained	All year	<2 mmhos in top 100 cm	4.3-7.5	>50 cm	No restriction	No restrictions allowed
Sweet Potatoes	0-6°	>50 cm	Exclude clays and poor structures	Exclude poorly drained	All year	<2 mmhos in top 100 cm	4.3-6.0	>50 cm	No restriction	No restrictions allowed
Soyabeans	0-6°	>25 cm	Exclude clays and poor structures	Well to imperfectly only	Growing season	<4 mmhos in top 50 cm	5.5-6.5	>50 cm	<25 cm	No restrictions allowed
Chillies	0-6°	>25 cm	Exclude clays and poor structures	Well to imperfectly	Growing season	<4 mmhos in top 50 cm	5.0-6.8	>50 cm	<25 cm	No restrictions allowed
Vegetables	0-6°	>25 cm	Exclude clays and poor structures	Well to imperfectly	Growing season	<4 mmhos in top 50 cm	4.5-6.5	>50 cm	No restriction	No restrictions allowed
E. Tea										
Lowland Tea	0-20°	>100 cm	Exclude sands, clays	Well to imperfectly	All year	<2 mmhos in top 150 cm	4.0-6.0	>25 cm	No peat	N. I.
F. Grass										
Grasses (Tuf)	0-12°	>25 cm	Exclude LS and coarser	Well to poorly	All year	<4 mmhos in top 50 cm	4.3-7.0	>50 cm	No restriction	No restrictions allowed
Stylo	0-12°	>25 cm	Exclude sands	Well to poorly	All year	<4 mmhos in top 50 cm	4.3-7.0	>50 cm	Not known	No restrictions allowed
G. Citrus										
Citrus	0-20°	>125 cm	Exclude sands and heavy clays	Well, some imperfectly	All year	<2 mmhos in top 150 cm	5.0-7.0	>150 cm	<50 cm	No stones
Chiku	0-20°	>125 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 150 cm	Not known	>150 cm	<50 cm	No stones
Mangosteen	0-20°	>125 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 150 cm	Not known	>150 cm	<50 cm	No stones
H. Papaya										
Papaya	0-12°	>50 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	5.0-6.5	<100 cm	No peat	No stones
Pineapple	0-6°	>25 cm	All textures	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5-5.5	>50 cm	No restriction	No stones
Passion fruit	0-12°	>50 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5-6.5	>100 cm	<50 cm	No stones
Guava	0-12°	>50 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5-6.5	>100 cm	<100 cm	No stones

* N. I. - Not important.

Table 3. Major criteria used in assessing the soil suitability for crops. (cont.)

Crop Group Crop	SOIL CRITERIA									
	Slope	Effective Soil Depth	Soil Texture Structure	Drainage	Water Release	Salinity mmhos/cm at 25°C	pH	Depth to Acid Sulphate	Thickness of Peat (drained)	Workability
Sekai	0-12°	>50 cm	Exclude LS or coarser	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	No stones
I. Bananas										
Bananas	0-12°	>125 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	5.0-7.0	>125 cm	<25 cm	No stones
Durian	0-12°	>100 cm	Exclude LS or coarser, firm soils, oxisolic soils	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5-6.5	>100 cm	No peat	N. I.
Rambutan	0-12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5-6.5	>100 cm	<100 cm	No stones
Langsat	0-12°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N. I.
Duku	0-12°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N. I.
Soursop	0-6°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N. I.
Jackfruit	0-12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5-6.5	>100 cm	<100 cm	No stones
Chempedak	0-12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N. I.
[illegible]	0-12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 150 cm	5.5-6.5	>125 cm	No peat	N. I.
Kundangan	0-12°	>100 cm	Exclude clays	Well drained	All year	<2 mmhos in top 150 cm	Not known	>125 cm	No peat	N. I.
J. Cashew										
Cashew	0-20°	>100 cm	Exclude clays	Well to imperfectly	9 months	<2 mmhos in top 150 cm	4.0-7.3	>150 cm	<100 cm	N. I.
K. Cocoa										
Cocoa	0-12°	>150 cm	Exclude SL or coarser	Well to imperfectly	High all year	<2 mmhos top 150 cm	5.0-7.5	>150 cm	<50 cm	N. I.
Coffee	0-12°	>125 cm	Exclude sands	Well to imperfectly	All year	<2 mmhos in top 150 cm	4.5-6.5	>100 cm	<125 cm	N. I.
L. Coconut										
Coconut	0-6°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 150 cm	4.5-7.5	>100 cm	<100 cm	N. I.
M. Maize										
Maize	0-6°	>50 cm	Exclude sands and clays	Well to imperfectly	Good in growing season	<2 mmhos in top 50 cm	>5.0	>125 cm	No restriction	No restrictions allowed
Sorghum	0-6°	>50 cm	Exclude sands	Well to imperfectly	Good in growing season	<4 mmhos in top 50 cm	>5.0	>125 cm	No restriction	No restrictions allowed
Groundnut	0-6°	>25 cm	Exclude sands and clays	Well to moderately well	Good in growing season	<4 mmhos in top 50 cm	5.5-7.0	>50 cm	No peat	No restrictions allowed
N. Rice										
Lowland Rice	0.2°	>25 cm	SCL or finer	Drainage control necessary	Dry during harvest	<4 mmhos in top 25 cm	>4.0	>25 cm	No peat	No restrictions allowed

Table 4—Crop Suitability According to Soil Performance Groups[1]

Soil Performance Group[3]	Acreage	Crop Groups A Rubber	B Oil Palm	C Sago	D Tapioca	E Tea	F Grass	G Citrus	H Papaya	I Banana	J Cashew	K Cocoa	L Coconut	M Maize	N Rice
Soil Capability Class I															
I-1	790	W[2]	W	U[2]	W	S[2]	W	W	W	W	S	S	W	W	U
I-2	570	W	W	U	W	W	W	W	W	W	S	W	W	W	U
I-3	390	W	W	U	W	W	W	W	W	W	S	W	W	W	U
I-4	7,920	W	W	U	W	W	W	W	W	W	W	S	W	W	U
IEn-1	43,410	W	W	U	W	W	W	W	W	W	S	W	S	W	U
IEn-2	1,740	W	W	U	S	W	W	W	W	W	S	W	S	S	U
IEn-3	1,230	W	W	U	S	W	W	W	W	W	S	W	M[2]	S	U
IEn-4	22,560	W	W	U	W	W	W	W	W	W	S	S	M	W	U
IEn-5	12,210	W	W	U	W	W	W	W	W	W	W	S	S	W	U
IEn-6	1,060	W	S	U	U	W	M	W	S	W	S	W	U	U	U
IEn-7	740	W	S	U	U	W	M	W	S	W	S	W	U	U	U
IDPn-1	3,260	W	W	U	W	W	W	W	W	W	W	W	W	W	U
IDPn-2	9,170	W	W	U	W	W	W	S	W	W	W	S	W	W	U
IDPn-3	6,540	S	S	U	W	S	S	S	S	S	W	M	S	W	U
IDPn-4	1,570	W	W	U	W	W	W	S	W	W	W	S	S	W	U
IDPn-5	8,330	S	S	U	W	S	W	S	W	W	W	M	W	W	U
Soil Capability Class II															
IIEm-1	47,750	W	S	U	U	W	M	W	M	W	S	W	U	U	U
IIEm-2 ..	27,020	W	S	U	U	W	M	W	M	W	S	W	U	U	U
IIEm-3	1,640	W	S	U	U	W	M	S	M	W	W	S	U	U	U
IIEm-4	770	S	M	U	U	S	U	S	U	U	S	M	U	U	U
IIDmEPn-1 ..	2,440	S	S	U	S	S	S	S	M	S	W	U	M	S	U
IIDm-1 ..	26,950	M	M	W	U	U	S	U	S	U	U	U	M	S	W
IIDm-2 ..	15,130	M	M	W	U	U	S	U	S	U	U	U	S	S	S
IIPmEn-1 ..	4,110	W	W	U	S	W	W	S	W	S	S	M	M	W	U
IIPmEn-2 ..	2,600	W	S	U	M	S	W	M	S	M	U	U	U	S	U
IIPmEn-3 ..	2,800	W	S	U	M	S	W	M	S	M	U	U	U	S	U
IICmEn-1 ..	5,490	W	W	U	W	W	W	W	W	S	S	S	M	W	U
IICmEn-2 ..	1,820	W	W	U	S	W	W	W	W	W	M	S	M	W	U
IICmEn-3 ..	10,000	W	W	U	S	W	W	W	W	S	S	S	M	W	U
IICmEn-4 ..	870	W	S	U	W	W	W	W	W	S	W	S	S	W	U
IICmEn-5 ..	1,110	W	S	U	S	W	W	S	W	M	S	M	U	W	U
IICmEn-6 ..	3,870	W	S	U	S	W	W	S	S	S	S	M	U	W	U
IICmEn-7 ..	690	S	M	U	U	S	W	M	S	U	U	U	U	S	U
IICmEn-8 ..	660	S	M	U	U	S	W	M	S	U	U	U	U	S	U
IICmEn-9 ..	4,670	S	M	U	M	S	W	M	M	U	S	U	U	S	U
IICmEn-10 ..	1,990	W	M	U	U	W	M	S	M	M	S	M	U	U	U
Soil Capability Class III															
IIIEs-1 ..	6,410	S	M	U	U	S	U	M	U	U	M	M	U	U	U
IIIEs-2 ..	5,190	S	M	U	U	S	U	M	U	U	M	U	U	U	U
IIIEPm-1 ..	3,330	S	M	U	U	M	M	M	M	M	U	U	U	U	U
IIIEPm-2 ..	790	S	M	U	U	U	M	U	M	U	U	U	U	U	U
IIIEPm-3 ..	2,960	S	M	U	U	U	M	U	U	U	U	U	U	U	U

Table 4 —Crop Suitability According to Soil Performance Groups—(*cont.*)

Soil Performance Group	Acreage	Crop Groups A Rubber	B Oil Palm	C Sago	D Tapioca	E Tea	F Grass	G Citrus	H Papaya	I Banana	J Cashew	K Cocoa	L Coconut	M Maize	N Rice
							Soil Capability Class III (*cont.*)								
IIIPs 1	9,690	M	U	U	U	U	S	U	M	U	U	U	M	M	M
IIICLm 1 ..	4,760	W	S	U	U	W	M	S	M	S	S	S	U	U	U
IIICLm 2 ..	1,630	S	M	U	U	S	M	M	M	U	M	M	U	U	U
IIICLm 3 ..	8,610	W	S	U	U	W	M	S	M	S	S	M	U	U	U
IIICLm 4 ..	500	S	M	U	U	M	M	U	M	U	U	U	U	U	U
IIICLm 5 ..	7,140	S	M	U	U	S	M	M	M	U	M	U	U	U	U
IIICLm 6 ..	1,470	S	M	U	U	U	M	U	M	U	U	U	U	U	U
IIICLm 7 ..	1,630	S	M	U	U	U	M	U	M	U	U	U	U	U	U
IIICLm 8 ..	1,910	S	U	U	U	U	M	U	M	U	U	U	U	U	U
IIICLm 9 ..	2,900	S	M	U	U	M	M	U	M	U	M	U	U	U	U
IIICLm 10 ..	350	S	U	U	U	M	U	U	U	U	U	U	U	U	U
IIICs 1 ..	980	S	M	U	U	S	W	M	S	M	M	M	U	M	U
IIICs 2 ..	4,250	S	M	U	U	S	W	M	S	M	M	M	U	M	U
IIICs 3 ..	1,290	S	M	U	U	M	W	U	M	U	M	U	U	M	U
IIICSLm 1 ..	1,280	S	M	U	U	S	M	M	M	M	M	M	U	U	U
IIICSLm 2 ..	1,800	S	M	U	U	S	M	M	M	U	M	U	U	U	U
IIICsVm 1 ..	2,390	S	M	U	U	M	W	U	M	U	M	U	U	M	U
IIICsVm 2 ..	7,480	M	U	U	U	M	S	U	M	U	M	U	U	M	U
IIICsVm 3 ..	6,960	M	U	U	U	U	M	U	U	U	U	U	U	U	U
IIIDs 1	20,440	M	M	S	U	U	S	U	M	U	U	U	S	U	S
IIIDs 2	12,520	M	M	U	M	U	S	U	M	M	M	U	M	M	M
							Soil Capability Class IV								
IVEPs 1 ..	870	S	M	U	U	M	U	M	U	U	U	U	U	U	U
IVEPs 2 ..	760	S	U	U	U	U	U	U	U	U	U	U	U	U	U
IVEPs 3 ..	1,570	S	U	U	U	U	U	U	U	U	U	U	U	U	U
IVCFs 1 ..	1,520	S	M	U	U	S	U	M	U	U	S	U	U	U	U
IVCFs 2 ..	9,890	S	U	U	U	S	U	U	U	U	S	U	U	U	U
IVCFs 3 ..	630	M	U	U	U	U	U	U	U	U	U	U	U	U	U
IVCFs 4 ..	6,480	M	U	U	U	U	U	U	U	U	U	U	U	U	U
IVCVsLm 1 ..	1,120	S	U	U	U	U	M	U	U	U	M	U	U	U	U
IVCVsLm 2 ..	8,320	M	U	U	U	U	M	U	U	U	U	U	U	U	U
IVCVsLm 3 ..	6,370	M	U	U	U	U	M	U	U	U	U	U	U	U	U
IVDOs 1 ..	360	U	U	W	U	U	U	U	M	U	U	U	M	U	S
IVDOs 2 ..	3,320	U	U	U	U	U	U	U	U	U	U	U	U	U	U
							Soil Capability Class V								
VCvLVs 1 ..	3,160	M	U	U	U	U	U	U	U	U	U	U	U	U	U
VCvLVs 2 ..	2,800	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VCvLVs 3 ..	1,320	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VCvLVs 4	3,880	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VOv 1	61,350	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VIv 1 ..	46,970	U	U	U	U	U	U	U	U	U	U	U	U	U	U
VIIvLs 1 .	60	U	U	U	U	U	U	U	U	U	U	U	U	U	U
	561,145														

Table 4: Crop Suitability According to Soil Performance Groups. (cont.)

[1] Assumptions used in rating soil capability performance groups:

1. It is assumed that crops will be grown with at least a moderate level of management as determined by up-to-date research in equivalent environments. This means that fertilizers, lime, and green manures will be used in accordance with the needs of the crop, and that erosion and competition from weeds will be controlled.

2. The ratings are based on current levels of agricultural technology. Advances in technology may require a reevaluation of the rating.

3. The list of crops considered in this section are those which are widely grown or have been considered for commercial production. Absence of a crop from the list should not be interpreted as indicating that the crop cannot be grown.

4. The skill and resources of individual operators who can put in a higher level of management are not taken into account in the rating. Under extreme levels of management, applied with unusual skill, satisfactory yields of crops can sometimes be obtained on highly unfavourable soils. The ratings do not reflect such extreme levels of management.

5. The ratings are based on subjective rather than actual yield information, and should be interpreted in relation to this.

[2] Definitions of the individual suitability ratings are as follows:

(W) Well Suited

Soil capability performance groups having few or no limitations for the production of the named crop. Such areas have soils that have favourable physical conditions or ones which respond well to management, and they have terrain which is favourable for the cultivation of the named crop. Moderate to high yields can be expected provided there are no climatic restrictions.

(S) Suited

Soil capability performance groups having few limitations of moderate severity to the production of the named crop. Physical soil conditions and/or terrain are only moderately favourable, but these can be overcome by moderate levels of management. Yields in relation to well suited soil-land areas are somewhat reduced for similar levels of management.

Table 4: Crop Suitability According to Soil Performance Groups. (cont.)

(M) Marginally Suited

Soil capability performance groups having several limitations of moderate severity, or few limitations of significant severity to production of the named crop. Physical soil conditions and/or terrain are only moderately favourable, and these are difficult to overcome with moderate levels of management. High management inputs are necessary to obtain satisfactory yields.

(U) Unsuited

Soil capability performance groups having severe limitations to production of the named crop. Satisfactory production is not feasible without the implementation of severely high levels of management.

[3] Soil performance group key:

Hazards

C - compacted layer
D - drainage
E - erosion
O - organic soil
P - firm subsoil
V - stone content

Degree of hazards

n - minor
m - moderate
s - serious
v - very serious

Parent material

1 - recent alluvium
2 - granite
3 - arenaceous shale
4 - sub-recent and older alluvium

Table 5 Summation of Crop Suitability Acreages According to Soil Capability Classes and Crop Groups

Soil Capability Class I 119,380 acres

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	101,510	102,720	—	114,620	103,720	110,050	102,510
S	14,870	16,660	—	2,970	15,660	6,540	23,400

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	111,050	112,840	46,790	52,390	28,230	114,620	—
S	8,330	6,540	72,580	52,120	65,460	2,970	—

Soil Capability Class II 161,360 acres

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	111,050	21,420	42,080	6,350	105,650	38,670	92,940
S	9,230	90,080	—	23,350	14,620	44,530	15,930

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	23,390	78,216	4,940	74,760	—	27,260	26,950
S	52,690	26,780	106,780	19,810	16,000	55,940	15,130

Soil Capability Class III 118,660 acres

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	13,370	—	—	—	13,370	8,900	—
S	48,200	13,370	20,440	—	28,680	50,130	13,370

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	—	—	—	—	—	—	—
S	5,230	13,370	13,370	4,763	20,438	—	20,440

Soil Capability Class IV 41,200 acres

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	—	—	360	—	—	—	—
S	15,730	—	—	—	11,411	—	—

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	—	—	—	—	—	—	—
S	—	—	11,411	—	—	—	360

Soil Capability Class V 119,550 acres

	Rubber	Oil Palm	Sago	Tapioca	Tea	Grass	Citrus
W	—	—	—	—	—	—	—
S	—	—	—	—	—	—	—

	Papaya	Banana	Cashew	Cocoa	Coconut	Maize	Rice
W	—	—	—	—	—	—	—
S	—	—	—	—	—	—	—

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SOIL PROPERTIES AND THE USE OF THE U.S. *SOIL TAXONOMY* IN NORTHERN AND WESTERN AFRICA

Pierre Ph. Antoine[1]

The following remarks stem out of personal observations made in Northern Africa but can generally apply to other semi-arid regions of lesser developed countries.

There are two major ways to improve from the "outside" the knowledge on land resources of a given country. First, one can respond to a direct request made by officials of a government and agree to work on "urgent" problems involving survey work and land evaluation. This approach is often strictly technical and generally avoids or minimizes any type of interaction with local agronomists in order to maximize short-term efficiency (which in most cases can be read: profit).

On the other hand, one can also try to design long-term programs which involve cooperative efforts and training of local scientists. This second approach is not strictly technical but also implies some social interaction. It generally requires more effort from the individuals involved.

TECHNICAL ASPECT OF USING THE *SOIL TAXONOMY*

To many biased American pedologists, the best type of map is a comprehensive map which includes "all" soils properties, including physical and chemical characteristics and relationships between various members of soil sequences.

This type of map, however, which can be called a *soils map* "sensu stricto" is generally of little use to scientists in other fields of specialization involved in land resource evaluation, planning work, or fertility recommendations, since both the average pedestrian and the general agronomist often confuse soils units and archaeological findings.

If the above assumption is correct, a soils map therefore can simply be considered as a tool. It is the best tool -- and the cheapest on a long-term basis -- to be used to derive other types of maps (capacities, constraints, cultivation potential...) because, by definition, it contains all the information necessary to draw those maps.

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However, unless unlimited time, money, and expertise are provided -- and this is never the case in LDCs -- one has often to settle for reconnaissance or semi-detailed maps which do not fully provide the entire set of information requested by various land users.

Advantages

As far as the soils community in the U.S. is concerned, a great deal of money and effort has been spent on designing a soil classification scheme based primarily on morphological characteristics of soils. This is based upon the biased but respectable assumption that soil is mostly a support for plant growth. Among other traits of originality, the U.S. *Soil Taxonomy* differs from many other classification schemes in its obvious attempt to quantify every soil parameter and to express most soil properties by means of numbers and averages (thickness of horizons, percentages of organic matter, P_2O_5, etc.).

The U.S. *Soil Taxonomy* is also a system of classification which introduced the concept of soil *regimes* and *cycles*, i.e., moisture and temperature. This introduction obviously constitutes a step forward in soil studies since it provides a link between cultivation cycles, fertility constraints, and that support for plant growth called soil. It also reminds the scientist that soil is in constant evolution and must be studied in a dynamic perspective. As a side remark, we might regret that the *Taxonomy* did not pursue its efforts further and ignored a whole series of other regimes present in soils: chemical and physical cycles involving pH, levels of available nutrients during the year, osmotic and physical pressures, and so on.

In terms of survey work in North and West Africa, where lack of sufficient moisture during certain periods of the year is perhaps the most severe constraint to crop production, the characterization of soil moisture regimes is certainly essential to build a good knowledge of soils and understand their behavior. The prediction of a soil moisture regime is a difficult exercise and the relationship between rainfall and soil moisture regime is very general and does not always fit the goals of crop production.

In the region of Midelt for example, at an elevation of about 1600 m one has observed within a distance of less than 300 m, a succession of at least three moisture regimes: aridic, xeric, and udic. In terms of land use and crop production, those different characteristics result in sizable differences.

Disadvantages

However, unfortunately, the U.S. *Soil Taxonomy* offers some serious disadvantages. As in most countries of Africa, Asia, and South America, available soil moisture data are very scarce in Northern and Western Africa. Moreover, the definition of

soil regimes involves not only one set of observations, but rather measurements scattered throughout the year and over long periods of time (e.g., averages over a ten-year period). This, of course, makes the problem even more complicated.

Consequently, the use of the *Soil Taxonomy* in a map legend implies too many assumptions, guesses, and erroneous interpretations. Even though the adjectives "tentative" or "temporary" can be used in the legend, having to "update" a mapping unit by changing the names of taxa, sometimes at the highest level of classification (e.g., going from an Aridisol to an Inceptisol), is a painful exercise.

Suggestions

Remarks similar to those made for moisture regimes can also apply to other soil properties or characteristics. Some of these may also affect directly the classification of soils (e.g., the evolution of soil structure during the year, which frequently must be taken into consideration when characterizing Mollisols in Mediterranean regions, and which requires observations at times which are not best suited for other soil observations). Some other properties may influence less directly the classification of soils, at least at the highest levels of classification, but are of great importance for fertility recommendations, and therefore should be clearly integrated into a system which aims at linking soil properties and crop production. For example, little is known yet concerning chemical properties of soils of subtropical regions as they relate to fertility: rates of mineralization of organic matter, yearly cycles of available K^+ and nitrate levels in soils, constraints linked with the absence or overabundance of minor elements (toxicity) in some Alfisols, are still generally ignored.

In conclusion, unless the users of the *Soil Taxonomy* working abroad decide to abandon their sophisticated tool and to adopt other and sometimes more "simple" (easier to use) soil classification schemes, it is the feeling of this writer that the knowledge of the properties listed above must be greatly improved if *Soil Taxonomy* is to be used successfully. In this respect, among all properties essential for characterization in semi-arid regions, a high priority must be given to the characterization of moisture regimes. To achieve that goal, a few options are available among others:

1. The soil scientist may improve his knowledge of vegetation species which usually provide excellent indications concerning moisture parameters, and try to relate physiological properties of plants to the soils environment. Too often, the pedologist is more a good geomorphologist or a mineralogist than a botanist.

2. The scientist may also design computer models which relate climatic data to soil moisture regimes for all kinds of

soils environments and soils characteristics: different slopes, aspects, surface, temperature, vegetative cover, texture, succession of horizons. This involves the establishment of field plots and bench mark programs in many different locations and requires a good dose of enthusiasm and confidence.

Improving the knowledge of moisture regimes, not to mention the other soil properties upon which the *Taxonomy* insists, may be a costly proposition. However, because of the critical importance of water for crop production in semi-arid regions, there is much to gain in that direction and the results should be worth the investment.

USE OF MAPS, INTERACTION WITH LOCAL SCIENTISTS, AND TRAINING OF SOIL SURVEY EXPERTS

Proving that the *Soil Taxonomy* is useful and eventually may be used in LDCs constitutes only one of the goals of the taxonomist, and a really minor one.

Long term objectives of overseas work often imply the creation in each country of an organization capable of handling local agricultural problems. Too often, it has been observed that technical masterpieces which are not generated from within a host government have no impact upon the future and only benefit "academia" or the more developed countries. This is true of many types of activities in land resource evaluation, soil conservation work, plant breeding programs, etc. Incredible amounts of money have often been invested for the making of elaborate reports which are comfortably installed inside drawers and remain locked for years and years. Too many soil maps have been considered as sleeping beauties by scientists of various LDCs.

To have a significant impact, a technical report or a technical recommendation must always carry some credibility. One of the best ways to gain that credibility is to involve local scientists in every study (whenever possible) and invest time and efforts in the training of future experts who can, hopefully, share an identical technical point of view.

The preceding remarks are of much importance to the users and the "missionaries" of the *Soil Taxonomy*. Northern and Western African countries have a limited number of pedologists. For the most part, these pedologists have been trained in France and most of their survey work has been accomplished by means of references to the French Classification. Using the *Soil Taxonomy*, therefore, becomes a very risky venture if local agronomists do not see the need for it. Caution and patience must be exercised.

Eventually, the basic question: "Why use the *Soil Taxonomy* in such conditions?" will arise and the answer is not easy.

Specific recommendations must be adapted to local conditions. It is a fact that soil scientists are often reluctant to switch from one system of classification to another. Taxonomists are not an exception to that rule. "Chauvinistic" attitudes are common and may be the major reason why soil symposiums are generally so colorful.

The history of development of soil classifications in European countries and in North America and this common "chauvinistic" attitude of mind can lead to a major danger which must be avoided by all means: the birth and development of new local soil classifications based on the introduction of local terms. All efforts must be made to encourage scientists of developing nations to integrate themselves into an already existing classification scheme and to participate directly in its development.

From experience in North Africa, the following remarks can be made. We have been somewhat successful in doing soil survey work at a large scale in pilot areas and in training Moroccan soil scientists in the French and American systems of classification at the same time. To do so, whenever possible, we have used identical quantified parameters to define taxa in the two systems, without departing from existing rules. (The major permissible effort in that direction deals mostly with the selection of horizon thickness and depth of solum. For this, depths listed in the *Taxonomy* have been selected to characterize different categories of soils.) A legend has been written in terms of both classifications, the series and phase column being shared by both systems (Figure 1).

The major advantage of such an effort is to allow scientists trained in different countries to use this type of survey work and to keep the door of the future open to those people who will, some day, make decisions concerning the choice of soil classifications in their own country.

GENERAL CONCLUSIONS AND SUMMARY

The successful use of the U.S. *Soil Taxonomy* in Northern and Western Africa is technically feasible, but must still involve massive efforts in collecting quantitative information before full use of the *Taxonomy* can be made.

In addition, the possibility of using the *Taxonomy* does not imply, by definition, its acceptance in various countries. Attempts must be made at training African soil scientists in the *Taxonomy* before trying to "force" upon them the acceptance of the system. Whenever possible, it is also highly desirable to relate and bring together both the French and American systems of soil classification.

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Figure 1

CLASSIFICATION FRANCAISE C.P.S -1967			Symboles des séries et phases	Définition des séries et phases intégrant la U.S. Soil Taxonomy, 1973
Classe S/Classes	Groupe S/Groupes	Familles		
Sols minéraux bruts non climatiques	Sols d'érosion, lithosols	Sur matériaux d'âge primaire et sur tertiaire	A (indifférencié)	-Affleurements géologiques ou Xérorthent lithique, squelettique, thermique, pentes fortes: (> 15%)
Sols peu évolués non climatiques	Sols d'érosion, lithiques	Sur chistes	Bf	-Xérochrept lithique, thermique, texture fine, squelettique; pente forte supérieure à 15%
			Bg	-Xérochrept lithique, thermique, texture moyenne peu profond; pente forte supérieure à 15 %
	Sols d'apport colluvial et alluvial modal	Sur apports colluviaux et alluviaux	Bc	-Xérofluvent typique, thermique, limon sableux, profond, pente faible
			Bd	-Xérofluvent typique, thermique, sableux profond pente faible
	Sols d'apport colluvial et alluvial hydromorphes	Sur apports colluviaux et alluviaux	Be	-Xérofluvent aquique, thermique, limon sableux , profond, pente faible
Sols calcimagnésiques	Sols bruns calcaires à encroûtement calcaire	Sur marne calcaire	Eb_1	-Xérochrept calcixérollique; thermique, texture fine, peu profond, pente forte(> 15%), couverture sableuse en surface
			Ed_{12}	-Xérochrept calcixérollique, thermique, texture fine, squelettique, (< 20cm), pente forte supérieure à 15%, mince couverture sableuse avec galets (4 a 5 cm et 15 à 20%)
			Ef_1	- Xérochrept calcixérollique, thermique, texture moyenne, moyennement profond, pente forte (> 15%), mince couverture sableuse avec galets (4 à 5 cm et 15 à 20%)
		Sur gres calcaire	Eg	-Xérochrept calcixérollique, thermique, texture moyenne, peu profond, pente forte (> 15%).
			Ef	-Xérocrept calcixérollique, thermique, à texture fine, squelettique, pente forte (> 15%)

SESSION VII

Wednesday morning, April 6, 1977

SOIL DATA PRESENTATION

Chairman: A. A. Klingebiel

Speakers

G. A. Nielsen - Presentations of Soil Resource Inventory Data

J. B. Collins - Soil Resource Inventory for the Small Farmer

G. W. Olson - Principles of Presentation of Soil Survey Data for Immediate Use and Application

PRESENTATIONS OF SOIL RESOURCE INVENTORY DATA

G. A. Nielsen[1]

Soil survey reports are potentially the most useful source of land resource information available. Their actual utility depends not only on the design and technical reliability of the survey, but also on how the data are presented. This paper notes a variety of maps, reports, and techniques used to deliver resource inventory data to those who make decisions about land use. Graphic methods of data presentations are described.

A check list developed at Montana State University lists 1,400 factors that might be included in a biophysical land resource inventory (Plantenberg, Montagne, and Nielsen, 1974). Nearly one-fourth of the factors can be estimated from soil survey reports. No other commonly available source provides as much information. Renowned planners, Ian McHarg and Phillip Lewis, agree that few, if any, inputs to a land use plan are more important than a soil map and report.

ACTIVITIES, PRODUCTS, AND USERS OF A SOIL RESOURCES INVENTORY

Figure 1 schematically represents the activities, products, and users of a soil resources inventory process. The products column begins at the bottom with technical papers on soil genesis, proceeds upward through data banks, soil classification systems, basic land resource maps (at several scales), interpretation guides, and culminates at the top with maps showing potentials and hazards for various land uses. Products at the top of the column are in the greatest demand by the largest number of users. Inventory data move primarily upward through the soil inventory process but some informational items are presented at various levels (laterally in Figure 1) to specialized audiences. Following are brief descriptions of products and some comments on their effective presentation to users. Illustrations are drawn largely from experiences in Montana.

Technical Papers

Research and technical papers on soil genesis and morphology provide basic knowledge that facilitates classification and mapping. Publication is usually in technical journals directed to professional soil scientists and a few profiles and landscapes add much to the effectiveness of journal articles

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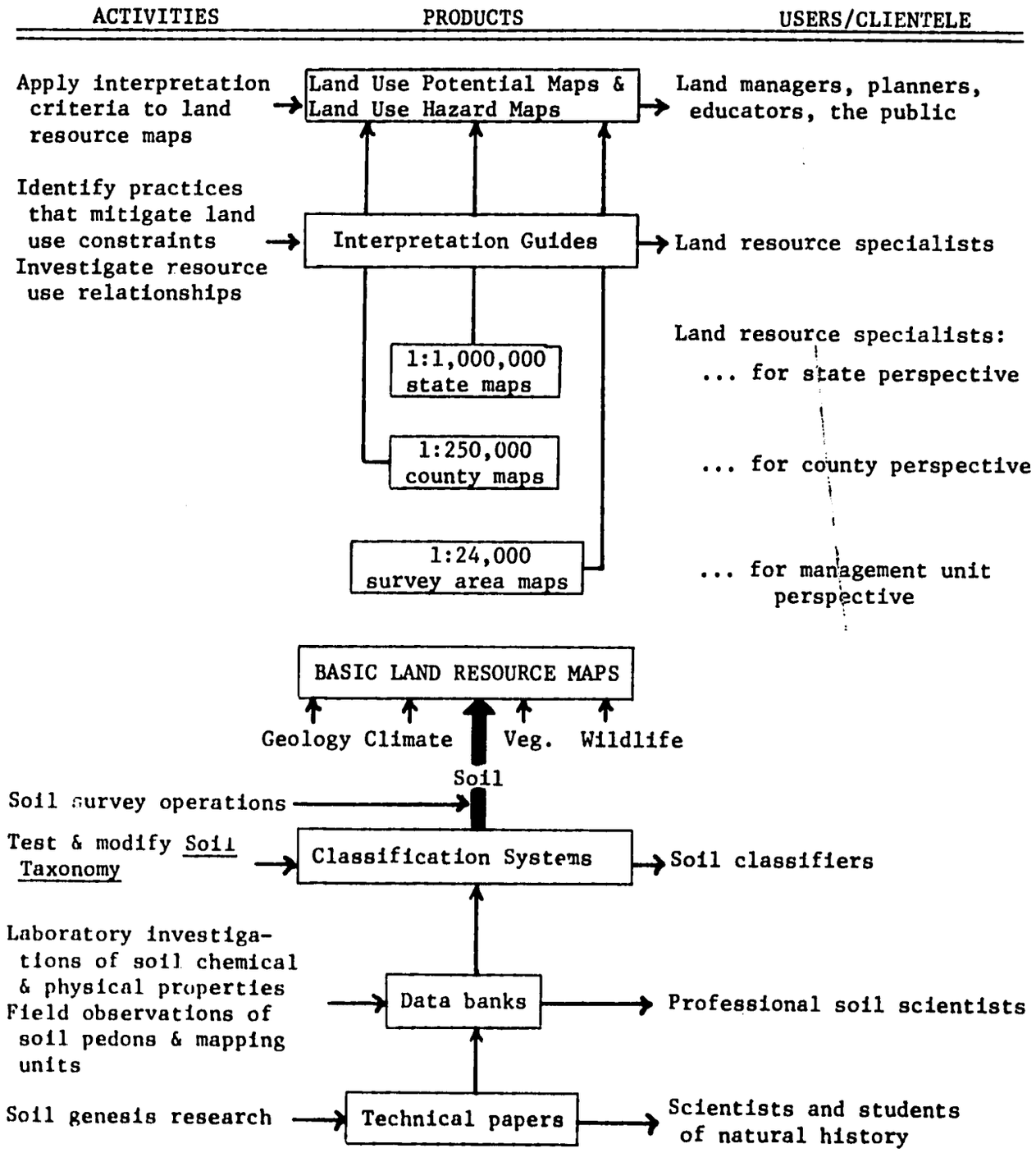

Figure 1. Activities, products and users of soil surveys for technology transfer and land use decision making. Modern soil survey reports present much of what is noted in the products column but most exclude maps showing land use potentials and hazards.

and benchmark soil monographs as well as to public presentations on land use potentials and hazards.

Data Banks

In the soil resource inventory process, data accumulates from innumerable field observations and laboratory tests. These data are presented to other professionals in soil pedon descriptions and soil investigations reports. Coded data are exchanged on computer cards, magnetic tapes and directly by telephone hook-up of computer terminals. This massive collection is essentially a soil data bank, drawn upon for purposes of classification, mapping and evaluating land use potentials and hazards. Electronic computers can be powerful tools in processing and presenting these data. We record data in the field on mark-sense forms. Computers are programmed to print out descriptions of soil pedons and mapping units and rate soil limitations as "slight," "moderate," or "severe" for many potential uses (Decker, Nielsen, and Rogers, 1975). The ratings are based upon criteria developed by the SCS (Soil Conservation Service). The results appear as typewritten descriptions and tables. Processing and display of laboratory data are also automated.

Computers are used to store, process and print out soil pedon descriptions on an operational basis for all new surveys in Montana. The system is used routinely in university classes. SCS has proposed a national code system for computer storage and retrieval of soil pedon data and improved mark-sense forms for encoding data are being tested.

Soil Classification

Classification systems define kinds of soils that can be mapped and that have predictable sets of soil properties. *Soil Taxonomy* (USDA, SCS, 1975) illustrates a documented system that facilitates the exchange of ideas about soils in different geographic areas. This system is readily adapted (using soil phase concepts) to recognize features that are important for local evaluations of soil potentials. The system can be modified as new knowledge of soils is obtained.

Basic Land Resource Maps

Inventory data are presented at several levels of detail. Several states have chosen 1:1,000,000 scale to give a statewide perspective, 1:250,000 for a countywide view, and 1:24,000 for operational planning and decision making.

In planning for agricultural development there is a need to identify environmentally analogous areas where a particular cropping practice will give the same results. Locating analogous areas is a first step in transferring research conclusions within and among countries. Soil surveys may not be adequate in themselves for delineating environmentally analogous

areas. Our work with land use planners and land managers has shown that more detailed information about climate, water, and other land resources is often needed. Dr. R. Dudal, Director of Soil Surveys for FAO and Executive Secretary of the International Soil Science Society, has stated that present soil surveys are inadequate to define land potential. Integration of basic land resource data with information on social, economic, and human resources is the most difficult task of all. A goal of at least two regional research projects in the United States is to develop more effective methods of disseminating soil resource data and interpretations. One approach has been to supplement general soil maps with companion maps of geology, topography, and ground water.

Interpretation Guides

Basic maps of soils and other land resources are interpreted according to criteria which research and experience have shown influence land use potentials and hazards. Interpreting these maps singly and in combination is a multidisciplinary task. Soil scientists should take an active role in this and can assist with socio-economic considerations as well.

Current interests in soil resource interpretations in Montana have included the following: fertilizer recommendations, outdoor recreation activities, nutrient and microbiological problems of waste disposal, taxation, zoning, definition of prime agricultural land, archeological studies, habitat identification for grizzly bears and other endangered wildlife species, livestock range potential, timber production, wilderness protection, barley and alfalfa production, definition of carrying capacity for land, route selection for transportation systems and utility corridors, planning and implementing strip mine reclamation, home site selection, ground truth for remote sensing, and saline seep identification.

Potentials and Hazards Maps

Many people, including planners, managers, and the general public, seek information about land and how potentials for agriculture, urban development, recreation or wildlife can be identified and realized. They are concerned about hazards of land use and how they can be overcome or avoided. Soil resource inventories do not provide all of the data needed to make maps showing potentials and hazards of land use, although they are usually the most useful single data source. Soil inventory data are most useful when presented in a form that is readily integrated with other critically needed data on both biophysical and socio-economic factors.

GRAPHIC METHODS OF DATA PRESENTATION

A soil map of Gallatin County, Montana, was published in 1931 (De Young and Smith, 1931). Hundreds of copies remained on shelves until 1970 when a supplemental report (USDA and Montana Agric. Exp. Stn., 1971) was prepared in which the use limitations of each soil were rated.

Color-coded soil limitation maps were prepared on transparent films using the ratings in the supplemental report. Colored felt-tip markers were used to identify the degree of limitations: green, yellow, and red for slight, moderate, and severe, respectively. Similar maps were colored to show soil limitations for cropping, roads, building foundation sites, sewage lagoons, septic tank filter fields, recreation areas, and other soil uses.

Groups of soil limitation maps were overlaid to show composite limitations for several uses. For example, one composite demonstrated that land being subdivided for housing had soils poor for homesites (roads, foundations, septic tanks) but good for crops.

Soil monoliths models, photographic prints, and *35 mm slides* were used to illustrate soil limitations and related land use problems.

Dollar costs to overcome soil limitations were documented (Leeson, 1972) by talking with contractors and homeowners. Audiences were reminded that most soil limitations can be overcome with technological inputs. Extra costs were $1,900 for a home septic tank and $60,000 per mile for inappropriately placed roads. The high cost of overcoming "severe" limitations sometimes prevented development.

These interpretations and display techniques increased demand for the original soil inventory and in a matter of months the entire supply was used.

Black and white maps were prepared from hand-colored maps and were reduced photographically for publication in newspapers. Most newspapers accept maps that accompany short articles on land use potentials and hazards and publish them without cost. Maps were published free and reached thousands of people. Publication in color is more effective but very expensive.

Interactive overlay techniques graphically integrate soil resource constraints with those imposed by geology, climate, vegetation, and other components of the land. Interactions of physical land capabilities with present and potential land uses are demonstrated. Overlays can show the location of roads, land ownership patterns, taxation districts, school districts, irrigation and drainage networks, marketing centers,

and an almost endless number of social and economic factors that influence land use.

The *shaded window display technique* uses transparent overlay maps on which constraints for a particular land use are indicated in shades of red using color films.

A LOOK AT THE FUTURE

Efforts to communicate ideas about land potential to decision makers will certainly use more composite overlay maps. But overlays have some limitations. Eventually computers may be used to print individual soil constraint maps as well as composite maps in which each component is, in a sense, weighted according to its importance. The importance of each input (soil, climate, present land use, etc.) would be previously assigned by experts.

Land information systems will eventually incorporate computer graphic displays, remote sensing from satellites, computer data processing and systems analysis techniques. Integrated land capability maps will appear on television monitors. Planners will simulate compatible future uses for decision makers. Advisors and lay audiences will participate by changing value judgments involved in the land resource evaluations and by changing assumptions about future prices, populations, etc. Effects of these changes will be displayed immediately. Although these advanced systems will undoubtedly be common in the future, they are expensive, and examples of useful applications are still rare.

We have partially developed a *Computer Graphic System* for interactive display of land resource maps. The system produces plotter-drawn maps of Montana at a 1:1,000,000 scale. Data are manually encoded in about 40 man-hours per map using a point-change technique that stores data for 17,600 cells, each measuring 3 minutes by 3 minutes (about 8.2 sq. mi.).

The following data are being encoded from state maps: soils, length of frost-free season, date of first freeze, date of last freeze, potential evapotranspiration, annual precipitation, growing season precipitation, snowfall, 50-year peak precipitation, R-factor, potential sediment yield, consumptive use, climax vegetation, chinook belts, and elevation.

WORKSHOPS AND A LAND RESOURCE INVENTORY HANDBOOK

A workshop on resource inventories and land use problems was conducted at Montana State University for county commissioners and planning board members from throughout

the state. This workshop reaffirmed our conviction that much useful information about land resources remains unused because: (1) potential users are not aware of its existence, and (2) the information is in relatively unusable form.

In a formal evaluation of statewide county workshops on planning and regulation of land use, presentations on using soils information in planning were ranked by participants as 6.38 on a 1 to 7 scale (7 indicates information "very much worth my time"). The soils information received the highest mean rating and the highest number of positive open-ended comments for any of the 12 presentations delivered on various aspects of land use planning. A total of 107 requests were received for information on methods of producing overlay maps showing constraints of soils and other natural resources.

In press is a *Resource Inventory Handbook* that: (1) gives sources of information about land qualities and land use, (2) suggests common map scales and inexpensive techniques that citizen groups can use to display resource data in local newspapers, (3) tells how to interpret land resource data, and (4) explains how overlay maps can be prepared for public meetings. The handbook tells how resource information that is already available in files can be assembled to enhance land resource analyses.

CONCLUSIONS

The utility of soil maps is dependent upon effective methods of presentation. Composite maps showing potentials and hazards of specific land uses do present data effectively. Such maps include properly interpreted soil maps as the key component. Development of interpretation guides will constitute a major future thrust in soil science research. Clearly, a formal system is needed to appraise the relevance, quality, and adaptability of soil maps and other land resource inventory products.

Presented 4/6/77.

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SOIL RESOURCE INVENTORY FOR THE SMALL FARMER

J. B. Collins[1]

The world's food needs can only be met by a rapid increase in productivity per unit area of available land (Biggs and Tinnermeier, 1974; Ezumah, 1972; Reaching the developing world's small farmers, 1974). The entire agricultural system of a nation depends on the productivity of the soil. One of the world's greatest potential resources for food production is the small farmer (defined as an operator of 2-10 hectares of land who receives the majority of his food and income from agricultural products produced on this land). In most tropical countries the small farmers make up 60% of the food production sector (Biggs and Tinnermeier, 1974; Kirkwood and Dean, 1975; Reaching the developing world's small farmers, 1974). The small farmer is particularly vulnerable to any deterioration of his soil resources, for the quality of his life depends on the preservation and productive capacity of his land. Its proper use is essential to food production on a continuing basis. It is important, therefore, to increase the capability of the small farmer to evaluate his soil resources for increased food production.

The concept of a soil resource inventory for the small farmer was developed from principles used by professional soil scientists in making "utilitarian type" surveys (Guide for preparing soil survey legends, 1957; Handbook for making resource inventories, 1963; Storie, 1964). This type of survey is useful in areas where there are no modern soil surveys. The survey is the vehicle for the transfer of technology via the para-professional to the small farmer.

The para-professional can be utilized to help the small farmer to evaluate his soil resources (Kirkwood and Dean, 1975; Strickland and Soliman, 1976). A diagram of a suggested mechanism for working with the small farmer is shown in Figure 1. In preparing the para-professional to teach the small farmer, it must be recognized that few if any para-professionals will have formal training in soils, chemistry, botany and other related scientific fields. Therefore, scientific knowledge must be simplified for understanding, but without loss of accuracy. Scientific facts and principles must be presented in such a manner as to overcome communication barriers and build upon the knowledge base already possessed by the small farmer.

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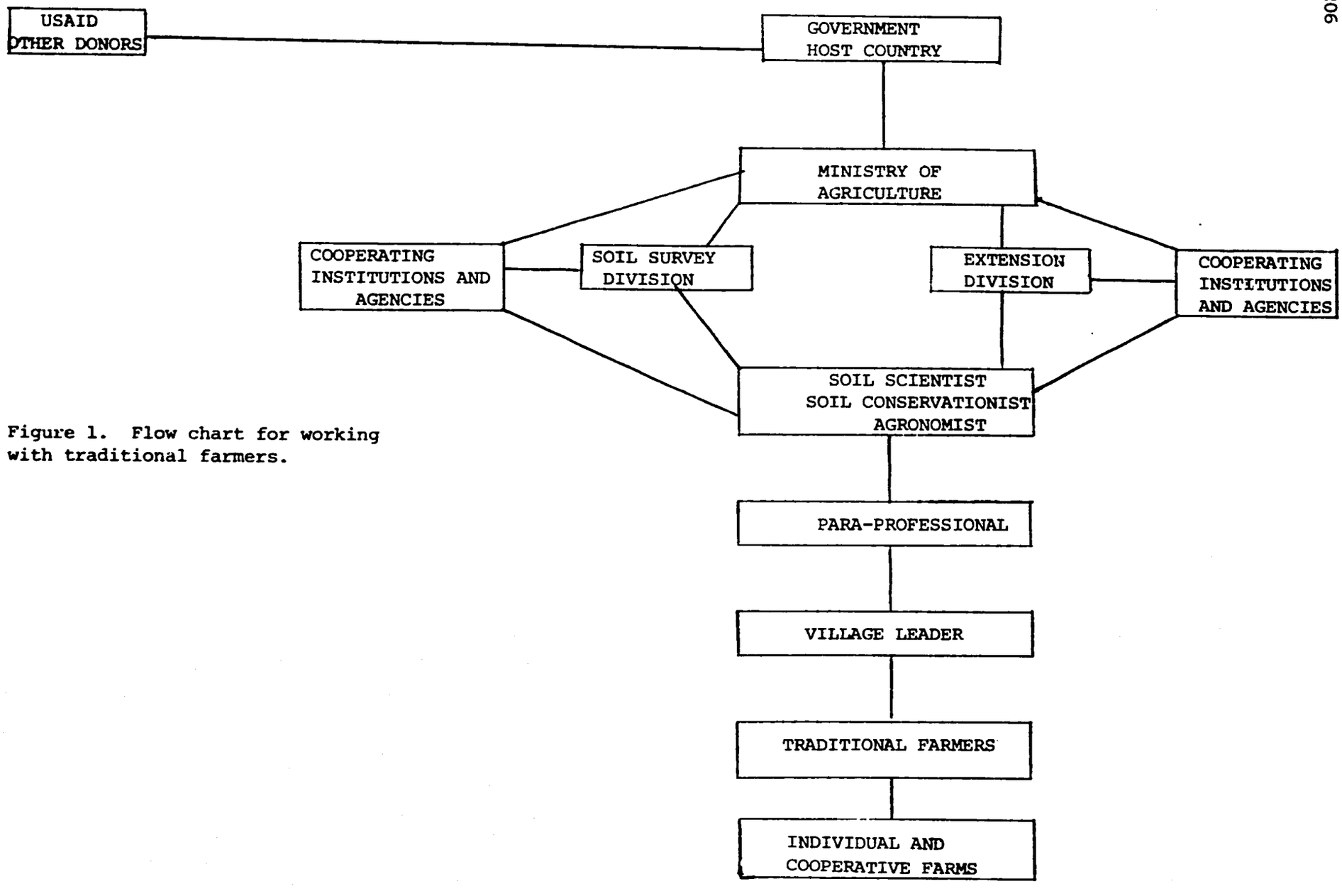


Figure 1. Flow chart for working with traditional farmers.

In teaching the small farmer to evaluate his soil resources for increased food production, consideration should be given to: (1) how soils differ, (2) how differences in soils are related to the use and management of the soils, (3) how to make a soil survey, (4) soil management principles, and (5) alternative practices and crops.

HOW SOILS DIFFER

There are many differences in soils that affect their use and management. These differences are of two kinds: permanent and temporary. Permanent differences are those not normally changed by management, e.g. soil depth, texture, and slope. Permanent differences form the basis for long-term plans and capability classification. Temporary soil differences are those that can be corrected by management, e.g. surface crust and traffic pans. Temporary differences tend to mask the effects of permanent differences.

Differences in soils can best be taught by on-site examination and by the use of visual aids. In teaching the small farmer how soils differ, attention should be given to the following:

Depth. Emphasis should be placed on how limited depth restricts root development and the fertility and moisture storage capacity of the soil. Actual field sites, soil profile monoliths, and soil depth charts are effective visual aids.

Texture. It is best to use only three major texture groups: fine, medium, and coarse. Demonstrate how to distinguish between each group by rubbing a moist sample between the thumb and forefinger. Actual samples of the three groups are excellent visual aids. On field trips take along samples of known textures so that comparison can be made at each stop.

Permeability. Stress the differences in soil porosity and the resulting difficulty with which water and plant roots move both vertically and horizontally in the soil. Demonstrations with actual samples and field trips are effective teaching aids.

Erosion. Stress the actual amount of soil that has been removed from or added to the soil profile. Field examples are the best visual aids. On field trips, point out the different forms (gully, sheet, rill) of erosion.

Slope. Slopes are usually quite evident to farmers. Demonstrate how to determine slope gradient with an abney hand level or a simple slope finder. Stress aspect and shape of slope. Field examples and demonstrations are the best teaching aids.

Traffic pans and surface crust. Emphasize that these differences are due to a deterioration in soil structure and that these

conditions often cause widely different soils to act alike, reducing infiltration, root development, and air supply and increasing runoff. Examination of actual samples for appearance, weight, and structure is an effective teaching aid.

Natural fertility. Stress the importance of plants as indicators of soil fertility. Here again, field examples are the best visual aids.

Inhibitory and other modifiers of the field mapping unit should be explained where significant. These become more important when working with an individual farmer on his own land.

MANAGEMENT PROBLEMS CAUSED BY DIFFERENCES IN SOILS

Management problems are of a permanent nature based on the characteristics of the soils and the landscape on which they occur. This can best be taught by demonstrations and field examples. Management problems that should be considered include:

Water-holding capacity. It is best to divide the actual inches of available water that can be stored in the soil profile into three classes: low, medium, and high. This is done by an evaluation of the various textural layers in the profile. An excellent method to demonstrate water-holding capacity is to use three small tin cans with holes punched in the bottom. Each can is partially filled with equal amounts of different textured soil material and placed in a jar. Equal amounts of water are then poured into each can. The amount of water collected in the jars illustrates the ability of each soil material to store water. Emphasis should be placed on the effects of water-holding capacity on: choice of crops, design of irrigation systems, and rainfall utilization.

Plant-soil-moisture-air relationship. Stress the need for a deep rooting zone with adequate amounts of air and water. These relationships can be easily shown by contrasting profile in the field. Monoliths of contrasting soil profiles are very effective for indoor discussions.

Fertility-holding capacity. This is a direct interpretation of the exchange capacity or the ability of the soil to store nutrients. Stress the relationship between fertility-holding capacity and the amount of nutrients that can be retained from fertilizer applications. Point out the problems associated with variability in fertility-holding capacity with increasing depths in the soil profile. The effects of organic matter, texture, and mineralogy on fertility-holding capacity can be shown effectively by the use of visual aids.

Damaging overflow. Stress how the frequency of flooding can

be determined by the position in the landscape. Flooding, if not corrected, dictates choice of crops.

Workability. Emphasize the moisture content at which the soil can be worked or trampled by animals without damaging the structure of the soil.

Natural drainage. Stress how natural drainage can be determined by noting the depth of mottles below the surface. Emphasize how this can be used to determine the need for the removal of excess water or to determine the choice of crops to be grown.

Depth. Depth is of extreme importance in determining the potential for terracing, leveling, diversion, and pond construction. Soil monoliths and field examples are effective teaching aids.

Susceptibility to erosion. Stress why some soils are more susceptible to erosion than others. In teaching about erosion emphasis should be placed on conservation practices.

MECHANICS OF MAP-MAKING

After the farmer has an understanding of how soils differ and how these differences are related to the use and management of the soils, he can then be taught by the para-professional how to make an inventory of his soil resources. The latter consists of making a base map and delineating mapping units (soil, slope, erosion) on the base map.

Base map. A drawing board, scale, compass, protractor, pencils, steel pins, notebook, drawing paper, and thumb tacks are all that is needed to make a base map without a plane table, alidade, and chaining equipment (Soil Survey Manual, 1951). All ground measurements should be done by pacing. The average person will count 33 steps in a distance of 99 feet. After selecting the scale and orienting the map with a compass, a series of clockwise or counterclockwise traverses, starting from a known point, are made to establish boundaries, establish corners, and locate physical features by triangulation (Figures 2-5).

Delineating mapping units. In his route across the farm to delineate mapping units (soil, slope, erosion) on the base map the surveyor should make periodic stops to note and record useful information. All that is needed for this purpose is a spade or bucket auger, field pH kit, abney hand level or slope finder, soil color chart, pencil, and notebook (Soil Survey Manual, 1951). Figure 6 is an illustration of a survey in progress and Figure 7 is an illustration of a completed map.

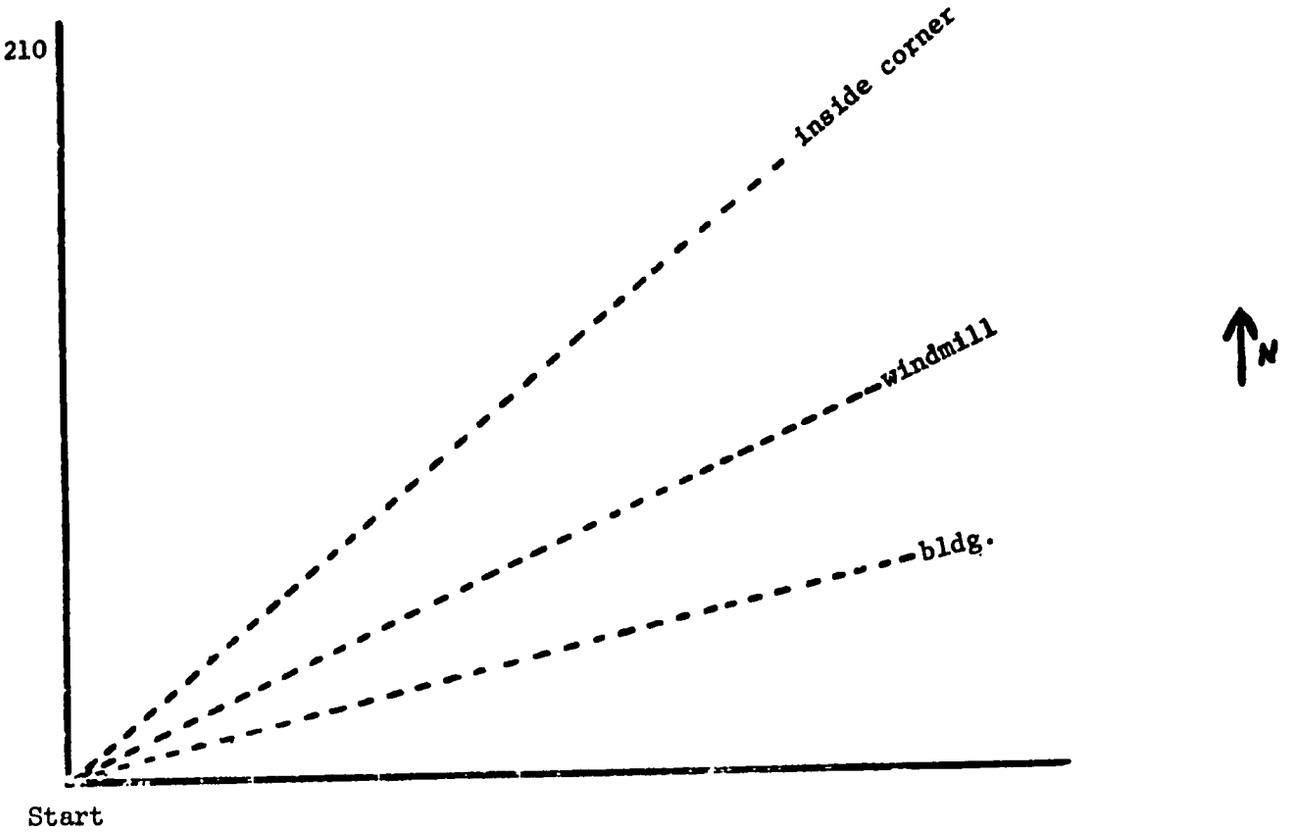


Figure 2. Making a base map.

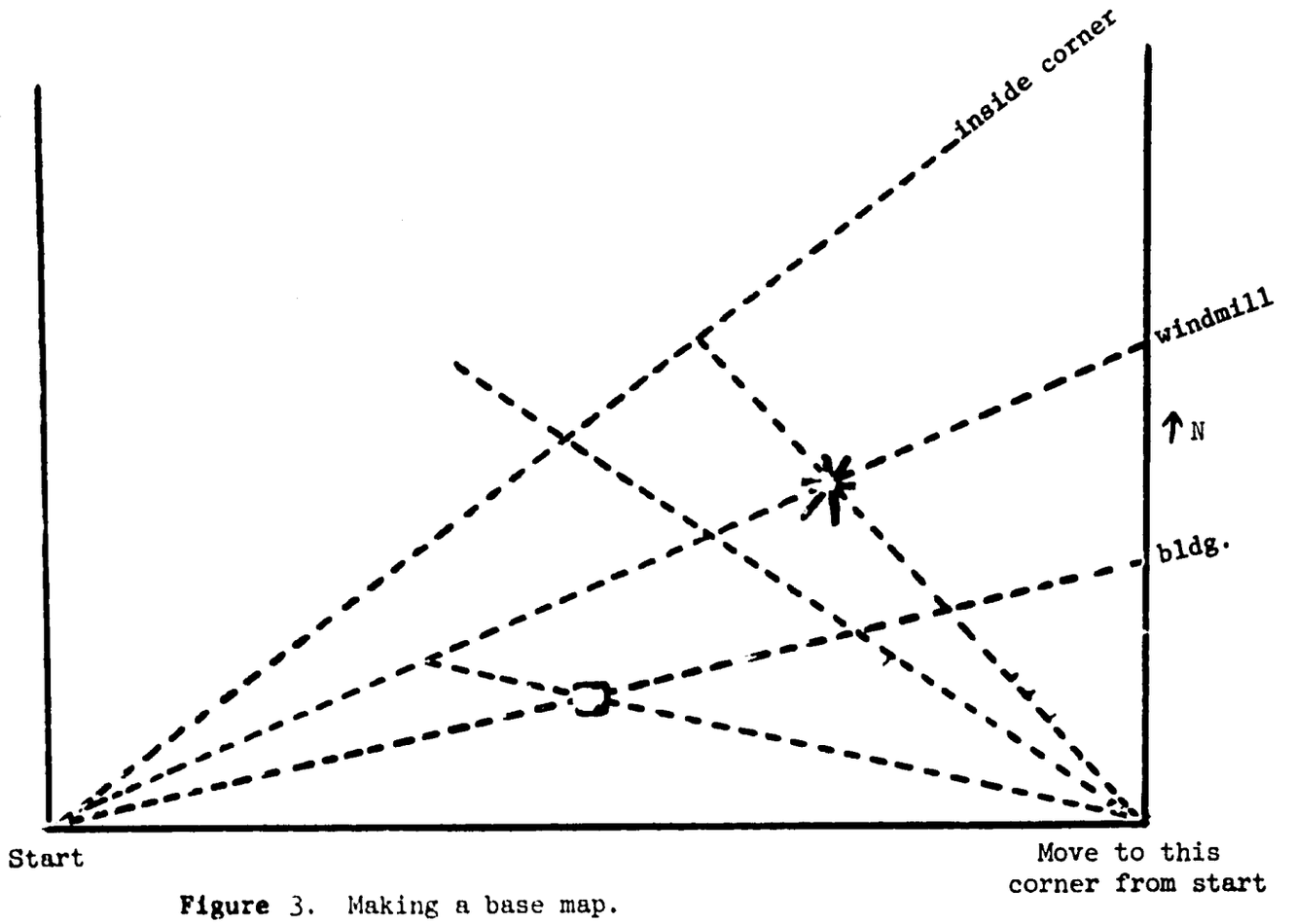


Figure 3. Making a base map.

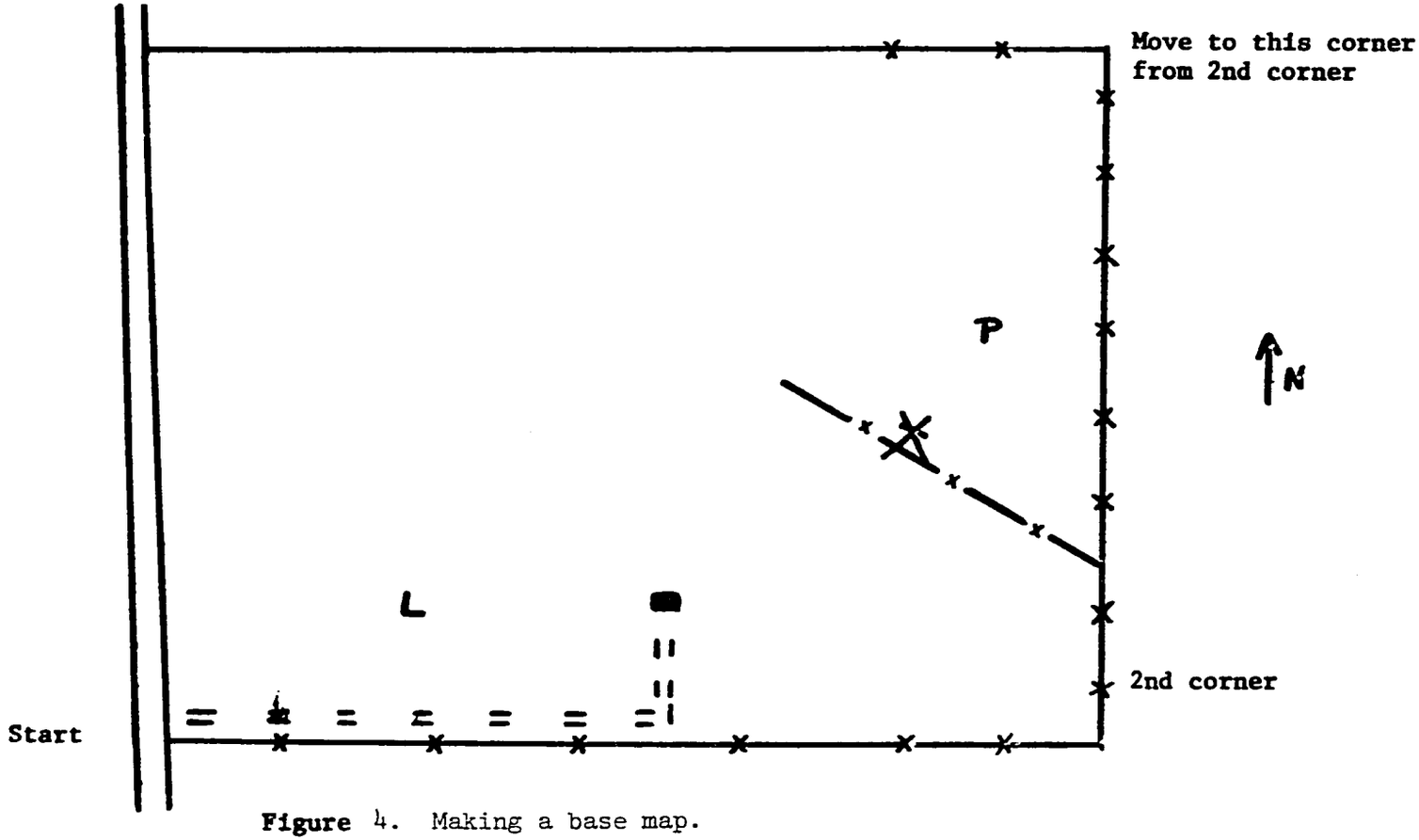


Figure 4. Making a base map.

Scale 4" = 1 mile

Legend

Boundary fence

Inside fence

Building (or House)

Windmill

Private road

Country road

Cultivated - L

Pastureland - P

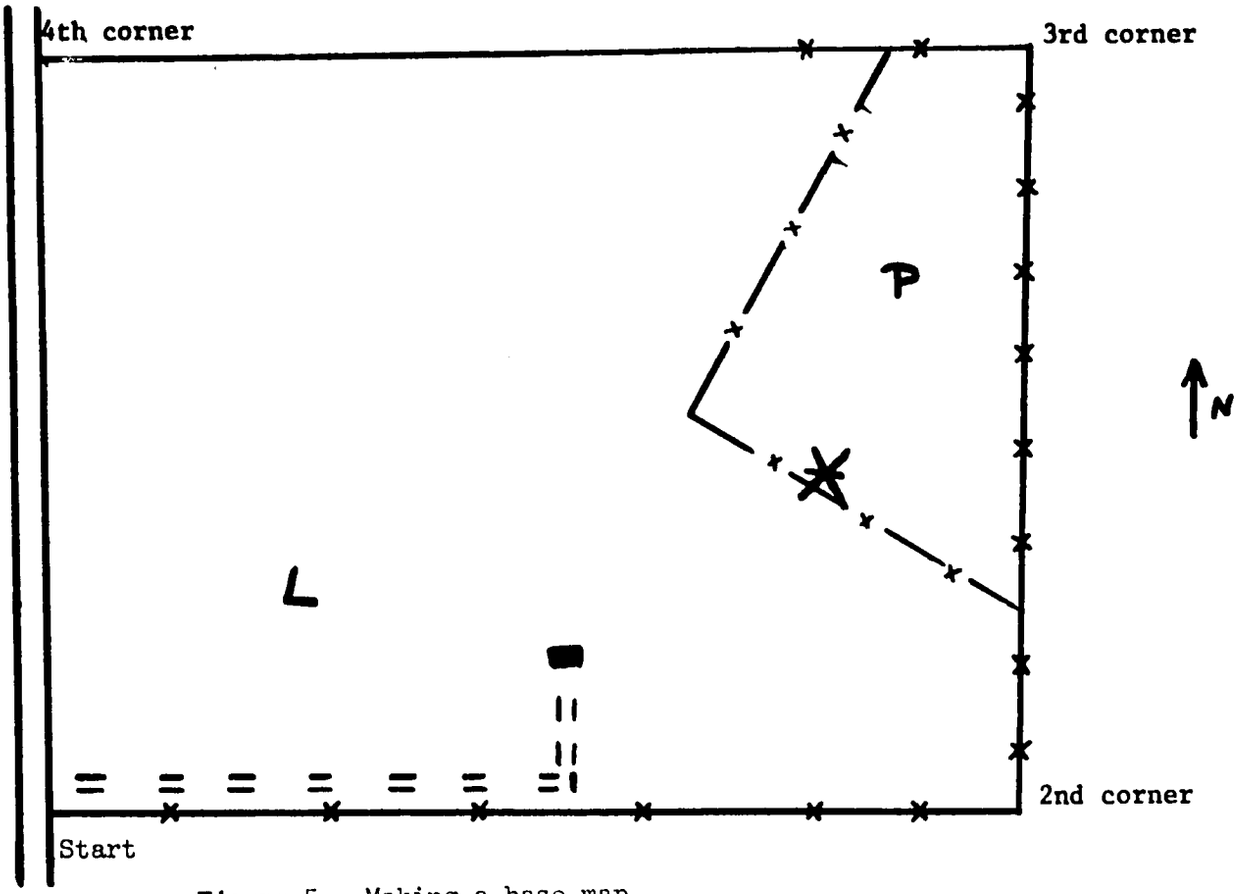


Figure 5. Making a base map.

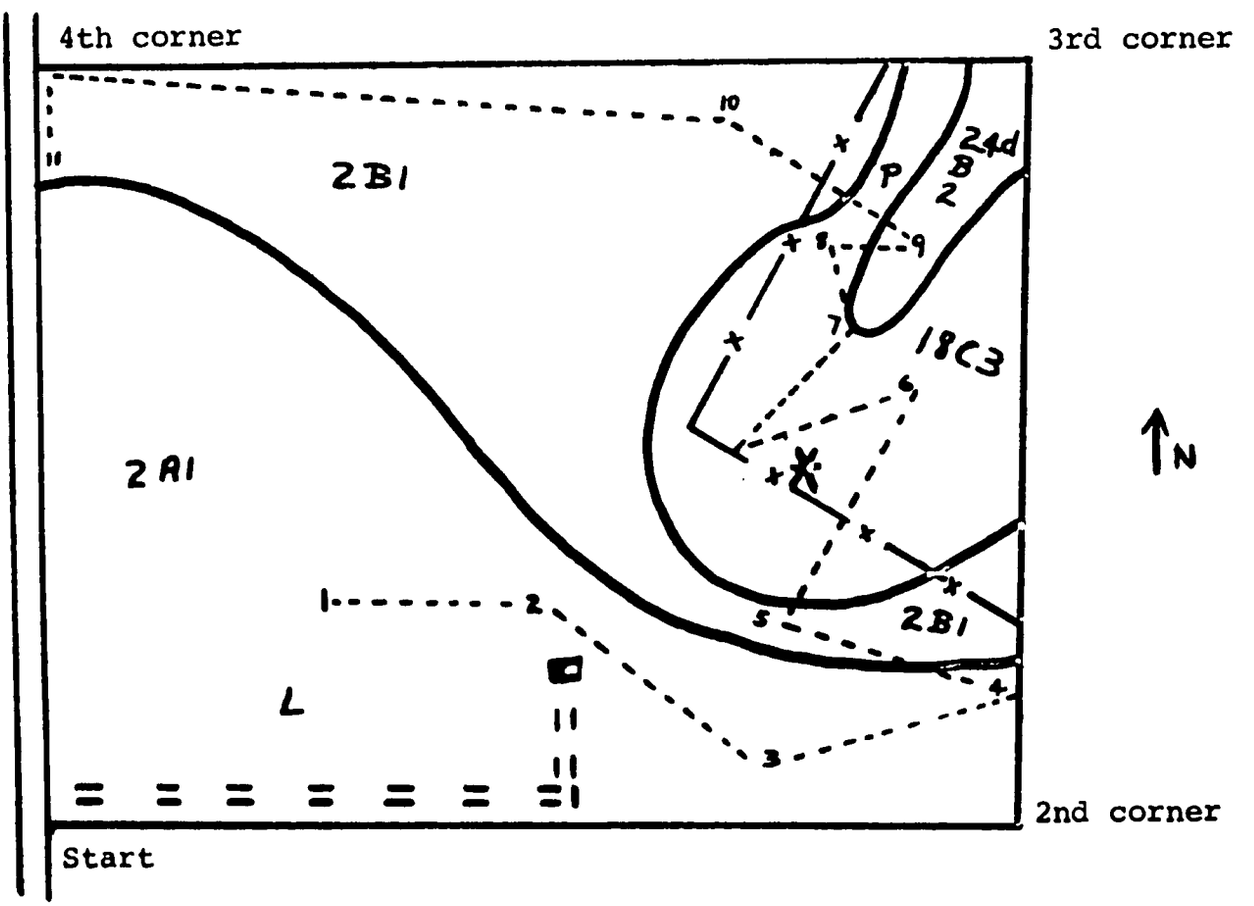
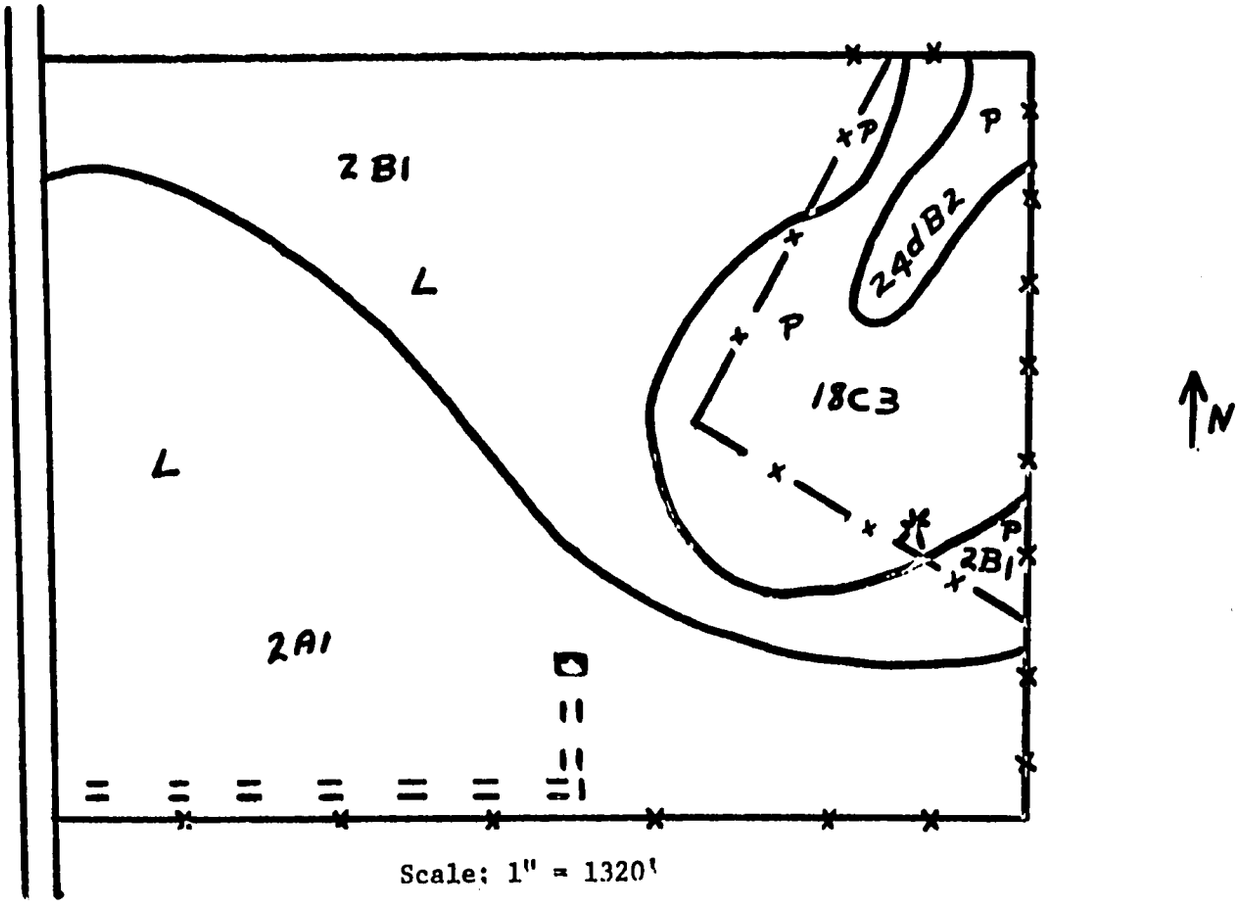


Figure 6. **Making a utilitarian soil survey map.**

UTILITARIAN SOIL SURVEY

Name: _____ Surveyed by: _____

Location: _____ Date: _____



Scale: 1" = 1320'

Legend

Soil---
2 - Deep, fine textured, slowly permeable soil
18 - Shallow, fine textured, permeable soil
24 - Very shallow, fine textured, gravelly soil

Slope-
A- Nearly level (0 to 1%)
B- Gently sloping (1 to 3%)
C- Sloping (3 to 5%)

Erosion-
1 - Slight
2 - Moderate
3 - Severe (or moderately severe)

Land Use-
Cultivated - L
Pasture - P

Other-
Public Road
Private Road
House
Boundary fence
Inside fence
Soil Boundary
Windmill

Figure 7. Completed map.

DISCUSSION

Once the farmer knows where the different soils on his farm occur and has an understanding of the management problems, he and the para-professional can develop land use plans and soil management systems (Etuk and Collins, 1976; Kirkwood and Dean, 1975; Strickland and Soliman, 1976). Listed below are some alternative crops and alternative practices that should be considered:

1. Crops with deep root systems that will supply large amounts of organic matter to the soil.

2. Crops with fibrous root systems that will supply moderate amounts of organic matter to the soil.

3. Drought-resistant crops.

4. Water-tolerant crops.

5. Salt-tolerant crops.

6. Fast or slow maturing crops.

7. Crops with vigorous root systems.

8. Crops that will supply large amounts of carbonaceous or nitrogenous organic matter.

9. Practices that will allow for timely tillage of the soil.

10. Practices that will allow for effective application of plant nutrients.

11. Practices that will conserve soil and water.

12. Practices that will not destroy soil structure.

CONCLUSION

The capability of the small farmer to evaluate his soil resources for use and management forms one of the most important bases for agricultural development. Therefore, it is imperative that such a project be launched.

Received 5/15/77.

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PRINCIPLES OF PRESENTATION OF SOIL SURVEY DATA FOR IMMEDIATE USE AND APPLICATION

G. W. Olson[1]

The purpose of this writing is to provide some principles and materials illustrating techniques by which soil information can be made more understandable and useful to all people. These materials are intended to accompany slide presentations of soil survey reports, publications, and maps. Examples from selected areas in Africa, Asia, Australia, Europe, Latin America, and North America will be used -- but the principles illustrated for selected areas are applicable anywhere. Although this information is intended primarily for use by soil scientists in preparing materials for presentation to laymen untrained in pedology, the principles are also equally applicable for improvements in communications among soil scientists themselves.

Soil information is often inherently difficult to use, especially by people untrained in pedology. Partly this difficulty is due to the unique definitions that pedologists have given to words that may be in common use with other connotations. Often laymen have difficulty in obtaining the precise definitions of pedological terms. Economists, for example, often state that the terms "silt loam," "silty clay loam," and "silty clay" look very much alike to them when the words appear in soil profile descriptions -- yet the significant differences in the definitions of these terms can mean differences of hundreds of thousands of dollars in developmental or reclamation costs of soil areas. The first and most important principle in improving uses of soil data is that soil information must be presented in terms meaningful and understandable to each user of the soil survey. For an economist, soil differences must be relatable to cost and benefit figures so that economic decisions can be made correctly based on the proper interpretation of the different soil characteristics. Other users (engineers, farmers, planners) similarly must have soil information made relevant to their own immediate situation of use.

USE OF PHOTOGRAPHS

Photographs are one of the best tools to make soil information more understandable to many different types of users of soil surveys. Soil maps on aerial photographs (Figure 1) can

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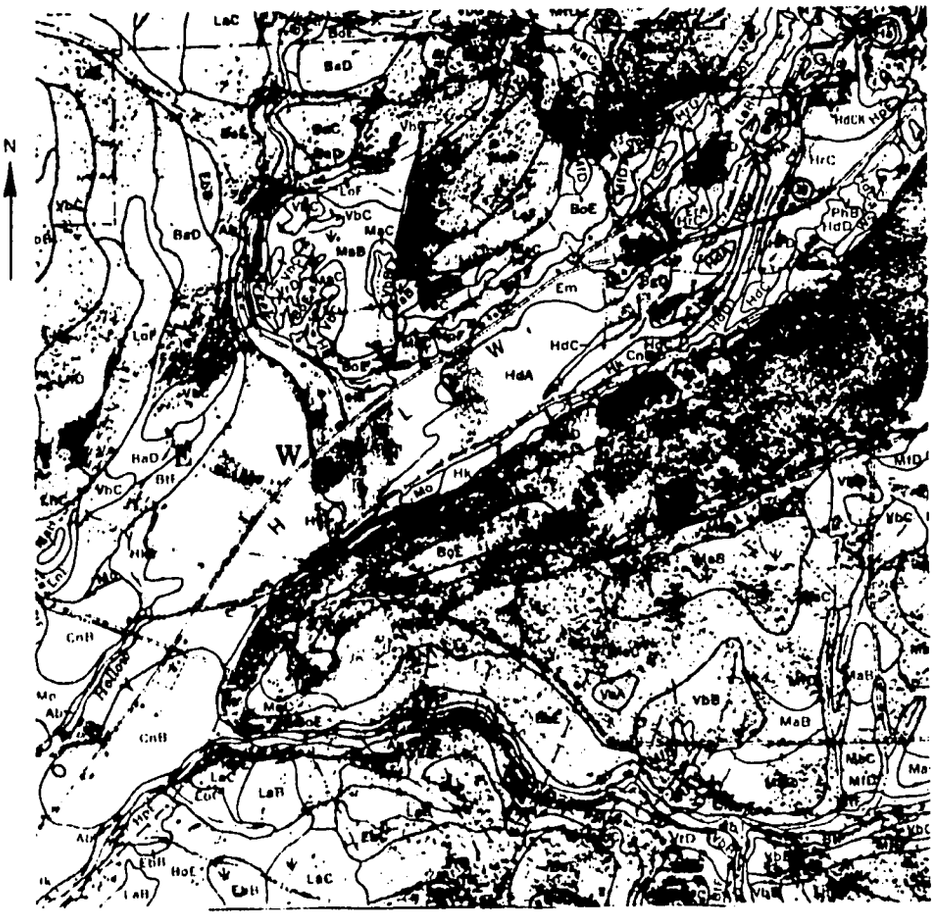


Figure 1. Detailed soil map from part of map sheet 31 of soil survey of Tompkins County, New York (Neeley et al., 1965), reduced from a scale of 1:20,000.

be immediately related visually to the pattern of land use. Figure 1, for example, excellently illustrates how most of the nearly level farmed valley has soil formed in alluvium (Em, Mo) and glacial outwash (CnB, HdA); the forested soils on steep slopes (BtF, LoF) are formed in glacial till only moderately deep to bedrock in places, and the soils on upper slopes (MaC, VbB) have seasonal seepage water at shallow depths in the glacial till. Soil map displays on aerial photographs can be understood quickly and easily by everyone with a minimum of explanations, and the air photo provides also a base map for ready orientation of the user.

Perhaps the greatest opportunities in soil survey interpretations are in innovative and imaginative techniques to use photos of soil conditions to better illustrate concepts of improving uses of soils. Figure 2 gives an example of a pair of photographs showing the best and worst soil conditions in an irrigation area -- illustrating the application of land classifications in soil survey interpretations. Paired photographs showing contrasting soil conditions are extremely effective, as are paired photographs showing before and after soil conditions, good and bad land use, cause and effect relationships, etc. Numerous paired photos illustrating soil conditions are given in several publications (Olson, 1969, 1971, 1977). Possibilities for imaginative display of the importance of soil characteristics through photography are enormous; much of the effectiveness of the photos is involved with the display through page layouts, slides, and other visual presentations. Clustered and sequential photos are also extremely effective. Figure 3 gives a sequence of photos showing erosion, sedimentation, reclamation, and productive management of soil areas in Venezuela; these photos are also available as slides to show to large audiences to spread the good word further about improving uses of soils. Photographs are remembered much longer by users of soils information than mere words in soil survey reports. A photograph can convey a whole concept about soil use and potential that will influence many future decisions that an individual or group of people makes about area development.

RELATING LAND USE DATA TO SOIL MAP UNITS

Unfortunately, relatively little work has been done to collect land use data that can be directly related to soil map units. Even after decades of costly soil fertility research in the U.S., the relating of yield data to detailed soil map units is still in its infancy (Soil Survey Staff Committee, 1977). Yet the most important data for use of soil surveys are those data that demonstrate the specific value of each soil to each use. In the following discussions are given some of the few data that do exist about the practical relations of soil properties to use.

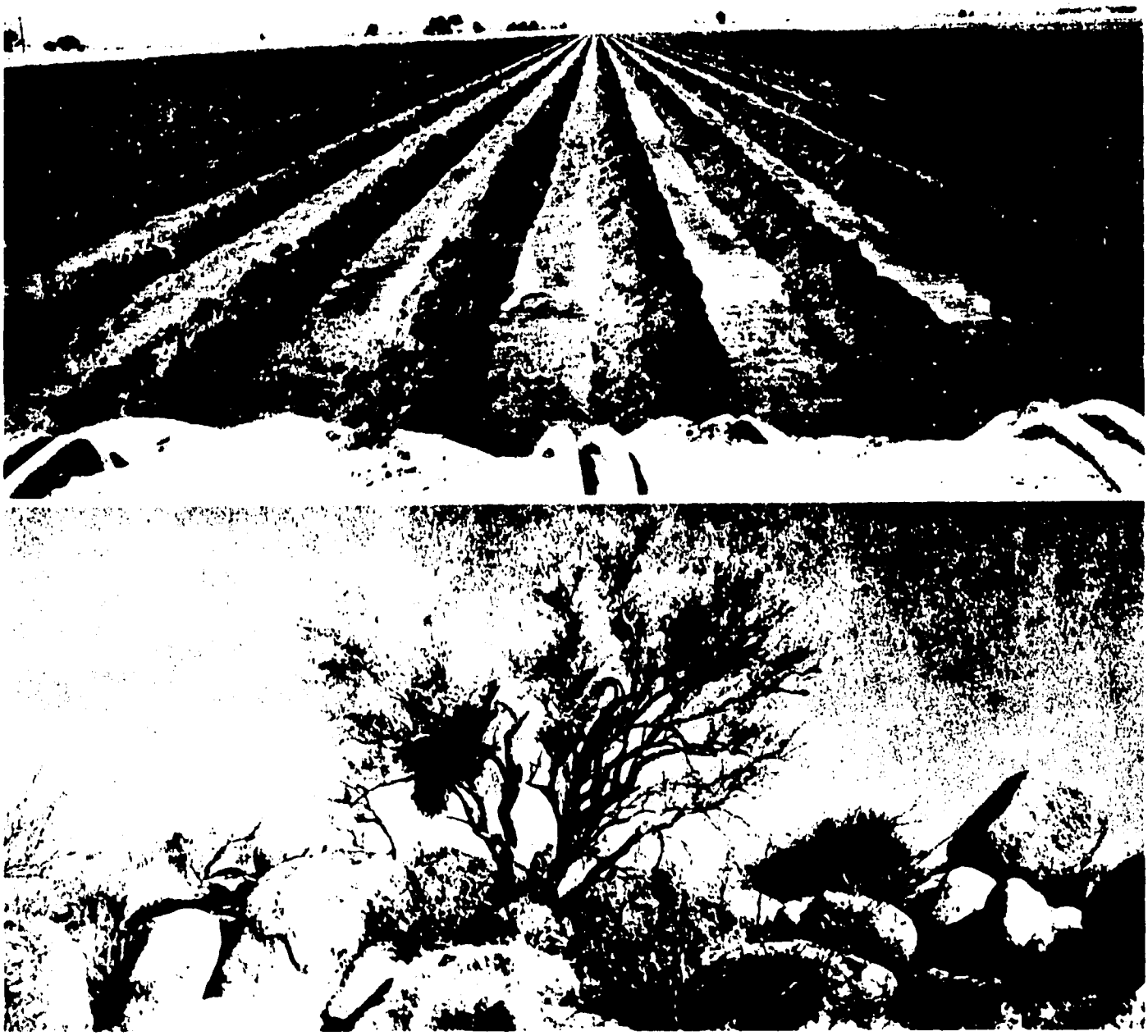
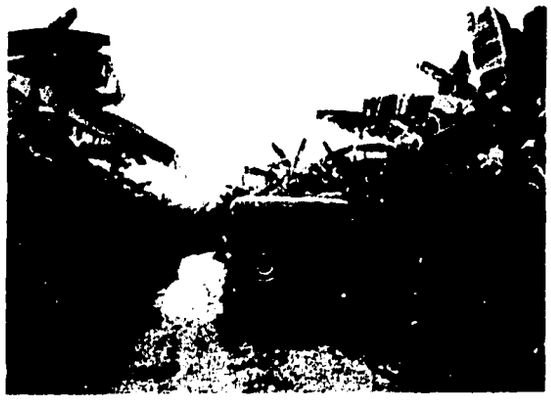


Figure 2. View of the best soils (upper) and the worst soils (lower) for farming in an area near Phoenix, Arizona. (Adapted from Olson, 1974).

Gullies induced by farming on steep slopes

Sedimentation in drainage channel

Dredging a channel for soil drainage



Banana plantation on improved soils

Figure 3. Sequence of photos showing erosion, sedimentation, dredging, and a banana plantation on improved soils in Venezuela. (Adapted from Olson, 1977).

Cost values, of course, are of extreme importance because (ultimately) almost all decisions about soils are influenced by or based on economic considerations. In Australia, excellent work has been done to isolate some of the effects of soil conditions in economic terms. Figure 4 shows how slopes of different soils affect cost of land areas for construction around Melbourne. The soil categories priced in Figure 4 are: (1) stiff well-drained stable clays or sands and decomposed sedimentary rock; (2) unstable erosive or slightly expansive soils, loose sands, and soils with moderately poor drainage; (3) deep soft soils, organic soils, fills, expansive soils, and soils with poor drainage; and (4) decomposed rock difficult to excavate, highly variable or unstable skeletal soils, faults, slides, etc. Table 1 illustrates very well how the values of Figure 4 are reflected in real economic terms in the price of land around Melbourne. Cheap suburbs like Coldstream (Table 1), Saint Albans, and Werribee have problem soils including flat black cracking unstable Vertisol clays, and higher priced suburbs like Glen Waverley have better soils with more efficient and aesthetic neighborhoods.

Of critical importance to improving uses of soils are studies relating land use to soil map units. In the northeast Abeokuta area, for example, over 70 percent of the cocoa (Table 2) was grown on soils classified as good and fairly good although these favorable soils occupied only 36 percent of the area (Smyth and Montgomery, 1962). In spite of this, a considerable acreage of these soils remains in the area under other less intense land uses. Such data have considerable implications in planning developmental programs for future improvements in the region.

Table 3 illustrates how economic studies can be related to soil map units to predict agricultural prosperity in an area. Areas can be classified by economists relative to the economic viability for farming, and then the land use delineations on maps can be compared with the soil maps at the same scale. When the land use measurements are compared to the soil areas, ratios can be calculated to indicate prosperity and compatibility of soil with the observed land uses. Future investments should be concentrated in those soil areas where the return is most likely to be greatest; these data help to determine the priority areas.

More commonly, significant soil characteristics are groups so that recommendations for use can be simplified. For a local area, soil texture is often correlated with fertilizer response. Figure 5 illustrates how pH measurements can be easily related to lime recommendations for general soil texture groups in New York State. Recommendations for soil use, however, are most valuable when they can be specific to each detailed soil map unit. Figure 6 is an illustration of how yields can be predicted for each treatment of each soil map unit when the soils are precisely identified and mapped.

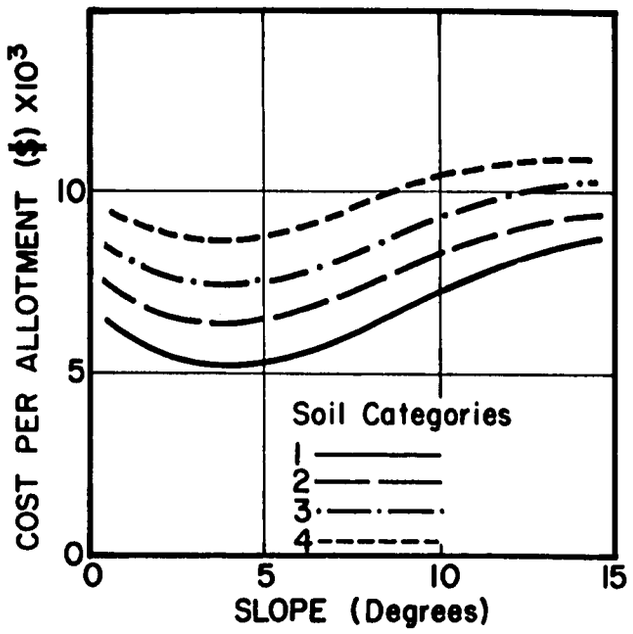


Figure 4. Effect of slopes of different categories of soils upon cost per allotment of dwelling construction sites near Melbourne, Australia. (Adapted from Neil and Scales, 1977).

Table 1. Extract from newspaper in Melbourne, Australia, illustrating effects of soil conditions (and other factors) upon the price of land in major subdivisions.

24 THE AGE, Wednesday, November 17, 1976

PROPERTY

Blockbuster!

PROPERTY FOR PROFIT

VALERIE CHRISTIAN

MORE than $70 million worth of land is on sale around Melbourne in major subdivisions.

Today's column gives an invaluable guide on just where the land is and how much it costs.

The list covers main new estates — not odd blocks up for resale on old ones.

Prices start about the $10,000 mark at Coldstream and St. Albans and peak at $35,000 at Glen Waverley.

At present about 110 blocks are sold a week, according to Mr. Alan Williams, managing director of Land Sales and Development.

This rate has been virtually steady in the past six months with some improvement in the past month, he says. This time last year the public was buying at the rate of about 75 blocks a week.

Builders are buying about 150 blocks a week, Mr. Williams estimates.

But this figure could soon rise to about 200 a week.

Most of the land is sold on average terms of $1,000 a block, be more than $1,000 at present, compared with about $14,000 in March.

Mr. Williams estimates land is coming on at an average rate of $100 a week.

A few points about the table:

PRICES are based on terms contracts — cash usually brings a 10 per cent discount.

PRICES vary within suburbs — so do the blocks. Only usually a view, underground services, proximity to services will bring a premium.

JENNINGS gives a 12 per cent discount if you build a Jennings home on a Jennings block. And as it is a builder, only 33 per cent of its land is on a "land only" basis.

WHERE TO BUILD: TO LAND

Estate and Location	Av. Price $	Range	No. of Blocks	Phone
Altona Beach	15,750	15,500-16,250	20	Land Sales & Dev
Baxter				
Station Estate	14,250	11,750-14,950	40	Land Sales
Berwick				
Berwick Heights	26,500	17,550-32,400	48	Gordon Morris
Berwick Lodge	13,620	11,890-17,950	100	Jennings
Boronia				
Stoneleigh	17,500	16,500-18,500	14	Treb. Revill
Bundoora				
Bradford Downs	17,026	16,750-17,400	13	Moore Williams/ Gelfand
La Trobe Village	15,800	14,000-17,000	90o	Taunton
Mill Park	18,100	16,800-19,500	445	Moore Williams
Carrum				
Patterson Lakes	25,186	20,300-31,500	15	Moore Williams
(Lakeside)	15,010	14,700-15,100	19	Moore Williams
Purrawa Village)	21,900	17,400-25,600	23	Jennings
(Lakeside)	15,350	14,200-17,400	12	Jennings
(Off Water)				
Carrum Downs				
Botany Park	N/A	15,000-16,000	40oo	Stocks & Hldgs.
Chadstone Rise	22,000	18,000-25,000	20	Hooker Res
Clayton Meadows	17,500	15,500-20,000	90	DUL
Coldstream				
Cheviot Park	13,000	10,450-15,950	40	Ralston Gray
Craigieburn				
Stratford Estate	14,512	13,750-24,750	61	Moore Williams
North Croydon				
Billanook Views	18,000	15,950-19,950	14	N. R. Reid
Dandenong North				
Studville Park	17,500	17,200-18,300	10+	Stocks & Hldgs.
Doncaster				
Doncaster Heights	24,500	16,500-29,000	51	DUL
Eltham				
Woodridge	19,500	16,000-23,000	31	DUL
Endeavour Hills				
Endeavour Hills	16,100	13,000-21,000	170	Moore Williams
Chalet Lodge	16,000	15,100-[illegible],300	123	Jennings
Sherwood	15,300	12,800-17,200	110	Jennings
Frankston				
Baywood Heights	15,500	14,000-17,800	40	Taunton
Lakewood	14,200	13,700-14,500	10oo	Hooker Res
Casuarina Ridge	14,570	13,700-16,300	45	Jennings
Karingal	13,475	12,500-13,900	10	Jennings
Bayview Ridge	16,500	15,250-16,950	34	G. Janides
Timberton	16,950	15,750-17,950	20	Land Sales
Bayview Park	13,950	11,950-15,500	15	Land Sales
Skyeline	14,000	13,800-15,000	54	DUL
Marylands	18,000	15,500-23,500	67	DUL
Skye Road	14,769	14,200-16,900	101	T. M. Burke
Glen Waverley				
Woodlea	32,000	29,000-35,000	64	Morrell, Riddle
Greensborough				
St. Helena Park	18,000	14,000-22,000	160	DUL
Diamond Hills	18,500	13,250-22,000	120	DUL
Hampton Park				
Hampton Grange	16,950	14,950-17,950	20	Land Sales
Keilor Downs	N/A	N/A	145	M. Wms./Dillon
Lilydale				
Beresford Park	15,950	13,250-16,500	15	Land Sales
Melton				
W. Melton Estate	16,200	16,200	30	Delphic Realty
Moorooibark				
Rolling Hills	16,750	15,000-18,150	22+	Spacelina
Castle Hill	16,000	14,700-17,300	81	Jennings
Manchester Road	15,750	14,500-16,850	90	Land Sales
Mulgrave				
Valley Views	17,700	16,750-19,250	20	Land Sales
Waverley Foothills	17,000	14,850-19,950	25	RDC Homes
Narre Warren				
Fountain Gate	15,500	N/A	60	Land Sales
Noble Park North				
Union Village	16,750	16,300-17,500	25	Land Sales
Oakleigh				
Heatherleigh	18,000	N/A	60++	Hooker Res
St. Albans				
Albanvale	12,550	11,950-13,350	20	RDC Homes
Kealba Village	13,010	10,700-14,050	140	Jennings
Scoresby				
Caribbean Ridge	17,000	15,000-19,000	75	Taunton
Seville				
Glen Heights	14,000	12,800-14,950	50	R. Moreland
Springvale				
Sandown Lodge	15,894	15,600-16,800	24	T. M. Burke
Sydenham				
Taylors Lakes	18,000	17,500-19,000	24	Abbott, Dean
Thomastown				
Hartwood Downs	15,302	13,750-15,950	94	M. Wms./Gelfand
Norwood Rise	15,106	14,950-15,600	26	M. Wms./Gelfand
Wallaroo				
Wellington Park	19,000	16,000-21,000	63	DUL
Wantirna				
Regency Park	19,000	18,000-22,000	40	Stocks & Hldgs.
Lots at the Top	18,030	15,800-22,030	38	Hooker Res
Carramatha Park	19,150	17,950-19,950	28	RDC Homes
Warrigee				
Windermere	12,500	11,750-13,500	40	J. McNaughton
Wheelers Hill				
Wheelers Heights	18,950	17,700-20,000	56	M. Wms./N. R. Reid & Stocks Sale

o 10% more in new year, 20 [illegible] more, p 15 more soon, ++ 112 more by Christmas, + 67 more this month, o + this month

Table 2. Relationship between soil quality and land use in the northeast Abeokuta area in central eastern Nigeria. (Adapted from Smyth and Montgomery, 1962).

LAND USE	SOIL QUALITY				ALL SOILS
	Good	Fairly Good	Poor	Very Poor	
	%	%	%	%	%
Cocoa	33.2	37.4	17.2	12.2	100
Farmland	15.3	21.0	33.2	30.5	100
Thicket	15.1	25.9	34.0	25.0	100
Grassland	1.4	4.9	30.4	63.3	100
Forest	9.8	19.7	37.5	33.0	100
All Vegetation	14.0	21.7	32.7	31.6	100

Table 3. Areas in farms and relative agricultural prosperity in some of the largest soil associations in the region around Syracuse, New York. (Adapted from Olson, 1969).

Soil association (1)	*Area (mm^2) and intensity of use for farming*			*Prosperity index (5)*
	High (2)	*Medium (3)*	*Low (4)*	*Ratio (2)/(4)*
Palmyra	85	20	5	17.0
Honeoye-Lima	318	87	27	11.8
Lansing-Conesus	49	38	9	5.4
Ontario-Hilton	109	82	22	5.0
Langford-Erie	43	44	24	1.8
Muck-Peat	16	14	13	1.2
Langford-Erie-Lordstown	28	75	32	0.9
Volusia-Mardin-Lordstown	24	45	30	0.8
Lordstown-Volusia-Mardin	38	56	69	0.6
Minoa-Lamson Canandaigua	6	25	30	0.2
Collamer Niagara	3	17	26	0.1
Sodus-Ira	11	51	98	0.1
Ira-Sodus	2	26	51	0.0
Worth-Empeyville	0	9	37	0.0
Total	732	589	473	1.5

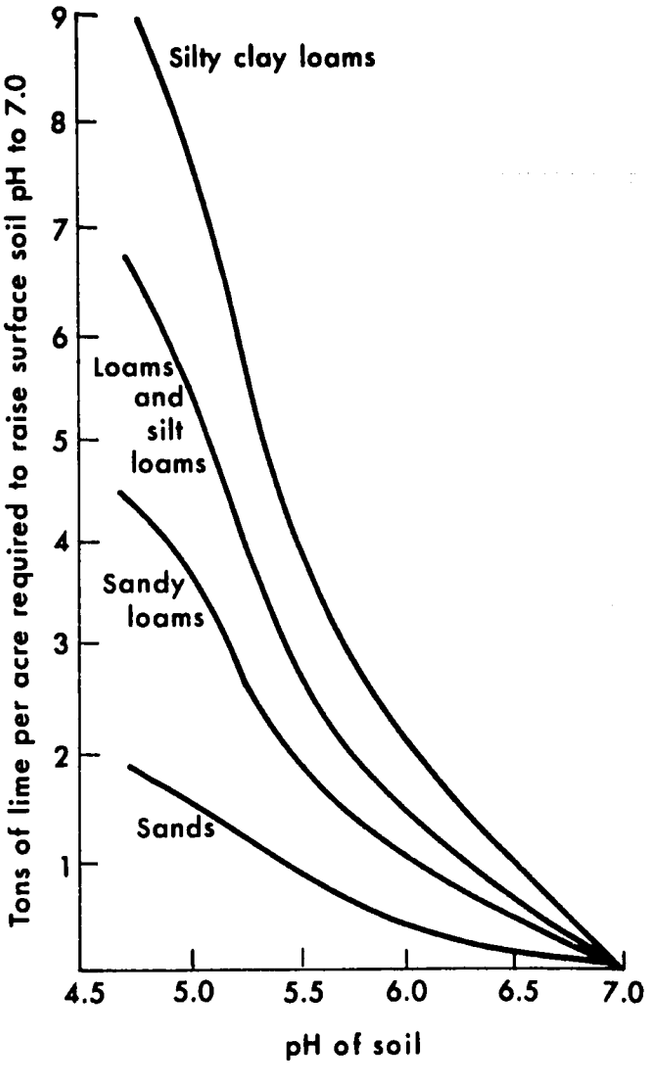


Figure 5. Lime requirements of common soil textures in New York State, showing amount of lime required to raise surface soil pH to 7.0 as a function of initial pH and textural class. (Adapted from Lathwell and Peech, 1964).

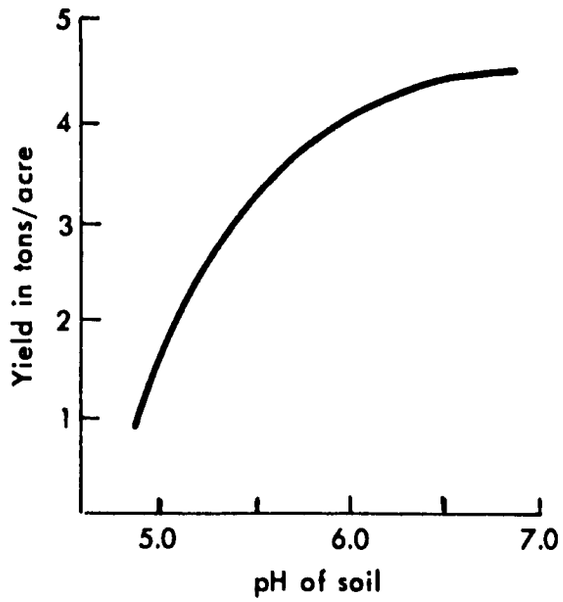


Figure 6. Yield of forage (alfalfa-birdsfoot trefoil-timothy mixture) on Mardin silt loam as a function of pH of surface soil. (Adapted from Lathwell and Peech, 1964).

Techniques which enable prediction of future soil performance, based on past precise soil data, are probably the most important to planners. Predictions can be estimated from the soil characteristics (as is commonly done), but the soil information is most valuable when actual data on soil performance are available. Figure 7 illustrates one example of such performance predictions. These kinds of data can be used with considerable validity to predict success and failure of soil systems and treatments, and to improve soil treatments and engineering designs where these are needed.

VISUAL PRESENTATIONS

Many visual presentations are useful when soil information is published or presented to users. Increasing computerization and standardization of soil reports tends to make them less individualistic (Smith et al., 1976); imagination and innovation should not be sacrificed in the presentation of soil information to the public. Lengthy tables of data and ratings tend to be efficient (Rivera et al., 1970), but not particularly inspiring to the readers; colored general maps (Smith et al., 1976) and colored interpretive maps (Edward et al., 1970) are excellently received by readers of soil survey reports. Block diagrams (Figure 8) and catena diagrams (Figure 9) can help to show relationships between soils; these are particularly useful for general soil maps or land systems maps.

For the future, innovations of new ideas and techniques for improving uses of soil information are particularly vital. Considerations must be increasingly given to reclamation of disturbed areas (Figure 10), measures of variability of soil map units (Table 4), improvements in transfer of technology about soil character (Figure 11), and to multiple efforts and imagination in application of soil maps and reports. Great progress has been made in the recent past in soil classification, description, and mapping; the challenge for the future is to make better use of the soil information already compiled to improve soil survey interpretations and the accompanying educational programs.

Presented 4/6/77.

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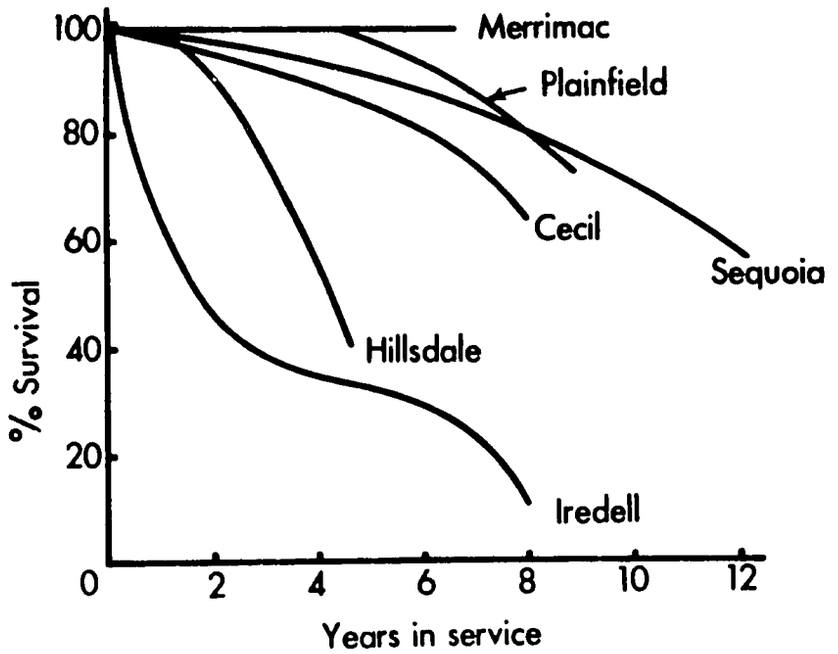

Cecil (slowly permeable soil with clay loam subsoil from North Carolina)
Hillsdale (sandy loam soil over variable stratified subsoil from Michigan)
Iredell (impermeable soil with clay loam subsoil from North Carolina)
Merrimac (permeable sandy loam soil from New Jersey)
Plainfield (permeable loamy sand soil from Michigan)
Sequoia (slowly permeable silt loam soil with blocky structured silty clay subsoil from Tennessee)

Figure 7. Survival curves for septic tank seepage fields in some different soils from eastern United States. (Adapted from Olson, 1964).

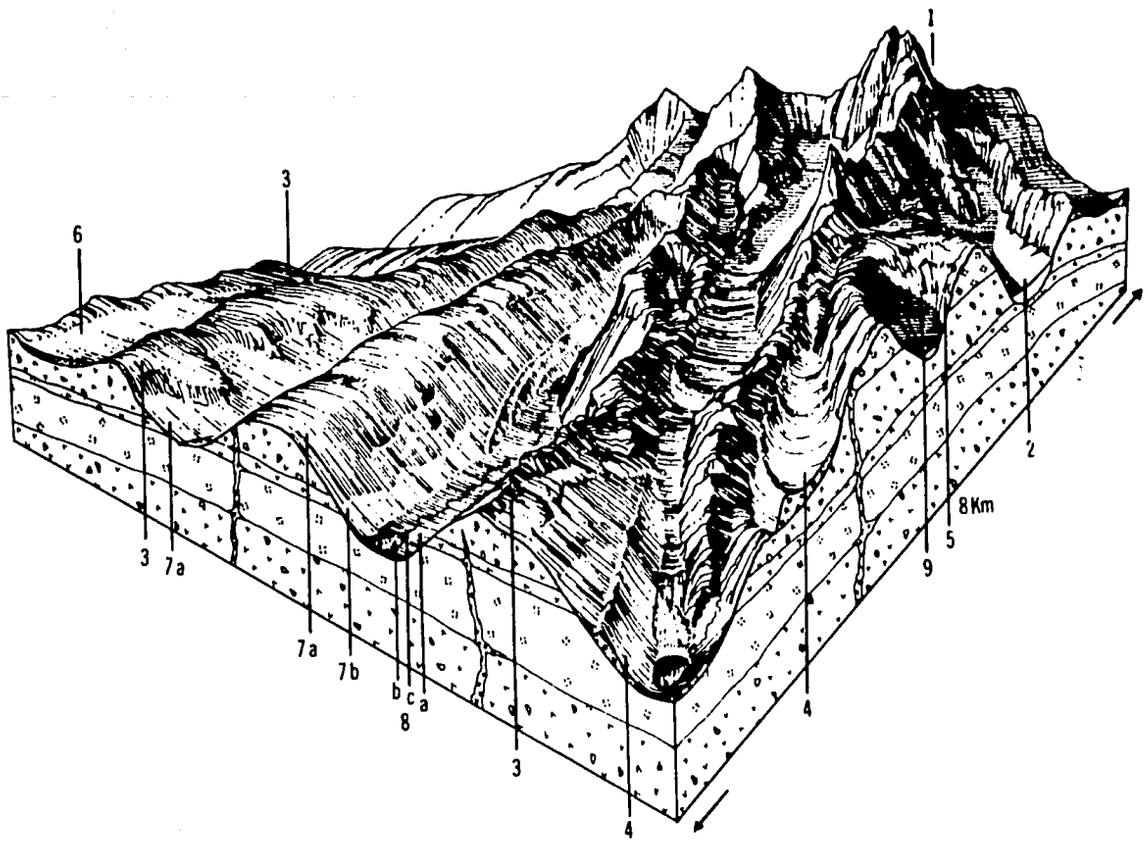

Figure 8. Block diagram of Mount Kenya (Scott et al., 1971) land system. The facets of the system are: (1) crags and rock outcrops, (2) glaciers, (3) rocky slopes, (4) moraines, (5) screes, (6) smooth slopes, (7) valley sides (a, steep upper slopes; b, moderate lower slopes), (8) valley floor (a, flat to undulating land; b, swamps; c, small watercourses), and (9) tarns, roughly circular in plan, 100 to 800 meters across, wholly or partially frozen over.

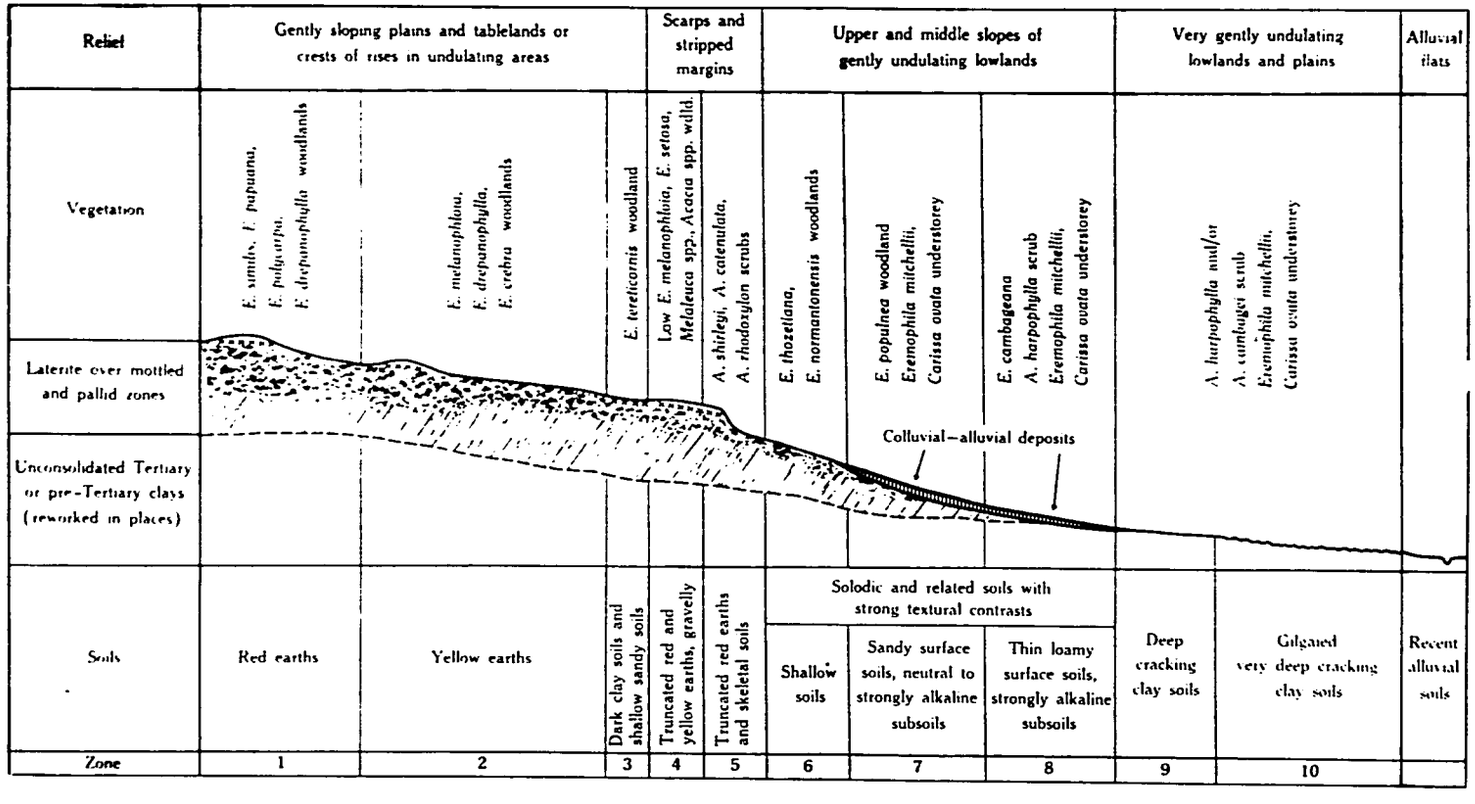

Figure 9. Soil catena and correlated vegetation on denuded laterite profiles in Queensland, Australia. (Adapted from Gunn, 1967).

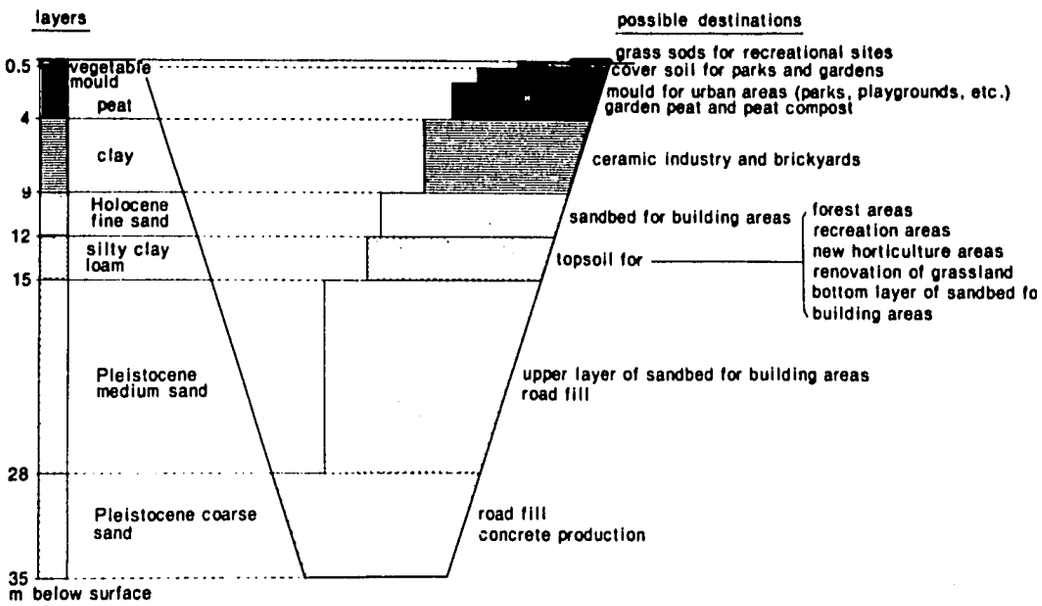

Figure 10. Cross section of a sand pit and possible end-uses for the available spoil. (Adapted from Haans and Westerveld, 1970).

Table 4. Number of samples necessary to estimate the mean of population within plus or minus 10 and 20 percent accuracy levels using 95 percent confidence interval from analyses of soil samples from selected soil bodies in the Bicol Ragay Irrigation Project in Luzon, Philippines. (Adapted from Concepcion, 1977).

	Bantog		Bigaa		Libmanan		Pamplone	
Property	±10%	±20%	±10%	±20%	±10%	±20%	±10%	±20%
pH(1:1)	4	1	6	1	6	1	4	1
pH(1:2)	6	1	3	1	5	1	9	2
Organic Carbon	82	20	29	7	79	20	61	19
Phosphorus	327	81	217	54	184	45	249	63
Potassium	44	11	72	18	54	13	50	13
Free Fe_2O_3	234	58	85	21	485	97	87	23
Exchangeable Cations:								
Ca + Mg	67	17	16	4	20	5	28	7
Na	148	42	87	21	116	29	208	49
K	357	86	2062	515	175	58	290	34
H	54	15	69	17	542	131	35	7
Cation Exchange Capacity	32	8	12	3	7	2	14	3
Percent Base Saturation	17	4	2	1	7	2	6	1
Electrical Conductivity	128	32	40	10	182	45	77	19
Percent Sand	196	49	81	20	230	57	120	30
Percent Silt	66	16	95	11	27	7	24	6
Percent Clay	14	3	3	1	7	2	10	2
Field Capacity	12	3	5	1	7	2	8	5
Wilting Coefficient	30	7	5	1	30	7	22	6
Available Moisture	17	4	37	9	47	12	27	7
Settling Volume	12	3	3	1	18	4	6	2

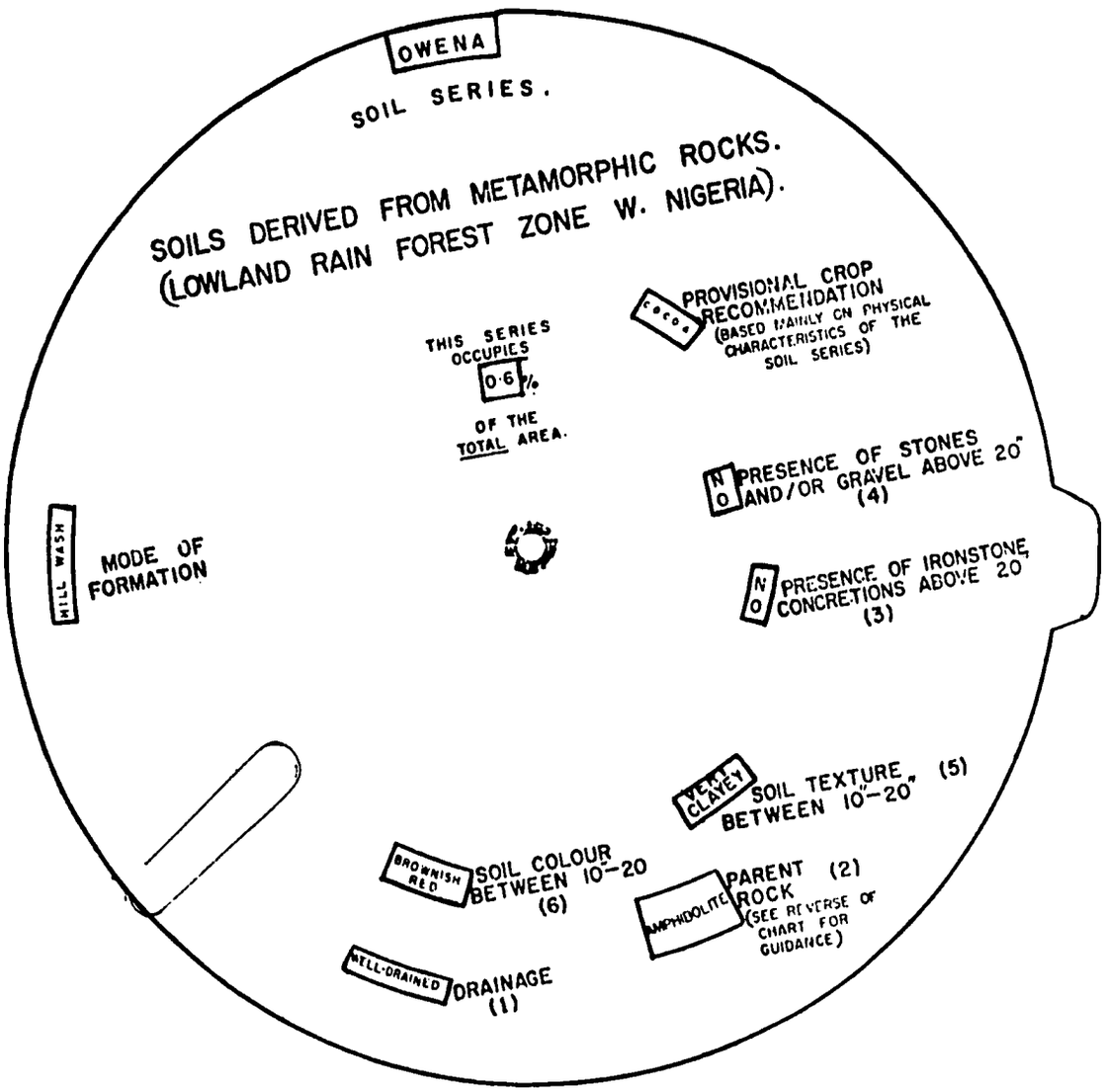

Figure 11. Circular movable chart giving the soil names, critical soil characteristics, and crop recommendations for some soils in central western Nigeria. (Adapted from Smyth and Montgomery, 1962).

SESSION VIII

Wednesday morning, April 6, 1977

THE ROLE OF SOIL SURVEYS IN THE DECISION-MAKING PROCESS FOR DEVELOPMENT PLANNING

Chairman: K. J. Beek

Speakers

F. L. Gilbert - Planning Principles

E. G. Knox - The Role of Soil Surveys in the Decision-making Process for Development Planning

PLANNING PRINCIPLES

F. L. Gilbert[1]

There are two planning principles that may be employed in evaluating usefulness of a soil survey. A statement of these principles and some applications will be helpful.

SOIL USE AND FUNCTION

All Uses and Functions of Soils Are Interdependent

Planning then, requires simultaneous consideration of all functions and uses regardless of the particular function or functions being planned. There generally is great competition for soils that are well suited for growing crops because most are also well suited for other uses. This competition should direct a planner to consider secondary sites for the primary function or use being planned. Examples are abundant and are not difficult to apply. Planners commonly need to be cautioned not to interchange land use or functions.

Interaction of Refinement of Distinctions

The interaction of the refinement of distinctions among mapping units and the purity of the mapping unit delineations establishes a given confidence level in a soil survey for making predictions. The refinement of the distinctions among mapping units is in competition with the purity of the mapping unit in most places. Planners, therefore, are concerned with some statement concerning mapping unit purity particularly where the impurity presents a severe limitation to the primary function or land use being planned. Typical examples are inclusions of rock outcrop or very wet spots.

PLANNING NEEDS

Planning is the process which guides deliberate actions. It includes study, evaluation, and selection from existing alternatives of the future courses of action. It also includes the programming or allocation of functions in terms of amounts and relationships.

It has been stated at this workshop that soil maps need to be appraised for very specific uses (Cline). How, then, do we

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appraise the adequacy of a soil map for preparing a plan that will recommend actions for an undeveloped area? As all uses and functions of soils are interdependent, planners need an array of ratings that clarifies the geographical potential for soil uses or functions that meet the planning objective. A composite interpretation for different soil functions and uses hasn't proved useful. The role of the decision maker is thus insured.

Presented 4/6/77.

THE ROLE OF SOIL SURVEYS IN THE DECISION-MAKING PROCESS FOR DEVELOPMENT PLANNING

Ellis G. Knox[1]

Soil surveys present factual information about one of our most important land resources and provide predictions about how that resource, the soils, will behave or perform under new and untried conditions.

Development planning attempts to devise programs and projects to improve the utilization of resources, including human, land, economic, and technical resources, to achieve increased production, greater efficiency, higher-quality products, better environmental conditions, or some combination of desirable goals. Much development planning is concerned with land use and management for agricultural, silvicultural, or other vegetation-based land use. Sound decisions for this planning require the information and predictions supplied by soil surveys. Other important land uses, dependent on soil characteristics but not related to plant growth, are not considered in this paper.

There are good reasons for restraint in making this claim about the role of soil surveys and for skepticism about the effectiveness of planning for economic and agricultural development. After all, the major part of the world's agricultural technology was developed and applied to particular land areas without benefit of soil survey and planning, largely by trial and error involving innumerable individual farmers. For example, much of Oregon's pear production is on Vertisols. How could any soil scientist have been wise enough to predict that pear trees could survive, let alone produce, on these difficult soils? Many farmers attempted to establish orchards throughout southern Oregon. Many failures resulted from these widespread trials on diverse soils, but the suitability of the Xererts for pear production was established in the process. Failures, at best, give inadequate or no production; at worst they degrade or destroy the land resource, eliminating the possibility for future trials. The role of soil surveys and development planning is to substitute for trial and error to the fullest extent possible and to eliminate predictable failures in production and in resource conservation.

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FOUR MAJOR AREAS OF DEVELOPMENT PLAN NG

Overall Program Development

At this level, the major orientations of development are established. Decisions are made about production for internal food needs vs. exports, agriculture vs. forestry, grazing vs. cropping, dryland cropping vs. irrigation, hand-labor methods vs. mechanization, small farms vs. large plantations, and so on. Within the orientations established, ideas for specific development projects are formulated in broad outline. Obviously, the soil resources are only one factor among many, but in many cases the soils factor is critical for achieving the best decisions and projects.

Selection of Areas

Programs must be applied to specific regions and projects are carried out in specific areas. Although considerations of existing infrastructure, population distribution, and distances to markets and sources of supply are very important, in many cases the soils are the dominant factor in selection of areas to achieve the greatest production, the lowest costs, the least environmental damage, the most efficient utilization of resources, etc.

Project Development and Feasibility

Once a project for a specific area is identified, the next step is to develop quantitative plans in sufficient detail to establish the physical and human inputs, estimate costs, and predict returns. This is the basis for determining the feasibility of the project and the relative desirability of alternative projects. Soils control yield, technology, and costs. Consequently, they are crucial for this step in the development process.

Operational Planning and Implementation

The actual execution of a project demands even more detailed planning and decisions. These include exact field lay-out; locations of fences, roads, and ditches; choice of machinery; type of irrigation; kind of sustained management; etc.

ROLE OF SOIL SURVEYS

For all four of the planning stages, soil surveys provide determinations and predictions of the following soil qualities:

Susceptibility to Deterioration

For the great majority of soils, erosion is the most obvious and serious hazard resulting from agricultural or other

vegetation-based land uses. Susceptibility to erosion must be recognized and emphasized in all soil survey activities.

We seldom consider the other ways in which soils can be damaged or destroyed when brought into use. Identification of soils susceptible to deterioration is an important contribution toward successful development planning.

Important hazards restricted to specific soils include hardening of plinthite with clearing and drainage of Plinthaquepts, Plinthaquox, and other soils; formation of acid sulfates with drainage of Sulfaquents and Sulfihemists; burning and subsidence of Histosols; salt and sodium accumulation in soils of Hydrandepts exposed to drying. Development planners should be informed of the seriousness of these hazards and of the land uses and management practices that must be avoided to prevent deterioration.

With agricultural use, almost all soils are susceptible to exhaustion of the original supply of nutrients (in one or five or one hundred years, depending on the soil), to downward adjustments in organic matter content under dry farming conditions, and to some loss of tilth. These losses are largely inevitable consequences of the cropping system.

In many cases, the levels of organic matter in equilibrium with the cropping system are adequate to maintain suitable physical conditions and nutrients can be supplied in fertilizers at reasonable cost. In these cases, the extra production or lower costs in the first years of production are what Marlin Cline has called "God's gift to pioneers." Long-term planning should be based on the behavior of the soil faced by the children and grandchildren of those pioneers.

On the other hand, deterioration resulting from exposure of the soil surface and clean tillage is quite serious for some soils, particularly those in very humid tropical areas. These soils should be identified and interpretations presented for cropping systems that maintain continuous vegetation or mulch cover and eliminate or reduce tillage.

Susceptibility to deterioration is a very important soil quality and one that needs to be considered early in development planning. Responsible and satisfactory land use and management must conserve the basic resource for future production. Fortunately, it is a relatively straight-forward prediction that in most cases can be made quickly and presented briefly and simply to the planners because it depends largely on soil characteristics that are already considered in the definition of soil units.

Suitability for Management Operations and Land Preparation

Most land management operations are carried out by means of hand labor, animal traction (or portage), or motorized

machinery at some scale. In some cases, harvest is carried out by grazing animals. Development planners need to know how easily the management operations can be performed on specific soils.

Management operations of interest here include the full range of soil and plant management practices. In developed, temperate countries it is easy to think of the use of chemicals as somehow dependent on the use of machinery. Of course, this is not so; the most sophisticated fertilizer or pesticide applications can be made by hand. Moreover, wage scales, economic conditions, population pressures, and kinds of crops grown in many developing countries make hand labor and animal traction realistic alternatives to motorized machinery. For these reasons, planners need to have information about the suitability of the soils for management operations separate from predictions about productivity and hazards of deterioration. Criteria for the evaluation of the suitability include slope, depth, rock fragments, limitations on field size due to gullies, rock outcrops, etc., and wetness (Knox et al., 1975).

Irrigation and drainage are management operations that require somewhat different considerations. Specific methods need to be considered separately. For example, soils well suited for sprinkler irrigation may be poorly suited for furrow irrigation because of irregularity of slope or poorly suited for flood irrigation because of excessive permeability.

Still other considerations apply to evaluation of soil suitability for the operations required to prepare the land, such as clearing, leveling, diking, fencing, road construction, and so on.

Obviously, not all soils need to be rated for all kinds of management operations. Soil scientists should consult with crop scientists, planners, economists, and others to select the kind of technology pertinent to planning in specific regions.

Response to Management

Predictions of productivity are meaningful only when yield is related to the set of management inputs required to achieve that yield. Development requires change in land management and in developing countries large differences in management inputs are common. Predictions may be required for several quite different combinations of inputs. Large interactions between specific inputs are very common, so it is necessary to consider the complete system of practices.

In economic terms, the net income is more important than the gross income. Accordingly, the difference between input (corresponding to costs of production) and yields (corresponding to gross income) is at least as important as the yield itself.

Systems of management practices should be based on considerations of susceptibility of the soils to deterioration and suitability for management operations. The amount of detail in specification of the system depends on the level of planning. For project feasibility, the inputs must be defined so that accurate cost estimates can be made.

The yield prediction can seldom be taken directly from yield observations. More commonly, the prediction must be extended geographically or from one kind of soil to another, or both. In many cases, adjustments must be made for differences in management between the few field observations available and the conditions of the predicted yield. Yield data are expensive, and require years of observations. It is almost safe to say that the information is never sufficient. Soil survey interpretations should indicate the reliability of the yield predictions and stress the need for small-scale field experimentation and pilot studies ahead of full commitment to large projects using innovative technology. In a feasibility study for a large upland rice project in Africa, the Soil and Land Use Technology team found they had to make a yield prediction based on one variety trial on-site without sufficient management information, one machinery experiment on-site without satisfactory yield measurements, experience with sugar-cane in an adjacent project area, extensive experimental and project yield data from other parts of the same country on quite different soils, and the general worldwide fund of information about management and yields of upland rice. Obviously, we recommended pilot studies before construction of the rice factory.

Constraints on Land Use

In addition to the interpretations included above, a separate consideration of the limitations on land use and management focuses the attention of research scientists and development planners on possible points of attack. Identification of constraints facilitates the development and selection of alternative management systems to overcome or compensate for specific soil constraints and the design of reclamation projects to eliminate the constraints.

Some constraints are permanent (e.g., slope); some can be eliminated permanently (thin, shallow duripan); some can be removed but require continuing attention from time to time (restricted drainage); and some can be overcome with continuing management (lack of nutrients). The soil surveyor needs to help make these distinctions. He also should identify the nature of the constraint. That is, he should indicate whether it limits plant growth, interferes with harvest, hinders the management operations, or leads to deterioration of the soil.

CONCLUSIONS

Soil surveyors often have bad news to tell. Soil resources commonly have less potential and stronger limitations than

planners, economists, politicians, and the general public want to believe. World around, the best areas of agricultural development have already been found and exploited. Many areas now being farmed with traditional, labor-intensive methods are producing as much or more than would be possible with highly-mechanized modern methods. Many countries with low or moderate overall population density have such high proportion of poor soils that they have a severe population problem. The soil surveyor must document his predictions very carefully and fully because there will be a strong tendency to discount any that are disappointing.

Because so much of our news is bad, we should be alert for soils with good development potential and for management systems that make the most of available resources. But, we must be forthright about limited soil resources and production potentials and about the need for development planning to consider both sides of the population-resource problem.

Presented 4/6/77.

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PAPERS APPENDED †

M. G. Cline	-	Thoughts about Appraising the Utility of Soil Maps (A Working Paper for Discussion Purposes)
T. R. Forbes	-	A Proposal for Evaluating Soil Survey Reports
H. Eswaran	-	An Evaluation of Soil Limitations from Soil Names
H. Eswaran	-	Soil Analysis for Soil Surveys
M. C. Laker	-	Relationships between Potential and Soil Properties

† Papers not actually presented at the workshop, but important to its subject matter. These papers were produced by the Soil Resource Inventory Study Group at Cornell University, sponsored by U. S. Agency for International Development Supplemental Grant No. AID/csd-2834.

THOUGHTS ABOUT APPRAISING THE UTILITY OF SOIL MAPS (A WORKING PAPER FOR DISCUSSION PURPOSES)

Marlin G. Cline[1]

Soil maps[2] are graphic representations of the geography of sets of soil properties. Depending on the point of view, some would also include maps that show only single soil properties or soil attributes.[3] The maps with accompanying legends and descriptive material are, at best, incomplete records of soil conditions within areas of land. Their potential usefulness depends on the degree to which they accurately represent the geographic distribution of soil conditions that are critical for soil use and management. Their actual utility also depends on presentation in a form that can be used intelligently by those who may wish to apply the information. Both their potential and actual usefulness for a given purpose also depend on the degree to which they satisfy the level of detail or generalization required by objectives of the user.

One must ask two basic questions to appraise soil maps: (1) What does one need to know to appraise the soil itself for use and management? This question is discussed in section II A. (2) To what degree does a soil map and associated material provide the things we need to know. This question is discussed in section II B.

I. A PROPOSED FORMAT

Appraisals of the utility of soil maps could be presented as a narrative, which would offer advantages of flexibility to identify attributes that would enhance or detract from map utility. If a narrative were used, it should follow a specific outline to insure that relevant aspects are covered. The

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[2]For purposes of this discussion, the term *soil map* includes the map itself, a legend, and any text or tabulated information that defines or describes the area and the map units. *Soil map* is used instead of *soil survey* to include those which are compiled from sources other than field studies.

[3]The term *soil attribute* is used here for characteristics such as soil drainage condition, parent material, fertility, erodibility, and others that are inferred from soil properties observed or measured. Their identification requires one step of reasoning from the properties observed or measured directly.

organization of forms to assist in the interpretation should probably conform with the logic of a narrative outline.

More detailed discussion of concepts and approaches is provided in section II A and B. Section II C describes a methodology that is summarized in the following outline. Any of several outlines or forms could be developed for appraising the utility of soil maps. This individual sees some logic to organization along the following lines. A narrative should give brief, simple statements about each item.

1. *Complexity or simplicity of soil pattern in the field* (from item II C3). It would seem desirable to orient potential users quickly to characteristics of the area in nature as background for appraisal of the map. This item might come first in a narrative appraisal or at the beginning of a form.

2. *Reliability of information provided* (from item II C4). It would appear reasonable to alert users quickly about the degree to which they can or cannot trust the data presented.

3. *Size of planning area* (from item II C1). This identifies the geographic scope of projects for which the information can be used effectively -- and greatly narrows the range of utility. It would appear logical to place this item toward the beginning of either a narrative or form.

4. *Size of areas for which soil potentials can be determined within planning areas* (from measures of delineation sizes). This tells the user how much or how little geographic detail he can incorporate in his project on the basis of this map. In addition, he should be told:

4a. Proportion of those that are homogeneous for land use (from II C3).

4b. Proportion homogeneous for soil management (from II C3).

4c. Proportion heterogeneous for use and information does not describe pattern of differences within areas (from II C3).

4d. Proportion heterogeneous for soil management but information describes pattern of differences within areas (from II C3).

5. *Adequacy of information about soil attributes within map units for identified uses* (from II C2). It is this part which would tell whether or not the map can be interpreted for identified uses or management systems. Table 1, or a comparable device, would be a primary source, and could well be included as part of the appraisal. In addition, some explanation would probably be in order, and appraisals for uses not identified on any form one might develop would be needed for some maps. For example,

Table 1. Information About Soil Attributes Within Map Units.

Soil Attributes	Broad Land Use Classes	Cultural Systems	Broad Plant Character	Specific Plants	Management
A. Soil Moisture 1. Soil Moisture Regime a. Intergrades 2. Available Moisture					
B. Soil Temperature 1. Soil Temperature Regime a. Intergrades					
C. Chemical Properties 1. Colloidal Behavior a. Clay Mineralogy b. Cation Exchange Cap. 2. Soil Fertility a. Nutrient supply b. Nutrient fixation 3. Soil Acidity 4. Soil Salinity & Sodicity					
D. Physical Properties 1. Related to rooting a. Aeration b. Physical obstruction 2. Permeability 3. Tilth Potential 4. Obstructions to culture a. Stoniness b. Rock outcrop c. Slope gradient					

Table 1 provides a check list for "cultural systems" as a generalization. Presumably, one would check attributes which would be critical for any of the cultural systems one might envisage. Different cultural systems, however, have different soil requirements. If permeability were not known with some specificity it would drastically limit an interpretation for irrigated systems or paddy culture but would be much less serious for interpretations for dryland farming. It is points like this which make a narrative appraisal attractive.

6. *Quality of the base map* (from II C5). The check list of section C5 could be used in a form. A simple statement would suffice in a narrative appraisal.

7. *Legibility of soil information* (from II C6). For this too, a check list could be included in a form, and a simple statement would suffice in a narrative appraisal.

Guidelines would have to be provided if different people having different backgrounds were to arrive at similar appraisals. The most difficult to provide are those for appraising information about soil attributes within map units for identified kinds and levels of soil use.

One might face the problem of how to appraise the information one may glean from the legend and the text. The attributes revealed by names of taxa would have to be identified for each taxonomic system likely to be encountered. One can visualize a series of tables in which attributes in some kind of list comparable to that of Table 1 would be identified as revealed or unrevealed by taxonomic names. Probably a thorough appraisal would require some system to show the level of information the names imply for each item. Part of this could be analyzed by categories, but in many systems the criteria differ among taxa within categories. If it were necessary to analyze the information implied by each taxonomic name, the task would be very complicated. There may be no good alternative to this.

Another major guideline would entail identifying which of a list of soil attributes is critical for a given category of land use classes at different levels of generalization (such as those identified by headings in Table 1). In Table 1, for example, one could identify which of the soil attributes listed are potentially prohibiting for one or more of the land use classes that would fall under each heading. For the broad land use classes (crops, grazing, forestry), items A1, B1, C4, D1b, D4a, D4b, and D4c are most likely to prohibit cropping in mechanized systems. The other items may affect performance, perhaps drastically. Some of these are subject to correction (a management factor). Depending on assumptions about how much weight to give soil performance and management requirements, the seven attributes given above might be considered the primary requirements of soil maps for this category of uses.

Perhaps more significant would be check lists for specific kinds of use within categories. For the category of broad land use classes, a check list would probably represent information critical for the most demanding kind of use, namely cropping. The same would apply to each of the other categories. Tables showing attributes that are (1) potentially prohibiting, (2) potentially limiting for performance and difficult to correct, and (3) potentially limiting but feasible of correction could be prepared for each of several bench mark kinds of land use within categories at different levels of generalization.

These are aspects that have not been explored. There may be much simpler approaches, but at this writing some comparable mechanism seems necessary if appraisals are more than subjective judgments. It is likely that more careful consideration of land use categories could lead to much simpler guidelines. No attempt has been made, for example, to identify groups of land use classes, cultural systems, or plants having similar soil requirements. Maps could be appraised for such groups as units.

II A. APPRAISING SOIL ITSELF

The following are at least some of the more important things one needs to know to appraise soil for use and management:

1. The use for which the soil is to be appraised.
2. The level of detail or generalization required by the objective.
3. The soil properties or attributes that are important for this use.
4. The degree of limitations imposed by soil properties or attributes.
5. The distribution of critical soil conditions within the area.

Land Use for Which Soil Is To Be Appraised

Different kinds of land use have different soil requirements. Soil requirements are different for lowland rice, for example, than for coffee or cacao. The need to know the use or uses for which soil is to be appraised is so obvious that it would rarely not be specified for an on-site investigation. Yet many soil surveys are made without clearly defining the purposes for which the information is intended. Some are used incorrectly for purposes for which they were not intended.

Level of Detail or Generalization

This subject includes (1) the level of generalization of the soil appraisal and (2) the level of generalization of land use classes for which soil potential is to be estimated.

Soil appraisals for different purposes require different levels of geographic detail of information about soils. For

some purposes, one only needs to know approximately how much of the soil of areas involving hundreds or thousands of square kilometers has properties that are good, fair or poor for a given use. Precise geographic location of local differences among soils is not important. For other purposes, one needs to know precisely where soils of different potential are found within areas of a few hectares. In an on-site investigation, we can adjust data gathering to fit the geographic requirements of the objective. For soil maps, the geographic detail is fixed, presumably by some preconceived notion of the purposes for which the map will be used. Geographic detail of the map is an important criterion of its utility for different purposes.

Land use can also be conceived at different levels of generalization independently of geographic distribution. For some purposes, one only needs to know the soil potential for broad use groups, such as crops, grazing, forestry, or urban uses. For others, one needs to know soil potential for specific uses, such as wetland rice or dryland wheat. This kind of conceptual detail or generalization of land use may be applied to either very large or very small areas. Many soil appraisals for broad land use groups are made in general geographic terms involving areas hundreds of square kilometers in size. Many judgments are also made, however, about relative soil potentials of areas a few hectares in size for broad land use groups, such as crops, pasture, or woodland. It is also true that, while judgments of soil potential for very specific uses are commonly made for areas the size of individual fields, they are also made for areas of hundreds of square kilometers. Consequently, a system for appraising the utility of soil maps must accommodate a very broad range of combinations of conceptual detail of land use and geographic detail of soil distribution.

Usually when soil potentials are appraised for general land use classes, however, the land use terms imply much broader concepts of land use than is actually intended. An appraisal for "crops" in the temperate regions, for example, obviously excludes crops suited only to the tropics. An appraisal for unirrigated grazing in regions of xeric soil moisture regimes clearly does not consider plants that require summer rainfall. This should be recognized in any general scheme for appraising soil maps of the world.

Important Soil Properties and Attributes for Use

It is self-evident that one must know what soil properties are important for a given use before he can intelligently appraise the potential of soil for that use. It is not so obvious that individual soil properties must be considered in combination and that the interactions among them commonly determine their relevance. Coarse texture, for example, carries one set of implications for use of soils having ustic moisture and different implications for use of udic or aquic soils. Soil acidity has different implications for management depending on cation exchange properties. In an on-site appraisal, a soil

scientist would mentally integrate the implications of sets of properties, including their interactions. He would, furthermore, arrive at judgments of critical soil attributes from clues provided by individual properties in combination. A scheme for appraising the utility of soil maps must provide mechanisms for judging the effects of combinations of soil properties as sets that collectively determine soil potential.

Degree of Soil Limitations

A soil scientist commonly approaches an on-site appraisal of the potential of soil resources with a concept of a near-ideal set of properties for a pre-determined use or uses. He commonly searches for soil limitations that would detract from the maximum potential of an ideal soil in the environment. Some limiting soil properties prohibit certain uses absolutely; very steep slope would be such a property for mechanized farming. Some limit soil performance though they would not prohibit the use. Some of these can be corrected feasibly, and others cannot. The point is that, for a given use, sets of soil properties and their interactions may range from absolutely prohibiting to nearly ideal. The vast majority limit soil performance to varying degrees and may be corrected with varying degrees of difficulty. A final judgment of soil potential should reflect the impact of these variable degrees of soil limitations and the feasibility of correcting them in the physical environment of the area. A general scheme for appraising the utility of soil maps should provide a mechanism for assessing the adequacy of the information provided for making such judgments.

Geographic Distribution of Critical Soil Conditions

It is not enough to appraise the soil in one place, for the soil of land areas large enough for most uses is not uniform. In an on-site appraisal, a soil scientist would determine not only which soil limitations vary and how much but also the geographic pattern of different degrees of limitations. For some uses, the geographic pattern is more critical than the limitations at one place or the amount of an area affected. Five percent wet soil in a field otherwise suited to mechanized farming, for example, may be no more than a nuisance if it is all in one place. It can control cultural operations and timeliness of work if it is distributed in small pieces throughout the field. A scheme for appraising the utility of soil maps should include provision for assessing the adequacy of information about soil patterns within delineations as well as among them.

II B. APPRAISING SOIL MAPS

The utility of soil maps is approached here in terms of the degree to which they provide the information one needs to appraise the soil itself. The point has already been made that they provide only part of the information one could obtain from on-site

investigation. This section is organized according to the five items of the section on appraising the soil itself. The last four items involve attributes of soil maps; the first item is independent of soil maps but must be a factor in appraisal of their utility.

Land Use for Which Soil Maps Are To Be Appraised

Objectives differ in both the level of generalization and kinds of land use for which soil maps are appraised. Both affect the soil information needed for meaningful interpretation. The number of specific uses is so great that it is not feasible to provide guidelines to appraise soil maps for them all. Table 2 is suggested as a first approximation of the kinds of land use groups for which guidelines might be provided. It should be understood, however, that soil maps also need to be appraised for very specific uses.

Level of Detail or Generalization

This subject, as stated, could include both (1) the cartographic detail of the map itself and (2) the categorical (classification) detail of the map legend. The first concerns the number and size of delineations in relation to land area and is discussed in this section. The second concerns the definition of map units in relation to the range of sets of soil properties in the area. It is more appropriately discussed in the next section on "Composition of Map Units."

Cartographic detail is a function of scale on most soil maps. Some soil maps, however, are at scales much larger than would be necessary to present the map units legibly. Others crowd so many boundaries and symbols on a small piece of paper that the map is not legible. A measure of cartographic detail that is independent of the scale actually used is needed. It is suggested that the minimum scale at which the map data could be presented legibly would be a potential index of cartographic detail.

Such a "legibility scale" would have deficiencies as a measure of cartographic detail. The delineations of some soil maps may be mainly large, but a few may be so small that they would not be legible if the scale were reduced. The legibility scale of such maps might be based on legibility if the small delineations were identified by "spot" symbols. Spot symbols, too, detract from legibility, so their numbers should not be great.

Another potential deficiency of a legibility scale as a measure of cartographic detail would be the unknown relationship between detail of the map and complexity of the soil pattern in the field. The soil pattern of some areas is very complex; in other areas it is very simple. Degrees of cartographic detail, in one sense, could reflect the relationships between map unit patterns and soil patterns in the field. As the soil pattern in nature commonly cannot be determined with certainty from soil

Table 2. A tentative scheme for identifying elements of soil use and management at different levels of intensity.

Broad Land Use Classes	Cultural Systems within Use Classes	Broad Groups of Plants in Cultural Systems	Specific Plants	Management Systems
1. Cropping	1.1 Shifting cultivation	1.11 Annual crops	Maize, etc.	
	1.2 Wet culture	1.21 Annual crops	Rice, etc.	
	1.3 Dryland culture	1.31 Annual crops	Maize, etc.	
		1.32 Perennial crops	Cacao, etc.	
	1.4 Irrigated dryland crops	1.41 Annual crops	Cotton, etc.	
		1.42 Perennial crops	Sugar cane	
2. Grazing	2.1 Dryland	2.11 Native species		
		2.12 Introduced species		
	2.2 Irrigated	2.21 Introduced species		
3. Forestry	3.1 Dryland	3.11 Native species		
		3.12 Introduced species		

It is not suggested that guidelines should be developed for appraising soil maps for all of these uses.

maps alone, one is probably forced to depend mainly on map definitions in relation to land areas as an index of cartographic detail.

An experienced soil scientist could possibly judge legibility scale by inspection as accurately as may be justified, considering other unmeasured factors related to its significance. It is by no means certain that two experienced soil scientists would judge it the same. Persons who are not experienced field soil scientists or cartographers need less subjective ways to appraise cartographic detail. Soil scientists need objective criteria of exactly what "legibility scale" may be. Relationships between legibility scales and measurable map attributes can be established. Such attributes as number of delineations per unit land area, average or median size of delineation in land-area dimensions, and counts of transect intercepts with soil boundaries can be measured and related to minimum scales of maps that experts agree would provide legibility. Guidelines for scale in relation to legibility may have been established by cartographers for soil or other kinds of maps. If this has been done, it would be desirable to use established cartographic conventions.

The use of map scale as a criterion of soil map utility would be greatly facilitated by a set of standard scale classes. In many respects, it would be desirable to use the ranges of scales identified as criteria for "orders" of soil surveys in the United States. These ranges, however, were conceived as guides for future soil surveys--not as criteria for classifying existing maps. Consequently, map scale is tied to kinds of map units and levels of taxonomic soil classes. The relationships defined do not fit those of many existing maps throughout the world. Also, the ranges of map scales defined for the five orders of soil surveys overlap and would be difficult to apply objectively for soil map appraisal.

For the reasons given above, a classification of map scales is suggested here, as follows:

Class A - Greater than 1:13,000
Class B - 1:13,000 to 1:26,000
Class C - 1:26,000 to 1:130,000
Class D - 1:130,000 to 1:650,000
Class E - Less than 1:650,000

Class limits are suggested to bracket the map scales most commonly used. Unusual fractions are suggested as class limits to avoid problems when map scales happen to coincide with class limits.

Class A would include only maps of those highly detailed soil surveys which are made for special purposes. In English units, maps at 8 inches to 1 mile would be included. Class B includes the common scales of so-called detailed surveys (order 2) in humid parts of the United States--1:15,840; 1:20,000; 1:24,000; and 1:25,000. Class C includes many of the older soil

survey maps of the United States, which were mainly at scales of 1:31,680, 1:63,360, and 1:63,500. Some soil maps of order 2 published at scales of Class B would be Class C at a legibility scale. Many of the "general" soil maps included in recent published surveys of the United States would also be included, although some of these would be Class D on a legibility scale. Note that maps at 1:125,000 and, in English units, at 2 miles to 1 inch would be near the lower limit of Class C.

Class D includes many soil maps designed to give perspective of soil resources of large areas. The most common scales are 1:250,000 and 1:500,000. In English units, Class D would exclude scales of 2 miles to 1 inch at the larger limit and include scales of 8 miles to 1 inch at the smaller limit. Class E includes many schematic and compiled maps, as well as those made by exploratory methods with field observations at very wide intervals. The most common scales are probably 1:750,000 and 1:1,000,000 but the very small-scale maps of continents and other large areas at scales of 1:5,000,000 and smaller would be included.

Composition of Map Units

This subject relates to the headings "Important Soil Properties and Attributes for Use" and "Geographic Distribution of Critical Soil Conditions" in section II A of this paper. It refers to the information provided by the legend and related descriptive material about sets of soil properties and their geographic distribution within the boundaries of soil maps. It includes two interrelated elements: (1) the kinds of map units identified in map legends and (2) the definition of those units in terms of kinds of soil they contain. The two are considered individually here.

Kinds of map units. The two distinctive kinds of map units are (1) those that can be identified as single taxa without distorting concepts of homogeneity and (2) those that must be identified as two or more intermingled taxa to create a realistic picture of heterogeneity. The first has recently been called a *consociation.* The second has long been called an *association* or *complex*, depending on scale. The first implies that the unit can be interpreted as a single kind of soil confined to specific places by boundaries on the map. The second implies that the unit must be interpreted in terms of a mixture of at least two, commonly contrasting, kinds of soil. The first signifies that the map shows by its boundaries the important geographic variability of soils at some level of categorical detail. The second signifies that the map boundaries identify only part of the important geographic variation. The remaining part is within soil boundaries, but one does not know precisely where. This is an important difference for interpreting soil maps.

Other kinds of map units are used. An *undifferentiated group*, as used in the United States, includes two or more kinds of consociations which have been combined because they would be interpreted similarly for most purposes. They differ in their taxonomic

classes. Areas of the two may or may not be contiguous, but they are not so intimately intermingled they could not have been delineated separately at the map scale. Undifferentiated groups can be treated as consociations for purposes of interpretation. They can be appraised in that context for utility of soil maps. Undifferentiated groups of soil associations are also used on some maps. As they must be similar for interpretation, they can be appraised like single associations for map utility.

A fifth kind of map unit, recently called an *unassociated group* includes areas of two or more unlike kinds of soil at some level of categorical generalization. The soils identified within one unit are unlike not only in taxonomy but also in use potentials. Such units may be used deliberately in exploratory surveys or for compiled maps when the limited information available provides evidence that two or more contrasting kinds of soil may exist in identifiable areas, but the evidence is not adequate to decide which ones. Individual delineations may be one or the other, or both. These kinds of map units are more likely to be found or suspected as inadvertent errors due to poorly conceived legends, incompetent mappers, or both. They are likely to represent only part of the legend, but their presence should be identified.

Kinds of soil. The second element in composition of map units is the kinds of soil they contain. Kind in this context does not imply taxa in some taxonomy but sets of soil properties, classified or unclassified. Map unit definitions derive from connotations of the names of the taxa that identify them, phase or other qualifying terms used to modify the taxonomic name, and descriptive material in the text.

Most delineations on soil maps are identified by names of taxa in some system of soil classification. The name itself implies a set of soil properties, which is defined explicitly in some systems and implied in only very general terms in others. The name of a taxon at a low taxonomic level implies a relatively narrow range of a set of many soil properties. A soil family in the U. S. system is an example. A name at a higher taxonomic level, such as great groups of the U. S., implies that a smaller number of properties range within narrow limits, selected properties range within broader limits, or both. At the soil family level in the U. S. system, for example, soil texture, mineralogy, and attributes related to moisture regime range within narrow limits. At the great group level, attributes related to moisture regime range more widely but are defined. Soil texture and mineralogy, however, are undefined and, therefore, must be presumed to range as widely as is possible within whatever limits may be imposed by genetic requirements for formation of features diagnostic at the great group level. Both texture and mineralogy of great groups may range far beyond limits critical for appraising soil potential for some uses, and their character in a specific map unit defined as a great group is unknown from the taxonomic name alone.

The taxonomic level of soil names in a map legend implies a great deal about the level of generalization at which one can make valid predictions about the utility of maps. It does not, however, identify which soil attributes critical for land use are defined and which are undefined. This commonly varies among taxa of the higher categories of a given system and even more widely among the taxonomic systems used throughout the world.

Phases are very important features of legends. They are used to increase critical information about attributes of soils in map units defined at any taxonomic level. They increase the prediction value of the map immensely. It should be noted emphatically that map units identified as appropriate phases of taxa of high categories may be more useful for some interpretations than others identified only as taxa of categories low in the same system. Even the term *steep soils*, which is effectively a phase of the entire population of soils, defines a single attribute that may control land use.

Phases are defined in the United States as subdivisions of single taxa. Critical attributes of entire areas of soil associations are also designated in map unit names for some maps. Though these are not phases by definition, they serve the same purpose for mixtures of taxa that phases serve for single taxa. The term *qualified units* has been proposed for them.

A text should accompany every soil map to provide important information that cannot be inferred from the map and legend. It is as important to appraise the information in the text as to determine that provided by the map and the legend.

It may be useful at this point to recapitulate the elements of legends and texts that determine how much or how little is recorded about the composition of map units:

1. *Kinds of map units.* (a) Consociations and undifferentiated groups of consociations; (b) Associations, complexes, and undifferentiated groups of associations (complexes); (c) Unassociated groups. These imply by their names whether or not map units can be interpreted as: (a) one kind of soil, (b) geographic mixtures of two or more contrasting kinds of soil, or (c) areas in which either of two or more contrasting kinds of soil may dominate.

2. *Taxonomic level of taxa used to identify map units.* This implies a level of generalization to which interpretations should be adjusted. It does not imply which attributes of soils are defined.

3. *Definitions of taxa used to identify map units.* These should identify sets of soil properties from which one can infer the kinds and ranges of some of the soil attributes that control use potentials within map units. These definitions may be understood from the name of the taxon or may be stated in a text.

4. *Phase and other qualifying criteria.* These should add to the list of soil attributes that control use potentials.

5. *Soil properties and attributes described in the text.* The text of well-conceived and well-executed soil surveys gives critical information about map units not implied by the names of taxa or phase criteria and adds to the list of attributes that control use potentials.

Beyond these elements, one needs to consider the extent to which map unit names and descriptions accurately represent the character of delineations. It should be noted that *inclusions* comprise a large part of most map units. They may or may not be identified. If inclusions are *similar soils*, i.e. have potentials for use comparable to those of identified taxa, they detract little from interpretations based on named taxa and phases. If they are *dissimilar*, they should be elements in appraisal of map utility. A major problem must be faced when inclusions are not mentioned. The omission detracts greatly from certainty of map appraisal. Many soil maps identify map units in terms of single taxa without reference to associated soils or inclusions. These should be suspect.

Degree of Soil Limitations

The utility of a soil map depends heavily on the extent to which it permits one to identify the limiting attributes for which a soil scientist would search in an on-site investigation and to segregate them geographically. Some limiting attributes are direct consequences of single soil properties (e.g. steep slope) that are recorded in definitions of map units. Others (e.g. periodic wetness) are inferred from recorded evidence. They may be identified in taxonomic names or in soil descriptions for a given map, or they may have to be inferred from information that is given about the soil.

For an appraisal of the utility of soil maps, this individual sees no good alternative to a system that includes determination of the extent to which the map and associated documents identify the kind and degree of soil limitations for use. This suggests need for a check list of limiting soil conditions against which the legend and text can be appraised in terms of the completeness of information they provide. Following is a first approximation of a list of soil attributes that are important for a broad range of uses.

A. Soil moisture relationships

1. Soil moisture regimes

a. Intergrades among them

2. Available moisture capacity (In relation to rooting depth)

B. Soil temperature relationships

1. Soil temperature regimes

a. Intergrades among them

C. Chemical properties

1. Colloidal behavior

a. Clay mineralogy
b. Cation exchange capacity

2. Soil fertility

a. Nutrient supply (organic matter, weatherable minerals)
b. Nutrient fixation

3. Soil acidity

4. Soil salinity and sodicity

D. Physical properties

1. Related to rooting

a. Aeration
b. Physical obstruction (depth to pans, bedrock)

2. Permeability

3. Tilth (texture, consistence)

4. Obstructions to culture

a. Stoniness
b. Rock outcrop
c. Slope

It should be important to determine which of the items in this list, as well as others, are revealed by the definitions of taxa listed in the legend, phase criteria used, and information in the text. Some may be inferred from general information about the area as a whole -- such as inferences about soil moisture and temperature regimes from description of the climate. Some of the items listed may be inferred though not mentioned specifically -- absence of reference to salinity in a humid region is likely to suggest that salinity is not a problem.

It should also be possible to rate items of the list according to the degree of specificity or level of generalization with which they can be appraised for map units. This would be a factor in assessing the level of generalization of land use classes for which soil maps would be useful. Possibly a 3-class system could be used:

1. Adequate for predicting management requirements.

2. Adequate for predicting crop adaptation.

3. Adequate for predicting adaptation of broad classes of land use.

To implement a scheme like this, it would probably be necessary to develop a list of the attributes which taxa at various categorical levels reveal, directly or by inference, for each of the various major taxonomies used throughout the world. This should not be an impossible task, including the level of generalization at which statements can be made about them.

Geographic Distribution of Critical Soil Conditions

The approach in the preceding section relies on appraisal of the homogeneity of "performance characteristics" within map units. There is another way to conceive of the same ideas. If one can determine how much each of the performance attributes listed varies within the area of the map, he might be able to identify three segments according to geographic characteristics of the map:

1. An identified segment stratified geographically by map unit boundaries. Slope gradient, for example, may be stratified by slope classes among different delineations by use of slope phases.

2. An identified segment confined geographically by soil boundaries but unstratified within them. The variation among taxa or phases of taxa within delineations of a soil association is an example.

3. A segment that is both unstratified and unconfined geographically. This would include all attributes which are not identified with map units in any way.

It would be very difficult, if not impossible, to develop a scheme to appraise the information provided by soil maps in this way. Nevertheless, the concept can be useful, and some elements of it should be considered in map appraisal.

The idea of total variation of soil attributes is relevant. The prediction value of a map is not decreased by failure to identify soil attributes which vary little throughout the area. If, for example, soil temperature regime varies little, failure to identify it for each map unit does not detract from homogeneity of the unit. It would be helpful, if possible, to record the total range of variation of critical attributes as a bench mark against which segregation can be appraised. Such a record would also help to identify the magnitude of variation of unclassified attributes.

The geography of variation within associations and complexes can be critical for map unit interpretation. It would be important in appraising their ability to record whether or not they are defined in terms of proportions and patterns of their constituent taxa.

Reliability of Information

None of the factors discussed above is relevant if a soil map is unreliable. Few maps are totally unreliable, but many contain information that should be questioned. An appraisal of map utility should indicate an estimate of reliability. This may rate the reliability of cartography, soil identification and definition, or more commonly both.

Objective criteria of poor reliability related to human error or incompetence are difficult to establish. Some measure of ground truth is required for absolute determination. This is rarely available. There may, however, be clues on the map itself, such as identification of soils in places where they are unlikely to be found or map unit boundaries that do not conform to diagnostic landscape features. These kinds of errors may be detected by comparison with reliable topographic maps and information that may be available from other sources.

More objective criteria can be established for reliability related to techniques and methods of data gathering. Such factors as dependence on remote sensing alone, poorly designed or inadequate frequency of sampling by field methods, and poor ground control of base maps contribute to poor reliability. If the text does not describe the methods used, the fact should be noted and reliability should be questioned. Some appraisals report the predominant survey methods in lieu of a reliability rating. An example based partly on definitions of the 1951 *Soil Survey Manual* of USDA might be:

Schematic compilation
Remote sensing techniques
Exploratory field methods
Reconnaissance field methods
Detailed field methods
Methods unknown

If information is available, ratings of good, fair or poor may be applied to each method, indicating the estimated reliability within the range of precision of the method.

Geographic Control of Base Maps

A soil map has little value if the base map does not permit geographic location of boundaries relative to accurately located ground features. The quality of the base map should be indicated, considering both the amount of ground control and its accuracy.

II C. METHODOLOGY

Sections A and B discuss factors that should be considered in a scheme to appraise the utility of soil maps. The question remains, how can one integrate all, or part, of the factors that bear on the problem to arrive at a workable and valid system? This individual began this execise with the idea that one should be able to classify soil maps according to their attributes and then interpret the resulting classes according to utility. As the exercise developed, it became increasingly evident that a classification of maps on the basis of such characteristics as scale, kinds of map units, taxonomy of map unit identities, and other factors discussed in this paper would be extremely complex and, perhaps, unmanageable.

A mechanism should provide for appraisal of the following attributes of soil maps:

1. *Minimum legible map scale.* This can be interpreted in terms of the size of area for which interpretations would be appropriate, i.e. individual fields or farms, communities, states, nations -- these should be defined in terms of area. The descriptive terms above are merely suggestive.

2. *Definition of soil attributes within map units.* This is needed to assess whether the soil map, legend, and text collectively provide enough information about the soil areas delineated to permit appraisal of their potential for use and/or management requirements.

3. *Geography of soil variability.* This is needed to assess how much of the total variability is within map units and, therefore, not identifiable in terms of precise geographic location.

4. *Reliability of the map and supporting data.*

5. *Adequacy of ground control on the base map.*

6. *Legibility of soil information.*

It should be possible to record criteria for appraisal of all of these items in a check list, from which a final rating for a specified use might be determined or, perhaps more meaningful, a list of deficiencies might be compiled.

Minimum Legible Map Scale

A tentative classification of scales has been suggested in section B. These can be interpreted in terms of minimum size of delineation and size of planning units to which they might commonly be applied. A tentative interpretation follows:

Class A - Greater than 1:13,000. Suitable for appraisal of soil in delineations as small as 1/2 ha for planning units of 1 to 500 ha, such as experimental areas, truck gardens, or housing sites.

Class B - 1:13,000 to 1:26,000. Suitable for appraisal of soil in delineations as small as 1/2 to 2 ha, or larger, commonly for planning units of 5 to 2500 ha, such as farms and ranches.

Class C - 1:26,000 to 1:130,000. Suitable for appraisal of soil in delineations as small as 2 to 65 ha, or larger, commonly for planning units of 100 to 10,000 square kilometers, such as communities and local political units.

Class D - 1:130,000 to 1:650,000. Suitable for appraisal of soil in delineations as small as 65 to 2000 ha, but mainly larger, commonly for planning units of 20,000 to 1,000,000 square kilometers, such as states and small nations.

Class E - Less than 1:650,000. Suitable for appraisal of soil in delineations as small as 50 square kilometers at the larger scales, but mainly much larger, commonly for planning units larger than 100,000 square kilometers, including large states, nations and continents.

Note that the minimum size of delineations suggested is not strictly the smallest that could be shown at the scale in all classes. Note also that the sizes of planning areas suggested are not mutually exclusive. The numbers are based on maps with which this individual is familiar and should be adjusted.

Definition of Soil Attributes within Map Units

A check list could be developed for a list of potentially limiting attributes like that outlined in section B3. It should provide for rating each significant attribute in terms of the level of detail of the information which can be gleaned, directly or by inference, from: (a) known attributes of the area covered by the map as a whole (such as soil temperature regime), (b) connotation of named taxa, (c) phase and other qualifying criteria, and (d) information in an accompanying text. That which follows is intended only as an example of a kind of check list which might be developed. The list is not intended to be complete, nor are the items necessarily the best. Indeed, little time was spent in serious thought about the list and none was spent reviewing soil surveys of different environments. Many items could be added. A note of caution is needed, however. It would be very easy to compile a long list of individual soil properties that would lose utility by sheer complication.

The items listed are mainly interpretations of information given in soil maps and accompanying documents. If the interpretation were not made at this point, it would have to be done in another step. The idea is to record whether or not a soil map and supporting documents provide information that would make this step feasible for a competent soil scientist.

The levels of information are meant only to suggest a type of rating system that would adapt easily to an appraisal of maps at different levels of detail of land use and soil management. The terms would need definition and examples before they could be applied consistently by different individuals. These might be needed for another level -- no information at all.

Geography of Soil Variability

This refers to the subject discussed in section B5. Considering the lack of information about total soil variability given for most soil maps, it is probably unrealistic to attempt to rate geographic field complexity in more refinement than two classes -- such as simple *vs* complex. To be most useful for appraising the utility of soil maps, such a rating should probably be assessed in terms of geographic complexity of sets of soil attributes that are critical for use and management. To be comparable from map to map, the assessment should also be in terms of soil patterns conceived at some standard scale. This should probably be at a relatively large scale, such as 1:20,000, to provide concepts of complexity that would be meaningful for a wide range of scales. Considering the dearth of information about many areas, it would also be desirable to indicate a degree of certainty for each rating.

Although ratings of field complexity would necessarily be quite subjective for many areas, some guidelines would be necessary as standards. Very tentatively, standards might be like the following:

Simple soil patterns. At a scale of 1:20,000 delineations representing areas having similar use potential would be predominantly larger than 1000 ha, and those representing areas having similar requirements for management systems of intensive uses such as crops, would be predominantly larger than 10 ha.

Complex soil patterns. At a scale of 1:20,000 delineations of similar use potential would be predominantly smaller than 1000 ha, or those of similar needs for management systems would be smaller than 10 ha, or both.

By use is meant broad use groups, such as cropping, grazing, or forestry. By management systems is meant general systems involving similar, but not necessarily identical, plants, conservation measures, fertility maintenance and the like. The quantitative values of area proposed represent, at best, crude concepts, which might or might not be realistic.

Unless the supporting documents provide specific information about field variability, judgments would have to depend mainly on inferences from other attributes of the area. Commonly, statements in the text or the character of mapping itself provides clues that the map does or does not reveal the degree of complexity that exists. Information about geology, geomorphology, and topography may permit one to predict the complexity of soil patterns. Land use patterns, if available, can be used as evidence though they are not infallible. Ratings based on inferences of this kind should be labeled as uncertain.

Variability within map units is a very important criterion of the kinds of interpretations that can be made. This subject is discussed in part in the paragraphs on "Kinds of map units" and "Geographic distribution of critical soil conditions" in section B. One suggestion for recording relevant information about this attribute follows:

1. Map units which can be evaluated as consociations _____ % of area.
   a. And are homogeneous in attributes controlling land use _____ % of area.
   b. And are homogeneous in attributes controlling management _____ % of area.
2. Map units which must be interpreted as geographic soil mixtures _____ % of area.
   a. Components differ in use potentials ____ % of area.
   b. Components differ in management requirements _____ % of area.
   c. Proportions of components defined _____ yes; _____ no.
   d. Patterns of components described _____ yes; _____ no.
   e. Are identified as associations or complexes _____ part; _____ all.

The distinction between 1 and 2 requires appraisal of more than map unit names. Some map units identified as consociations are, in fact, associations and should be evaluated under 2.

A third factor which could be evaluated under this heading is the extent of critical soil attributes which are not identified with map units in any way in the legend or in the text. These, if they are factors in the area, must be assumed to vary within segregation by map units. (Some which are not mentioned may not be factors in the area and, therefore, are unimportant. Others may be inferred to be uniform for all areas and, therefore, are effectively known.) This would not be recorded in

Table 1 as it is constructed. The item might be included in that table as "no information".

Reliability of the Map and Supporting Data

Drawing on the list in "Reliability of information," section II B, the following could be used as a check list:

Method of Compilation	Reliability Within Limits of Method		
	Good	Fair	Poor
Detailed field methods, with remote sensing			
Detailed field methods, without remote sensing			
Reconnaissance field methods, with remote sensing			
Reconnaissance field methods, without remote sensing			
Exploratory field methods, with remote sensing			
Exploratory field methods, without remote sensing			
Remote sensing techniques only			
Schematic compilation			
Methods unknown			

Quality of Base Map

The following is a suggested check list:

Base map adequate for the purpose ___ yes ___ no
If no is checked:

Inadequate ground control ___ yes ___ no
Inaccurate ground control ___ yes ___ no
Culture illegible ___ yes ___ no
Culture obscures soil information ___ yes ___ no

Legibility of Soil Information

The following are items that may be relevant:

Legibility is adequate for the purpose:	___ yes	___ no
If no is checked:		
Too much detail for scale	___ yes	___ no
Symbols illegible	___ yes	___ no
Color pattern detracts	___ yes	___ no
Overprint patterns detract	___ yes	___ no

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A PROPOSAL FOR EVALUATING SOIL SURVEY REPORTS

T.R. Forbes[1]

Accelerated agricultural development has become a goal for many countries. In this effort a sound knowledge of a primary agricultural resource, soils, is a necessity. Soil survey reports provide the only consistent means of recording data on the kinds and distribution of soils in most countries.

The contents and presentation of soil survey reports are varied and are written in many languages. An evaluation of the existing body of soil survey reports must deal with this variety. These reports were based on diverse soil concepts, classification systems, intended land uses or scientific studies, and other concerns.

As varied as the existing body of soil survey reports is, there is a unifying factor. In the LDCs of the tropics, for example, most of the existing soil survey reports were compiled and written by technicians representing former colonial powers. As a result most of the existing reports in these countries are written in English, French, Portuguese, Spanish or Dutch (with some exceptions), and they are based on the concepts of soils and use a format characteristic of the respective colonial country. Therefore one of the first stages in the evaluation of existing surveys must include a familiarity with and comprehension of the concepts, viewpoints, methodologies, and techniques for soil survey existing in the developed countries.

CHECK LIST

In view of the abundance of soil survey reports and formats, it was decided that as a starting point an efficient method was needed to summarize the kinds of pertinent information contained in any particular soil survey report. Obviously the real value of a soil survey map and report is derived ultimately from the accuracy with which these represent the real soil conditions existing in the surveyed area. However, leaving a check of the "ground truth" aside in the first stages was necessary from a practical point of view, and this also permitted a sharper focus on the kind of information content existing in the published reports and maps. As an aid in this exercise several approximations of an "information content check list" were formulated. In compiling this check list an effort was made to envisage all the categories of subject areas which any given soil survey report would include and which are relevant towards a judgment

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of its completeness or usefulness. An example of the last check list approximation is included. A description of the categories given on the check list and the reasons why they were chosen is given in the following paragraphs.

This check list is a working document currently being used by members of the Cornell Soil Resource Inventory Working Group on a USAID 211(d) project. The initial purpose of the check list is to gather sufficient bibliographic and background data to compile an information storage and retrieval program for the Cornell IBM/370 computer. This stored data will then be used for further analyses and investigations. Some of the categories on the check list are only bookkeeping entries for the information storage and retrieval system.

General Background Information

This includes essential details such as the country or geographic area covered by the report, the map scale, the ground area, the other general kinds of information covered for the study area (aside from the soils), and pertinent bibliographic data.

Objectives of the Survey

A general listing of objectives for soil surveys is given to anticipate all the possible reasons for which a soil survey might be undertaken. A critical aspect of evaluation of soil survey reports depends upon a clear idea of the objectives that were in mind and upon which the soil surveyors constructed their methodology and presentation. The objectives, which unfortunately in most soil survey reports are implied rather than stated, will dictate the various categories of supporting information and data which must be included in the report. The listing of objectives attempts to incorporate also levels of use intensity.

Kind of Survey

This section sets forth a tentative classification of soil surveys.

Map and Legend Characteristics

This section gives relevant properties of the map and legend which, it is hoped, will eventually form a basis for refining the classification given previously.

Methodology of Preparation

An attempt has been made to summarize relevant aspects of the soil survey methodology for all of the soil survey reports. Included are divisions of field methods, legend determination and kinds of analyses. Again this kind of detailed information is unfortunately generally not included in published reports.

Relevant Background Information

It is anticipated that other data such as present land use, physiographic data, climatic data, etc., may eventually be relevant for discussing possible soil survey methodologies for new areas. Also, given the existing body of background information at the time of the actual survey, the resulting methodologies and presentation of the published report may be put into a clearer context.

Narrative Evaluation and Other Remarks

Since all of the possible kinds of information and cases cannot reasonably be included for all surveys, a narrative evaluation becomes increasingly important.

Received 7/5/77.

LITERATURE CITED

U. S. Department of Agriculture, Soil Conservation Service. 1977. Soil survey manual, rev. ed. (4th draft, 1974-75.)

SOIL SURVEY CHECK LIST

Schedule A: General Background Information

1. Field Number†:
2. Date of Report:
3. # of Map Sheets:
4. Country:
5. Title of Report:
6. Report Prepared By/Author: (last name, first name)
7. Map Scale:
8. Area: (km^2)
9. Book reference†:
10. Publisher:
11. City (publisher):
12. Number of pages:
13. Other Bibliographic Information (Report #; Gov. Agency; Division, etc.)

14. Report Accompanied by the Following Maps:

Type	No	Yes	Actual Scale	/	Scale Code*
Geology				G	
Vegetation				V	
Physiography				P	
Climate				C	
Land-use (present)				U	
Land Capability/ Potential				L	
Irrigation potential				I	
Erosion hazard				E	
Other				O	

*Scale Code	
1	——→ 1:12,999
2	1: 13,000 - 1: 25,999
3	1: 26,000 - 1: 59,999
4	1: 60,000 - 1:129,999
5	1:130,000 - 1:259,999
6	1:260,000 - 1:649,999
7	1:650,000 - ——→
8	None indicated

15. Report Accompanied by the Following Information

Type	No	Yes	/
Geology			G
Vegetation			V
Physiography			P
Climate			C
Land-use (present)			U
Land Capability/ Potential			L
Irrigation Potential			I
Erosion hazard			E
Other (Specify)			O

Evaluation done by:

Evaluation completed on:

16. Supplementary Field Numbers‡:

† Refers to a bookkeeping entry for computer storage and retrieval.

‡ Library and library call number of book location are included.

Schedule B: Characterization of the Survey

Objective(s) of Survey† Indicated	Yes	No
1. BROAD LAND USE PLANNING		
National Planning and Inventory		
Identification and Broad Development		
Regions		
for purposes below:		
Cropping		
Grazing		
Range Lands		
Forestry		
Wildlife and recreation		
Watersheds		
Urban or settlement areas		
Others (specify)		
2. SOIL INVENTORY OF A REGION (some management requirements stated or implied)		
Regional Planning (general)		
Selection of promising areas for a specific purpose		

Cultural Systems General Planning (including:)	Yes	No
Shifting cultivation		
Wet culture (paddy rice, sugar cane, etc.)		
Rainfed permanent culture		
Irrigation dryland culture		
Other (specify:)		
Grazing		
Dryland		
Irrigated		
Rangelands		
Forestry		
Wildlife and Recreation		
Settlement Areas		
Assess drainage and requirements		
Background for soil conservation or reclamation program		
Delineate areas for watershed development		
General location of transport infrastructure, secondary industries or urban development		

† Add asterisks (*) to "check-mark" if you believe that a particular objective is implied or that the report seems to meet the requirements for that particular objective.

SOIL SURVEY CHECK LIST - Page 3

3. PLANNING AND EXECUTION OF EXTENSIVE PROJECTS†	Yes	No
Siting areas of rainfed crops and pastures (based on specific management requirements;- (specify crops or pastures:)		
Irrigation feasibility		
Rangelands		
Forestry		
Wildlife and Recreation		
Land Settlement Sites		
Engineering and urban purposes (specify)		
Others (specify)		
4. PROJECT EXECUTION AND SITING‡		
Irrigation siting (specify crops)		
Site experiment stations and field plots (specify crops)		
Crops for which management systems are indicated (specify)		
Engineering and urban uses		
Site roads and pipelines		
Site foundations, sewers, septic tanks		
Landscaping plans		

5. GENERAL OR CROSS-OBJECTIVES	Yes	No
Scientific advancement		
Provides data for soil classification and genesis		
Provides data for geomorphology, geography or ecology		
Others (specify)		

† Soil information should be specific enough to assess the suitability for broad groups of plants in cultural systems.

‡ Soil information should be specific enough to assess the suitability for specific crops.

Schedule C: KIND OF SURVEY †

	Yes	No
Schematic Survey (compiled without identification by original observations in the area. Compiled from limited information on climate, vegetation, geology and landforms)		
Topographic or airphoto base		
No topographic or airphoto base		
Reconnaissance Survey (mapping units are identified by observations of the soils within the area, but the soils boundaries are largely compiled from other sources)		
Identification of the soils is mainly based on field data		
Identification of soils is supported by laboratory data		
Detailed Reconnaissance Survey		
With remote sensing		
Without remote sensing		
Semi-detailed survey		
With remote sensing		
Without remote sensing		
Detailed Survey		
With remote sensing		
Without remote sensing		
Ultra-detailed Survey		
With remote sensing		
Without remote sensing		

Kind of Survey - As indicated in Report by Authors	Mixed ‡ Intensity	Uniform
Broad Scale		
Semi-Broad Scale		
Semi-Detailed		
Detailed		
Preliminary/Provisional		
Reconnaissance		
Comprehensive/Final		
No Indication		
Other (specify)		

† Some criteria for survey descriptions were taken from the revised *Soil Survey Manual* (1977).

‡ See "Soil Map Parameters and Classification" in this monograph for a definition of "map intensity."

Schedule D: MAP & LEGEND CHARACTERISTICS

Kinds of Map Units	Mixed Intensity	Uniform
USDA or translated to USDA (if translated by checker, mark with asterisks *)		

	† Intensity Level 1	2	3
Consociations			
Associations			
Complexes			
Undifferentiated Group			
Taxonomy			
Classification System			
Comprehensive			
Non-Comprehensive			
Name:			
"Tailor-made" for study			
No taxonomic system			
Land capability classes			
Soil potential classes			
Map Unit Components			
Number of categories			
Kind(s) of system used			
USDA Equivalents			
Phases of soil series			
Depth			
Effective depth			
Slope			
Other			
Soil series			

	Intensity Level 1	2	3
Phases of Soil Families			
Depth			
Effective depth			
Slope			
Stony			
Other			
Soil Families			
Phases of subgroups			
Depth			
Effective depth			
Slope			
Stony			
Other			
Soil Subgroups			
Phases of Great Groups (specify)			
Soil Great Groups			
Phases of suborders (specify)			
Soil Suborders			
Phases of Soil Orders (specify)			
Soil Orders			
Other			
Not Comparable			

† Use column 1 if one intensity only. Asterisks (*) denote the predominant mapping unit.

SOIL SURVEY REPORT CHECK LIST - Page 6

Map Legibility †	Intensity Level 1	2	3
Average number of map units per unit area (km^2)			
Least-size delineated (ha)			
Largest size area delineated (ha)			
Largest number of delineations surrounding least-size delineations			
Use of wet symbols or other spot symbols used for areas smaller than the least-size delineation			
Sizes of Delineations on Published Map			
Number of Delineations per 20 cm^2 ‡			
Size of Largest Delineation cm^2			
Nature of Contrasts between Map Units			
On a Taxonomic Basis			
Fairly Similar			
Moderately Different			
Widely Different			
On a Land-Use Potential Basis			
Fairly Similar			
Moderately Different			
Widely Different			
Not Relevant			
General Shapes of Delineations			
Average-size delineations			
Round			
Oval			
Linear			
Other			

Least-size delineations	Intensity Level 1	2	3
Round			
Oval			
Linear			
Other			
Relation of Published Map Scale to Field Map Scale			
Actual Ratio			
Ratio Class			
> 1:1			
1:1			
1:1 - 1:2			
1:2 - 1:5			
1:5 - 1:10			
< 1:10			
Actual Field Scale			
Actual Published Scale			

†See "Soil Map Parameters and Classification," this volume.

‡See page 10 of this check list.

SOIL SURVEY CHECK LIST - Page 7

Schedule E: METHODOLOGY OF PREPARATION

	Intensity Level 1	2	3
Average Number of Profiles Sampled per Map Unit			
Type of Analyses Done for Most Profiles			
Routine			
Fertility-related properties and routine			
Special properties (salinity, acid sulfate etc.)& routine			
special properties (mineralogy etc.) and routine			
Other (Specify)			
Field Methods			
Quality of base map			
Enlarged topo sheets			
Poor planimetry for ground control			
Inadequate altimetry			
Type(s) of base map			
Airphoto			
Topographic			
Other - Specify			

	Intensity Level 1	2	3
Scale of base map - specify			
Number of observation points per cm^2 on field map, indicated (use code given below) D341; 1 = 1 pt. 2 = 2 pts. 3 = 2 - 4 pts. 4 = 4 - 8 pts. 5 = 7 - 8 pts. 6 = not indicated			
Soil map was generalized			
Effective scale			
Type of survey			
Rigid grid			
" " w/ airphotos			
Grid survey w/ addit'nl observations to locate boundaries			
As above but w/ aerial photos			

	Intensity Level 1	2	3
Random survey			
Random survey with airphotos			
Legend determination			
Fixed prior to survey w/minor alterations			
Fixed prior to survey with major alterations			
Made during progress of survey			
Not Indicated			

SOIL SURVEY REPORT CHECK LIST - Page 8

Schedule F - Relevant BACKGROUND INFORMATION (may be significant for grouping or classification of soil surveys)

	Intensity Level 1	2	3
Present land use or natural condition shown on maps (check off following that apply):			
Field crops and/or pastures			
Tree crops			
Rangeland			
Forests			
Savannas			
Desert			
Wildlife or recreation preserves			
Urban or settlement areas			
Areas of irrigation farming			
Present land use not shown on maps			
Intended land use specified (check off) following that apply):			
Field crops and/or pastures			
Tree Crops			
Rangeland			
Forests			
Wildlife or recreation			

	Intensity Level 1	2	3
Irrigation farming			
Urban or settlement			
Intended land use not specified			
Physiographic data given			
Physiographic data not given but found in other studies or surveys			
Range in relief (meters)			
Topography †			
Parent rock and/or material			
Climatic data given			
Climatic data not given but found in other studies or reports			
Mean annual rainfall (mm)			
Number of seasons			
Wet			

	Intensity Level 1	2	3
Dry			
Predominant type of vegetation in survey area‡			

† Use SCS terminology, i.e. undulating, rolling, etc.

‡ Write in brief description

Schedule G: NARRATIVE EVALUATION AND OTHER REMARKS

SOIL SURVEY CHECK LIST - Page 10

Schedule H: CIRCLE COUNTS FOR DETERMINING NUMBER OF DELINEATIONS PER UNIT AREA†

2.5 cm Radius count: Area of circle 19.64 cm^2

Title:

Scale:

Intensity Area	# Delineations Per Observation									
	1	2	3	4	5	6	7	8	9	10
A										
B										
C										
D										

† For methodology involved, see M. C. Laker, "Selection of a Method for Determination of Map Intensities of Soil Maps," this volume.

AN EVALUATION OF SOIL LIMITATIONS FROM SOIL NAMES

H. Eswaran[1]

Soil limitations may be identified in taxonomic names or in soil descriptions for a given map, or they may have to be inferred from information that is given about the soil (Cline). Cline further adds that the utility of a soil map is related to the amount of such information that can be extracted.

Our initial purpose was to evaluate the type of limitation implied in the names of some taxonomies. This is attempted for the USDA *Soil Taxonomy* and the French classification system. The FAO legend will also be attempted.

If a soil map employs one of these taxonomies in its legend, the attached list of categories and their implied limitations are useful. In some cases, map units are translated to taxonomies. If this is not available, it is useful to make a table of limitation implied or inferred in the map unit names.

The next step according to Cline is to assess the level of generalization for which the soil map would be useful, based on the limitations indicated by the mapping units.

DIRECT OR INFERRED LIMITATIONS IN THE NAMES OF CATEGORIES IN *SOIL TAXONOMY*

The name of a category in *Soil Taxonomy* indicates its class in all categories of which it is a member. Names generally reflect the most important property of the category.

Some names also reflect the limiting properties of the soil, e.g.:

1. Lithic Dystropept has hard rock at shallow depth;

2. Sulfaquept has sulfuric materials at shallow depths;

3. Vertisols have vertic properties.

[1]Geological Institute, University of Ghent, Krijgslaan 271, Ghent 9000, Belgium. (Visiting Professor, Cornell University)

In other names, limiting properties may be used to define the category and so the name infers the property, e.g.:

1. Oxisols have low CEC;

2. Typic Acrorthox has a net positive charge.

In some names, a specific property is included in the category though it is not a diagnostic feature, and is not inferred in the name, e.g.:

1. Torriorthents have salic conditions;

2. Albaqualfs have low hydraulic conductivity.

The term *limiting conditions* is subjective; to be specific one has to define the conditions or uses of the soil. In the following evaluation, the term is used very broadly to imply that the property "could be limiting." This is to be considered as a first approximation. A final assessment can be made only when one deals with specific soils and specific conditions or uses.

Some properties may be limiting only for parts of the year. For example an aquic Haplustult experiences moisture stress during the year and may have a high water table for short periods. Both are considered as limitations. The use of the soil is a function of the duration of either condition.

Six orders and all categories up to the subgroup level are considered in the attached list. The most important limitations, as indicated by the concept of the category, are given. Eighteen limiting conditions are considered. No indication is given for the level at which a property becomes limiting.

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Soil Categories Taxonomy: USDA	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature	Type of Charge		
OXISOLS						X	X		X			X						
Aquox	X			X		X	X		X			X						
Gibbsiaquox	X			X		X	X		X			X				X		
Plinthaquox	X			X		X	X		X			X						
Ochraquox				X		X	X		X			X						
Umbraquox				X		X	X		X			X						
Humox						X	X		X			X			X			
Acrohumox, Typic						X	X		X			X			X	X		
Petroferric	X					X	X		X			X			X			
Gibbsihumox	X					X	X		X			X			X	X		
Haplohumox						X	X		X			X			X			
Sombrihumox						X	X		X			X			X			
Orthox						X	X		X			X						
Acrorthox, Typic						X	X		X			X				X		
Haplic						X	X		X			X						
Plinthic	X					X	X		X			X						
Eutrorthox, Typic						X			X			X						
Haplohumic						X			X			X			X			
Sombrihumic						X			X			X			X			
Tropeptic						X			X			X						
Gibbsiorthox, Typic	X					X	X		X			X				X		
Haplorthox						X	X		X			X						
Aquic				X		X	X		X			X						
Epiaquic						X	X		X			X						
Plinthic	X			X		X	X		X			X						
Quartzipsammentic		X				X	X		X			X						
Tropeptic						X	X		X			X						
Ultic						X	X		X			X						

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature	Type of Charge		
Sombriorthox						X	X		X			X						
Umbriorthox						X	X		X			X						
Tropeptic						X	X		X			X						
Torrox					X	X	X		X			X						
Ustox					X	X	X		X			X						
Acrustox					X	X	X		X			X				X		
Eutrustox					X	X			X			X						
Tropeptic					X	X			X			X						
Haplustox					X	X	X		X			X						
Tropeptic					X	X	X		X			X						
Ultic					X	X	X		X			X						
Sombriustox					X	X	X		X			X						

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
VERTISOLS			X								X							
Torrerts			X		X						X							
Uderts			X								X							
Chromuderts			X								X							
Aquentic			X	X							X							
Aquic			X	X							X							
Entic			X								X							
Pelluderts			X								X							
Entic			X								X							
Usterts			X		X						X							
Chromustert			X		X						X		X					
Entic			X		X						X							
Paleustollic			X		X						X		X					
Udic			X		X						X							
Udorthentic			X		X						X							
Pellustert			X		X						X							
Entic			X		X						X							
Udic			X		X						X							
Udorthentic			X		X						X							
Xerert			X		X						X							
Chromoxerert			X		X						X							
Aquic			X	X	X						X							
Entic			X		X						X							
Palexerollic			X		X						X							
Pelloxerert			X		X						X							
Chromic			X		X						X							
Entic			X		X						X							

Soil Categories Taxonomy: USDA	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
ULTISOLS							X											
Aquults				X			X											
Albaquult			X	X			X											
Aeric			X				X											
Fragiaquults			X	X			X											
Aeric			X				X											
Plinthic	X		X	X			X											
Plinthudic	X		X	X			X											
Ochraquults				X			X											
Aeric							X											
Paleaquults				X			X					X						
Aeric							X					X						
Arenic		X	X				X					X						
Arenic, Plinthic	X	X	X				X					X						
Arenic, Umbric		X	X				X					X						
Grossarenic		X					X					X						
Plinthic	X		X	X			X					X						
Umbric			X	X			X					X						
Plinthaquults	X		X	X			X					X						
Oxic	X		X	X		X	X											
Tropaquults				X			X											
Aeric, Umbric							X											
Plinthic	X			X			X											
Umbric				X			X											
Umbraquults				X			X											
Humults							X								X			
Haplohumults							X								X			
Andeptic							X		X	X					X			
Aquic				X			X								X			
Xeric					X		X								X			

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Palehumults							X					X						
Epiquic				X			X					X						
Orthoxic						X	X					X						
Plinthic	X			X			X					X						
Ustic					X		X					X						
Xeric					X		X					X						
Plinthohumults	X						X											
Sombrihumults							X											
Tropohumults							X											
Anthropic						X	X											
Aquic				X			X											
Arenic		X					X											
Epiaquic				X			X											
Humoxic				X		X	X								X			
Orthoxic						X	X											
Ustic					X		X											
Ustoxic					X	X	X											
Udults							X											
Fragiudults	X		X	X			X											
Aquic	X		X	X			X											
Arenic	X	X	X	X			X											
Glossaquic	X		X	X			X											
Glossic	X		X				X											
Plinthaquic	X		X	X			X											
Plinthic	X		X				X											
Hapludults							X											
Aquic				X			X											
Arenic		X					X											
Humic							X								X			
Lithic	X						X											
Ochreptic	X						X											
Psammentic	X						X											
Vertic							X				X							

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Paleudults							X					X						
Aquic				X			X					X						
Arenic		X					X					X						
Arenic Plinthaquic	X	X	X	X			X					X						
Arenic Plinthic	X	X	X				X					X						
Arenic Rhodic		X					X		X			X						
Fragiaquic	X		X	X			X					X						
Fragic	X		X				X					X						
Grossarenic		X					X					X						
Plinthaquic	X		X	X			X					X						
Plinthic	X		X				X					X						
Psammaquentic	X			X			X					X						
Rhodic							X		X			X						
Spodic		X					X					X						
Plinthudult	X		X				X											
Rhodudults							X		X									
Tropudults							X											
Aquic				X			X											
Arenic Oxic		X				X	X											
Dystropeptic							X											
Epiaquic				X			X											
Orthoxic						X	X											
Petroferric	X		X				X											
Plinthaquic	X		X	X			X											
Plinthic	X						X											
Vertic							X				X							
Ustults					X		X											
Haplustults					X		X											
Aquic				X	X		X											
Arenic		X			X		X											
Epiaquic				X	X		X											
Lithic	X				X		X											

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Ustults (cont'd)																		
Oxic					X	X	X											
Petroferric	X				X	X	X											
Plinthic	X				X	X	X											
Paleustults					X		X					X						
Plinthustults	X				X		X											
Rhodustults					X		X		X									
Xerults					X		X											
Haploxerults					X		X											
Ruptic Lithic	X				X		X											
Palexerults					X		X					X						

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Alfisols																		
Aqualfs				X														
Albaqualfs			X	X														
Aeric			X															
Arenic		X	X	X														
Mollic			X	X														
Udollic			X	X														
Vertic			X	X							X							
Duraqualf	X			X														
Fragiaqualf	X			X														
Aeric	X																	
Umbric	X			X														
Glossaqualf				X														
Aeric																		
Arenic		X		X														
Mollic				X														
Natraqualfs				X										X				
Albic			X	X										X				
Glossic			X	X										X				
Ochraqualfs				X														
Aeric																		
Arenic		X		X														
Grossarenic		X		X														
Mollic				X														
Udollic				X														
Umbric				X														
Vertic				X							X							
Plinthaqualfs	X			X	X													
Tropaqualfs				X														
Abruptic				X														
Aeric																		
Umbraqualfs				X														

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Boralfs															X			
Cryoboralfs															X			
Andeptic									X	X					X			
Aquic				X											X			
Glossic															X			
Lithic	X														X			
Mollic															X			
Psammentic		X													X			
Eutroboralfs															X			
Aquic				X											X			
Arenic		X													X			
Glossic															X			
Mollic															X			
Psammentic		X													X			
Fragiboralf	X														X			
Aquic	X			X											X			
Glossoboralf															X			
Aquic				X											X			
Eutric															X			
Lithic	X														X			
Psammentic		X													X			
Natriboralfs														X	X			
Paleboralfs		X													X			
Aquic		X		X											X			
Mollic		X													X			

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Udalfs																		
Agrudalf																		
Ferrudalf																		
Aquic				X														
Fragiudalfs	X																	
Albaquic	X			X														
Aqueptic	X			X														
Aquic	X			X														
Glossaquic	X			X														
Glossic	X			X														
Mollic	X																	
Ochreptic	X																	
Fraglossudalfs																		
Glossudalfs																		
Aquic				X														
Arenic		X																
Fragic	X																	
Haplic																		
Hapludalf																		
Albaquic				X														
Albaquultic				X			X											
Andeptic									X	X								
Aquic				X														
Aquollic				X														
Aquultic				X			X											
Arenic		X																
Glossic																		
Lithic	X																	
Psammentic		X																
Ultic							X											
Vertic											X							

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Natrudalf			X											X				
Glossic			X											X				
Vertic			X								X			X				
Paleudalfs																		
Albaquic				X														
Aquic				X														
Arenic		X																
Glossaquic				X														
Glossic																		
Grossarenic		X																
Mollic																		
Plinthic	X																	
Psammentic		X																
Rhodic									X									
Vertic											X							
Rhodudalfs									X									
Tropudalfs																		
Aquic				X														
Lithic	X																	
Oxic						X												
Ultic							X											
Vertic											X							
Ustalfs					X													
Durustalfs	X				X													
Hapustalfs					X													
Aquic				X	X													
Arenic		X			X													
Aridic					X								X					
Lithic	X				X													
Oxic					X	X												
Psammentic		X			X													
Ultic					X		X											
Vertic					X						X							

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Natrustalf			X		X									X				
Aquic			X	X	X									X				
Mollic			X		X									X				
Petrocalcic	X		X		X								X	X				
Salorthidic			X		X									X				
Paleustalfs					X								X					
Aquic				X	X								X					
Arenic		X			X								X					
Aridic					X								X					
Calciorthidic					X								X					
Grossarenic		X			X								X					
Oxic					X	X												
Petrocalcic	X				X								X					
Psammentic		X			X								X					
Rhodic					X				X				X					
Udertic					X						X							
Plinthustalf	X				X													
Rhodustalf					X				X									
Lithic	X				X				X									
Oxic					X	X			X									
Xeralfs					X													
Durixeralfs	X				X													
Abruptic	X				X													
Haplic	X				X													
Natric	X				X									X				
Haploxeralfs					X													
Aquic				X	X													
Aquultic				X	X		X											
Calcic					X								X					
Lithic	X				X													
Mollic					X													
Natric					X									X				
Psammentic		X			X													
Ultic					X		X											
Vertic					X						X							

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Natrixeralfs			X		X									X				
Aquic			X	X	X									X				
Palexeralfs					X													
Aquic				X	X													
Calcic					X								X					
Mollic					X													
Natric					X									X				
Petrocalcic					X								X					
Ultic					X		X											
Vertic					X						X							
Plinthoxeralf	X				X													
Rhodoxeralf					X				X									
Calcic					X				X				X					
Lithic	X				X				X									
Petrocalcic	X				X				X									

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
INCEPTISOLS																		
Andepts									X	X								
Cryandepts									X	X					X			
Dystric							X		X	X					X			
Entic									X	X					X			
Lithic	X								X	X					X			
Durandepts	X				X				X	X								
Entic					X				X	X								
Xeric	X				X				X	X								
Dystrandepts							X		X	X								
Aquic				X			X		X	X								
Entic							X		X	X								
Hydric	X						X		X	X								
Hydric Lithic	X						X		X	X								
Lithic	X						X		X	X								
Oxic						X	X		X	X		X						
Eutrandepts					X				X	X			X					
Duric	X				X				X	X								
Entic					X				X	X								
Lithic	X				X				X	X								
Udic									X	X								
Ustollic									X	X								
Xeric					X				X	X								
Hydrandept									X	X		X						
Lithic	X								X	X		X						
Placandept									X	X								
Vitrandept		X							X	X					X			
Aquic				X					X	X					X			
Lithic	X								X	X					X			
Mollic									X	X					X			
Plaggic									X	X					X			
Umbric									X	X					X			

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature		Trace Element	
Aquepts				X														
Andaquepts				X					X	X								
Aeric									X	X								
Haplic				X					X	X								
Mollic				X					X	X								
Cryaquepts				X											X			
Aeric															X			
Aeric Humic				X											X			
Andic				X					X	X					X			
Histic				X											X		X	
Humic				X											X		X	
Pergelic				X											X			
Fragiaquepts	X			X														
Aeric	X																	
Humic	X			X													X	
Halaquepts				X										X				
Aeric														X				
Vertic				X							X			X				
Haplaquept				X														
Aeric																		
Humic				X			X											
Lithic	X			X														
Mollic				X														
Sulfic				X				X										
Vertic				X							X							
Humaquepts				X													X	
Cumulic				X													X	
Histic				X													X	
Placaquept	X			X														
Histic	X			X													X	
Plinthaquept	X			X														
Sulfaquept				X			X	X										

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature		Trace Elements	
Tropaquept				X														
Aeric																		
Histic				X													X	
Lithic	X			X														
Plinthic	X			X														
Sulfic				X			X	X										
Vertic				X							X							
Ochrepts																		
Cryochrept															X			
Alfic															X			
Andic									X	X					X			
Dystric															X			
Lithic	X														X			
Pergelic															X			
Durochrepts	X			X														
Dystric	X			X														
Entic	X																	
Dystrochrepts																		
Andic									X	X								
Aquic				X														
Fluvaquentic				X														
Fluventic																		
Lithic	X																	
Umbric																		
Eutrochrepts																		
Andic									X	X								
Aquic				X														
Arenic		X																
Dystric																		
Fluventic																		
Lithic	X																	
Vertic											X							

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Fragi ochrept	X																	
Andic	X								X	X								
Aquic	X			X														
Ustochrept					X													
Andic					X				X	X								
Aridic					X								X					
Fluventic					X													
Lithic	X				X													
Udic					X													
Vertic					X						X							
Xerochrept					X													
Andic					X				X	X								
Aquic				X	X													
Calcixerollic					X								X					
Dystric					X		X											
Fluventic					X													
Lithic	X				X													
Vertic					X						X							
Plaggepts		X																
Tropepts																		
Dystropepts							X											
Aquic				X			X											
Fluventic							X											
Lithic	X						X											
Oxic						X	X											
Ustic					X		X											
Vertic							X				X							
Eutropepts																		
Andic									X	X								
Aquic				X														
Fluventic																		
Lithic Vertic	X										X							

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature		Trace Elements	
Humitropept																		
Andic									X	X								
Fluventic																		
Lithic	X																	
Oxic						X												
Ustic					X													
Sombritropept																		
Ustropept					X													
Fluventic					X													
Lithic	X				X													
Vertic					X						X							
Umbrepts																		
Cryumbrepts															X			
Andic									X	X					X			
Aquic				X											X			
Entic															X			
Lithic	X														X			
Pergelic															X			
Fragiumbrept	X																	
Andic	X								X	X								
Aquic	X			X														
Haplumbrept																		
Andic									X	X								
Cumulic																	X	
Entic																		
Fluventic																		
Lithic	X																	
Pachic																	X	
Xerumbrept					X													
Andic					X				X	X								
Entic					X													
Fluventic					X													
Lithic	X				X													
Pachic					X												X	

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature		Trace Elements	Bearing Capacity
ENTISOLS																		
Aquents				X														
Cryaquents				X											X			
Andaqueptic				X					X	X					X			
Fluvaquents				X														
Aeric																		
Andaqueptic				X					X	X								
Histic				X													X	
Mollic				X														
Sulfic				X			X	X										
Tropic				X														
Vertic				X							X							
Haplaquents				X														
Aeric																		
Mollic				X														
Sulfic				X			X	X										
Hydraquents				X														X
Psammaquents		X		X														
Humaqueptic		X		X														
Lithic	X	X		X														
Mollic		X		X														
Spodic		X		X														
Sulfaquents				X			X	X										
Tropaquents				X														
Arents		X																

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Fluvents																		
Cryofluvents															X			
Andeptic									X	X					X			
Aquic				X											X			
Mollic															X			
Torrifluvent					X								X	X				
Anthropic					X								X	X				
Durorthidic	X		X		X								X	X				
Ustertic					X						X		X	X				
Ustic					X								X	X				
Vertic					X						X		X	X				
Xeric					X								X	X				
Tropofluvents																		
Udifluvents																		
Aquic				X														
Mollic																		
Ustifluvents					X													
Aquic				X	X													
Mollic					X													
Vertic					X						X							
Xerofluvents					X													
Aquic				X	X													
Mollic					X													
Vertic					X						X							

Soil Categories Taxonomy:	DIRECT OR INDIRECT LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Orthents																		
Cryorthents															X			
Alfic Andeptic									X	X					X			
Aquic				X											X			
Lithic	X														X			
Pergelic															X			
Torriorthent					X								X	X				
Aquic				X	X								X	X				
Durorthidic	X				X								X	X				
Lithic	X				X								X	X				
Ustertic					X						X		X	X				
Ustic					X								X	X				
Vertic					X						X		X	X				
Xeric					X								X	X				
Troporthents																		
Andeptic										X	X							
Lithic	X																	
Udorthent																		
Andeptic										X	X							
Aquic					X													
Lithic	X																	
Vermic																		
Ustorthent					X													
Aquic				X	X													
Lithic	X				X													
Vertic					X						X							
Xerorthent					X													
Aquic				X	X													
Durorthidic	X				X													
Dystric					X													
Lithic	X				X													

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Psamments		X																
Cryopsamments		X													X			
Alfic		X													X			
Aquic		X		X											X			
Lithic	X	X													X			
Pergelic		X													X			
Spodic		X													X			
Quartzipsamments		X			X							X						
Aquic		X		X	X							X						
Haplaquodic		X		X	X							X						
Lithic	X	X			X							X						
Orthoxic		X			X	X						X						
Spodic		X			X							X						
Tropaquodic		X			X							X						
Ustoxic		X			X	X						X						
Torripsamment		X			X													
Durorthidic	X	X			X													
Lithic	X	X			X													
Ustic		X			X													
Xeric		X			X													
Tropopsamment		X			X													
Aquic		X		X	X													
Lithic	X	X			X													
Udipsamment		X			X													
Alfic		X			X													
Aquic		X		X	X													
Lithic	X	X			X													
Plaggeptic		X			X													
Spodic		X			X													
Ultic		X			X													
Ustipsamment		X			X													
Alfic		X			X													
Aquic		X		X	X													
Lithic	X	X			X													

Soil Categories Taxonomy:	DIRECT OR INFERRED LIMITING CONDITIONS																	
	Root Restriction Layer	Texture	Hydraulic Conductivity	Reducing conditions	Moisture stress	Low CEC	High Aluminum	Acid Sulphate	Anion fixation	Nitrogen Mineralization	Vertic properties	Low mineral content	Carbonates (c) Gypsum (G)	Salinity (s) Alkalinity (A)	Soil Temperature			
Xeropsamment		X			X													
Alfic		X			X													
Aquic		X		X	X													
Dystric		X			X													
Lithic	X	X			X													

SOIL ANALYSIS FOR SOIL SURVEYS

H. Eswaran[1]

Although a useful and necessary component of soil survey reports is profile description and soil analysis, many reports tend to omit this information. In some cases no analyses were performed due to lack of facilities or the analyses were not complete at time of publication of the report.

As the soil report is the only means that the soil surveyor has to communicate his findings to the users, it is necessary that he define his units in the most unambiguous terms. Soil analyses aid him to do this and the quality of the report is greatly enhanced if all his mapping units are described in morphological, geographical, and physico-chemical terms.

There are few guidelines to assist the soil surveyor in deciding the number of pedons to be described and analyzed, the type of analysis to be performed, and perhaps also the use of this information in his report. This contribution attempts to evaluate some of these questions and provide some suggestions.

WHY SOIL ANALYSES

Soil analyses in soil survey reports are included to define in numerical terms the physico-chemical properties of the major soils of the area. The morphological descriptions and physico-chemical properties are employed to classify the soil. As the analyzed profiles are considered to be representative samples of the area, the measured properties are extrapolated to generalize the behavior or response of the soil to specific uses.

The several different uses of soil analyses are:

In Relation to the Soil Survey Reports

1. To characterize numerically the properties of some or all of the mapping units. If some data are available at the commencement of the survey or during the early part of the survey, they enable the surveyor to calibrate himself. At the end of the survey they enable him to establish relationships between soil properties and other morphological and landscape parameters.

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2. To aid in the correct classification of the soil and enable others to place the soil in other taxonomies.

3. To serve as a basis for more detailed evaluation of the soils; preliminary information on nutrient, physical, or other limitations needed for developing a capability classification may be extrapolated from such analyses.

In Relation to Developing a Resource Inventory of the Region or Country

1. For correlation purposes, it is necessary to build up a soil data bank. Creating new series or grouping old ones is then done on a rationale basis.

2. To use in other areas where no data is available but physiographic conditions indicate possibility of similar soils.

3. To develop soil property interrelationships which enable one to predict a property which is difficult or inconvenient to measure.

In Relation to Evaluating Limiting Properties

1. To determine levels of elements which may be toxic or deficient or levels of soil conditions which may be limiting to use of the soil. As the surveyor is frequently called upon to assess the potentials of the soils, he needs these limits.

2. To delineate soils which require various levels of investment for their economic utilization.

In Relation to Their Genetic Properties

1. To aid in an understanding of their composition and formation. These investigations are generally the most comprehensive but in some cases tend to deal with the unique or the obscure.

2. To evaluate the changes induced by management practices and thereby determine optimal types of management.

TYPES OF ANALYSES

The objectives of the survey determine the types of analyses to be performed. Soil analyses are grouped into classes (Table 1) to reflect these objectives.

Class Ia analyses are those which are necessary to classify the soil in most taxonomies and form the minimum type of analyses that should accompany profile descriptions. In some cases Ib or Ic analyses are necessary but an estimate of some of the latter may be made from Ia analyses. Every soil survey laboratory must be equipped to perform most or all of Class I analyses.

Table 1. Types of analyses in relation to objectives.

Class I Analyses required by *Soil Taxonomy*	Class II Analyses performed for specific objectives or problems. (Generally performed on site, or on undisturbed samples or on auger samples.)	Class III Analyses performed for genetic studies
a. General analyses required on all horizons on all profiles 1. Particle size distribution 2. Organic carbon, nitrogen 3. Cation exchange capacity (NH_4OAc, pH 7) 4. Exchangeable bases: Ca, Mg, Na, K 5. pH in H_2O and 1*N* KCl (1:1) 6. 1*N* KCl-extractable Al 7. $BaCl_2$ - triethanolamine (pH 8.2) H^+ 8. CBD-extractable Fe_2O_3	a. Physical and engineering properties 1. Infiltration 2. Permeability 3. Available water 4. Bearing capacity 5. Other engineering properties	1. Extraction or dissolution techniques 2. Mineralogical 3. Micromorphological 4. Equilibration
b. Analyses required on a few selected profiles to test specific requirements of *Taxonomy* Analysis — Examples in *Taxonomy* where required 1. Bulk density — Andepts, 'Huma' suborders and GG 2. pH in 1*N* NaF — Andepts, Spodosols 3. 15 bar H_2O — Inceptisols, Alfisols, Ultisols, Oxisols 4. CEC by 1*N* NH_4Cl — Oxisols 5. COLE value — Vertisols, Vertic SG 6. Conductivity — Aridisols, some families 7. $CaCO_3$, $CaSO_4$ — Aridisols, Mollisols	b. Chemical properties on soil 1. Salinity, alkalinity 2. pH fresh, dry, or with oxidisers 3. Toxic substances (Arsenic, Boron, Nickel, Chromium, Sulphides, Iron) 4. Fertility-related properties employing different kinds of extractants 5. Eh	(The above are performed in addition to some or all of Class I and II analyses.)
c. Analyses required on a few selected horizons to test specific requirements of *Taxonomy* 1. P_2O_5 — Anthropic horizon 2. Pyrophosphate-extractable Fe, Al — Spodic horizon 3. Fine/coarse clay ratio — Argillic horizon 4. Mineralogy of clay — Argillic horizon 5. Mineralogy of fine sand — Soil families	c. Chemical properties on water at site or incoming water 1. Suspended solids 2. Dissolved salts (electric, SAR) 3. Toxic substances (Boron, Magnesium, Lithium, Cl^-, SO_4^{--}, CO_3^{--}, HCO_3^-) 4. pH	

Class II are performed for special surveys. The number of samples is usually large and samples may be taken at specific depth intervals in the soil. Auger samples are generally employed and samples from unit areas may be bulked to reduce sampling error. Single property maps are based on such data.

Class III analyses generally do not appear in soil survey reports of LDCs as these are considered "academic." These studies are useful to develop concepts and build up classification systems.

NUMBER OF PROFILES OR HORIZONS TO BE ANALYZED

The number of profiles to be analyzed is a function of the scale of the map and the objectives of the survey. Table 2 attempts to determine the basis for selection of profiles for characterization and the types of analyses to be performed. Profiles are selected to show not only the basic characteristics but also the range in properties.

Most profiles are sampled to a depth of 2 m unless particular soil conditions or objectives require shallower or deeper samples. The normal procedure is to sample morpho-genetic horizons and when a horizon is thicker than 25 cm, one sample is taken for each 25 cm.

CONSIDERATIONS ON COST OF SOIL ANALYSES

Many a soil surveyor hesitates to send in soil samples for analysis due to the costs involved, particularly if done by a commercial lab. This is a limiting factor with respect to the number and type of analyses.

Costs of soil analysis must be considered in relation to:

1. cost of the whole soil survey, and
2. cost of development of the area.

Cost of the soil survey is indicated on a ha basis and in many LDCs, this does not exceed 10 or 20 cents per ha (for a map of 1:63,000). No estimate of cost per ha of soil analysis is available but this is not expected to be more than 10% of the cost of the soil survey. However, both the costs are a small fraction of the total developmental costs of the area.

For example, in Malaysia it costs about $500 per ha to bring an area into rubber or oil-palm. The benefits accrued due to the recommendation of the soil survey far outweigh the cost of soil survey and soil analyses. Consequently, cost of soil analyses should not limit the number or types of analyses within the limits suggested in Table 2. Obviously a survey can use analytical data obtained in earlier work.

Table 2. Selection of profiles for analyses and types of analyses to perform.

Kinds of Soil Survey	Scale Publ. Map	Selection of Profiles for Analyses	Types of Analyses
Class A	< 1:7,920	Minimum one per taxonomic unit plus other samples to show limiting or specific characteristics	All or part of Class I or II
Class B	7,920 - 24,000	Minimum one per dominant soil series or equivalent	All or part of Class I or II
Class C	24,000 - 62,500	Dominant soil families or equivalent	Class Ia with or without others
Class D	62,500 - 250,000	Dominant subgroups or equivalent	Class Ia, Class III with or without others
Class E	250,000 - 500,000	Dominant great groups or equivalent	"
Class F	> 500,000	Dominant soil orders or equivalent	"

QUALITY OF SOIL ANALYSES

Quality control is very important and there are several ways to attain this:

(1) Inter-laboratory cross-checks,
(2) Sample duplication, and
(3) Statistical approach.

(1) and (2) are followed by some labs. Quality control deals with not only the laboratory but also the surveyor. When the same soil series is identified in different parts of the country, it is necessary to verify the similarity of their physico-chemical properties. The coefficient of variation (CV) is a good parameter to evaluate this. The acceptable CV is determined to a large extent by the property in question. Beckett et al. (1971) have provided some levels.

SOIL ANALYSES IN LDCs

Constraints to Good Analyses in LDCs

Many soil data from LDCs tend to be less reliable for several reasons:

1. *Lack of qualified lab personnel.* Training of lab personnel in analytical methods should be an equally important contribution of aid programs. FAO personnel in Thailand, faced with this problem, have organized in-service training programs and provided a manual which gives all details.

2. *Equipment.* Two situations generally prevail. If there was a technical aid project, the labs are equipped well, but as lab personnel are not trained to maintain equipment and spare parts are difficult to get, the equipment is no longer used after the departure of the experts. In the absence of a foreign project either the labs are bare or stocked with the most fancy equipment. However, a survey by FAO of more than 225 labs in LDCs (Brogan et al., 1965) indicated that most of the labs were well equipped to perform the general analyses required for soil surveys.

3. *Chemicals.* This is the most expensive item in LDCs as most chemicals are imported. Even if money is available, one may have to wait six months to a year to obtain chemicals.

Minimum Equipment Needed for a Soil Survey Laboratory

A soil survey laboratory is perhaps one of the cheapest laboratories to establish and maintain. The instruments indicated below will suffice for most soil survey requirements. A more comprehensive list of equipment needed for soil survey laboratories is given by Golden et al. (1966).

1. Atomic absorption spectrophotometer
2. UV - visible spectrophotometer
c. pH meters (at least two)
4. Conductivity meters
5. Electrical balances (two to four)
6. Hot plate with magnetic stirrers (ten)
7. Water-bath (two)
8. Ovens (two)
9. Furnaces (two)
10. Glassware

Optional:

1. Flame photometer
2. Teflon bombs or platina and nickel crucibles
3. Centrifuges

If funds are available the following are useful:

1. X-ray diffraction units
2. DTA-TGA thermoanalyses
3. C, H, N analyzer
4. Equipment for making thin-sections

Types of Analyses

Table 1 lists most of the analyses employed and procedures are given in the manual on laboratory techniques (Soil Conservation Service, 1972). There is a trend in many countries to adopt most of these methods, perhaps because they have stood the test of time. However, there are local modifications which one has to be aware of. The danger comes when the lab uses the name of an established method but a totally different procedure. For example, free iron is usually determined by the CBD method. There are reports where free iron is determined by: (a) Deb procedure, (b) a 6 *N* HCl extract, or (c) Ammonium oxalate - oxalic acid extraction in the dark, in the light, or with UV light. Each of these methods gives a different value. There is perhaps a need for adopting conventions regarding names of methods.

An Assessment of Published Soil Survey Reports

In Table 3, some information is given on a few soil survey reports of LDCs (randomly picked out, one from each country). A few have all class Ia analyses; some include other data, and a few have none. In some, profile descriptions are so vague that the analytical data become less meaningful. In one, the profile that was described is not the same as the one analyzed. In the same report the modal profile was sampled in another locality. In many reports, the profile description and analytical data are addendums to the report; reference to these are absent in the text.

Table 3. Types of analyses in soil reports of LDCs.

Areas of Survey and Reference	Map Scale	Area of Survey (Km^2)	No. Pedons Analysed†	Average Sample Pedon	Texture		pH			Exchange Properties					B.S. %	H^+ 8.2	KCl Al	C	N	B.D.	Free Fe_2O_3	Cond. mmhos/cm	$CaCO_3$
					Int.	USDA	H_2O	KCl	Other	CEC	Ca	Mg	Na	K									
Bangladesh (1)	126,000	3000	23(5)	4	X		X				X	X	X	X				X	X				
Thailand (2)	100,000	4100	19(23)	5		X	X	X		X	X	X	X	X	X	X		X	X			X	X
Malaysia (3)	126,000	800	8(23)	5	X			X		X	X	X	X	X	X			X	X				
Philippines (4)	200,000	13430	0/36																				
Sierra Leone (5)	50,000	2590	14/16	3	X		X		X	X	X	X	X	X				X	X				
Lesotho (6)	250,000	30344	(20)	3	X	X	X		X	X	X	X	X	X	X	X		X	X				X
Usutu Basin, Swaziland (7)	50,000	910	?	?	X		X	X	X	X	X	X	X	X	X			X	X			X	X
Songhor Area, Kenya (8)	50,000	526	(41)	7		X	X			X								X	X				
Antsohihy, Madagascar (9)	20,000	10000	(30)	3	X		X			X	X	X	X	X	X			X	X				X

† Numerals in brackets give the number of mapping units in legend.

The number of profiles analyzed bears no relationship to the mapping or taxonomic units. The number of horizons sampled is clearly a function of the training of the surveyor.

CONCLUSION

Despite the importance of soil analyses, in general the least attention is directed to them. There is a lack of appreciation of soil analyses and many soil surveyors of LDCs do not seem to be informed on the interpretation that could be made.

It will be useful and perhaps a valuable contribution if aid projects are directed to:

1. Training of laboratory personnel in analytical techniques.

2. Training of soil surveyors, especially soil survey assistants, on soil analyses and interpretation of data.

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RELATIONSHIPS BETWEEN POTENTIAL AND SOIL PROPERTIES[1]

M. C. Laker[2]

"The term *agricultural potential* therefore means that which is agriculturally possible.

"However, the term *that which is possible* begs the question *under what conditions*? And it is immediately clear that what is agriculturally possible depends upon the nature of the land (climate, etc.) and the input of management. If we keep the nature of the land constant, it follows that potential depends upon management input. Conversely, if we keep the management input constant, it follows that potential depends upon the nature of the land" (Macvicar, 1974).

According to Hensley (1976) it can be summarized that "agricultural potential can be described as an expression of possible production per unit area over a period of time and the production techniques used to achieve this production."

Knowledge of potential is needed in order to be able to select the most suitable land use for each area of land. Agriculturally it means selection of the most suitable agricultural enterprise (type of farming) for each area of agricultural land.

The production potential of any area of land <u>at a specific time</u> is a function of a series of factors. These factors can be grouped into two major categories, viz.:

(a) the physical-biological characteristics of the area, and

(b) the prevailing socio-economic situation in the area (Laker, 1976).

The physical-biological factors *inter alia* include soil (with all its various characteristics), climate (with its different characteristics such as quantity and distribution of rainfall, temperature, evapotranspiration, frost period, etc.), topography, hydrology, vegetation, disease incidence, etc.

Socio-economic factors *inter alia* include the traditional attitudes of the people towards agriculture in general and specific types of farming enterprises in particular, educational

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level and management capabilities of the farmers, availability of capital and modern technology, infrastructure, systems of land tenure, the political situation (regulation of production of certain commodities, enforced socialism, terrorist activities, border disputes, etc., etc.), the availability of adequate research and extension facilities and well-trained staff to man them, distance from suitable markets, etc. (Laker, 1976).

AGRICULTURAL POTENTIAL

The agricultural potential of land can be expressed in "agricultural" terms (e.g. tons per hectare per annum, with a proviso for quality when quality is of major importance) or in monetary terms (Macvicar, 1974). The latter, which is highly variable over relatively short periods of time, is derived *inter alia* from the former. For a simple farming enterprise, e.g. maize for grain, the yield component of potential can be expressed simply in terms of kg/ha/annum, or some other relevant quantity. For more complex agricultural enterprises, such as milk production, the expression of potential is more complicated. When the "agricultural" potential of a particular area of land is discussed, both the agricultural enterprise and the production techniques must be specified. Otherwise it is of no significance to indicate potential (Hensley, 1976). In many instances it is not even sufficient to specify the kind of crop (e.g. wheat); the specific cultivar (variety) must be specified.

Expressing potential in level of production terms ("agricultural" terms) involves making a prediction about the future on the basis of what has happened in the past (Macvicar, 1974). Macvicar (1974) also indicates that simple agricultural potentials can be expressed at five different broad levels, viz., maximum potential, exploratory potential, experimental potential, best farmer potential, and specific farmer potential. He concludes that "best farmer potential and the management needed to achieve it are suitable universal standards for being stored in a data bank in terms of the kind of land."

Specific Farmer Potential

According to Macvicar (1974) specific farmer potential is the agricultural adviser's "estimate of what the farmer he is advising can achieve. The estimate is made by beginning with best farmer potential and making an adjustment according to the agricultural adviser's evaluation of what is likely to be achieved by the specific farmer in the immediate future."

Best Farmer Potential

In order to make a realistic estimation of what can possibly be achieved by a specific farmer in the near future the planner or adviser needs to have a realistic "best farmer potential" to use as a guideline. It is highly doubtful whether best European

or American farmer potentials can be used as criteria in less developed countries where the traditional farmers at present do not have high levels of education or management capabilities. These "best farmer" criteria may, however, be used in special cases such as production projects into which special management is introduced or in areas where sophisticated farmers are found. An example of the latter is the group of so-called "commercial" farmers in Zambia, who farm on only two percent of the agricultural land of that country, but produce about fifty percent of the country's total volume of agricultural produce.

Economic Potential

If the nature of the land is constant and we consider best farmer potentials for it, then *economic potential* will vary with *inter alia* time (i.e., in accordance with changes in price structures), position (distance from factories and markets), and size (of field or farm). This potential is normally subject to large short-term fluctuations and is not a suitable universal standard (Macvicar, 1974). On the other hand it should form the direct basis for short-term planning, such as decisions about type of crop, fertilizer rates, etc. It usually becomes more critical in sophisticated farming systems than in non-sophisticated farming systems.

Potentials in Long-Term Planning

The first step in defining potentials and their required management is to define the quality of the land. For this purpose the physical components of each area of land, viz., climate, soil, slope, hydrology, and, where necessary, vegetation, must be described as accurately as is practically possible. The different characteristics of the area of land are then judged according to the present knowledge about the relationships between them and production potential. A realistic best farmer potential is then allocated to the area of land to serve as a basis for comparison.

Thus far the discussion has dealt mainly with direct, relatively short-term decisions and planning. In many less developed countries, regional planning programmes are presently compiled in which the emphasis should be more on medium- and long-term planning. One of the major concerns in such planning should be to identify potentially good agricultural land and to preserve this for agriculture even if there is no intention or possibility of developing it for agriculture soon. The problem is that once a township or industrial area is developed on a tract of land, then that land is permanently lost for agriculture. In these decisions very high level farmer potentials should be used to describe the agricultural potential of the land. Physically high potential land should in these cases not be rated down because the present low management capability of the farmers is the limiting factor. Whenever the management capabilities of the farmers are increased to such a level that they can utilize

this land, then the land must still be available for agriculture (especially for food production), even though it may take several decades to reach the required management level.

The above can be illustrated with the following example, stated by Moormann (1977): "Major alluvial areas largely composed of potential category I land for rice, like the middle and upper parts of the Niger Delta in Nigeria, remain largely unused because of a lack of an adequate rice-growing technology." These areas should be identified, demarcated clearly, and preserved for rice production until the necessary technology is introduced into the areas to make their development possible.

To summarize, it can be stated that to make quantitative, semi-quantitative, or even qualitative judgments or determinations about the agricultural potential of any area a good knowledge of at least the following is necessary:

1. the environmental or ecological characteristics (soils, climate, etc.) of each homogeneous area,
2. the specific type of crop (its characteristics, requirements, etc., and,
3. the prevailing socio-economic situation. (See also Kellogg, 1961).

SOIL QUALITY IN RELATION TO LAND CAPABILITY AND AGRICULTURAL POTENTIAL

From the discussion in the preceding section it is evident that soil forms just one component of a complex set of factors which determine the production potential of, and actual production on, any specific tract of land. On the other hand it is a very important factor in the determination of the agricultural potential of land. In the following subsections a few very simple relationships between soil quality (Kellogg, 1961), or soil potential, and other individual factors determining agricultural potential or actual agricultural production will be considered.[3]

Management Capability and Technology

Cunningham (1976) indicated that in Pennsylvania little agreement was found "between what we consider the best soils and the highest yields." They are of the opinion that management is the factor responsible for this situation. The implication of this statement is that management level and technology is more important than soil quality.

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[3]In the present paper the relationship with only one factor, i.e., management capability/technology is presented.

Young (1976) states: "In particular, in the normal farming situation in less developed countries, differences in standards of farm management have greater effects on yields than differences between soil types." In the case of the Niger Delta in Nigeria cited by Moormann (1977), lack of adequate management and technology is definitely the factor determining the potential use of the land at present. The huge difference in production levels between the commercial farmers and traditional farmers in Zambia (preceding section) is also an effect of difference in management capability and technology and not a soil difference.

Oschwald (1966) also expressed the opinion that: "In an industrial economy, such as the United States, inputs, such as commercial fertilizers, herbicides, large-capacity machinery, and others, may have greater influence on the crop production potential of a soil than do qualities such as natural soil fertility."

The above statements are basically correct and true. They are one-sided, however, and do not give a complete, balanced reflection of the actual situation. Oschwald (1966), for instance, qualifies himself immediately by stating: "In appraising the productive capacity of the soils of an area, one needs to know the kinds and distributions of the soils, their input requirements, and expected responses to the input applications... The prediction of input needs and expected outputs requires knowledge of soil characteristics and the effects of the characteristics on response to applications of technology." Young (1976) also clearly recognizes the importance of the differences between soils.

Miller (1969) states: "Of course, fertilizer and other management practices may tend to reduce the yield differences between soils with high and low production capabilities. Yet, there are many farmers in Maryland who are striving for yields on soils incapable of consistently high production. These farmers are receiving little or no return on the additional management of the soils...The fact that some soils respond better to management...has been recognized for a long time by farmers..." The first sentence of this quotation actually contradicts the rest of the quotation. The latter part of the quotation clearly indicates that even the farmers realize that the differences between high potential and low potential soils are increased with increased management inputs. In other words, within a specific agro-climatic region and under a specific level of management, the inherent quality of the soil actually dictates responses and yields. (See also Table 39 in Vink, 1975.) In the first sentence Miller (1969) apparently actually means to state that differences in management level between the farmers in an area unfortunately tend to obscure this effect of inherent soil quality.

Soil Performance Related to Management

The interrelationships between soil and management at different management levels become extremely important when soils must be evaluated for specific land use purposes for the near future. This means that the criteria which are used to evaluate a soil for a specific purpose should be a function of the general management capability of the farmers of the area. It does not mean that different types of criteria should necessarily be used, but it means that the importance of different criteria must be weighted differently. For crop production in a situation of low management abilities and/or a low level of available technology, inherent soil fertility is, for example, usually found to be much more important than where moderate to high levels of management and/or technology are available (where soil fertility = availability of essential plant nutrients in the soil). The principles of some of these relationships between soil potential and management and/or technology can be illustrated by means of the six hypothetical response curves presented in Figure 1.

High potential soils. In Figure 1 soil 1 represents the "ideal" soil, which gives the best relative yields under any level of management and technological input. A deep, medium-textured soil in an intermediate stage of weathering on a fairly flat, fairly young river terrace (not the present alluvial terrace) would represent such a soil (accepted that climate is not a limiting factor). Such soils are very scarce and of extremely limited extent in the less developed countries, however. Such soils would have a relatively high fertility, favourable chemical characteristics (favourable pH, low P-fixing capacity, no toxic elements, etc.) as well as favourable physical conditions.

Soil 2 is a kind of soil that would normally be classified as a soil with a very high potential for the specific crop, but what is often not stated is that very high levels of management capabilities and recurrent technological inputs are required to convert this "potential" into a practical reality and that this soil actually has a low production potential under low or moderate levels of management and technology. A deep, medium- to fine-textured soil in a fairly advanced stage of weathering would be an example of such a soil. In this example the soil will have excellent physical conditions but severe fertility and other chemical problems (extremely low pH, Al toxicity, very high P-fixing capacity, Mo deficiencies, etc.).

It may not be far from the truth to state that the majority of the so-called "high potential arable soils" of tropical and sub-tropical areas have response curves similar to that of soil 2. In an area where the vast majority of the farmers have high management capabilities and adequate technological backing, i.e., class A or upper level class B farmers (Figure 1), a "high potential" rating would be meaningful for both long-term and short-

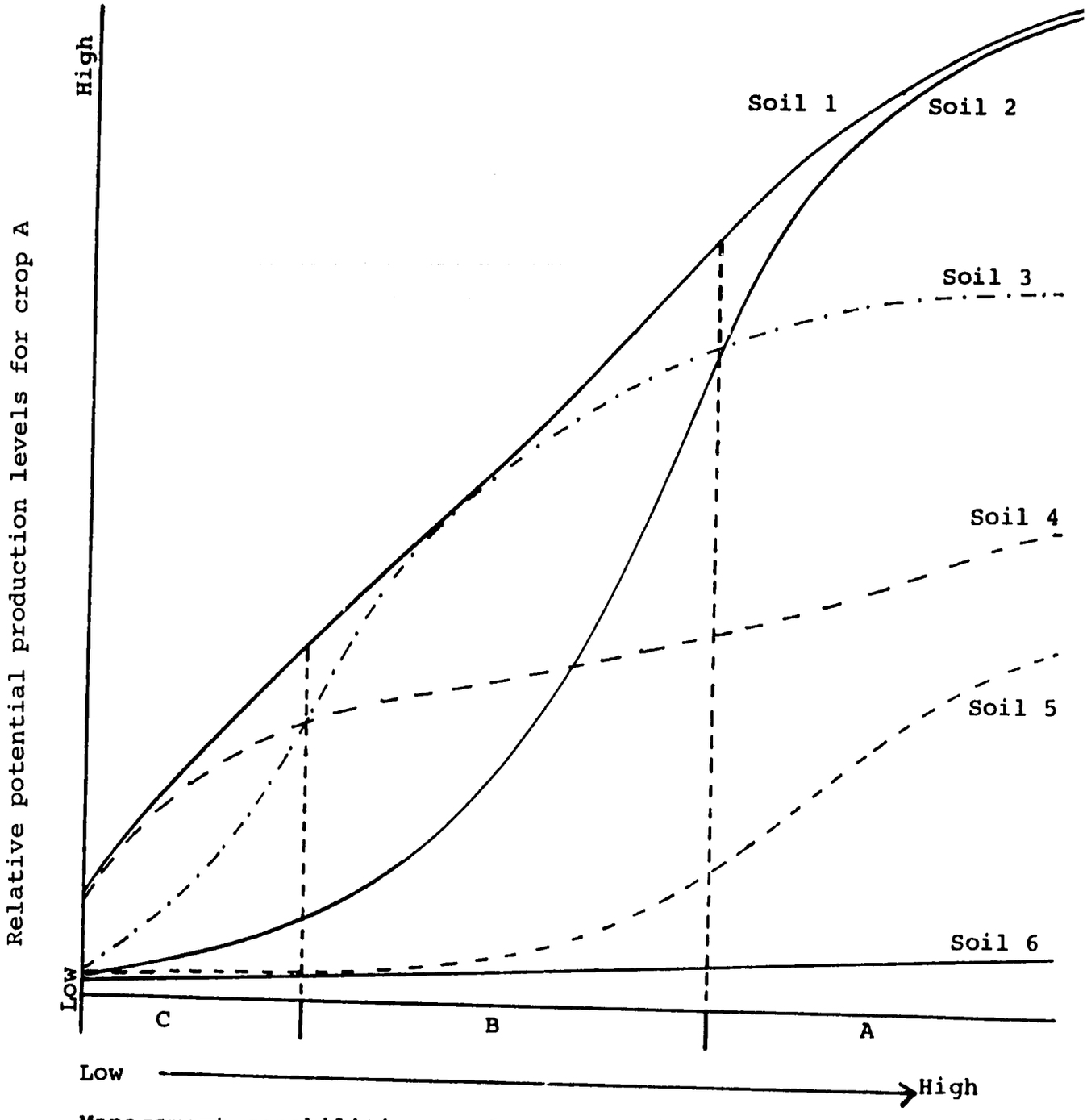

Figure 1. Hypothetical relationships between management/ technology and potential production levels of a crop, as related to kind of soil.

term planning. In areas where the majority of the farmers are no more than class C or lower level class B managers, a "high potential" rating will only have long-term significance, i.e., to indicate areas which should be reserved for agriculture with the hope that the farmers will at some stage in the future be able to manage it properly. Unfortunately most traditional small farmers in many less developed areas are no more than class C managers at present.

Medium potential soils. Soil 3 is representative of a kind of soil that gives very poor results under low management levels, reacts very favourably upon slight improvements in management and does not have the ability to give very high production under high levels of management. An example of such a soil would be one with low inherent fertility (e.g. severe P deficiency) but which reacts favourably upon fertilizer applications (e.g. has a low P-fixing capacity), and has some physical limitations (e.g. a bit too shallow or sandy). The latter would be causing the "ceiling" against further responses at high management levels. Normally such soils are rated as soils with "moderate" potential, because of their moderate production levels under high management levels. This type of soil (accepted that climate is not a limiting factor) should be an attractive proposition if it is found in a less developed country, because it means that production could be increased significantly by a modest increase in the management capabilities of the farmers (by education, motivation, etc.) and a relatively modest capital investment.

Soil 4 represents a soil that gives relatively good yields under low levels of management and input (i.e. relative to production levels on other soils at this level of management), but does not respond much under higher management inputs. This is usually a soil with a relatively high inherent fertility (the reason for the relatively good performance under poor management), but severe physical limitations (the reason for the relatively small response under improved management). These soils are usually classified as "marginal" or low potential soils for crop production. Traditional small farmers are often advised to stop cultivating these soils and to switch to soils with "higher" potential (such as soil 2 and soil 3). Their yields then actually decrease as long as they remain class C managers or cannot obtain the necessary technological aids (compare the curves in Figure 1).

Low potential soils. Soil 5 is an example of a soil that is normally regarded as having no potential for a specific type of farming enterprise, but which can respond to a specific type of high level management. A soil with good physical conditions in an area where rainfall is just too low to sustain crops under normal management practices would be an example. With top-class moisture conservation practices these soils can provide fair yields.

Soil 6 represents a soil that has no potential for the production of a specific crop as well as no potential to respond

to improved management. An extremely shallow Lithosol would be an example of such a soil.

It must be kept in mind that the above discussions are dealing with "potential" in an "agricultural production" sense only and do not include economic considerations.

Soil Response Related to Changes in Land Use

Another very important interrelationship between soil and management/technology is the nature of the response of different soils to changes in land use or changes in technology for the same land use (Young, 1976; Ponnamperuma, 1976). Predictions about these aspects are of utmost importance in development planning. Unfortunately, this need is not yet widely recognized (Young, 1976). Two soils may, for example, both have a high infiltration capacity when an irrigation survey is made, due to the fact that a dense grass cover provides an excellent physical condition. Once the soils are brought under cultivation their organic matter levels drop and infiltration and permeability may decrease so sharply on one that it becomes a serious problem. On the other the effect may be less severe and less problematic.

Another example: in some areas farmers occasionally get fair crop yields by means of collection of water in "basins" whenever there is a flood. This is usually done on fertile soils and the results of these occasional basin "irrigations" look magnificent. This often induces planners to recommend the development of irrigation systems to provide intensive irrigation for these "marvelous" areas. The results are more often than not disastrous, because the soils are of relatively poor physical quality (low permeability, poorly drained, etc.) and not suited to intensive irrigation. In such a case "improved" technology actually decreases the potential of the soil.

Moormann (1977) also states: "Land deterioration by erosion in tropical areas is globally very severe and is frequently aggravated to a great extent by the introduction of "modern mechanized agriculture" modelled on that of the temperate moist climatic zones. In this way, much category II land and even more category III land in the tropics is rapidly losing most of its inherent qualities and is becoming unsuitable for the major current land utilization types."

Failure to recognize the differences in response to management between different soils leads to the situation which Moormann (1977) describes: "More numerous, unfortunately, are the cases where extremely expensive development projects failed because inherent limitations remained so severe that the sharply increased recurrent costs are not covered by the improved productivity of the land." He concludes that such failures are usually also simply attributed to deficiencies in the socio-economic situation, which would be a complete misinterpretation.

The spatial distribution of soils also determines the type of technology which can be applied (type of management system which can be used) and in this sense determines the potential of the soil for production under a specific management system. (See also Oschwald, 1966.) Vink (1975) states: "There is also a difference between comparable land used with or without extensive farm mechanization. Highly mechanized, industrial systems of agriculture need a land pattern with homogeneous surfaces to facilitate efficient land use, whereas in smaller, traditional types of land use this requirement is much less important." If the potential of a soil is rated purely in terms of performance under mechanized agriculture, then many areas with good potential for non-mechanized agriculture would (quite wrongly) be completely discredited.

Unfortunately, management level is too often equated to level of mechanization (number of machines and implements used, and lately the number of large implements used). Use of mechanization in areas not suited to it or use of large implements in areas better suited to small implements or using these as the sole basis for decision-making, would actually be expressions of bad management (i.e. wrong decision-making).

Much attention was given to this interrelationship between soil potential and management because it will be important in the discussions of the actual parameters for the assessment of the capabilities of different soils for specific land uses. As far as such assessments and estimates are concerned the following statements of Young (1976) are unfortunately far too often true: "There is a further class of information which might be obtained from soil survey but at present is rarely given, namely estimates of crop yields under specified management. Soil surveyors and agriculturalists are reluctant to make these owing to the many sources of uncertainty...If those technically qualified to provide realistic estimates of yields do not do so, then economists are forced to make rough approximations which will be soil non-specific." Kellogg (1961) also stressed that this is a responsibility which the soil scientist may never try to dodge. To do a good job the soil scientist must, however, have a good knowledge of crops, economy, sociology, etc. and he must solicit the assistance of experts in these fields in the decision-making process (Kellogg, 1961).

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SUMMARY OF DISCUSSIONS

Each session of the workshop consisted of a presentation period followed by lengthy group discussions. The participants each time divided into three groups, resulting in a total of more than 20 group discussions.

Represented here are a number of the most important points raised during these discussion groups. They do not represent decisions taken by the participants to the workshop, nor do they represent firm recommendations from the workshop. This summary is solely intended to stimulate future thoughts, discussions, and research. It must be clearly understood that individual participants to the workshop may personally disagree completely with some statements contained in this summary.

ORDERS OF SOIL SURVEYS

Possible Refinements

The U. S. D. A. orders of soil surveys are broad guidelines, not intended to provide criteria for the evaluation of soil surveys. Their purpose is to provide guidelines for the selection of soil maps to meet the needs of decision makers.

The main problem that needs refinement is that the different orders are not mutually exclusive.

Map Scales

The optimum scale of mapping is a function of the objectives of the soil survey. The intended use of the map will determine the amount of detail that is needed. In turn it is found that map scale primarily determines the amount of detail that is presented on a map. The objectives of the survey must be clearly defined before the survey is started. It is important that map users be consulted before a map scale is determined, to see what scale they would most prefer.

It is preferable to publish supporting maps, such as geological, vegetation, and climatological maps, at the same scale as the soil map, but this is not always practically possible.

Map scales having round figures such as 1:5,000, 1:10,000, 1:50,000, etc., are preferable to maps with odd scales such as 1:15,840, 1:63,360, etc., although it is recognized that these latter scales are derived from the English units "x inches to the mile."

No scales that are commonly used should be implemented to define class limits for orders of soil surveys. Dr. Cline's proposals in this regard are supported.

It is hazardous to enlarge maps, even if it is clearly stated that the map is enlarged and that this imposes certain limitations on the usefulness of the map. Maps can be generalized.

EVALUATION OF SOIL SURVEYS AND MAPS

The question is whether an attempt should be made to evaluate existing soil maps or whether guidelines should rather be developed to improve future soil surveys. The general feeling seemed to be that both may be needed but the vast majority seemed to believe that the latter, i.e. development of guidelines to improve future soil surveys, could be more useful and will be much more worthwhile to pursue.

Classification System

A classification system is needed so that the users of a soil map can classify and evaluate the map (and survey). The classification system should serve as a vehicle to facilitate communication between the users and makers of soil maps.

The first step must be to determine what the useful characteristics of a soil survey and map are and from these a classification system for soil maps can then be developed.

A soil map can only be evaluated if one has some specific purpose or use in mind. According to the requirements for this purpose it can then be determined how useful the map is for that specific type of decision-making. The question remains whether uses can be categorized into certain groups so that these groups can be used in map evaluation (vide Dr. Cline's paper).

Determination of Reliability

It is doubtful whether the reliability of a soil survey can be determined from the published map and report because the main questions at stake here are:

a. Are the lines on the map in the correct place?

b. Did the surveyors correctly describe what is inside each delineation?

The problem in judging reliability is that there is usually no indication where observations were made and what was seen.

Some rules of thumb which may assist in evaluating the reliability of a map are:

a. Study the relationships between topography and kind of soil area. In general there are relationships which fit pedological logic.

b. If highly contrasting soils are indicated side by side it may indicate areas which should be checked.

c. Maps on which the delineations vary from very large to very small are suspect.

d. Knowledge of the man who did the study, his proven reliability and experience, etc., may be a great help.

For final evaluation of reliability some ground control will be needed.

Map Legibility

The following aspects of map legibility should receive attention:

a. Use and choice of colors affect legibility;

b. Associated "stripes" reduce legibility;

c. Excess information reduces legibility; and

d. Symbols on delineations improve legibility.

Map Legends

The legend of a map should also be evaluated. A legend should be designed in such a way that a symbol on the map could easily be related to the legend or a symbol on the legend could easily be related to the map. The legend must be simple, but clear, and must enable the reader to understand the map easily. The legend determines the "efficiency" of a map to a large extent.

General Remarks

The minimum planning area seems to be related to the average-size delineation. Another concept of the minimum planning area is that it is the smallest area for which one can change management practices.

A soil map must be self-explanatory. Too much or too little information on a soil map are both bad. Too much information is hard to use; too little information is inefficient. The ease with which a layman can read a map is one aspect of quality. The artistic appeal of soil maps has also been used to judge maps. A group could be used as "guinea pigs" to evaluate maps, e.g. as done by a consumer association.

The general experience is that most of the base maps available in less developed countries are of poor quality and this must be taken into consideration before a map is criticized too harshly. Some of the new base materials are much better.

The effectiveness of a soil survey should be evaluated by measuring how much the total variability has been accounted for by mapping.

The "Cornell procedure" might have tremendous value for evaluating commercial maps.

Evaluation should be done by a team of experts who choose different properties important for different uses.

SOIL SURVEY METHODOLOGY

Establishing Purposes

Purely "utilitarian" surveys should not be made. To make any kind of soils interpretation the soil should be described, even if only a few soil properties are actually described and recorded. There is no substitute for a good soil survey. A soil map should be a *de facto* presentation of the data in each parcel on the map. Soil classification is just a device to organize information.

When a contract is made for a soil survey it is necessary that it be very specific and that there are clear cut objectives on what needs to be done. This will avoid many problems. Many LDCs do not know what they need or what they can expect from a specific type of survey; they must be advised in detail.

A dialogue should be established and maintained between the soil surveyor and the user of the map.

If a multi-purpose map can be made at little extra cost it would be better than to make one just for the immediate purpose.

A country may already have surveys which were done. An approach should be worked out how to evaluate these and to use the results of this evaluation for planning future surveys.

Survey Procedure

It is good policy to survey various parts of an area at different intensities if the patterns or general usefulness of the soils vary a great deal. These should be done on base maps of different scales and the areas should be clearly indicated on the final map. The legends of the parts of the map are usually combined.

The ratio between field map scale and published map scale is a function of the scale of the published map and the complexity of the area. Detailed maps of cropland (>1:20,000) have frequently the same scale as a field map. Small scale maps are frequently based on field maps of larger scale.

A grid system of surveying has a tendency to make a person slave to statistics. In some cases a grid system can be used beneficially, however.

Sometimes it is important to indicate small areas, especially small alluvial areas along streams. These areas are often exaggerated on a map in order to be able to indicate them.

In broad-scale surveys taxa are usually named at higher categorical levels. Any time a taxon is named at such a level it is, however, not implied that the soils in the specific case cover the whole range of permissible limits for that taxon.

Every soils report should have a section which indicates how the survey was made. Many state maps in the U. S. do not provide this information.

Mapping Units

It is not possible to determine the number of mapping units or the size of delineations at the beginning of a survey because this will depend on the pattern of the soil landscape.

Map unit components: phases which indicate key factors such as slope, depth, wetness, salinity, etc., should be indicated at all scales. The classes in *Soil Taxonomy* give some useful information, but most of them do not reflect important key factors for crop production. Soil taxonomy plus additional information is needed.

The kinds of mapping units should be specified, giving very clear indications of what is really in each mapping unit. Some statement about the purity of the mapping units should be made in a soils report. Too little quantitative information in this regard is normally given at present.

Preferably a unit must represent at least 80 percent of what it is supposed to represent. More components must be mentioned until this level is attained. This should be integrated with map scale. Descriptions of mapping units would be different at one scale than at another.

The opinion was also expressed that slightly more than 50 percent accuracy may be more realistic for small-scale maps and that 80 percent accuracy would require unnecessarily expensive operations for maps at these scales.

In some cases the soils within a map unit component vary within narrower limits than those permitted for the specific taxonomic class. It is important to indicate that the soils vary within such narrow limits. This would make the map more useful.

In a very homogeneous area boredom may lead to the mapping of units that are too narrowly defined. This is really a waste of time and money if the intended purpose of the map does not require such narrow definitions.

Purity of mapping units should be related to limitations of use and management. It must be considered whether a concept of purity for interpretation should be developed.

The homogeneity of the soils in a mapping unit is very important in regard to land use and therefore soils having contrasting properties must be clearly delineated, mapping units containing different soils must be clearly defined, and estimates of the percentages of different soils must be given. A medium potential homogeneous soil may be more useful than a high potential soil with a large number of severely limiting inclusions. If the inclusions have higher potential (for the use in question) than the dominant soil, then they pose no problem but may make a piece of land more useful than initially expected.

The relationships between soils and geomorphology and the geographical relationships between soils are very important. Statements or diagrams of toposequences in mapping units may be of great value. This is especially true in regard to soil conservation, because management practices in one position in the landscape may affect soils in other positions. Too much emphasis must not be placed on geomorphology alone, however. Many present land systems maps contain insufficient pedological information.

Density of Observations

Density of observations is important. Some schools require one observation per each 0.25 cm^2 on the published map. This is equivalent to one observation per "basic mapping unit" as defined by Vink. This defines the so-called "pedological" scale. Some members were of the opinion that this requirement is too high, especially for less developed countries.

The number of field observations can be reduced by introduction of the so-called "K-factor." The K-factor indicates how much the number of field observations can be reduced without losing accuracy. The K-factor depends upon:

a. Help from other sources, such as aerial photographs;

b. The experience of the field worker; and

c. The homogeneity of the area.

These must be taken into account when this aspect is evaluated.

Landform Classification

Complex map units such as catenas or landforms or soil landscape models may be valuable. Land systems maps are especially valuable for small scale surveys.

It is difficult to arrive at a consensus of opinion on an international basis for the classification of landforms. There is a great need for such a classification in order to improve the utility of land systems or soil landscape surveys. Some group should make a study of landform classification. (The Canadians will be publishing a system for landform classification soon.)

Remote Sensing

Aircraft and satellite remote sensing is a powerful tool in landform classification and soil survey. The applicability of satellite (ERTS, Landsat) remote sensing is largely restricted to classification and mapping at higher categories. Landsat imagery is available for nearly all parts of the world.

Enhancing satellite imagery is often useful for separating soil units, but automatic classification techniques, if based only on spectral reflectances, are of limited value for soil investigations. Enhancing of satellite imagery without ground truth control can lead to misinterpretation, however.

People from LDCs should be trained to use and interpret remote sensing data.

It would be useful to prepare a handbook on the most effective strategies and methods for applying aircraft and satellite remote sensing in soil survey. Conferences allowing various researchers to exchange views would be necessary before criteria could be set, however.

Map Quality

The necessary checks on quality should be built into the survey procedure.

It is very important that soil maps in new areas must be of high quality and utility. Otherwise it may put off the decision maker from using soil surveys at all. The planner might decide that there may be no need for future surveys.

Costs of Soil Survey

The cost of soil surveys in relation to development and other costs is important. There is an exponential relationship between map scale and cost.

A phased survey procedure is proposed for undeveloped and unknown areas to cut down on survey costs. Small-scale surveys should be done first and progressively larger scale (more detailed) surveys done only in relatively small areas selected from the smaller scale maps.

The scale and level of det il of a soil survey should be such that the cost of the surve, is not more than 10 percent of the development cost of the project. In most cases a realistic survey costs only about 2 percent of the development cost of a project.

SOIL PROPERTIES IMPORTANT FOR GIVEN LAND USES

Land Classification

A soil map is just one tool that is used in land use planning. Soil scientists must strive to improve the quality and efficiency of soil surveys as an input into the planning system.

If the predictions that must be made are soil-related, then the classification system which is used should take into account the relevant soil properties which are important. The purpose of a survey and the level of examination should, therefore, be specified ahead of time.

A taxonomy for a technical classification of soil properties important for use is needed. A classification system should not have rigid limits on the properties for a specific class. There should rather be a range of limits for any property.

A distinction must be made between general purpose land classification and special purpose land classification.

The reason why many interpretations could be done with a high degree of confidence from one soil map in the past is because so much spread is allowed within ratings. Soils are usually just vaguely rated as good, moderate or poor for a specific use (or for a general group of uses).

Old soil maps are often used too blindly by soil scientists to make re-interpretations. Soil scientists should be involved in the making of new interpretations.

Soil Potential

The U. S. Department of Agriculture concept of potential is as follows:

Soil potential = Performance - Cost.

The actual potential of an area of land is as important as the input necessary to attain this potential.

Technically quantified land potentials are needed in order to enable agricultural economists to consider reasonable alternatives. The assumptions on which any such quantifications are based must be defined and indicated very clearly and precisely.

Production potentials can be predicted from recorded soil properties if you know their relationship to performance or they can be predicted on a basis of overall similarities to other soils.

Techniques used by highly capable farmers in temperate climate regions cannot simply be translocated to less developed areas in the tropics. Apart from differences in soils and climate, a lack of knowledge of modern farming techniques and a lack of money are prohibitive factors.

It is important to consider the capability of the farmers when predictions about potential are made. For comparison purposes the best ordinary farmers of a country and an ordinary input of work must be considered. Sometimes more than one level must be considered. In Mexico separate soil potential ratings were made for subsistence farmers and for commercial farmers. Sometimes the capabilities of the present population cannot be used in soil potential ratings, as in the case of the nomads in the Sudan, who are just not interested in farming. In most cases economic factors are not taken into consideration for primary comparative purposes of potential. These factors must be included before the final decisions about development projects can be made.

A soil suitability map is a map depicting the combination of inherent soil quality, climate, management, etc. Soil potential seems to be more than just land capability in the traditional SCS sense.

Perhaps the best approach to the evaluation of soil properties is to consider them in terms of capabilities or constraints for a particular use. This is related to the concept of soil potential, but really is rather a concept of land use.

Soil Limitations

Relative cost ratings (which do not include definite monetary terms such as amount of dollars or pounds) indicating inputs needed to overcome the limitations of different soils, should be useful.

It will also be important to make recommendations on how some soil limitations can be diminished or corrected. In this regard it was agreed that much attention must be given to the study of marginal soils. When overcoming limitations on marginal soils are considered, then the factors of risk and uncertainty must receive much attention because this can place a great burden on the small farmer. Again, this is likely to be

of greatest importance to less developed countries with high population densities, where people have to try to live off marginal soils, and where the consequences of crop failures can be more devastating than in developed countries.

Crop Requirements

There is not really enough specific knowledge on what the soil requirements of many crops are. There are even differences between different varieties of the same crop. There is still a lot of work needed in this connection. In this regard it is important to keep in mind that landowners are more interested to know what they can grow than in what they cannot grow. This is especially true of tropical soils, in less developed countries.

Of special importance are the interrelationships between soil, landscape, and climate. For example, if the climate is unfavorable for a specific crop, then it would be a waste of time to do grading of soils for that crop. The way in which the soils in a landscape react to each other is important.

In most areas good knowledge is available on what can grow where. In most less developed countries present land use is not a good enough indication of potential land use because the people are tending to grow just subsistence crops which they can eat. It may be a good policy to start by rating the soils of an area in terms of the crops which are presently being grown there.

When soil properties are considered and rated, then a distinction must be made between what is needed to make a plant grow well and what is needed to facilitate certain farming operations (e.g. the use of machines). Almost all types of operations can be done equally well by hand as by machines. It is just a matter of scale and availability of labor. Some areas can actually be worked better by hand than with machines.

Analog Models

As far as analog models are concerned the critical issue is that a lot of inputs are needed to have an effective model. Some models should be devised and recommended from current studies occuring in developing countries. A production model is needed for each soil map unit.

SOIL DATA PRESENTATION

Planners and soil scientists are poles apart in LDCs and there is generally little communication between them. Planners need information that they can use and do not want the high-powered academic stuff. If a soil surveyor cannot communicate his information, he has failed and the soil survey might just as well not have been done. The quality of a map is also a function of the language used in the report - language which the planner can understand.

More than one kind of soil report is needed - a pedological report and simplified or interpretive reports for planners. These could form different sections of one report. Derivative maps should also be made for use by planners.

The legend should be well designed. If there is no clear cut objective, then the legend is pedological. The ideal is when the legend reflects both pedological considerations and the objectives of the survey. Legends should stress the soil properties important to most users.

Users of soil maps want to know where they can find soils of a certain kind or quality on the map, going from the legend to the map. For this purpose color is needed on the map. When there are too many mapping units these may be grouped into larger units which are then colored while the detailed map is still presented underneath the colored overlay. Cost of publication is often a factor which limits the actual quality of the published map.

The ranges of characteristics of map unit components should be indicated and modal profile descriptions should be given for all dominant soils. The number of permissible limiting inclusions should be specified.

Analysis of samples and the final cartographic work are the two main bottlenecks (timewise) of soil surveys.

Soil maps should be prepared in such a way that they do not become outdated. Only the interpretations could become outdated.

THE ROLE OF SOIL SURVEYS IN THE DECISION-MAKING PROCESS

There should be more interaction between pedologists and planners. Pedologists are getting closer to making more quantitative recommendations on which decision-making can be based. There should be more feed-back from planners to pedologists to indicate how useful a certain map or information was to the planner.

It should be useful to have a center for soil resource inventories. Aid agencies should seriously consider the establishment of a center for the storage and retrieval of SRI information. FAO is organizing a meeting in Rome to consider some of this.

CLOSING ADDRESS

A. Van Wambeke[1]

We have now arrived at the last session; I was told that I had used up the number of people I could normally invite to help to get smoothly through the different sessions of this workshop, without doing too much myself.

It is my pleasure to thank all of you for your assistance. I now have precise instructions as to how to carry out the Soil Resource Inventory study.

Everyone seems to have a place in the complex way of making soil surveys more efficient. And the important thing is that everyone really wants to do that, although he may have some different opinions as to how to achieve this purpose.

As a good soil surveyor, (and I am glad that no one wanted to write a definition of such an individual), I accept all of your recommendations and will try to adapt and apply them to local, specific, regional conditions. This is not an excuse which I am looking for to go my own way. Just as in 1950 we needed a *Soil Survey Manual*, I am convinced that we now need a *Soil Survey Methodology Handbook*.

I think we will try to develop a classification of soil surveys, and the narrative description proposed by Marlin Cline may be the best way to arrive at such an objective. I want the system to provide mutually exclusive classes defined by properties which can be recognized by non-soil scientists, independent of soil classification systems. We should accept that many countries use methods, names, and criteria which vary markedly from one region to another.

We will have to measure soil survey inventories with respect to sets of properties, i.e. number of delineations, map scale, type of base map, proportion of total soil variability accounted for in the map, soil contrast, information content of mapping units. All these attributes in fact tell us how complete an image the survey made of the actual soil pattern in the field.

This is obviously not enough.

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At an early stage we will have to include ground-truth as a key property, and develop methods of checking reliability of soil maps.

Once the problems of completeness and reliability are solved, we may enter, I think, the utility aspect. Effectiveness and usefulness are both purpose-dependent. I think that if we want to do a good job, we will need to reduce the purposes to a reasonable number.

Utility will depend on the degree to which survey characteristics match purpose characteristics, in aspects of geographic extent (size of planning area versus the size of map delineation), and classification content (plant requirements and soil limiting factors). The effectiveness will be increased by the number of purposes that are served and the prospective time they will be served by the survey. Finally, the extent of similar soils in the world may tremendously expand the technology transfer component.

The last point is certainly not the least important. It brings us to the problem of reaching as many people as we can with our "inventory" package. We will have to multiply our utility index by a "delivery factor." The latter has very often been close to zero.

This is a brief summary of our workshop; it outlines the pathway for the first preliminary steps. The final objective is to devise alternative methods of how to make soil surveys, develop strategies, and make cost analyses for different conditions. This would be the topic of another workshop, once we get through the task you have so well defined for us.

I should not close this session without expressing my thanks to the participants. In the name of the Agronomy Department I thank the sponsoring agency; I also thank the soil scientists who came from France, The Netherlands, the United Kingdom, and Canada to join us here.

I thank the members of the Consortium on Soils of the Tropics who could attend, the members of the U.S.D.A. Soil Conservation Service, and the members of other departments of Cornell University.

I express my gratitude to Dr. R. Arnold who was the first to point out the problem of soil survey evaluation, and convinced the sponsoring agency about the need of this study. Without his drive, we would not have had this opportunity to discuss these problems.

I should also mention Marlin Cline. He helped tremendously in writing down his ideas about soil survey evaluation; he contributed considerably in organizing the thinking of the Cornell group. We all regret that he could not attend.

And finally, let me mention the complete team who worked in the organization of this workshop. I never had such a nice team and spontaneous cooperation. An applause will express our thanks.

SOIL RESOURCE INVENTORY WORKSHOP

Cornell University
4-6 April 1977

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