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SOIL-RESOURCE DATA FOR AGRICULTURAL DEVELOPMENT

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Preface

Central planning and the issuance of regular multiyear plans are normal procedures for most tropical countries Much of the planning deals with agriculture because in these countries about 65 percent of the people are directly involved with agricultural production A need to know about soils is usually assumed in preparing the plans, but soils information is seldom used effectively

There are several reasons Often the necessary data do not exist When they do, their value becomes greatly diluted by the time they are incorporated into the planning process The farmers who know the most are not consulted Soil scientists who know a lot present the information qualitatively and in a jargon all their own Planners far removed from the soils and under pressures of time quietly ignore the qualitative data phrased in language they do not understand or use their own best judgment about what the scientists mean

This book is an attempt to change this course It provides a state-of-the-art compilation of the classification, collection, interpretation, and presentation of soil-resource data for land-use planning in tropical agriculture, and it gives some illustrative examples of effective use of soils data for agricultural development mainly in the tropics It presents some recommendations for changes in current methods of obtaining and presenting soils data made by a joint seminar of natural resource planners and soil scientists from 19 tropical and 9 temperate countries

The seminar entitled "The Uses of Soil Survey and Classification in Planning and Implementing Agricultural Development" was held at Hyderabad, India from 18 to 23 January 1976 It was jointly sponsored by the University of Hawaii, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the U S Universities' Consortium on Tropical Soils and was largely financed by the U S Agency for International Development It was attended by senior natural resource planners and soil scientists from Australia, Bangladesh, the Central African Empire, Ethiopia, France, Ghana, India Indonesia Iran, Italy, the Ivory Coast Kenya Malawi, Malaysia, Nepal the Netherlands New Zealand, Nigeria, the Philippines, Rwanda South Korea, Sri Lanka, Sudan Tanzania, Thailand, the United Kingdom, the United States, Western Samoa, and Zaire

The papers in this book were presented at the seminar, but they have been rearranged, revised, and edited for more effective presentation in written form

Part I deals with the classification and collection of soil surveys W M Johnson describes the philosophical background to the systematic collection of soil-resource data, how soil surveys of different scales are designed to serve different purposes, and how and why the data collected need to be classified systematically His paper and the two subsequent papers by F H Beinroth and H Ikawa outline technical details of *Soil Taxonomy*, a system of soil classification recently published by the U S Department of Agriculture This system, which was developed over 25 years by the U S Soil Conservation

Service and which has many collaborators in other lands, is the most precise and comprehensive classification of soils yet devised The fifth level in the Taxonomy, the soil family, is designed to group the soils that have similar responses to management and manipulation for use The three papers pertaining to Soil Taxonomy provide a technical introduction to subsequent papers in the book, many of which use Soil Taxonomy and its terminology to relate soil-resource data to soil uses in agriculture In the last paper in Part I, M Vakilian describes the soil- and land-appraisal programs of Iran

Part II deals with soil-survey interpretation The first paper by H Y Chan gives quantitative and practical examples of the interpretations of surveyed and classified soils for a specific agricultural crop, in this case, rubber The second paper by Y H Shin describes how soil-survey interpretation was used to determine which lands should be selected for the production of a new high-yielding crop, in this case, rice These two papers are impressive examples of the value of soil-survey interpretations in agriculture and of how to combine agronomic experimentation with soil-survey data to achieve sound and practical predictions about crop yield

The third paper by Y P Bali and R L Karale describes procedures for developing qualitative ratings of soils for irrigated rice production, it provides a theoretical example of how these ratings could be used to determine the comparative advantages of two development areas The final paper in Part II by A J Smyth explains the relationship between soil-survey interpretation and land evaluation and describes the strength and the all-too-apparent weaknesses of many current forms of soil-survey interpretation In anticipation of the conclusions of the seminar, he states that there is a "growing conviction that interpretations must be specific as to purpose and to site if they are to provide the needed basis for immediate development"

Part III contains four papers about the use of soil-resource data in land-use planning G A Nielsen describes many effective techniques, most of them simple and inexpensive, for displaying soils data R S Murthy, H S Shankaranarayana, and L R Hirekerur give case studies, from two different regions of India, about the use of soils data to maximize land use for agricultural purposes J Bennema provides theoretical and procedural frameworks for combining physical and socioeconomic data into decision-making packages for land-use planning Bennema emphasizes, as Shankaranarayana's and Hirekerur's study demonstrates, that the same area of land may need to be evaluated at different scales for different purposes

Part IV contains several case studies of the use of soil-resource data for agricultural development H B Obeng illustrates how the same soils data is used to serve several national development goals in Ghana, C R Panabokke describes how a combination of soil investigation and agricultural research is being used to transform a virtually uninhabited region of problem soils in Sri Lanka into a major development area M L Dewan examines the successes and failures of four case studies from FAO programs to extract some principles for the future Among the contributors, he alone discusses the importance of legislation to the effective use of resource data in development In the final paper of Part IV, F R Moormann provides a conceptual model linking agricultural land utilization and land quality He maintains that land quality is changed by land improvement and by crop adaptation

Part V contains four papers dealing with agrotechnology transfer G B Baird calls for an agrotechnology transfer network focused on soils He proposes the establishment of a research and transfer network in tropical soils and illustrates how similar networks have been established for major agricultural commodities, having the International Agricultural Research Centers as their foci A W Moore, using experience gained in Australia, illustrates how the lack of a common methodology in gathering soils data and the lack of a common system of soil classification can effectively prevent the transfer of soil-management information G Uehara discusses in general and L D Swindale describes in specific how the soil family of the Soil Tax-

onomy can be used for agrotechnology transfer and as the basis for a research and technology network Both advocate classifying the soils of all agricultural research stations in the tropics at the family level

Part VI, in recognition of the host institution for the seminar, deals with soils and soil management in the semiarid tropics Two papers from ICRISAT, one by S M Virmani, S Singh, and B A Krantz and another by B A Krantz and J Kampen, discuss the type of soil information needed for successful agricultural development in this region Ch Krishnamoorthy describes how this information is being collected and applied in semiarid India Past approaches to soil and water management and conservation have not provided the basis for increased food production in the semiarid tropics, but the new technologies these authors describe appear to have the potential to succeed

The Appendixes contain the proceedings of the seminar the welcome, inaugural and keynote speeches, the program, a summary of the discussions and recommendations, the list of participants, and the organization of the seminar. The seminar agreed with the keynote speaker, W P. Panton, that soil surveys can be designed to produce the types of data that planners can best use, that is, single-factor interpretations of soil units, arranged either quantitatively in tables or spatially in maps Yield predictions at defined levels of management are the most useful forms of quantitative data Soil-data banks to store data in computer-retrievable form are seen as useful facilities because they can provide several alternative interpretations for the same soil units, and these alternatives can be displayed quantitatively or spatially It was agreed that the Soil Taxonomy provides a basis for agrotechnology transfer and for the effective communication of the results of site-specific research on soil and water management

The capacity and ability to collect soil-resource data for agricultural development now exist in tropical countries The papers in this book describe in principle and practice how these data can be and are being used.

L. D. SWINDALE

PART I: CLASSIFICATION AND COLLECTION OF SOIL-RESOURCE DATA

Soil Classification and the Design of Soil Surveys

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The origins and the philosophy behind the recently published *Soil Taxonomy* are traced This new system of classification has been designed with the particular requirements of soil survey and interpretations of soil survey in view It attempts to consider all the soil properties that affect soil use it considers soil genesis because surveyors make much use of the knowledge of soil genesis in mapping soils, it can be uniformly applied by soil scientists whatever their background and training it proceeds from the properties of the soils themselves, and it classifies all known kinds of soils The fifth level in the Taxonomy the soil family, is the level that groups soils with similar use potentials and thus relates directly to the interpretations of soil surveys

A scientifically sound and practical soil survey can be interpreted in many useful ways In the United States the useful life of a modern soil survey is considered to be 25 to 30 years Different intensities of soil use require different intensities of soil survey Broad-scale exploratory surveys can provide much of the earth-resource information needed for national and regional planning They have mapping units based on great groups or subgroups Intermediate-scale surveys are useful in semiarid grazing land They are based on subgroups or families Highly detailed surveys are used for specific agricultural and engineering applications They have mapping units of narrowly defined phases of soil series

All soil surveys, whatever the intensity, must be designed according to the purposes for which they are to be interpreted, and experts in those interpretations are required as part of the soil-survey planning team to ensure a sound product result

The trouble with soil classification is that no one knows much about it except pedologists Yet people who make plans and decisions about land-resource use ought to understand soil classification and how to use it The aim of this paper is to describe a modern soil classification scheme and to suggest how pedologists and resource-development planners should work together to communicate more effectively

Soil Classification in the Past

Men have probably recognized soil differences ever since they became conscious of any features of their surroundings and certainly since they began harvesting roots and searching for other natural foods They probably gave names to different kinds of soils as soon as they had a spoken language

The first soil classification reported in the literature is that of the Chinese engineer Yu about 4,000 years ago (Thorp, 1936) Yu grouped soils according to color and structure and made practical interpretations based on these criteria

In the latter part of the 12th century, a Moorish scholar, Yahya Ibn Muhammad, called Ibn al Awam, wrote *The Book of Ag-*

riculture, a compendium of knowledge about farming, engineering, plant growth, and livestock, derived partly from his own knowledge, observation, and experience and partly from the manuscripts of many other Moorish, Persian, Spanish, African, Roman, and Greek writers

It is a remarkable book that must have had a great influence on farming practices, for several centuries at least, in parts of the world where Arabic was spoken Until recently, *The Book of Agriculture* existed in the form of old manuscripts, in a Spanish translation (1802) and in a French translation (1864-1867) Now the book is being translated into English for the first time, and it should soon be available for purchase

Yahya Ibn Muhammad's discourse on soils emphasized practical matters, such as productivity of the principal food crops, suitability for growing specific grains, fruits, and vegetables, need for irrigation, and the like He also explained the formation of clay by weathering of rocks He called attention to the difficulty of growing crops on soils that crack when dry, and of the crop-growing soils, he awarded first place to the black, friable, porous soils Moreover, although he did not present an orderly scheme of soil classification, he wrote of soil color in relation to soil temperature and recognized the importance of differences in soil texture, soil moisture regimes, soil acidity, and salt content One of Yahya Ibn Muhammad's favorite sources, the Sheikh Abu Omar Ben Haggag, is quoted as writing, " the first step in agriculture is recognizing the soil and knowing how to differentiate between the good and the poor one" This principle, so simply stated about 1,500 years ago, is equally valid today

In the 18th and 19th centuries, geologists and geographers proposed classifications of soils based on the presumed rock source of soil material Among these, the classification of the German professor Fallou (1862) and those of the Americans, Shaler (1891) and Merrill (1906), are well known Although these attempts at soil classification missed the point that dynamic processes of soil genesis, controlled by climatic and biological forces, are more powerful in synthesizing soils than the hardness, mineralogy, and chemistry of the parent rocks, we see and hear even today references to "granitic soils," "shale soils," and "glacial soils"

The Start of Modern Soil Classification

Modern soil classification had its beginning in the latter half of the 19th century Separately, and at about the same time, V V Dokuchaiev (Glinka, 1927) in Russia and E W Hilgard (1906) in the United States expressed the concept that soils are independent natural bodies, each kind having a unique morphology resulting from a unique combination of the five soil-forming factors climate living organisms, relief, parent material, and age of land surface According to this concept, or model, the kind, thickness, and arrangement of horizons or soil layers in the profile are the result of interaction of the specific temperature, moisture, vegetation, animals, and microorganisms on the parent material of the soil over time in the particular body of soil This principle of soil genesis led to the concept of three-dimensional, identifiable bodies of soil at the earth's surface Because these kinds of soils could be defined and thus identified in the field, identification of their boundaries and their delineation on base maps became possible The basic model thus makes possible rational, comprehensive, and reliable soil classification Consistent and reliable soil classification, in turn, makes soil surveys possible, that is, it makes possible consistent mapping of soils and accurate interpretations of surveys for specific soil uses

The importance of this soil model to soil research and to the extension of knowledge about soil behavior can hardly be overemphasized, for without the powerful tools of modern soil classification and soil surveys, we should all be forced to depend on trial and error in selecting soils for new developments and in programming soil treatment and management systems Cultivators would have to use empirical techniques for guiding

the use of improved crop varieties, application of fertilizers and lime, and irrigation and drainage measures Engineers and developers could only hope that new structures would be stable and function properly in new locations Resource planners could have little confidence that their plans would result in effective resource development and management

After Dokuchaiev, soil classification in Russia quite naturally tended to emphasize soil genesis In 1895, Sibirtsev (Afanasiev, 1927) proposed a system of three soil divisions, which he subdivided into eleven soil types Table 1 outlines the scheme

The Russian investigators around the turn of the 19th century focused their attention on broad, regional soil characteristics They did not concern themselves much with the local soil types that might be of more importance to soil interpretations for practical farming In time, of course, soil surveys and soil research in the Soviet Union as elsewhere, were directed more and more toward practical problems of soil management for crop production

Soil Classification and Soil Surveys in the United States

Systematic soil surveys began in the United States in 1899 The early soil classification used by the National Soil Survey was pragmatic and fragmentary, emphasizing soil texture and parent rock, along with groupings according to geographic-physiographic provinces

Since 1899, four systems of soil classification have been used in the United States The first, developed by Milton Whitney and his associates (Whitney 1909) early in the 20th century, had as the lowest unit in the system a narrowly defined group of soils called the *soil type* The collection of soil types developed from the same kind of geologic material was called the *soil series* Soil series, in turn, were grouped into *soil provinces*, which correspond closely to physiographic-stratigraphic provinces

The second classification system was developed by C F Marbut between the years 1922 and 1936, and the last version was published in the *Atlas of American Agriculture* (Marbut, 1935) Strongly influenced by the Dokuchaiev school, Marbut accepted the concept of the Russian soil type but called it the *great soil group* Although Marbut's was the first strong voice calling for classification of soils on the basis of their own properties rather than on the basis of soil-forming factors, his own scheme of soil classification was based in part on assumptions concerning soil genesis Moreover, although classification of United States soils at the series level was well along by 1935, many of the series

Table 1 Sibirtsev's soil classification (1895)

Division	Type
A Soils fully developed (zonal)	1 Laterite soils 2 Aeolian-loess soils 3 Desert-steppe soils 4 Chernozem soils 5 Gray-forest soils 6 Podzolized soddy soils 7 Tundra soils
B Intrazonal soils	8 Alkaline soils 9 Moor and bog soils
C Immature soils (azonal)	10 Coarse soils 11 Alluvial soils

could not be placed in Marbut's system because the scheme did not recognize immature soils, such as Rendzinas, organic soils, and hydromorphic soils

The classification system of Baldwin, Kellogg, and Thorp was published in the *Yearbook of Agriculture* in 1938 (Baldwin et al, 1938) Based mainly on Marbut's scheme, but more comprehensive and better documented, this classification had 6 categories The highest category, soil orders, comprised zonal, intrazonal, and azonal soils (like Sibirtsev's system) There were 10 suborders, described but mostly unnamed, and 37 great soil groups A family category was proposed between the great soil group and series, but neither the category nor any of the families themselves was defined By 1938, some 2,000 soil series and 6,000 soil types had been recognized in the United States

In 1946, as the Soil Survey Staff started to arrange soil series into families and great soil groups, serious problems arose Some series seemed not to fit in any of the existing great soil groups, whereas others could be placed equally well in two great soil groups But there were no guidelines for grouping series into families As a kind of stopgap strategy, in 1949 a somewhat revised classification was offered (Thorp and Smith, 1949) which defined three new great soil groups and which combined three others with existing great soil groups

Still it was apparent that the classification system was unequal to the task of reflecting the great advances in soil science that had been made during the preceding decade and a half Also, at this time, just after World War II, there was a growing demand for a comprehensive soil taxonomy that would help to evaluate the soils in developing countries, especially with regard to their potential for food production For these reasons and also because the old system had so many troublesome defects, a decision was made in 1951 to devise a new soil classification This was the beginning of the 20-year effort, carried through a series of "approximations," that led to *Soil Taxonomy* Besides the United States Soil Survey Staff, assistance came from cooperators in many institutions and in many countries Ideas were borrowed from other classifications, and each approximation was tested by trial placements of different kinds of soils around the world In 1960, the *7th Approximation* (USDA, 1960) was published and presented at the 7th International Congress of Soil Science in Madison to widen the scope of testing and criticism Then a supplement to the *7th Approximation* was prepared in 1964, and later, a second supplement The system was put into official use in the United States Soil Survey in 1965 By that time, some 8,000 soil series had been recognized, which had all been tentatively grouped into families It is essentially that system that has been published (USDA, 1975) It is being used daily in the United States Soil Survey and in soil survey organizations and institutes in many other countries of the world From its inception, *Soil Taxonomy* was designed to serve soil-survey needs

Philosophy of Classification

Cline (1949) emphasized three important principles of classification

1 Classification should deal with the knowledge existing at the time As knowledge changes, the classification must also change
2 Classification is a creation of man for a specific purpose, and the classification should be designed to serve that purpose
3 Classification consists of creating classes by grouping objects on the basis of their common properties

Soil classification is an essential operation of soil surveys Soil taxa are the conceptual building blocks for the mapping units that are delineated on soil maps (Johnson, 1963*a*) They enable pedologists to maintain consistency in soil surveys from place to place And, perhaps most important of all, soil taxa are the vehicles for transfer of technology from research stations and farms to new and untried areas of like soils In the United

States, the requirements of the Soil Survey have had a profound influence on the concept and design of *Soil Taxonomy* (Smith, 1965)

Soil-Survey Requirements in Soil Classification

Certain characteristics of a soil classification system are needed specifically to serve the objectives of soil surveys First the classification must consider all the soil properties that affect soil use It must also consider soil genesis, because the pedologist uses his knowledge of the genetic factors to make his maps and interpretations more accurate The classification should be usable and applicable uniformly by competent soil scientists working independently but having diverse kinds of education and experience This uniformity can be had only if the application is objective rather than subjective, that is, objective in the sense that classification proceeds from the properties of the soils themselves and not from the beliefs of the pedologist about soils in general

To be useful, the classification must embrace all the soils that are known In particular, it must include cultivated soils and other disturbed soils, as well as the virgin ones

The system should be multicategoric, with few taxa in the highest category and many in the lowest This permits the arrangement and comprehension of soil information by classes at different levels of generalization and provides an orderly scheme for remembering what is known about soils without an undue burden on human memory And it provides convenient bases for the design of mapping units for soil surveys and soil maps of different scales and different degrees of detail

Soil taxa are conceptual, they are not the real soils that are classified The taxonomy should provide a linkage, a concept for relating to the conceptual taxa the real soils being classified and the real soil bodies delineated on maps

The building blocks of soil taxonomic classes and soil-mapping units are called *pedons* Pedons are real, natural soil volumes just large enough to show all the soil layers present and their relationships (Johnson, 1963*b*)

Soil individuals, called *polypedons*, are the real objects that are classified (Johnson, 1963*b*) They are collections of contiguous pedons all of which have characteristics lying within the defined limits of a single soil series They are comparable to individual pine trees, individual fish, and individual men

Finally, it is helpful if the nomenclature of the taxonomy is phonetic, distinctive, and easily remembered, with names that indicate something about the properties of the soils and their places in the system

Structure of Soil Taxonomy

Soil Taxonomy (USDA, 1975) satisfies to a great degree the requirements discussed above It has six categories and includes all the currently recognized soil series of the United States as well as soils in other parts of the world that have been sufficiently described and characterized The six categories are discussed briefly below

Orders

There are 10 soil orders, with different sets of diagnostic horizons representing differences both in kind and degree of horizon development

Entisols and Inceptisols show minimum degrees of development of horizons

Vertisols, Aridisols, Mollisols, Spodosols, Alfisols, Ultisols, and Histosols represent differences in the dominant kinds of genetic horizons

Oxisols represent a combination of both the kind and degree of weathering and soil formation

Halomorphic and hydromorphic soils are not classified in separate orders but are distributed according to other characteristics thought to be more important in a comprehensive scheme The hydromorphic soils can be drawn out of the various orders and grouped as aquic soils if one wants to discuss and interpret them separately

Suborders

There are 47 suborders, from a maximum of 7 in the Mollisols to only 2 in the Aridisols The differentiae vary, but most tend to emphasize similar moisture and temperature regimes, with closely associated natural vegetation Suborders are about comparable to the old Great Soil Groups in degree of abstraction

Great Groups

Some 227 great groups are defined in the system, of which about 185 are known to occur in the United States The major emphasis is on the kinds and arrangement of diagnostic horizons, except in Entisols, which have no distinctive horizons

An attempt was made to select soil characteristics to define groups that have had a different genesis from the others

Subgroups

There are more than 1,000 subgroups, about 970 of which are recognized in the United States Three kinds of subgroups are defined

There is a typical, central concept for each group This is the *typic* subgroup It is not the most extensive subgroup of all great groups

Intergrade subgroups are transitional to other orders, suborders, or great groups

Extragrade subgroups have properties that are not representative of the great group but that do not indicate transition to any other known kind of soil

Families

Some 4,500 soil families are currently recognized in the United States alone The intent here is to group the soils within each subgroup that have similar chemical and physical properties that affect their responses to management and manipulation for use It is expected that the responses of comparable phases of all the soils in a family are nearly enough the same to meet most of our needs for practical predictions of such responses Thus, the family occupies the critical position in the Taxonomy between the heterogeneity of the subgroup and the homogeneity of the series In many parts of the world, the family embraces the most narrowly defined classes in the Taxonomy

Families are defined by a number of properties, the most common of which are

1 particle-size distribution in the horizons of major biologic activity below plow depth (the "family control section"),
2 mineralogy of the same horizons that are considered in naming particle-size classes, and
3 soil temperature regime

Other characteristics, such as soil depth, content of polysulfides, and the like are applied if they are important in the particular subgroup Soil family properties are particularly significant to the movement and retention of water and to aeration and so affect the use of soils for growing plants and for engineering purposes

Series

About 10,500 soil series are now used in the United States In this, the lowest category in the system, the differentiae are mainly the same properties used to define classes in higher categories, but with much narrower ranges Soil series, like soil families, are used mainly for practical purposes, and the taxa in both of these categories are closely related to interpretive applications of the system

Soil series are conceptual The soil bodies delineated on detailed soil survey maps are real things, and in the United States we give them the name of the series that is areally predominant in their composition In countries where soil series are not uniformly defined, phases of soil families may be used to give names to soil-mapping units

Soil Classification and Design of Soil Surveys

Soil surveys are more than just maps with colored-block legends. Surveying of soils

entails the following studying and describing soils in the field, identifying soil taxonomic units and naming them, classifying kinds of soils into units that can be shown on soil maps, locating and plotting soil boundaries on base maps, studying the behavior of soils when used for crop production, forestry, grazing and a variety of non-farm uses, and synthesizing interpretations of the survey that predict the behavior of different kinds of soils used in different ways Soil surveys are expensive to make and to publish, and they must serve a useful purpose if they are to gain the support of taxpayers and governments Soil properties that are important for plant growth are the same properties that affect the behavior of soils for engineering and other non-farm uses A good soil survey, a scientifically sound and practical soil survey can be interpreted in many useful ways for a long time In the United States we estimate the useful life of a modern soil survey to be at least 25 to 30 years

Soil surveys of different scales and different degrees of detail are needed In Alaska a broad reconnaissance survey at a scale of 1 500,000 was recently completed This kind of generalized survey uses phases of associations of subgroups as building blocks for the mapping units It provides an overview of the important soil-resource regions of the entire state and identifies areas that have potential for different kinds of development farming, grazing forestry, and recreation (Kellogg, 1975) It does not provide enough detailed soil information for either feasibility studies or design and construction of development projects

After selecting an area for future farming development or other use, a more detailed soil survey is needed to guide and design the development In most rain-fed farming areas, a detailed survey having a scale of about 1 20,000, with mapping units designed with phases of soil series or soil families, provides the detail and refinement of soil information required to support precise interpretations for alternative cropping and soil-management systems

In the United States, we use five different intensities of soil surveys, depending on the nature of the soil landscapes and the different intensities of projected land use or different objectives of the survey

These different intensities of soil surveys require different sorts of mapping units to display spatial soil data in ways that are useful for different purposes The mapping units of broad-scale exploratory soil surveys generally are based on soil subgroups or even great groups Intermediate-scale surveys, such as those for semiarid grazing regions, commonly have mapping units based on phases of subgroups or families The mapping units of highly detailed surveys are usually refined, narrowly defined phases of soil series In countries where soils are not classified in series and in areas where the series classification is incomplete narrowly defined phases of soil families serve as convenient bases for soil-mapping units

Agencies of government all over the world are making more use of soil surveys for a variety of purposes generally grouped under the heading resource-use planning Planning agencies have learned that soil surveys of low intensity will provide a large part of the earth-resource information they require for making country-wide or region-wide allocations of resources for new development projects Then when areas proposed for irrigated farming development or for urban and recreation development have been delineated with the aid of the soil survey, more intensive surveys can provide the detailed information needed for design, construction, and management of the projects

Soil-survey interpretations, traditionally made principally for agricultural operations, now cover a wide spectrum of soil uses – solid- and liquid-waste recycling, highway construction, water supply, recreation, wildlife, urban and industrial structures, and many more specialized activities The same soil survey if correctly carried out according to scientific principles, guided by the practical objectives of the survey, can provide the base for all these sorts of interpretations, because the same soil properties determine the behavior of a soil used for a variety of different purposes The content of clay, silt, and sand, the shrinking and swelling beha-

vior, the permeability to water and air, and the depth to rock are examples of soil properties important to plant growth that are also important in the strong influence they have upon matters of non-farm uses Soil surveys carry this kind of information, we are required only to make the correct interpretations accurately For example, a claypan or other slowly permeable layer in a soil restricts the movement of air and water It has an adverse effect on root growth, and thus on the plant's ability to grow vigorously, to resist drought, and to yield a good harvest Such a layer also limits the soil's suitability for septic tanks and other on-site waste disposal, and it makes a poor subgrade for highways Similarly, a soil high in soluble salts is a poor medium for plant growth, and it also is corrosive to iron and steel structures, such as pipelines and fences, leading to high maintenance and repair costs High organic matter content is generally favorable to plant growth, but it detracts from a soil's usefulness for road construction Many other examples could be given If we learn how to make the correct interpretations of soil surveys, we can use them to guide site selection and to choose the practices for soil management and manipulation to achieve our resource-use objectives

Teamwork in Designing Soil Surveys

Soil surveys are made for a number of practical purposes Among the common objectives are rural land classification for rainfed and irrigated crop production, land appraisal, selection of new lands for settlement, land-use planning at local, regional, and country levels; assessment of potentialities for special crops, forest management, and designing and constructing airports, highways, urban and industrial structures, waste-disposal facilities, and recreational developments

An effective and useful soil survey is designed to meet the specific objective for which it is organized and funded The basis for design is the list of soil interpretations and their refinement or precision required to satisfy the survey objective In the jargon of modern managers, we list the survey-output needs, and, working backward, we select and define the inputs that will result in the output required

The pedologist is skilled in soil classification and in designing surveys for different purposes He cannot be knowledgeable in all the various uses of soils for which survey interpretations may be wanted Other specialists (engineers, sanitarians, resource planners, landscape architects, and so forth) are needed to specify which kinds of soil interpretations will be made and in what detail and precision And these same specialists are needed to help evaluate the survey design as mapping progresses, to guide the pedologist to the most effective and useful mapping units

By the teamwork of interdisciplinary groups of scientists and engineers, and by scientific soil classification guided by practical objectives, soil surveys can be designed and carried out that will be sought after eagerly by all who plan the use and management of the earth's soil resources

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Some Fundamentals of Soil Classification

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The objective of taxonomic soil classifications is to provide a conceptual framework to accommodate the current knowledge of soils and concepts of soils derived from this knowledge in an organized manner Taxonomic classifications show the relationships inherent in the population of soils and allow comparisons of soils for both similarities and differences The principal practical application of soil classification lies in soil surveys, which can be interpreted for a variety of technical uses, including the transfer of agrotechnology If the experiences of the United States, the Soviet Union, and other countries are a guide, it is clear that taxonomic systems of soil classification that have a large number of precisely defined taxa in the lower categories are required Soil-survey interpretations for crop production provide qualitative groupings and do not circumvent the need for agronomic soil testing

The recognition of soils as independent natural bodies possessing various kinds and degrees of internal organization that reflect the integrated effect of the factors of soil formation provided the first model for the scientific study of soils This perception, developed some hundred years ago in Russia under the leadership of V V Dokuchaiev, marked the most fundamental change in the concept of soil and subsequently led to the establishment of soil science as a separate discipline Like most scientific models, the Russian concept underwent considerable change with time as the knowledge about soils increased One significant change has occurred in the quantitative aspects of the model The present concept is, therefore, more nearly a quantitative representation of our knowledge, since most soil properties can now be characterized in terms that have quantitative meaning at some level of precision (Cline, 1961) This has had great impact on the development of soil science. For, to quote Lord Kevin, " when you cannot measure what you are speaking about, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind, scarcely advanced to the stage of science "

Since soils, then, are objects whose inherent properties can be quantified, they may also be classified on the basis of these properties As a consequence, many systems of soil classification have been proposed and many more are possible Soils as they occur in nature, however, may not in all instances conform to the theories and schemes propounded by pedologists Yet, we should not blame the soils for this predicament since, as Bertrand Russell put it, "nature herself cannot err because she makes no statements It is men who may fall into error when they formulate propositions "

The intent of this paper is to examine some rationales and practical aspects of soil

classification and to describe briefly Soil Taxonomy, the U S system

Purpose of Soil Classification

In "Basic Principles of Soil Classification," Cline (1949) stated "The purpose of any classification is so to organize our knowledge that the properties of objects may be remembered and their relationships may be understood most easily for a specific objective The process involves formation of classes by grouping the objects on the basis of their common properties In any system of classification, groups about which the greatest number, most precise, and most important statements can be made for the objective serve the purpose best "

Logic of Soil Classification

In most existing systems of soil classification, it is assumed implicitly that there are individual soils, just as there are individual animals or plants, and that these small, discrete units can be treated as a population The aggregate of an almost infinite number of these individuals constitutes the soils of the world Whereas former concepts would regard the pedosphere not as a universe of individuals but as a kind of continuum varying from place to place in reflection of changing soil-forming conditions, the present view considers the pedosphere as a "collection of bodies" (USDA, 1960) Cline (1961) pointed out that "the perspective in which we view our model has changed from one in which the whole is emphasized and its parts are loosely defined and indistinct to one in which the parts are sharply in focus and the whole is an organized collection of parts "

The pedon is the smallest entity one may call "a soil," but it would be impractical to deal with all of these units in any system of soil classification However, the individual pedons are the sampling units used to define the lowest category of most soil classification systems, the soil series Moreover, pedons are the only entities that can be measured and analyzed, whereas the categories of soil classification systems are conceptual abstractions of these particulars made at different levels of generalization

I may note parenthetically that this kind of reasoning conforms to the theories of Realism, originally postulated by Plato and later moderated by Aristotle, according to which universals exist and are implicit in particular instances Reasoning that categories of soil classification may not exist independently of our mental constructions, Robinson (1949) prefers to regard these categories as "constructed universals," following the philosophy of the Representationists

Also of interest in this context are Kant's (1781) ideas about knowledge and experience as presented in his *Critique of Pure Reason* On the assumption that experience is necessary but not sufficient for knowledge, he set out to explain experience in terms of concepts rather than vice versa Knowledge that is in principle independent of experience is termed "a priori," and whatever is derived from experience is described as "a posteriori " As will be shown, both of these concepts have been used in developing systems of soil classification

Principles of Soil Classification

The population of soils can be grouped in segments that are similar in selected properties and distinguished from other segments of the population by differences in these properties Such classes, or taxa, can be conceived at various levels of abstraction For the diverse population of soils, several levels are required to evince the relationships desired In the resulting multicategoric systems, the detail of definition and consequently the homogeneity of classes increase with decreasing levels of abstraction or categorical rank Therefore, the greatest number of statements can be made about classes of the lowest category and the least about the highest category (Cline, 1949)

Classes are concepts of real bodies of soil and comprise individuals related in varying degrees to a hypothetical modal individual. They are defined on the basis of differentiat-

ing characteristics, which should be soil properties that can be quantitatively determined in the field or in the laboratory Well-conceived differentiae are associated with a number of covarying properties thus permitting statements about "accessory characteristics." By contrast, properties varying independently of the differentiae are "accidental characteristics," which cannot be inferred from the definition of a class

There is considerable divergence among pedologists regarding the choice of differentiating criteria Thus, the Russian classification gives prominence to climatic and ecological factors, whereas the French system emphasizes pedogenetic processes Although the ensuing classes of both systems may be well suited to show known relationships of soil genesis, such criteria have serious limitations for application in a taxonomic classification because they would conceal relationships yet unknown and do not conform to the principles of differentiation formulated by Cline (1949) The American approach has been to use quantifiable soil properties resulting from pedogenetic processes as controlled by the factors of soil formation rather than by theories of pedogenesis per se

Elaboration of Soil Classification Systems

There are basically two methods of setting up classification systems. In the a priori or descending method, the higher categories are conceived in terms of hypotheses and principles of generally pedogenetic nature, and more detailed categories are added as observation proceeds Many of the soil classification systems developed in Europe are examples of this kind Although such systems are the only possible ones when not much accurate data are available, they have the inherent defect of all preestablished schemes used to accommodate factual knowledge Bridgeman (1927) has pointed out that the scientist "recognizes no a priori principles which determine or limit the possibilities of new experience "

The second method is a posteriori or ascending, where the reasoning is from facts to concepts This approach requires, of course, a great amount of data about recognizable bodies of soil, especially those identified as soil series The U S Soil Taxonomy is essentially of this type It should be noted, however, that the organization of categories and classes of this system is a direct consequence of theories of pedogenesis and current concepts of soil science (Cline, 1961)

Kinds of Soil Classification Systems

Because soils may be classified for a great variety of specific objectives, there are as many systems of soil classification conceivable as there are objectives for grouping soils Each of these systems may be the best for the particular purpose for which it was designed Yet, as the means for attaining one objective are seldom suitable for attaining another, a single system will rarely serve two objectives equally well (Cline, 1949) For example, a system developed for classifying soils in terms of their suitability for septic tanks will not be very useful for determining their lime requirement

Systems limited by the special bias dictated by their purpose are called technical classifications They are opposed to natural or taxonomic classifications, where the objective is to show relationships amongst the greatest number of properties and most important properties without reference to a specific practical purpose (Cline, 1949) A taxonomic classification recognizes that soils have many properties, some of which are associated in an apparently causal relationship These attributes of the population are considered and those having the greatest number of covariant or accessory characteristics are selected to define and separate the various classes and categories (Mill, 1925). To quote Cline (1949) again, "the natural classification, therefore, performs the extremely important function of organizing, naming, and defining the classes that are the basic units used (1) to identify the sample individuals that are the objects of research,

(2) to organize the data of research for discovering relationships within the population, (3) to formulate generalizations about the population from these relationships, and (4) to apply these generalizations to specific cases that have not been studied directly"

The issue of technical versus taxonomic systems has been the subject of frequent arguments among pedologists Those more pragmatically inclined, on the one hand, tend to regard taxonomic classifications as purely academic labor, eminently respectable perhaps, but without practical meaning Taxonomists, on the other hand, are tempted to consider technical systems a more or less incoherent juxtaposition of facts (Manil, 1959) However, there appears to be no rational base for such discrepancies The fundamental differences in the two kinds of systems merely reflect the different purposes for which the systems have been devised

Soil Taxonomy, an Example of a Modern System

Soil Taxonomy, the new U S system of soil classification, is an attempt at a comprehensive classification of soils It represents a modern effort to tackle the three main problems encountered in setting up a taxonomic system the selection of differentiating criteria, the definition of classes and their grouping in categories, and the nomenclature of taxa

In recognition of the real need for an entirely new system, Soil Taxonomy has been developed over the past 20 years in the Soil Conservation Service of the United States Department of Agriculture, under the leadership of G D Smith, with the cooperation of soil scientists of U S universities and certain pedologists from other countries The system went through a series of approximations of which the *7th Approximation* was published in 1960 (USDA) After substantial revisions, it has now been published as a book entitled *Soil Taxonomy A Basic System of Soil Classification for Making and Interpreting Soil Surveys* (USDA, 1975)

In developing the basic rationales of the system, the authors of *Soil Taxonomy* were influenced by Bridgeman's *Logic of Modern Physics* (1927) They also drew on Western European experience, particularly on the definitions of concepts basic to the French classification (Smith, 1965) More than 70 years of soil survey provided the detailed information without which the development of the system would have been impossible

Like most taxonomic systems, Soil Taxonomy is a multicategoric system Each category is an aggregate of taxa, defined at about the same level of abstraction, with the smallest number of classes in the highest category and the largest number in the lowest category In order of decreasing rank, these categories are order, suborder, great group, subgroup, family, and series

Applying the concepts of pedogenic processes, the authors of *Soil Taxonomy* differentiate orders, suborders, and great groups on the basis of presence or absence of a variety of combinations of diagnostic horizons and soil properties Three levels of such sets are used in the three categories, each set of properties marking pedogenic processes that operate within the sets characterizing the higher category or categories Examples of differentiae used at the order level are diagnostic horizons, such as the oxic and spodic horizons or the mollic epipedon Soil moisture regime and extreme chemical or mineralogical properties, such as the presence of large amounts of allophane, are examples of criteria for differentiating suborders Properties that appear to be superimposed on the diagnostic features of the orders and suborders, such as various kinds of pans or the presence of plinthite, are used to differentiate great groups

Subgroups are subdivisions of great groups, representing either the central concept of the category, the intergrades to other groups, or the extragrades that have additional aberrant properties Families and series are distinguished on the basis of properties selected to create taxa that are successively more homogeneous for practical uses of soils Thus, families are intended to provide classes having relative homogene-

ity in properties important to plant growth, and series are subdivisions of families intended to give the greatest homogeneity of properties in the rooting zone, consistent with the occurrence of mappable areas at scales of detailed soil surveys

The classes of Soil Taxonomy have been formed in consideration of concepts of pedogenic processes However, as these causes are not fit as diagnostic criteria, some of their more prominent effects were selected as differentiae So far as possible, properties that are the result of soil genesis were chosen as differentiae because they carry the maximum number of accessory properties and have geographic implications of susceptibility to mapping As a basic principle, these differentiae are soil properties, and there are defined operations to identify them (Smith, 1965) The *Soil Survey Manual* (USDA, 1951) and the *Soil Survey Laboratory Methods* (USDA, 1967) provide the definitions and procedures for these operations

The nomenclature of Soil Taxonomy marks a complete departure from past practice It was not conceived to mystify the outsider, as some might think But because the old names were ambiguous, of diverse linguistic provenance, difficult to redefine, and generally unsuited for use in a systematic taxonomy, new names were coined, largely from Greek and Latin roots, that fit any modern European language without translation The name of each taxon clearly indicates the place of the taxon in the system and connotes some of its most important properties

Soil Taxonomy is not a perfect system It is an organized abstract of current knowledge of soils and of concepts derived from this knowledge and can, therefore, be no better than the state of that knowledge Yet our knowledge of soils is still incomplete, and this is particularly true for many soils of the tropics The classification of Oxisols, for example, has been based on a limited amount of factual data, hence, has lagged behind that of other orders of mineral soils, and thus is certain to have many shortcomings (USDA, 1975) However, the Soil Conservation Service is now beginning to direct efforts toward more meaningful methods of assessing organic soil materials and toward characterization of relevant properties of soils of the tropics (Flach, 1973) In all probability, this will lead to additional differentiae for classifying Oxisols and will entail changes in the present system

The definition of criteria, classes, and categories of Soil Taxonomy is factual and leaves no scope for subjective speculation However, the guiding rationales underlying the development of the framework of Soil Taxonomy are provided by concepts of soil genesis This genetic bias is also reflected in the choice of differentiae and class limits As many pedogenetically significant processes take place in the subsoil, criteria relating to subsoil properties tend to be used more frequently as differentiae than those relating to surface-soil properties Even a casual analysis of the key to Soil Taxonomy reveals that diagnostic subsoil properties commonly take precedence over surface-soil criteria This controls the kind and amount of information a taxon contains by virtue of its definition With few exceptions, a greater number of quantitative statements can be made about the subsoil than the surface soil However, because the criteria of Soil Taxonomy have many covariant properties and accessory characteristics, qualitative inferences of reasonable accuracy can be made about the surface soil

Soil Taxonomy is the official system of the National Cooperative Soil Survey of the United States, but it is also used in some other countries, particularly South America (Costa de Lemos, 1971) Of the numerous classifications used in tropical areas, Soil Taxonomy is among the most important ones (Aubert and Tavernier, 1972) Although it has not been accepted unanimously outside the United States, Soil Taxonomy is likely to be adopted as a system of reference for international communication, especially in technical papers

Use of Soil Classification

Natural or taxonomic soil classification

has two basic functions First, as pointed out earlier, it identifies, organizes, and names soils in an orderly fashion and stimulates the revelation and formulation of relationships within the soil population Second, it serves as a base for the application of soils technology, for the interpretation of soils as classified and delineated on soil maps, and for the transfer of experience

The principal practical application of soil classification lies in soil survey and its interpretation Soil-survey interpretations provide predictions about the behavior of a "defined kind of soil" under stated conditions, especially systems of soil use and methods of manipulation, which indicate reasonable alternatives and the expected results (Kellogg, 1961) Such interpretations can be, and have been, made for a variety of purposes including land-use planning, foundation and highway engineering, recreation, tax assessment, effluent disposal, and archeology These applications are the subject of two recent publications by Bartelli et al (1966) and Simonson (1974) and are excluded from the discussion below that centers on some aspects of agricultural interpretations and agrotechnology transfer in the tropics

Agricultural interpretations and extrapolations obviously have technical purposes, and thus an argument could be made in favor of using some kind of technical system of soil classification for these processes Yet, while this may be a reasonable statement of principle, it appears that interpretations and transfers have to be made on the basis of the existing soil maps and the classification systems employed in their construction The systems most widely used in tropical areas are the FAO/UNESCO Legend (Dudal, 1968, FAO, 1970), the French Soil Classification (Aubert, 1965, Commission de Pédologie, 1967), the Classification of Brazilian Soils (Bennema, 1966), and the U S Soil Taxonomy (USDA, 1975) Taxa of these systems can be correlated at various categoric levels and, in most cases, with some degree of accuracy (Beinroth, in press, Beinroth et al , 1974)

All of the mentioned systems are, in principle, taxonomic classifications Their application in soil surveys alludes to the rationale that these, although practical in purpose, must also have reasonable scientific standards to be useful In particular, a soil survey should not become obsolete with changing agricultural technology, and a soil survey should further facilitate the interpretation for a variety of uses, some of which might not have been anticipated at the time that the survey was made It is evident that these requirements can only be met if a taxonomic system is used (Smith, 1965) Although taxonomic systems have some inherent limitations for agricultural interpretations because of their emphasis on subsoil properties, there are compelling reasons for their use in soil surveys In cultivated soils, the surface is also the main management zone and, as such, is affected by frequent changes in physical and chemical properties If these properties were selected as differentiae, the classification and the soil maps of cultivated areas would also be subject to change with equal frequency

Whereas classifying and mapping soils are analytical processes that involve defined or specified measurable soil characteristics and differentiae, the interpretation of soil surveys requires a careful synthesis of many data in relation to less tangible soil qualities resulting from the interaction between soil characteristics and superimposed practices (Kellogg, 1961) Soil productivity, for example, is that quality of a soil that summarizes its potential for producing plants or sequences of plants under defined sets of management practices, it is also a synthesis of conditions of soil fertility, water control, plant species, soil tilth, pest control, and physical environment Soil survey interpretation, therefore, should be a team effort among pedologists and competent scientists from the relevant disciplines

The precision and detail of agricultural predictions resulting from soil survey interpretation depend on (1) the knowledge of the interactions involved between soil characteristics, crop requirements, and management practices, and (2) the degree of generalization and homogeneity of the mapping

unit interpreted Reliable interpretations are possible only if there is inductive and empirical knowledge of the behavior of the soils under consideration relative to various agronomic and cultural practices This is not always the case, particularly in the tropics Also, interpretations of the broad units of small-scale soil maps, usually associations classified at high categoric levels, must by necessity be more general than those for mapping units of high-intensity surveys showing phases of series We should further note that taxonomic units are not to be confused with mapping units because the latter may include quite contrasting soils Therefore, interpretations made for the dominant soil of a mapping unit do not necessarily apply to all soils of that unit

About transfer of agrotechnology, Smith (1965) contended that to be useful, the soil classification used "should be a multi-categoric system with a large number of taxa in the lower categories [These] must be as specific as possible about a great many soil properties Higher categories are essential for comparisons of the soils of large areas, but are of limited value for the transfer of experience" Classes are defined in terms of soil properties which correlate with patterns of soil management knowledge In the U S Soil Taxonomy, soil families are, within a given subgroup, differentiated primarily on the basis of soil properties important to plant growth and indicative of soil-water-root relationships Soils classified into the same soil families should, therefore, have nearly the same management requirements and similar potentials for crop production. This assumption was recently substantiated in a study of soils of the southern United States (DeMent et al, 1971) The study further showed that only general kinds of soil behavior can be predicted within classes of the more broadly defined higher categories

The systems of soil classification used in the tropics need to be evaluated relative to their usefulness for soil-survey interpretations and knowledge transfers To be useful in this respect, they must allow interpretive groupings that are meaningful for agricultural purposes If the systems fail to meet this requirement, they should be modified Although taxonomic classifications should not be biased by practical concerns, more or less arbitrary divisions among taxonomic units can be redefined in consideration of practical needs It should be realized, however, that soil classification cannot generate all of the information required for crop production and, in particular, cannot substitute for on-site soil testing for agronomic purposes On the basis of taxonomic classification, one can group soils according to the likelihood and degree of nutrient deficiencies under specific assumptions of past management and their probable response to fertilizers, but not according to specific annual applications needed

Finally, it should be emphasized that soil-survey interpretations provide predictions, not recommendations Decisions must depend partly on economic characteristics, not simply on the physical and biological environment

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Occurrence and Significance of Climatic Parameters in the Soil Taxonomy

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Climatic parameters influence the properties of soils and ultimately the utilization of soils Because these parameters are so important they themselves have been included as soil properties, that is, as soil moisture and soil temperature, in the Soil Taxonomy (USDA, 1975) These parameters, expressed to a different degree at the various categorical levels in the Soil Taxonomy, are important because the soil classification names can denote the different environments associated with the soils themselves In other words the different taxa can express the different ecosystems By knowing the system of soil classification one can know whether a soil is moist or dry or of a cool or warm area Furthermore other properties such as organic matter soil pH and base saturation, can be associated with the climatic parameters The objectives of this paper are (1) to describe or define these climatic parameters as soil properties (2) to indicate where in the Soil Taxonomy the climatic parameters are expressed and what significance these parameters have in making soil classification useful in technology transfer and in land-use planning and development and (3) to present some examples of how the different soil moisture or soil temperature regimes are associated with different crops

Soil Moisture Regimes

Climatic parameters such as soil moisture and soil temperature regimes are precisely defined in the *Soil Taxonomy* Quotations used in this paper are from various sections of this document

The soil moisture regime refers to the presence or absence of water in the soil at different times of the year A soil is considered to be dry when the moisture tension is 15 bars or more and moist when the moisture tension is less than 15 bars "A soil may be continuously moist in some or all horizons throughout the year or for some part of the year It may be moist in winter and dry in summer or the reverse In the northern hemisphere, summer refers to the months of June, July, and August, and winter means December, January, and February A soil or a horizon is considered to be saturated with water when water stands in an unlined borehole close enough to the soil surface or to the horizon in question that the capillary fringe reaches the surface or the top of the horizon "

Soil Moisture Control Section

To estimate the soil moisture regimes from climatic data, it is necessary to be familiar with the term *soil moisture control section* The soil moisture control section is that portion of the soil in which the upper boundary is the depth to which a dry soil will be moistened by 2 5 cm (1 inch) of water

within 24 hours, while the lower boundary is the depth to which a dry soil will be moistened by 7 5 cm (3 inches) of water within 48 hours (Figure 1) A dry soil is defined as one having a moisture tension of 15 bars but not being air dry The concept of the soil moisture control section does not apply well to the cracking soils or to soils that receive water that runs off other higher-lying soils because these soils do not remoisten evenly from the surface to the subsoil

Because soil texture influences the sorption and release of water, the soil moisture control section can be estimated when the particle-size class is known The control section "lies approximately between 10 and 30 cm (4 and 12 inches) if the particle-size class is fine-loamy, coarse-silty, fine-silty or clayey The control section extends approximately from a depth of 20 cm to a depth of 60 cm (8 to 24 inches) if the particle-size class is coarse-loamy and from 30 to 90 cm (12 to 35 inches) if the particle-size is sandy" (Figure 2) The limits of the soil moisture control section are also affected by differences in structure and pore-size distribution as well as by other factors that influence movement and retention of soil water

The basic assumption in calculating soil moisture in the moisture control section is "that half of the actual monthly precipitation comes as a single storm and enters the soil on the 15th day of the month This half of the moisture is depleted on the assumption that the amount of potential evapotranspiration required to remove one unit of water is inversely proportional to the amount of available water remaining in the soil In other words, the drier the soil, the more the energy that is required to extract a unit of water The other half of the water is assumed to come in small showers and is depleted at the full potential evapotranspiration rate "

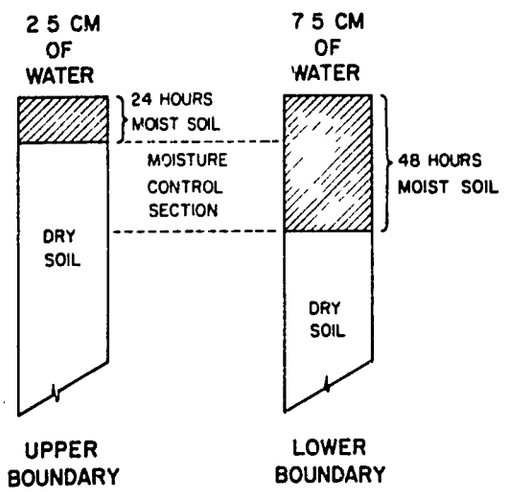

Fig 1 The upper and lower boundaries of the soil moisture control section

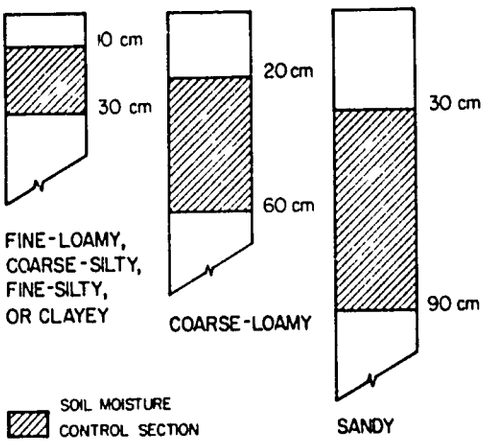

Fig 2 Approximation of the soil moisture control section based on particle-size class

Soil moisture has also been estimated from meteorological records that have charts showing climatic data and soil-water balance, but this method to date has some shortcomings Also, because these charts give an oversimplified picture of the moisture regime of the whole soil rather than of the moisture control section, when used, their limitations should be recognized

Classes of Soil Moisture Regimes

The names of the classes of soil moisture regimes are aquic, udic, ustic, xeric, and aridic (or torric)

Aquic soils

Aquic soils are saturated by ground water or by water of the capillary fringe and are in a reduced state because of the lack of dissolved oxygen The whole soil must be saturated in the highest categories of soils, but only the lower horizons are saturated in the subgroups The removal of dissolved oxygen from the ground water by biological activities makes it "implicit in the concept that the soil temperature is above biologic zero (5° C) at some time while the soil or the horizon is saturated" Although the ground water level can fluctuate with the season, being highest in the rainy season or during time of almost no evapotranspiration, the ground water can be at, or very close to, the surface of the soils, such as in a tidal marsh or a closed, landlocked depression with perennial streams Under such conditions, these soils have a *peraquic* moisture regime

Udic soils

Udic soils are moist soils "In most years the soil moisture control section is not dry in any part for as long as 90 days (cumulative) If the mean annual soil temperature is lower than 22° C and if the mean winter and mean summer soil temperatures at a depth of 50 cm differ by 5° C or more, the soil moisture control section is not dry in all parts for as long as 45 consecutive days in the 4 months that follow the summer solstice in 6 or more years out of 10 In addition, the udic moisture regime requires, except for short periods, a three-phase system, solid-liquid-gas, in part, but not necessarily in all, of the soil when the soil temperature is above 5° C" These soils are common in humid climates with well-distributed rainfall or with enough rain in summer "that the amount of stored moisture plus rainfall is approximately equal to or exceeds the amount of evapotranspiration Water moves down through the soil at some time in most years If precipitation exceeds evapotranspiration in all months of most years, there are occasional brief periods when some stored moisture is used, but the moisture tension rarely becomes as great as 1 bar in the soil moisture control section The water moves through the soil in all months that it is not frozen" Under such conditions, these soils have a *perudic* moisture regime The latter regime, however, is not used to define any taxa but is implied in some (Tavernier, 1971)

Ustic soils

Ustic soils are those of limited moisture but this moisture is present at a time when needed for plant growth "If the mean annual soil temperature is 22° C or higher or if the mean summer and winter soil temperatures differ by less than 5° C at a depth of 50 cm, the soil moisture control section in the ustic moisture regime is dry in some or all parts for 90 or more cumulative days in most years But the moisture control section is moist in some part for more than 180 cumulative days, or it is continuously moist in some part for at least 90 consecutive days If the mean annual soil temperature is lower than 22°C and if the mean summer and winter soil temperatures differ by 5° C or more at a depth of 50 cm, the soil moisture control section in the ustic regime is dry in some or all parts for 90 or more cumulative days in most years But it is not dry in all parts for more than half the time that the soil temperature is higher than 5° C at a depth of 50 cm (the aridic and torric regimes) Also, it is not dry in all parts for as long as 45 consecutive days in the 4 months that follow the summer solstice in 6 or more years out of 10 if the moisture control section is moist in all parts for 45 or more consecutive days in the 4 months that follow the winter solstice in 6 or more years out of 10 (xeric regime)" In tropical and subtropical regions with either one or two dry seasons, summer and winter have little meaning, and "the ustic regime is that typified in a monsoon climate that has at least one rainy season of 3 months or more" In temperate regions with subhumid or semiarid climate, the rainy seasons are usually spring and summer or spring and fall, but never winter

Xeric soils

Xeric soils are those associated with the Mediterranean climate—moist and cool winters and warm and dry summers "The moisture, coming in winter when potential evapotranspiration is at a minimum, is particularly effective for leaching In a xeric moisture regime, the soil moisture control section is dry in all parts for 45 or more consecutive days within the 4 months that follow the summer solstice in 6 or more years out of 10 It is moist in all parts for 45 or more consecutive days within the 4 months that follow the winter solstice in 6 or more years out of 10 The moisture control section is moist in some part more than half the time, cumulative that the soil temperature at a depth of 50 cm is higher than 5° C or in 6 or more years out of 10 it is moist in some part for at least 90 consecutive days when the soil temperature at a depth of 50 cm is continuously higher than 8° C In addition, the mean annual soil temperature is lower than 22° C, and mean summer and mean winter soil temperatures differ by 5° C or more at a depth of 50 cm or at a lithic or paralithic contact whichever is shallower"

Aridic soils

Aridic (or torric) soils are hot and dry soils The former term is used at the order category while the latter term is used within the other categories of the taxonomy In most years, the moisture control section is (1) "dry in all parts more than half the time (cumulative) that the soil temperature at a depth of 50 cm is above 5° C" and (2) "never moist in some or all parts for as long as 90 consecutive days when the soil temperature at a depth of 50 cm is above 8° C" These soils are normally in arid climates, although "a few are in semiarid climates and either have physical properties that keep them dry, such as a crusty surface that virtually precludes infiltration of water, or they are very shallow over bedrock There is little or no leaching in these moisture regimes, and soluble salts accumulate in the soil if there is a source of them"

Soil Temperature Regimes

The soil temperature regime is the actual temperature reading at a given soil depth or is a temperature that is estimated from climatological data The temperature regime, furthermore, consists of "the mean annual temperature, the average seasonal fluctuations from that mean and the mean warm or cold seasonal soil-temperature gradient within the main root zone which is the zone from a depth of 5 to 100 cm"

Because soil temperature, especially near the soil surface, is greatly affected by daily changes in air temperature a measurement at some depth is necessary Based on the findings of various investigations (USDA, 1975), a measurement at a depth of 50 cm at regular time intervals throughout the year appears to be satisfactory Where necessary, however soil temperature can be estimated from climatological data In the continental United States, the mean annual soil temperature for most areas can be estimated by adding 1° C to the mean annual air temperature The mean summer temperature, on the other hand of most areas can be estimated by subtracting 0 6° C from the mean summer air temperature

Classes of Soil Temperature Regimes

The names of the classes of soil temperature regimes are pergelic, cryic, frigid, mesic, thermic, and hyperthermic

Pergelic soils

Pergelic soils have mean annual temperatures lower than 0° C (32° F), and they have either permafrost if they are moist or dry frost if they do not have excess water

Cryic soils

Cryic soils have mean annual temperatures higher than 0° C but lower than 8° C (47° F) According to *Soil Taxonomy*

"1 In mineral soils, the mean summer temperature for June, July, and August at a depth of 50 cm or at a lithic

Table 1 Influence of the moisture regime on the suborder names

Orders	Histosols	Andisols	Entisols	Inceptisols	Spodosols	Mollisols	Alfisols	Ultisols	Oxisols	Vertisols
Suborders	—	—	Aquents	Aquepts	Aquods	Aquolls Udolls Ustolls Xerolls	Aqualfs Udalfs Ustalfs Xeralfs	Aquults Udults Ustults Xerults	Aquox Ustox Torrox	Uderts Usterts Xererts Torrerts

or paralithic contact, whichever is shallower, is as follows:

a. If the soil is not saturated with water during some part of the summer and
   (1) There is no 0 horizon, lower than 15° C (59° F),
   (2) There is an 0 horizon, lower than 8° C (47° F),

b If the soil is saturated with water during some part of the summer and
   (1) There is no 0 horizon, lower than 13° C (55° F),
   (2) There is an 0 horizon or a histic epipedon, lower than 6° C (43° F)

2 In organic soils, either

a The soil is frozen in some layer within the control section in most years about 2 months after the summer solstice, that is, the soil is very cold in winter but warms up slightly in summer, or

b The soil is not frozen in most years below a depth of 5 cm, that is, the soil is cold throughout the year but, because of marine influence, does not freeze in most years"

Having aquic moisture regime commonly, cryic soils are churned by frost, and in organic soils they show characteristic mounds Most isofrigid soils having a mean annual soil temperature above 0° C have a cryic temperature regime, and all of these soils without permafrost have a cryic temperature regime

Frigid soils

Frigid soils also have a mean annual temperature lower than 8° C (47° F) but are warmer in the summer than those in the cryic temperature. Furthermore, "the difference between mean winter and mean summer soil temperature is more than 5° C (9° F) at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower."

Mesic soils

Mesic soils have a mean annual temperature of 8° C or higher but lower than 15° C (59° F), and "the difference between mean summer and mean winter soil temperature is more than 5° C at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower"

Thermic soils

Thermic soils have a mean annual temperature of 15° C or higher but lower than 22° C (72° F) and "the difference between mean summer and mean winter soil temperature is more than 5° C at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower"

Hyperthermic soils

Hyperthermic soils have a mean annual temperature of 22° C (72° F) or higher and "the difference between mean summer and mean winter soil temperature is more than 5° C at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower"

Isofrigid, isomesic, isothermic and isohyperthermic soils

The difference between the mean summer and mean winter soil temperatures is more than 5° C (9° F) at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower, for the frigid, mesic, thermic, and hyperthermic soils If this difference is less than 5° C at the same depth or subsurface contact, as in most parts of the tropics, the temperature regimes of the respective soils are named isofrigid, isomesic, isothermic, and isohyperthermic

Climatic Parameters and the Soil Taxonomy

It must be emphasized that in many cases the moisture and temperature regimes must be considered together because of the influence of one on the other

The Soil Taxonomy is composed of six categories order, suborder, great group, subgroup, family, and series The order is the highest category, the series is the lowest category Climatic parameters are expressed at the various categorical levels above the series level When the moisture and temperature regimes are associated with soil genesis and with soil properties that serve as differentiating characteristics, they are expressed in the higher categories When the climatic parameter, for example, the soil temperature class, is more related to plant growth, it is expressed specifically in the lower category, the family

Expression of the climatic parameters can be either (1) defined within a category or of the class within a category An example of the former is the differentiation of the Histosols and the Aridisols at the highest category from the other orders The amount of organic material in Histosols is in general related to saturation with water Likewise, the Aridisols have in general an aridic moisture regime When using the key to the soil orders, the temperature regime is also used to distinguish certain orders such as the Vertisols and the Ultisols

The climatic parameters can also be specified by the name of the order, an example being the Oxisols The order Oxisols is limited to climatic conditions, which are typical of the tropics

It is in the suborder category, however, that the moisture regime is specifically recognized for most soils as shown in Table 1 The temperature regime, on the other hand, is limited to only a few suborders—the Tropepts (Inceptisols), Boralls (Mollisols), and Boralfs (Alfisols)

Although not expressed precisely, temperature regimes are implied in the suborder category for five of the orders—Mollisols, Alfisols, Ultisols, Oxisols, and Vertisols In general, udic soils are warm, ustic soils are warm or hot, and xeric soils are cool in winter and warm in summer (USDA, 1975) Similar relationships are expressed by Tavernier (1971) that the cold ustic regimes are associated with the steppes, the hot ustic with intertropical, the xeric with Mediterranean, and the aridic with desertic and subdesertic However, he mentions that in boreal

temperature regimes only the udic and aridic moisture regimes are considered at the subgroup level Thus, the suborder category, with some limitations, can be used to show the influence of climatic parameters in soil classification and interpretation

Because there is a hierarchy of classes in the Soil Taxonomy, climatic parameters expressed at the higher categories are also emphasized at the lower categories When the great group category is considered, the moisture and temperature regimes are definitely emphasized These regimes are not only the causes of soil properties but also the properties of the whole soil In a few taxa, moisture and temperature regimes may not be defined, but in most cases the accessory properties are defined (USDA, 1975)

If, however, the climatic parameters were not emphasized at the order or suborder, as in the case of the Entisols or Inceptisols, these parameters would be used to differentiate these particular orders at the great group category The great group category, therefore, considers not only soils similar in the kind, arrangement, degree of expression of horizon, base status, and other properties, but also those similar in soil moisture and those with very broad grouping of temperature regimes At this categoric level, the climatic parameters have been expressed for almost all, if not all of the soils, and similar behaviors are expected for similar soils

The significance of the expression of the climatic parameters at the suborder category is that a small-scale map can be prepared showing the distribution of the various soils An example is a map prepared by the Soil Geography Unit of the Soil Conservation Service, USDA, and presented by Aubert and Tavernier (1972) Taking into consideration that altitude as well as latitude can influence temperature, one can quickly obtain a general idea of soil distribution

An excellent illustration of such use on a small-scale map is offered by Orvedal and Ackerson (1972), who used both the moisture and temperature regimes to show the agricultural soil resources of the world in terms of soils that were (1) potentially arable, (2) nonarable but potentially grazeable, and (3) nonarable and nongrazeable Their presentation about the distribution of soils that have a udic moisture regime, for example, shows that these soils occur in regions having (1) cool (boreal), (2) temperate-to-warm, and (3) warm-to-hot (mainly isohyperthermic) climates The number of crops per year and the growing season are dependent on the temperature regime These authors attribute 47, 52, and 49% of the respective soils in the different temperature regimes as being arable, and 36, 33, and 36% of the respective soils as being nonarable but potentially grazeable The distribution of soils having other moisture regimes and modified by the temperature regimes are similarly presented Approximately one-half of these areas are now under cultivation A presentation such as that by Orvedal and Ackerson, using climatic parameters, emphasizes the availability of soils that are potentially available for food production, and this kind of information can be used to plan and implement food production on a broad basis

Soil classification, as with soil surveys, soil maps, and their interpretation, can be either generalized or detailed for land-use planning and development When a planner desires an overview, generalized information may be sufficient However, if he is in operation planning, more detailed information is necessary Obviously, a soil map on a 1 125,000 scale showing the great groups would have a higher precision and predictability than one showing only the soil orders or suborders However, as pointed out by Nichols and Bartelli (1972), the objective of interpretative soil maps is "to furnish information needed on soils without clutter of irrelevant information" Therefore, the minimum size delineation of a soil map should be consistent with the decision-making unit of the user

The great group level, therefore, can be used not only for making appropriate soil maps for land-use planning and development but also for technology transfer Soils possessing comm , properties and similar moisture and temperature regimes should show similar behavior Hydrandepts in Hawaii, for example, occur in areas of very

high, well-distributed rainfall (perudic moisture regime) and, by definition, have a soil temperature warmer than cryic In Hawaii, furthermore, they are used for sugarcane, pasture, woodland, wildlife habitat, and watershed and could be used for similar purposes elsewhere As mentioned previously, soil temperature classes are expressed at the family category and if this category is used for technology transfer the reliability for prediction becomes quite high For example, the thixotropic isohyperthermic family of Typic Hydrandepts is better suited for sugarcane production than the thixotropic, isomesic family of the same subgroup The crop is harvested in approximately 2 years instead of 3, and the yield in terms of tons of sugar per acre is much higher in the isohyperthermic soils Management techniques transferred to other areas of the world having similar soil are expected to give similar response

Regardless of the categoric level, however, the information of soil moisture and soil temperature regimes plays an important role in agriculture, and additional examples are presented to illustrate this importance Certainly aquic soils with warm temperature are better suited for paddy rice production than other soils In Hawaii, under non-irrigation management, ustic soils can be utilized efficiently for pineapple but not so for sugarcane The isothermic soils are better suited for coffee as well as for many vegetables, such as cabbage and celery, than the isohyperthermic soils The isohyperthermic soils are better suited for macadamia and papaya than the isothermic or isomesic soils

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Soils and Land-Resource Mapping in Iran

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Iran has a total land surface of about 165 million hectares, nearly 50% of which are mountains, rocky land, or desert Wheat and barley are the dominant agricultural crops A generalized soil map and a map grouping the soils in relation to their general potential for agriculture have been published

The major soil groupings are described in relation to the four physiographic zones of the country the plains and valleys, the high plateau, the Caspian piedmont, and the dissected slopes and mountains A correlation table relating the national soil groups to the legend of the FAO-UNESCO Soil Map of the World and to the Soil Taxonomy is given

Detailed and semidetailed soil surveys are used in Iran to provide the basis for development projects, which are usually associated with irrigated agriculture Regional land-resources inventories, which include land evaluations, are used as general guides for regional development planning and are much in demand

Iran's total land surface is about 165 million hectares, over 50% of which are mountainous and rough rocky lands, or desert, containing only small pockets of land suitable for agricultural production There are four main physiographic areas in Iran, each with its distinctive character

1 the Zagros and Elburz Mountains in the form of a great V,
2 the area within the V, which begins as a high plateau with its own secondary ranges and gradually descends into deserts,
3 the region of Khuzestan, a low-lying plain and a continuation of the Mesopotamian plain, and
4 the Caspian seacoast, which is below sea level and forms a separate climatic zone

Apart from the related factors of soil depth and slope, the main limiting factor to agricultural development is lack of moisture and adequate rainfall or water for irrigation

In the last few years, steps were taken to conserve and protect water supplies and ensure the correct use of natural resources These measures are of vital importance to Iran, whose major part receives less than 250 mm of rain per year and can be classified as arid or semiarid, except on the northern parts of the Elburz mountains, where rainfall varies from 1,000 to 2,000 mm per year

Vegetation varies with climate, the natural vegetation in humid regions consisting of oak and beech forests A thin cover of grasses and shrubs is natural to the semiarid and arid regions Wheat and barley are the dominant agricultural crops here because they are best suited to dry conditions. Regarding present land use in Iran, no exact

statistics exist, but a rough estimation has been made About 19 million hectares are agricultural land, including fallow and orchards, 10 million hectares, pasture; about 19 million hectares, forest and woodland; and the rest are wastelands, desert area, or mountains (as much as 33 million hectares are unused but potentially productive).

Soil surveys and land classifications have been carried out especially for irrigation development projects in Iran since 1953, and a generalized soil map of Iran has been prepared Table 1 shows an approximate correlation of the Iranian soil groupings with the legend of the FAO/UNESCO World Soil Map and the Soil Taxonomy of the USDA

Throughout the country, different types of land can be recognized The types of land are caused by varying combinations of environmental characteristics such as climate, topography (geomorphology), lithology, soils, hydrology, flora, and fauna

The object of land study is to portray the changes that are occurring in a landscape, to determine the reasons for them, to describe the land in terms of its characteristics, and subsequently to obtain an understanding of how a land unit may be safely modified by man to serve particular purposes Regional land-resource inventories have been prepared in Iran since 1967, using the integrated survey method The systematic inventory of

Table 1 Correlation of three soil classification systems

Iranian	FAO and UNESCO	USDA
Alluvial	Regosol or Fluvisol (if recent deposit)	Orthent or Fluvent (if recent deposit)
Stratified alluvial	Same as above	Same as above
Saline alluvial	Can be any of the above soil groups with a saline phase *or* Solonchak (according to salinization)	Can be any of the above soil groups with a saline phase (according to salinization)
Colluvial	Same as alluvial	Same as alluvial
Alluvic-colluvial	Same as alluvial	Same as alluvial
Desert	Regosol (without cambic)	Torriorthent
	Takyric Yermosol (with cambic)	Typic Camborthid
	Gypsic or Haplic Yermosol (with cambic or gypsic)	Gypsiorthid (if gypsic horizon)
	Orthoic Solonchak (with conductivity 16 millimhos in the first 50 cm)	Same as above
Desertic brown	Haplic Yermosol	Same as above
	Orthic Solonchak (if EC > 16 millimhos within 50 cm)	
Argillic desertic brown	Luvic Yermosol	Typic Haplargid
Calcic desertic brown	Calcic Yermosol	Typic Calciorthid
Brown	Haplic Xerosol	Typic Xerochrept (if EC < 2 millimhos)
	Orthic Solonchak (if EC > 16 millimhos within 50 cm)	Xerollic Camborthid
		Gypsiorthid (if gypsic horizon)
Argillic brown	Luvic Xerosol	Xerollic Haplargid
Calcic brown	Calcic Xerosol	Typic Calciorthid

—Continued

Table 1. Continued

Iranian	FAO and UNESCO	USDA
Chestnut	Luvic (Kastanozem)	Argixeroll
	Calcic (Kastanozem)	Calcixeroll
	Haplic (Kastanozem)	Haploxeroll
Calcisols	Calcic Cambisol Calcaric-Regosol or Xerosol or Yermosol (all according to moisture regime)	Calcixerollic Xerochrept or Xerothent Calciorthid
Rendsina	Rendzina	Lithic or Typic Rendoll
Solonchak		
External solonchak	Orthic Solonchak	Camborthid or Orthent, salic phase
Internal solonchak	Gleyic Solonchak	Salorthid, Aquent
Solonetz	Orthic Solonetz	Typic Natrargid
	Gleyic Solonetz	Aquic Natrargid
Solonchak or Solonetz	Solonetz, saline phase	Natrargid, saline phase
Alkali	Xerosol or Yermosol or Cambisol, sodic phase	Aridisol or Inceptisol, sodic phase
Saline or alkali	Xerosol or Yermosol or Cambisol, sodic and saline phases	Aridisol or Inceptisol, sodic and saline phases
Low humic gley	Eutric Gleysol-Calcaric Gleysol	Haplaquept
	Gleyic Luvisol	Aquic Camborthid, Aquent
	Gleyic Planosol	Albaqualf, Ochraqualf
Humic gley	Mollic Gleysol	Humaquept
	Humic Gleysol	Haplaquoll
Saline low humic gley	Gleyic Solonchak	Salorthid Aquept, saline phase, Aquent
Brown forest	Eutric Cambisol	Eutrochrept
Humic brown forest	Humic Cambisol	Haplumbrept
Acid brown forest	Dystric Cambisol	Dystrochrept
	Humic Cambisol (organic C between 1 and 2%)	Haplumbrept
Humic subgroup	Humic Cambisol	Haplumbrept
Calcareous brown forest	Calcaro Eutric Cambisol Calcic Cambisol (if there is a cambic and/or calcic horizon)	Eutrochrept-Calcixerollic Xerochrept
Humic subgroup	Same as above or Calcaro Haplic Kastanozem (if Mollic epipedon)	Haploxeroll
Brown Mediterranean	Orthic Luvisol	Haploxeralf
Red Mediterranean	Chromic Luvisol	Rhodoxeralf
Red yellow podzolic	Orthic Acrisol	Typic Hapludult or Typic Rhodudult (according to color)
	Ferric Acrisol	
Grey brown podzolic	Ochric Luvisol	Hapludalf
Grummusol	Chromic Vertisol	Chromoxerert
Bog	Eutric Histosol	Histosol
Half-bog	Mollic Gleysol	Humaquept
Regosol	Eutric Regosol	Entisol (Psamment, etc) Torriorthent
Lithosol	Lithosol	Lithic subgroups
	Other groups with *lithic phase* (rock between 10 cm and 25 cm)	

the land resources of the country was started with the following main purposes.

- to summarize available information on land resources,
- to make a broad, comparative and qualitative assessment of present and future land potentialities (based upon available information),
- to indicate present gaps in knowledge and to direct further studies of land resources (climate, topography, soils, vegetation, drainage),
- to identify major land-use problems and to carry out further land-use studies for alternative development, based on trials, experiments, agricultural surveys, etc , and
- to indicate where more detailed soil surveys should be undertaken to establish priorities and also to provide a framework for further soil-survey interpretation based on a preliminary assessment of limitations, problems, and land potentialities

Land-use Potential of the Soils of Iran

A general description of the soils of the country and their potential for use in agriculture and forestry is given in the following paragraphs

Soils of the Plains and Valleys

Fine-textured alluvial soils

These are more or less young alluvial soils, occurring either as alluvial fans, deltas, or flood plains, with little or no profile development in the pedological sense In many areas, deposition is continuing from annual floods They are normally level to gently sloping with moderate to good drainage

These soils comprise an area of 6 1 million hectares and are distributed mainly throughout the western part of the country They are usually reasonably fertile and lend themselves to the production of most crops, from annual crops to fruit and other trees, under irrigation, while some areas are suitable for dry farming of cereals and other crops

Coarse-textured alluvial and colluvial soils and Regosols

These soils vary considerably but are found normally as coarse to very coarse materials on moderate slopes with good to excessive drainage and are subject to gully erosion There are almost 6 million hectares of these soils, found mostly in the south and southeastern parts of Iran They have very low agricultural value in their present state and afford only sparse grazing for livestock The extreme stoniness of the surface, the low moisture-holding capacity, and the excessive internal drainage of the coarse-textured profile above a gravelly substratum render these soils poor for either dry farming or irrigation However, there are considerable areas where the above disadvantageous characteristics are not pronounced and where, by clearing the stones from the surface and carrying out some surface grading and control of surface-water runoff, these soils may be used for irrigation with reasonable success, provided that sufficient water is available and care is taken to restrict the length of the irrigation run The good internal drainage can be an advantage because water of quite high salinity may be used for irrigation of certain crops with less probability of salinity buildup in the soil

Sand dunes (including coastal sands)

These occur around the margins of deserts and along the coasts They may be fixed by vegetation, where sufficient moisture is available and wind velocities are not high, or they may occur as mobile undulating dunes

Desert dunes occur mainly in the central and southwestern parts of the country, while coastal dunes are found mainly on the coast of the Sea of Oman, in the coastal and southern arid zones Of the 3 million hectares of these soils, over 1,260,000 hectares are in the southern arid zone, mainly in Baluchestan,

and almost 1 million hectares are in the Dasht-e-Kavir Desert in the northeastern parts of the northern arid zone and in southeastern Khorassan.

Most of the remainder is in western Khuzestan and the northeastern part of the Caspian zone These are usually wastelands but may provide sparse grazing from dunes fixed by vegetation Moving dunes may cause considerable damage as they move over the country destroying crops, invading villages, and filling irrigation ditches

Low humic-gley, humic-gley, and half-bog soils

These hydromorphic soils arise mainly from the recession of the Caspian Sea, but some small areas are found in inland locations. Most of the 356,000 hectares occur on the Caspian coast in Gilan and in small areas in Mazandaran, North Azerbaijan, Kermanshah, and Khuzestan

These soils are too wet and have a drainage too poor for the production of most crops, but they are quite suitable for the production of rice Much of the current rice production occurs on these soils, and it is doubtful therefore if the installation of drainage works to allow for alternative cropping would be justified

Solonchak and Solonetz soils

These soils occur in the arid, semiarid, and dry subhumid regions of Iran

Occurring mainly in the more arid regions of the central and southern parts of the country, most of the 7 3 million hectares of these halomorphic soils are found in southern and southeastern regions close to the coast. They are either poorly drained or have developed under poor drainage conditions

Solonchak soils

These are light-colored soils, high in soluble salts, formed usually on alluvial sediments, often on old lake or sea beds They frequently have a high water table and are usually unsuitable for crop production without very expensive reclamation measures for use with irrigation. Normally, such measures would be uneconomical. These soils may be used for livestock grazing, and the halophytic vegetation offers some balance to the mineral diet of sheep and goats

Solonetz soils

The Solonetz soils normally have a dark-colored, columnar-structured B horizon of heavy structure They are usually the product of partial leaching and alkalinization of Solonchak soils This can result from irrigation without proper drainage and management, and Solonetz soils are often found as spots within the areas of Solonchak soils, hence, separate mapping of these soils is difficult Solonetz soils may be either wasteland or poor grazing country but may be used for dry farming, wherein only poor yields will be obtained Their use for irrigation is risky and can well result in complete loss of productivity Reclamation is possible but usually very costly, development of these soils therefore should be given a very low priority Only if very good management is available and strict control of water use is possible should reclamation of these soils be attempted

Saline-alluvial soils

Saline-alluvial soils result from poorly drained alluvial soils They may be moderately to severely affected by salinity in the fine-textured subsoil They are level with poor surface drainage and thus have slow internal permeability, with a reasonably deep water table where not irrigated The ground water may be sufficiently low in salts to be used for irrigation, but drainage is necessary where ground water is saline or where cropping is to be intensive There are 5 1 million hectares of saline-alluvial soils distributed through Iran where alluvial soils occur, especially in the Khorassan and southern arid zones It may be used for pasture or dryland cereal production where rainfall is adequate or for growing sugar beets and cotton where irrigation water of adequate quality and quantity is available Normally, a drainage system needs to be installed, and excess water is needed to ensure leaching of the salts in these soils Rice may be grown

while leaching is being carried out, before other crops can be planted.

Salt-marsh soils

These soils occupy low-lying areas where water is near or on the surface all year round They are normally poorly drained clays with a high salt content There are about 8 million hectares of these soils in valleys and particularly in the Dasht-e-Kavir Desert

Some poor crops of rice may be obtained in certain areas of these soils, but the soils are normally of no agricultural use They occur mainly in areas of occluded drainage and where there is no economic possibility now of constructing drainage systems

Soils of the Plateau

Grey and red desert soils

Formed under conditions of severe moisture deficiency, these soils are characterized by a thin, compacted A horizon (desert pavement), with surface grit or gravel and little profile differentiation They are highly calcareous and well drained, though normally almost level There are 2 million hectares of grey and red desert soils concentrated in the deserts of central and southeastern Iran

Lack of adequate rainfall prevents dry farming crop production on these soils, but they are usually high in plant nutrients, with the exceptions of nitrogen and phosphorus, and can be highly productive under irrigation, as has been proved where irrigation from ghanats is being carried out These soils have a very high potential for agricultural production if water can be made available for irrigation

Sierozem soils

Occurring usually on level sites, Sierozem soils are characterized by a light-colored, powdery A horizon, which becomes platy after rain, in the surface and mostly over a zone of lime accumulation The subsoil is usually loosely structured and gravelly External drainage is slow from the surface but moderate internally, and the substratum is always dry. Almost half the 10 4 million hectares of these soils are to be found in the Khorassan zone, another 3 5 million hectares are in the central zone, and 1 3 million hectares in the northern arid zone

These soils may be expected to yield only poor results when used for dry farming, but they can provide fair natural range grazing Given irrigation, they have a good potential for crop production if drainage is adequate and salt content of the soil is low For optimum yields, phosphorus and nitrogen will need to be applied

Brown soils

Brown soils occur in different parts of Iran's semiarid regions They are brown to light brown, usually overlying a calcareous horizon in the form of lime concretion The brown steppe soils are the most predominant soils in Iran, amounting to 7 million hectares, concentrated mainly in the northeastern, northwestern, and western regions

They are used either for pastures or for dry farming of wheat and barley, whose yields are reasonably good in an average year Very good yields may be expected from most crops under irrigation accompanied by proper cultural and management practices

Chestnut soils

Developed in semiarid and subhumid areas, these are friable soils, with a dark upper layer over a calcareous zone at 50 to 150 cm There are only 1 million hectares of these soils, occurring mostly in the northwestern and central Zagros zones Because chestnut soils are found mainly on slopes, their use for irrigated cropping is limited Hence, they are used mainly as pastureland, though some dry farming of cereals and cotton are carried out on the more level land, with supplemental irrigation

Desert soils and Regosols

Associations of desert soils and Regosols often occur. They are shallow, calcareous soils of light-to-coarse texture, gravel and

coarse sand usually predominating the profile. They may occur on level land or steep slopes and have good-to-excessive drainage

There are 7 6 million hectares of these soils mainly concentrated in the southeast in the Dasht-e-Lut Desert of the southern arid zone Lack of rainfall inhibits the development of these soils for agricultural production, but irrigation would make them suitable for many crops within the limits imposed by temperatures.

Desert soils–sand dunes

Undulating and frequently moving, 5 6 million hectares of sand dunes occur in the Yazd province of the northern arid zone and in the Dasht-e-Lut Desert area of the southern arid zone.

Normally a wasteland, these desert soils sometimes are used as very poor range

Desert soils–Sierozem and Solonchak soils

These are saline soils of the desert Normally fairly level with moderate-to-slow internal and moderate external drainage, 3 5 million hectares of these soils are found mainly in the Dasht-e-Kavir Desert and on the Sistan Plain; 1 4 million hectares in the Khorassan zone, in the Sistan Plain, and 0 8 million hectares in eastern Baluchestan in the southern arid zone The remainder is in the Dasht-e-Kavir Desert in the central and northern arid zones

These soils are wastelands, and they serve at best as poor range, with poor potential for irrigation

Sierozem soils–Regosols (including sand dunes)

This complex of soils, which are normally calcareous and only slightly saline, occurs on level to moderately sloping sites and has good-to-excessive drainage

There are over 9 million hectares of these soils 4 5 million in the Khorassan zone, 2 4 million in the southern arid zone, and 1 2 million in the northern arid zone The remainder is in the southern and eastern parts of the central zone and the extreme northern section of the southern Zagros zone

These soils are useless and thus serve only as very poor grazing in their natural state, but they do have good potential for production of orchard and vine crops if irrigation could be made available

Brown soils–Lithosols

These are the brown soils of the undulating-to-steep slopes and are shallow to deep depending on their situation on the slopes They have good-to-excessive drainage.

There are 2 6 million hectares of these soils, mainly in western and northwestern Iran in the northwestern and central Zagros zones

They are usable only as poor-to-moderate grazing lands But they will produce good crops of wheat where rainfall is adequate, and they are suitable for growing orchards and vineyards where irrigation water is available and correct terracing methods are used to control water retention and prevent erosion

Soils of the Caspian Piedmont

These are the soils of the sloping foothills of the Alborz Mountains descending to the Caspian Sea The climate of this area is humid in the western part and subhumid to semiarid in the east, making it a typical zone for Iran

Red and brown Mediterranean soils

Developed under reasonably high rainfall conditions, these soils have derived from either limestones or basalts and sandstones They have a well-developed profile with calcareous inclusions, which is well structured and has good-to-excessive drainage These soils occur on moderate-to-steep slopes and in spots rather than in large areas

Red-yellow podzolic soils

These podzolized and developed acid soils are formed on moderate-to-steep

slopes They derive from a wide variety of parent materials but rarely from limestones Drainage also varies from poor to good according to the parent material There are only 20,000 hectares of these soils, all in the Gilan Ostan, which are mostly pasture land and some forest lands on the steeper slopes Although they are being used for tea production, they can be used for other crops where slope permits Without the installation of adequate soil-conservation structures, these soils pose the danger of becoming unstable and slipping where forest cover is removed from slopes

Brown forest soils (including grey-brown podzolic soils)

These are acid soils developed in the more humid areas mainly on steep slopes They have medium-to-poor internal drainage There are 360 000 hectares of these soils in the Caspian zone, 280,000 hectares in Mazandaran Ostan, and the remainder in Gilan

The native vegetation is deciduous forest of beech, hornbeam some Persian oak, and scattered conifers in places Generally, they are topographically unsuited to cultivation and are best retained as forests but fruit trees could be planted on the lesser slopes

The grey-brown and brown podzolic soils found in association with the brown forest soils usually are on the more gentle slopes and are more acid Their present and potential land use is much the same as for the brown forest soils

Soils of the Dissected Slopes and Mountains

These are the soils of the steep hills and mountains of Iran, associated mainly with the Elburz and Zagros mountain complex, though they are also found in the hills of the plateau and western parts of Iran The better classes of soils associated with the Lithosols occur in small pockets, which can be important locally for annual cropping or fruit production, especially where spring waters are available, but they usually support forest and pastures of variable quality Overgrazing and deforestation are evident in most areas Their greatest potential is for pastures under controlled grazing and, where possible, reafforestation

In general, because the different classes of soils found in these associations occur as very shallow phases on excessive slopes, severe erosion takes place when cultivated by traditional methods Except where there is sufficient depth of soil on less acute slopes these soils are best used for grazing or, in some cases, afforestation Estimation of the area of soils that may be used for agriculture is impossible without intensive survey and study, but it is probable that much could be productive as small pockets, especially where water is available for irrigation and provided that more sophisticated cultural methods are adopted to prevent soil erosion and to conserve soil moisture

Brown soils–Rendzinas

These soils are limited to 720,000 hectares and are not highly productive mainly because of their shallow depth and low moisture retention They could be used for short-season spring crops where the degree of slope allows, but they are best used for grazing

Desert and Sierozem soils–calcareous Lithosols

Over 27 8 million hectares of these soils now provide only poor grazing but could be more productive if proper range management practices were to be adopted Some small areas could be cropped where irrigation water is available

Desert and Sierozem soils (including salt plugs)–calcareous Lithosols (from saliferous and gypsyferous marls)

Together with sand dunes, these 14 8 million hectares of soils are probably the least productive in Iran They usually occur as wastelands and are unsuitable for either cropping or grazing

Brown and chestnut soils–calcareous Lithosols

Over 21 3 million hectares of these soils are used mainly for grazing but are badly overgrazed and now have a very low carrying capacity A very extensive association, these soils in many small areas are used for dry farming

Brown and Sierozem soils–Lithosols from igneous rocks

Over 10 6 million hectares of these soils usually occur on very steep slopes, highly vulnerable to erosion if disturbed Although they are now being used for grazing and are severely overgrazed, proper range-management methods could turn these soils into small areas suitable for cropping

Brown forest soils and Rendzinas –Lithosols

Many of the over 2 3 million hectares of these soils carry good natural forest But severe erosion has taken place where the forests were cleared and bad farming practices were adopted These soils could become a valuable forest resource and produce some fruit and other tree crops if correct soil conservation practices are adopted and more discrimination is shown in the degree and method of forest clearing

Regosols–red-yellow podzolics

These soils also carry forest in their natural state, but they have eroded badly where forest has been cleared They are best used for reafforestation, but parts could be used for tea plantations There are 16,000 hectares of these soils

Brown forest and podzolic soils–Lithosols (mainly from igneous rocks)

These soils are very shallow and occur on steep slopes As is the case with the previous two soils mentioned, 20,000 hectares of these soils are found on the northern slopes of the Elburz Mountains, where a reasonably high rainfall renders them able to support natural forests They are best used as natural forest, but they can also be used, under careful management, for reafforestation where clearing of forests has led to soil depletion

Agricultural Potential of the Soils of Iran

The soil map produced by the Soil Institute of Iran provides a valuable basis for the planning of agricultural development in Iran But because this is a broad-scale map based on a combination of field studies and interpolation from aerial photographs, it needs to be refined Although studies of semidetailed and detailed soil surveys have been in progress for many years they have been confined largely to specific areas to provide a basis for planned or proposed development projects usually associated with irrigated agriculture The Soil and Land Evaluation Section of the Soil Institute of Iran is now carrying out a systematic study of the country, covering such natural resources as soils, climate, vegetation, and topography This is being done on a priority basis to cover those parts of the country where land-use potential is expected to be highest Studies have been completed and maps are now being compiled and reports published for an area of about 50 million hectares, or approximately 30% of the total land surface area of Iran

The regional land-resources inventories, which include land-evaluation assessments, are used as a general guide for regional development planning These inventories are not a substitute for soil surveys but rather a first approximation to a quick and broad assessment of the available land resources and their capabilities on the basis of which suitable areas can be selected for further study Examples are a semidetailed soil survey and land classification The system of classification used provides a comprehensive picture of the whole spectrum of land-use potential Cropping land is shown by various classes of suitability for either dry farming or irrigation, while land unsuitable for arable cropping is shown by separate categories of suitability such as pasture and forestry These

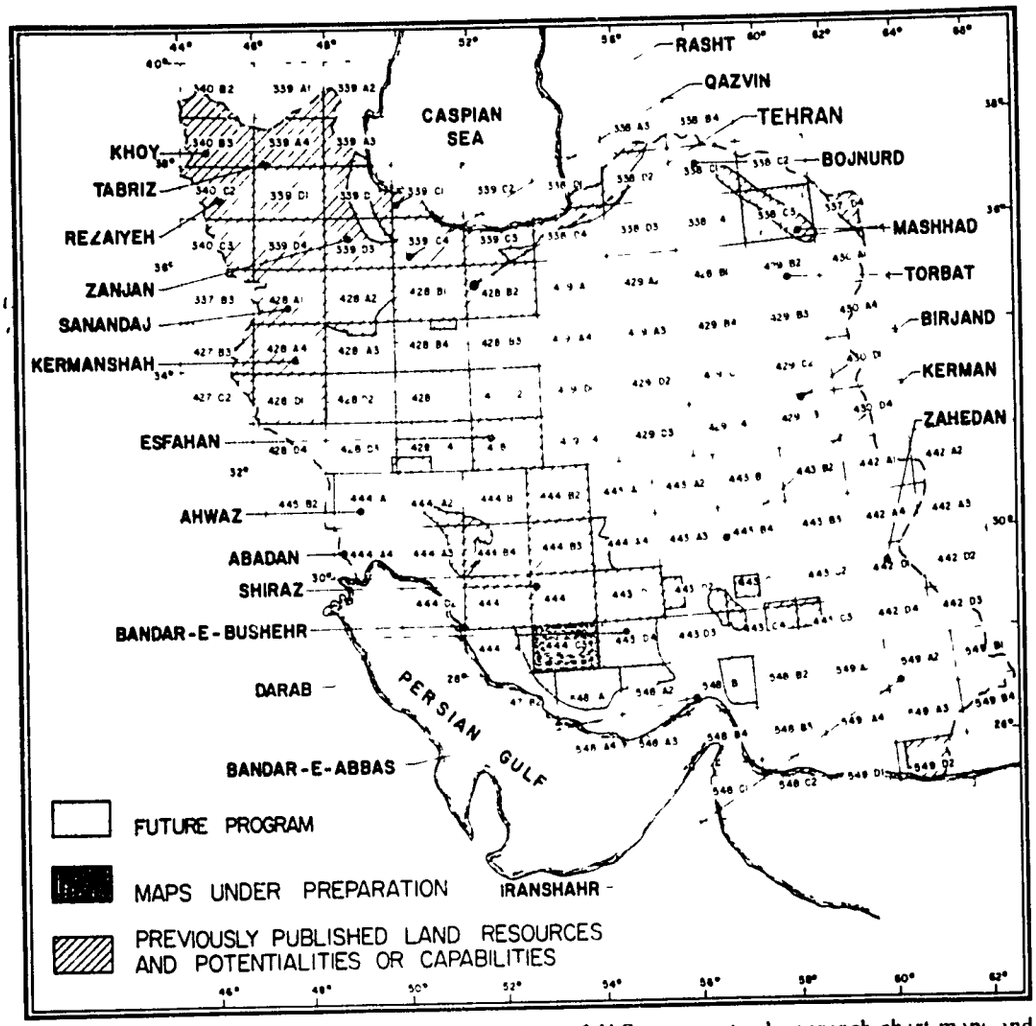

Fig 1 Map of Iran indicating the sheet numbers of U S aeronautical approach chart maps and location of land resources studies (1975)

surveys and the resultant maps are gradually overcoming the inadequacies of the broad-scale soil map of Iran The importance of the completion of this land-resource evaluation work to the planning of the agricultural and livestock development of Iran cannot be too heavily stressed

The working procedures used in preparing the land-resources map are those published by the Soil and Land Evaluation Section of the Soil Institute of Iran Figure 1 shows the various land-resources and land-capabilities maps of Iran either already published or now being prepared or being planned

PART II:
INTERPRETATION OF SOIL-RESOURCE DATA

Soil-Survey Interpretations for Improved Rubber Production in Peninsular Malaysia

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An appraisal of available experimental results and soil and crop data has shown that soil clone interaction has a strong effect on *Hevea* yields There is evidence to support this for such important pedological properties as soil texture soil depth "effective' depth slope and drainage This observation led to the idea of ranking soils which in turn resulted in the establishment of a soil-suitability technical grouping system for *Hevea* (based on a modified Storie index approach and substantiated by yield patterns observed) In general for the better soils there is not any or only minor soil limitations whereas for the poorer soils inferior *Hevea* performance is related to serious and very serious soil limitations

Agromanagement is important for improving yields in a particular soil situation There can be considerable economic benefit for the better-ranked soils but less benefit for the poorer soils Indexes of such relationships have led to the concept that the maximum productivity potential of a specific soil-crop situation is a reflection of not only the genetic plant material factor but also the soil factor the edaphic environmental features, and agromanagement Consequently, agromanagement inputs such as choice of planting materials discriminate use of fertilizers and soil-conservation practices are currently screened on the basis of such guidelines and especially soils

Thus there is a need for precise recognition and mapping of homogeneous soil units To achieve this, there must be proper classification of soils, which explains the importance of the roles of soil surveys and pedology in improving the agronomic efficiency of rubber production in Peninsular Malaysia To that end soil maps at various scales to serve specific objectives have been produced for most of the rubber-growing areas in the country A countrywide reconnaissance soil map is also available for broad planning in the optimization of land-resource use

Considerable variability has been found in the physical and chemical characteristics of soils that grow rubber in Peninsular Malaysia (Guha and Yeow, 1966, Rubber Research Institute of Malaysia, 1971*a* and 1971*b*, Chan and Ratnasingam, 1973) The influence of the physical and chemical properties of soils on fertilizer needs and their interactions on the performance of *Hevea* in Peninsular Malaysia has also been shown (Pushparajah and Guha, 1968, Chan and Pushparajah, 1972, Chan et al , 1972)

Soil properties were shown to be related to the fertilizer needs of *Hevea* and, to overcome chemical limitations, the use of nutrient surveys of soil and foliar was developed to diagnose fertilizer needs (Guha, 1969, Guha et al , 1971, Chan, 1971, Chan et al , 1972, Pushparajah and Ian, 1972) Variations in physical properties of soils have also

been shown to be strongly related to the yield patterns of *Hevea* (Chan and Pushparajah, 1972, Chan et al, 1974) There was also strong evidence of a clonal selectivity of soil series This led to the crystallization of the "environment" concept about choice of planting materials, wherein clonal recommendations are provided not only according to features of genetic material, disease, and wind-damage susceptibilities but also according to adaptability to a specific soil type Subsequently, information and a pooled collation of available agronomic data enabled the identification of major physical limitations of the poorer soils so that appropriate agromanagement practices could be employed to improve yields (Chan et al, 1973)

Additionally, Chan and Pushparajah (1972) showed further proof of the importance of discriminating agromanagement inputs according to soil type to achieve optimum yields and maximum profits from high-yielding clones

These findings emphasize the important role soil surveys and pedology play in the advances being made towards increasing the agronomic efficiency of rubber production in Malaysia This paper summarizes the principles and recent approach adopted by the Institute concerning soil surveys

History and Nature of Rubber Production in Peninsular Malaysia

The first seeds of *Hevea brasiliensis* that formed the genesis of the now 1 7 million-hectare (4 2 million acres) industry were brought to Malaysia about 100 years ago However, it was only at the turn of the century that the industry as it is today began to take shape and grow in pace with the demands of the motor and related industries throughout the world By 1925, the world rubber production was 530,000 tons, ten times more than that of 1905, by 1940, it had grown to 1 5 million tons, with the Malaysian production alone accounting for one-third of the world supply

During World War II, the invention of synthetic rubber and its commercial availability resulted in a different turn for the industry, since warring countries needed to be independent of the traditional natural source of rubber as their need for rubber for war machinery grew When the war ended, the position and future of synthetic rubber appeared well established to the loss of natural rubber's position of being the sole elastomer in demand

However, by the mid-sixties, confidence revived in the future of natural rubber because of the leading role Malaysia played in the modernization of the product Intense efforts of research and development enabled higher productivity, more rapid turnover of production, enhanced technological benefits of the product, and improved grading, quality control, and marketing Concerted efforts were aimed at increasing productivity and reducing production costs through the following optimum utilization of land resources, proper use of agronomic practices, earlier tapping and the use of clonal stimulants, intercropping and integrated area development, and improved processing methods All of these had in common a cost-benefit objective These efforts, the fruit of 50 years of intense research by the Rubber Research Institute of Malaysia, provided the necessary economic base for the rubber industry to compete against synthetic rubber and swung the world demand back in favor of natural rubber

Today, because of proven technological and cost benefits of natural rubber compared with synthetic rubber, there is no longer any doubt that the natural rubber industry is here to stay Moreover, the world's present concern for a healthier environment and its energy crisis gives greater credence to the future of natural rubber The process of producing natural rubber using natural inputs of sunlight, water, and soil hardly pollutes the environment, where energy is concerned, increasing production costs of synthetic rubber using fast depleting resources have raised doubts about its continued availability Continual research and development will no doubt establish further dependence of man on natural rubber

As a result of intensive research and de-

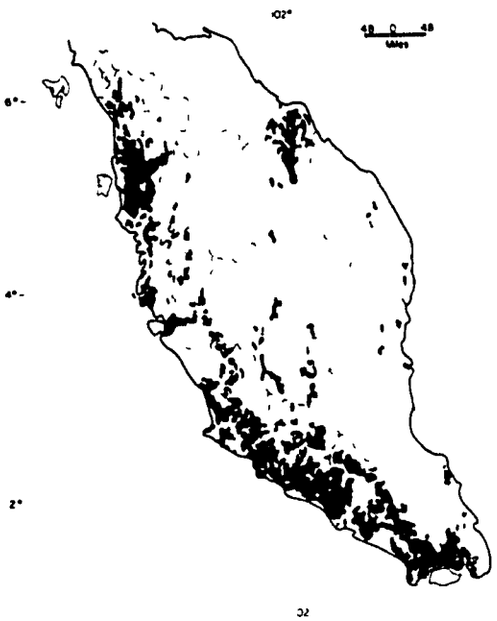

Fig 1 Reconnaissance map of rubber-growing areas in Peninsular Malaysia (Courtesy The Director, Department of Agriculture, Peninsular Malaysia and The Director of National Mapping, Malaysia)

velopment efforts, Malaysia today enjoys the position of being the largest rubber producer in the world, rubber production totaled 1 6 million tons in 1974 and is expected to reach 2 million tons by 1980 The rubber industry today retains its role as the mainstay of the Malaysian economy in terms of land use for agriculture (66%), employment (33%), foreign exchange earnings (30%), and gross national product (15%) This reflects the significant contribution of research and development and has made the Institute's role all the more significant The rubber-growing areas of Peninsular Malaysia are shown in Figure 1

Relationship between Soil Characteristics and Rubber Production

Influence of Morphology

The performance of *Hevea* in relation to the soil-texture variation on the Rasau series (Tropudult) and Jerangau series (Paleudult) is shown in Table 1 The performance of clone PB 5/51 (Experiment SE 108) improved as clay content increased from a textural range of sandy clay loam to sandy clay in the topsoil and sandy clay to clay in the subsoil The mean girth increased by 3% and the yield by 18% The better performance may be traced to the higher clay content, which stores more moisture (Soong, 1971) and nutrients (Rubber Research Institute of Malaysia, 1971*b*) The better performance of *Hevea* was also reflected in the leaf nutritional status, which showed comparatively high levels of nitrogen, phosphorus potassium, and magnesium Similar patterns were also observed in Experiment SE 107 (2% increase in girth and 9% increase in yield) and in Experiment SE 62 (5% increase in girth and 12% increase in yield)

Influence of Physiography

Soil depth to parent material layer

Table 2 shows the mean girth and yield measurements in relation to the soil depth to parent material layer on Serdang series (Tropudult) Both mean girth and yield are relatively higher, by 3 and 4%, respectively, for PB 5/51 (Experiment SE 90) in the deeper soil (> 125 cm), which also recorded higher leaf nitrogen, phosphorus, and potassium

Soil depth to an impenetrable layer

Table 2 also shows the mean girth and yield in relation to the depth of soil to the compact impenetrable ironstone or laterite layer found in the Malacca series (Petroplinthic Haplorthox) The growth and yield of PB 5/51 (Experiment SE 102), growing on soil 25 to 50 cm deep (depth from surface to laterite pan), were improved by 4 and 24%, respectively, compared with those of trees on shallower soil (0 to 25 cm) Leaf-nutrient status was also better for phosphorus, potassium, and magnesium

A similar pattern was obtained for the same clone on the same soil but with a steeper slope of 12 to 26% Girth and yield on the

Table 1 Mean girth and yield measurements of mature rubber in relation to soil texture

Experiment number	Planting material		Soil series	Soil classification on lower category					Mean girth		Mean yield		Mean leaf-nutrient content (dry weight percentage)			
				Slope percentage	Drainage	Depth (cm)	Texture									
	Clone	Age (years)					Topsoil	Subsoil	Cm	Relative percentage	Gram per tree per tapping	Relative percentage	N	P	K	Mg
SE 107	PB 5/51	7	Rasau	0–1	Well drained	125	Sandy clay loam	Sandy clay loam	61.26 (13)	100	44 73 (13)	100	3 19	0.22	1.37	0 35
	PB 5/51	7	Rasau	0–1	Well drained	125	Sandy clay loam	Sandy clay	62 71 (31)	102	48.77 (31)	109	3.29	0.23	1.47	0.35
SE. 108	PB 5/51	8	Rasau	0–1	Well drained	125	Sandy clay loam	Sandy clay	56 8 (28)	100	17.8 (26)	100	3 11	0.27	1.22	0.31
	PB 5/51	8	Rasau	0–1	Well drained	125	Sandy clay	Clay	58 5 (32)	103	21.0 (29)	118	3.23	0 28	1 44	0.33
SE 62	LCB 1320	4	Jerangau	8–16	Well drained	125	Sandy loam	Sandy clay loam	34 0 (3)	100	a	100[a]	2 44	0 16	0 89	0 25
	LCB 1320	4	Jerangau	8–16	Well drained	125	Sandy clay loam	Sandy clay	35 6 (6)	105	a	112[b]	2.42	0 16	1 08	0 22
SE 106	GT 1	10	Holyrood	0–1	Somewhat excessively drained	125	Loamy sand	Sandy loam	56 9 (30)	100	29 9 (29)	100	3 03	0.26	1.00	0.5
	GT 1	10	Holyrood	0–1	Somewhat excessively drained	125	Sandy loam	Sandy clay loam	57.3 (13)	101	30.8 (13)	103	2.96	0 26	1 04	0.5

SOURCE. Data from Chan, Wong, Pushparajah, and Sivanadyan, 1974

NOTES According to the U S *Soil Taxonomy*, the Rasau series is identical with Oxic Dystropept, the Jerangau series, with the Typic Paleudult, and the Holyrood series, with Typic Quartzipsamment

Figures within parentheses denote number of 0 2-hectare plots (60 trees) recorded in soil unit.

[a] Not available as area not yet in tapping.

[b] Estimated by using formula used by Ho (1974) yield = K(girth in cm)$^{2.5}$

soil property of 50 cm deep were higher by 2% and that of 75 cm by 19%, with appreciable increases in leaf potassium and magnesium compared with an area that has a soil-depth to laterite-phase relation of 0 to 25 cm

Even for immature rubber (stumped buddings) of RRIM 600 on the Malacca series soil (Experiment SE 117) of 25 to 50 cm deep, there was a girth increase of 8% compared with that of the same soil of 0 to 25 cm Though the comparison is based on one plot for the deeper soil phase, the value obtained (15 26 cm) was generally well above that for a shallower soil phase (14 11 cm) Since all other relevant soil and edaphic conditions were similar the effect of soil depth or effective depth (to impenetrable layer) is apparent and is consistent with soil-to-crop behavior, that is, deeper soil provides greater soil volume for better development of main and lateral roots (Soong, 1971) As the soil surface area increases exploitation of moisture and nutrients also increases in both the top and subsoils, resulting in more efficient nutrient uptake This is reflected by the generally higher leaf-nutrient levels of nitrogen phosphorus potassium and magnesium observed for the deeper soils A reduction in yield has been shown to occur by the lowering of tree density caused by losses from the uprooting of poorly anchored roots in shallow soils (Chan and Pushparajah, 1972)

Slope

Table 3 compares the mean girth and yield of four clones in relation to slope In the cases considered, both girth and yield increased as slopes increased (not exceeding 26%) For clone LCB 1320 on the Jerangau series (Paleudult) in Experiment SE 62, the girth increased by 2% and the yield by 2% when the slope increased from 3 to 8% to 8 to 16% For PB 5/51 on the Malacca series (Petroplinthic Haplorthox) in Experiment SE 102, in addition to increases of 2% for girth and 6 5% for yield, slightly higher leaf potassium (1 46%) and magnesium (0 19%) levels were obtained for the higher slope of 5 to 8% Further, for the highest slope of 12 to 26%, increases of about 3% for girth and 13% for yield were obtained There were also appreciable increases in leaf nitrogen and phosphorus and a marked increase in potassium For PB 5/51 (Experiment SE 101) on the Durian series (Plinthudult), the mean girth was increased by 4% and the mean yield by 10% when the slope increased from 3 to 8% to 8 to 16% Higher leaf nitrogen (3 0%) and potassium (1 63%) levels were also recorded For immature rubber (RRIM 600) on the Malacca series (Petroplinthic Haplorthox), there was a relative increase of 15% for girth when the slope increased from 3 to 8% to 8 to 16%

The above observations are consistent with the basics of soil-to-crop behavior, with particular reference to the modifying influence of topography on soil properties such as internal and external drainage, surface runoff infiltration, and soil structure It is likely that an increasing soil slope, up to a point (benchmark slope?), leads to better drained soils and hence better *Hevea* performance If the elevation is slight, water stagnation can occur, resulting in poor drainage conditions An example is the Durian series (Plinthudult) which are clay-textured, derived from finer-grained parent material Such conditions limit good aeration and penetration of roots and can have detrimental effects on the *Hevea* performance

If the slopes are steeper (e g , above 26%), more surface runoff can occur and, as shallower soils are usually the genetic result on soil tops, the cumulative effects of these two factors can be limiting to optimum performance

Effective soil depth to water table

Based on soil survey and agronomic data obtained, Table 4 shows the yield behavior of PB 86 on the Selangor series (Sulfaquept) under the influence of the water table at 50 cm and 100 cm from the soil surface Table 4 clearly demonstrates an additional yield of about 222 kg per hectare, or an additional cumulative yield of 1,333 kg per hectare over a period of 6 years, obtained where the water table was deeper, that is, at 100 cm

This phenomenon is consistent with the logistics of soil-to-crop behavior, where the

Table 2. Mean girth and yield measurements in relation to soil depth

Experiment number	Planting material		Soil classification on lower category						Mean girth		Mean yield		Mean leaf-nutrient content (dry weight percentage)			
							Texture									
	Clone	Age	Soil series	Slope percentage	Drainage	Depth (cm)	Topsoil	Subsoil	Cm	Relative percentage	Gram per tree per tapping	Relative percentage	N	P	K	Mg
Soil depth to parent material layer· mature rubber																
SE. 90	PB 5/51	5 years	Serdang	3–8	Somewhat excessively drained	0–50	Sandy loam	Sandy clay loam	50 01 (26)	100	26.84 (23)	100	2.96	0.19	1.50	0 29
SE. 90	PB 5/51	5 years	Serdang	3–8	Somewhat excessively drained	>125	Sandy loam	Sandy clay loam	51 40 (7)	103	28.02 (7)	104	2.98	0.22	1.55	0.29
Soil depth to an impenetrable compact laterite mature rubber																
SE. 102	PB 5/51	13 years	Malacca	8–12	Well drained	0–25 H L P[a]	Clay	Clay	63.96 (15)	100	29 14 (15)	100	3 23	0 24	1.32	0 16
	PB 5/51	13 years	Malacca	8–12	Well drained	25–50 M L P.[b]	Clay	Clay	66 72 (5)	104	36 26 (5)	124	3.13	0.27	1.68	0.21
SE. 102	PB 5/51	13 years	Malacca	12–26	Well drained	0–25 H L P.[a]	Clay	Clay	66 02 (3)	100	31.37 (3)	100	3 17	0 25	1.53	0 13
	PB 5/51	13 years	Malacca	12–26	Well drained	50–75 M L.P.[b]	Clay	Clay	67 19 (2)	102	37.32 (2)	119	3.19	0 26	1 64	0 18

Soil depth to an impenetrable compact laterite immature rubber

| greater soil volume in the latter case has allowed better exploitation of moisture and nutrients and superior root anchorage

Combined Pedological Effects on *Hevea* Yields

Although the discussion hitherto has shown singular effects of a specific soil or physiographic characteristic on *Hevea* yields, varied combinations of a soil property constituting different pedological units also affect yield trends markedly (Chan and Pushparajah, 1972)

Yield patterns of popular clones on soils

Yield patterns considered according to the soil units of the subgroup category of the preliminary abridged text of the *Soil Taxonomy* are shown in Table 5 There is a broad pattern of yield behavior for the different soil units The mean yield per hectare per year is 1,212 kg and the cumulative yield is 3,635 kg for a common clone like PR 107 on Typic Paleudults, compared with 895 kg (mean yield) and 2,684 kg (cumulative yield) per hectare on Typic Sulfaquepts or Typic Tropaquepts For modern clones like RRIM 600, the pattern is also in the order of Typic Paleudults, with the annual mean yield of 1,492 kg and the cumulative yield of 4,476 kg per hectare, followed by the Oxic Dystropepts (1,290 kg and 3,871 kg per hectare), and finally the Typic Sulfaquepts or Typic Tropaquepts (897 kg and 2,691 kg per hectare) This pattern is also obtained for the other modern *Hevea* clones like GT 1, PB 5/51, RRIM 605, and RRIM 623 in the general ranking order as follows Typic Paleudults > Petroplinthic (?) Haplorthox > Oxic Dystropepts > Typic Sulfaquepts or Typic Tropaquepts

The ranking order is also about the same for older planting materials like PB 86 and Tjir 1, Typic Paleudults ranking ahead of Typic Tropaquepts and Typic Sulfaquepts, although there is little significant difference in yield trends This is probably attributable to the poor genetic material that is unable

Table 3 Mean girth and yield measurements in relation to slope

Experiment number	Planting material		Soil series	Soil classification on lower category					Mean girth		Mean yield		Mean leaf-nutrient content (dry weight percentage)			
				Slope percentage	Drainage	Depth (cm)	Texture									
	Clone	Age					Topsoil	Subsoil	Cm	Relative percentage	Gram per tree per tapping	Relative percentage	N	P	K	Mg
Mature rubber																
SE. 62	LCB 1320	4 years	Jerangau	3–8	Well drained	>125	Clay loam	Clay	35.07 (4)	100	c	100[b]	2.74 (4)	0.17	0 94	0.24
	LCB 1320	4 years	Jerangau	8–16	Well drained	>125	Clay loam	Clay	35.92 (10)	102	c	106[b]	2.57 (10)	0.17	0 93	0.24
SE. 102	PB 5/51	13 years	Malacca	3–5	Well drained	0–25 H L P[a]	Clay	Clay	64 18 (7)	100	27 84 (9)	100	3 11 (7)	0.24	1.40	0.18
	PB 5/51	13 years	Malacca	5–8	Well drained	0–25 H L P[a]	Clay	Clay	64 93 (19)	101	29 64 (26)	106	3 10 (19)	0.24	1.46	0.19
	PB 5/51	13 years	Malacca	12–26	Well drained	0–25 H L P[a]	Clay	Clay	66 02 (3)	103	31 37 (3)	113	3 17 (3)	0.25	1 53	0 13
SE. 101	PB 5/51	9 years	Durian	3–8	Moderately well drained	0–25 H L P[a]	Clay loam	Gravelly clay	52 87 (26)	100	c	100[b]	2.93 (26)	0 22	1 53	0 41
	PB 5/51	9 years	Durian	8–16	Moderately well drained	0–25 H L P[a]	Clay loam	Gravelly clay	55 15 (4)	104	c	110[b]	3 00 (4)	0 21	1 63	0 37

Immature rubber																									
Differential manuring and mulching trial	RRIM 600	20 months	Malacca	3–8	Well drained	0–25 H L P	Clay	Clay	14 11 (9)	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	RRIM 600	20 months	Malacca	8–16	Well drained	0–25 H L P	Clay	Clay	16 23 (1)	115	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

SOURCE Data from Chan Wong Pushparajah and Sivanadyan, 1974

NOTE According to the U S *Soil Taxonomy* the Jerangau series is identical with Typic Paleudult the Malacca series with Petroplinthic (?) Haplorthox, and the Durian series with (Typic) Plinthudult

Figures within parentheses denote number of 0 2-hectare plots (60 trees) recorded in soil unit

[a] High laterite phase i e laterite horizon occurring within 0–25 cm from soil surface

[b] Estimated by using formula used by Ho (1974) yield = K(girth in cm)$^{2.5}$

[c] Not available as area not yet in tapping

to exploit the differences in soil pedological properties

Climate has a relatively smaller influence than soil pedological properties on yield trends (Chan and Pushparajah, 1972), where experience in Peninsular Malaysia is concerned, and the above-observed yield patterns are therefore considered attributable to differences in soil pedological properties

Yield patterns consistent with soil pedological properties

In terms of soil properties, the yield patterns discussed are found to be consistent with the soil pedological characteristics According to agronomic interpretations and field experience, desirable soil properties required for optimum growth of rubber are given (Chan et al , 1975) as follows

- Soil depth up to 100 cm free of hardpan and rock-outcrop hindrance that has homogenous pedological properties
- Well drained
- Good soil aeration
- Good soil structure (strong, moderately strong, and moderate-medium, and fine subangular blocky structure)
- Friable to firm in consistency
- Good water-holding capacity
- No peat or acid peat
- Soil texture with sufficient clay (preferably a minimum amount of 35% clay to retain moisture and nutrients well and also about 30% sand to allow good pedological soil properties like aeration and drainage)

The desirable environmental physiographic features are (1) gently sloping or rolling terrain with minimum soil erosion and surface runoff (slopes of 2° to 9° with an upper limit of 16°) and (2) water table deeper than 100 cm

The desirable chemical properties should be such that the soil has at least medium levels of total nutrient content of nitrogen, phosphorus, potassium, and magnesium (Pushparajah and Guha, 1968) and no defi-

Table 4. Influence of drainage on PB 86 yields on the Selangor series (Typic Sulfaquepts)

Drainage depth	Year of planting	Cumulative mean yield from 2nd to 7th year (kg/ha)	Mean yield per year from 2nd to 7th year (kg/ha)
Drained to 50 cm (16 sites examined)	1957/58	5,823	971
Drained to 100 cm (14 sites examined)	1957/58	7,156	1,193

SOURCE Data from Chan, Soong, Wong, and Chang, 1973

Table 5 Soil ranking by mean yield per year and cumulative yield of popular clones[a]

Clone	High yielding (>1,350 kg/ha)	Above average yielding (1,251 to 1,350 kg/ha)	Average yielding (1,001 to 1,250 kg/ha)			Below average to low yielding (<1,000 kg/ha)			
RRIM 600	T P 1,492 4,476 (42)	O D 1,290 3,871 (9)		—		T S /T T 897 2,691 (12)			
GT 1	—	T P 1,308 3,919 (74)	P H 1,214 3,643 (22)	O D 1,102 3,305 (9)		T S /T T 984 2,951 (9)			
PR 107	—	—	T P 1,212 3,635 (180)			T S /T T 895 2,684 (14)			
PB 5/51	—	—	T P 1,204 3,612 (98)	P H 1,157 3,471 (12)	O D 1,125 3,374 (17)	T S /T T 872 2,615 (9)			
RRIM 605	—	T P 1,298 3,894 (87)	O D 1,118 3,355 (15)			T S /T T 690 2,071 (5)			
RRIM 623	—	T P 1,255 3,765 (119)	P H 1,233 3,699 (24)	O D 1,091 3,272 (17)		T S /T T 957 2,871 (16)			
PB 86	—	—		—		P H 961 2,882 (17)	T P 939 2,818 (17)	T T 826 2,478 (10)	T S 710 2,130 (5)
Tjir 1	—	—		—		O D 905 2,716 (14)	T T 854 2,561 (13)	T T 758 2,274 (11)	T S 727 2,182 (90)

NOTE T P = Typic Paleudults, T T = Typic Tropaquepts, T S = Typic Sulfaquepts, O D = Oxic Dystropepts
P H = Plinthic Haplorthox

[a] In each soil grouping, the first number is the mean yield per hectare from the 2nd to 4th year, the second number is the cumulative mean yield per hectare from the 2nd to 4th year, and the third number (in parentheses) is the number of sites

Table 6 Wind damage (as percentage of total stands)

Soil series and association	Clones susceptible to wind damage[a]			Clones less prone to wind damage[b]	
	Branch break	Trunk snap	Uprooting	Branch break	Trunk snap
Munchong	6 3	5 1	—	2 6	1 0
Rengam	5 0	3 8	—	3 0	1 6
Jerangau	10 0	2 5	—	—	—
Durian and Batu Anam	—	1 7	3 0	1 3	3 0
Malacca and Gajah Mati	3 3	2 7	7 3	2 0	—

SOURCE Data from *RRIM Annual Report* 1972
NOTE Munchong series = Typic Haplorthox Rengam series and Jerangau series = Typic Paleudults Batu Anam series = (Aquoxic) Dystropepts Malacca series and Gajah Mati series = (Petroplinthic ? Haplorthox)

[a]Examples RRIM 501 623 and 605
[b]Examples RRIM 600 PR 107 and GT 1

ciency of trace elements a pH of around 4 5, and an absence of saline-acid sulfate conditions

Based on the morphological and pedological properties, there are, on the one hand, the Typic Paleudults and the Tropeptic Haplorthox (except Petroplinthic Haplorthox), which have the pedological properties that come nearest to satisfying the soil requirements of the rubber tree greater soil depth (> 150 cm) sandy clay loam and clay textures, friable-to-firm consistencies fine subangular body structures that are strong moderately strong, and moderate medium, and good drainage conditions There are, on the other hand, the Typic Sulfaquepts and Typic Tropaquepts, which have some pedological properties that do not come near to satisfying the soil requirements of the rubber tree shallow depth (< 50 cm in most cases), relatively high silty clay content, very firm consistencies, prismatic and angular body structures that are moderately strong to strong, very coarse, and coarse, and imperfect or poor drainage conditions Further, the Typic Sulfaquepts contain a sulfuric horizon, whose acid condition can be limiting to optimum tree growth

The contrast in soil pedological properties is well reflected in the yields obtained for all the cases of clones examined Typic Paleudults and Tropeptic Haplorthox gave highest yields when compared with Typic Sulfaquepts and Typic Tropaquepts, which gave the lowest yields The deeper and better pedological properties of Typic Paleudults and Tropeptic Haplorthox likely have provided firmer anchorage and sufficient well-aerated zones for root activity in relation to moisture and nutrient availability and uptake Hence, better performance of the rubber tree is obtained on these soils rather than on Typic Sulfaquepts and Typic Tropaquepts, which, besides other physical limitations, contain the acid sulfate layer that limits tree performance, in particular the Typic Sulfaquepts

Pedological properties of Oxic Dystropepts are considered to be intermediate as are their yields

Yields from the Petroplinthic (?) Haplorthox vary This behavior, according to a separate study, is related to the presence of a hard-ironstone (lateritic) pan, which occurs within 50 cm from the soil surface in this class of soils This hard-ironstone pan at varying depths from the surface in these soils is found to have an influence on tree anchor-

Table 7 Classification of soils under rubber cultivation in Peninsular Malaysia

Order	Suborder	Great group	Subgroup	Family	Series
Entisols	Psamments	Quartzipsamments	Orthoxic Quartzipsamments	Acidic isohyperthermic	Sungei Buloh, Holyrood
	Aquents	Fluvaquents	Tropic Fluvaquents	Fine mixed acid isohyperthermic	Briah
Inceptisols	Aquepts	Tropaquepts	Typic Tropaquepts	Fine loamy siliceous or mixed, acid isohyperthermic	Sogomana
			Oxic Humitropepts	Coarse loamy siliceous acid isohyperthermic	Subang
			Aeric Tropaquepts	Fine kaolinitic acid isohyperthermic	Pasir Puteh
				Very fine kaolinitic acid isohyperthermic	Sitiawan
		Sulfaquepts	Typic Sulfaquepts	Fine mixed acid isohyperthermic	Linau, Selangor[a]
	Tropepts	Dystropepts	(Aquoxic) Dystropepts	Very fine mixed isohyperthermic	Batu Anam
			Oxic Dystropepts	Fine loamy siliceous isohyperthermic	Rasau, Lunas, Ulu Tiram, Kuala Brang
				Fine kaolinitic isohyperthermic	Kampong Chempaka, Tok Yong
Ultisols	Humults	Palehumults	(Orthoxic) Palehumults	Clayey kaolinitic isohyperthermic	Senai
	Udults	Plinthudults	(Typic) Plinthudults	Clayey mixed isohyperthermic	Durian
			(Oxic) Plinthudults	Clayey-skeletal mixed, isohyperthermic	Jeram
				Clayey kaolinitic isohyperthermic	Pohoi, Kulai
		Tropudults	Orthoxic Tropudults	Fine loamy siliceous isohyperthermic	Batang Merbau
		Paleudults	Typic Paleudults	Clayey kaolinitic isohyperthermic	Rengam, Jerangau, Bungor Harimau
				Fine loamy siliceous isohyperthermic	Serdang
Oxisols	Orthox	Haplorthox	Tropeptic Haplorthox	Clayey kaolinitic isohyperthermic	Segamat, Kuantan
			Typic Haplorthox	Clayey, kaolinitic isohyperthermic	Munchong
			Plinthic Haplorthox	Clayey-skeletal, kaolinitic isohyperthermic	Malacca
		Acrorthox	Typic Acrorthox	Fine loamy, mineralogy uncertain isohyperthermic	Tampoi

SOURCE Data from Chan 1975

NOTE Soil classification is according to U S *Soil Taxonomy* Terms within parentheses suggest new subgroups

[a] This pedon is not a central concept of the Selangor series which should be more of a Typic Tropaquept

Table 8 Scores of common soils under *Hevea* in Peninsular Malaysia

Soil classification		Total scores[a] (maximum of 80 points)	
Soil series[b]	Great group	Scores	Relative percentage
Munchong	Haplorthox	78	98
Jeram	Plinthudults	77	96
Bungor	Paleudults	76	95
Jerangau	Paleudults	74	93
Rengam	Paleudults	73	91
Segamat	Haplorthox	73	91
Kuantan	Haplorthox	73	91
Harimau	Paleudults	72	90
Senai	Paleudults	70	88
Batang Merbau	Tropudults	68	85
Subang	Tropaquepts	68	85
Kulai	Plinthudults	66	83
Serdang	Tropudults	64	80
Ulu Tiram	Dystropepts	64	80
Pohoi	Plinthudults	63	79
Holyrood	Quartzipsamments	63	79
Tampoi	Haplorthox	63	79
Lunas	Dystropepts	62	78
Kuala Brang	Dystropepts	61	76
Durian	Plinthudults	59	74
Batu Anam	Dystropepts	59	74
Malacca	Haplorthox	57	71
Pasir Puteh	Tropaquepts	55	69
Kampong Chempaka	Dystropepts	55	69
Tok Yong	Dystropepts	55	69
Sogomana	Tropaquepts	55	69
Sitiawan	Tropaquepts	55	69
Briah	Fluvaquepts	52	65
Selangor	Sulfaquepts	50	63
Sg Buloh	Quartzipsamments	48	60
Linau	Sulfaquepts	42	53
Peat[c]	Tropofibrists	36	45

[a] Total scores are derived from the sum of 16 differentiating criteria

[b] Considerations are made based on the "norm" pedological units However, should there be deviation in degree of any one soil or in physiographic property used as differential due to localized situations, the scores should be adjusted accordingly

[c] No series name has been given to *Peat* For this discussion, the general grouping *Peat* is used

Table 9 Proposed soil-suitability technical grouping system for tropical soils under rubber cultivation

Soil-suitability class	Yield categories in kg/ha/year (on Panel 'A' basis)	Classification		
			Great group level	
		Series[c]	Soil taxonomy[a]	After Thorp and Smith, 1949
I	High yielding 1,350	*a)* Munchong	Typic Haplorthox	Latosol
		Jeram	Typic Haplorthox	Latosol
		Prang[b]	Tropeptic Haplorthox	Latosol
	High yielding (1,250–1,350)	*b)* Segamat	Tropeptic Haplorthox	Latosol
		Kuantan	Tropeptic Haplorthox	Latosol
		Rengam	Typic Paleudults	Red and yellow podzolic
		Jerangau	Typic Paleudults	Red and yellow podzolic
		Yong Peng	Tropeptic Haplorthox	Latosol
		Bungor	Typic Paleudults	Red and yellow podzolic
II	Above average yielding (1,150–1,250)	*a)* Senai	(Orthoxic)[d] Palehumults	Red and yellow podzolic
		Harimau	Typic Paleudults	Red and yellow podzolic
		b) Batang Merbau	(Orthoxic) Tropudults	Red and yellow podzolic
		Subang	(Oxic) Humitropepts	Half-bog
		Kulai	(Oxic) Plinthudults	Yellow podzolic
III	Average yielding (1,050–1,150)	Serdang	Typic Tropudults	Red and yellow podzolic
		Ulu Tiram	Oxic Dystropepts	Pale yellow podzolic
		Pohoi	(Oxic) Plinthudults	Yellow podzolic
		Holyrood	Typic Quartzipsamment	Pale yellow podzolic
		Tampoi	Typic Acrorthox	Latosol
		Lunas	Oxic Dystropepts	Alluvial
		Kuala Brang	Oxic Dystropepts	Pale yellow podzolic

IV	Below average yielding (950–1 050)	*a)* Batu Anam	(Agnoxic) Dystropepts	Gray podzolic
		Durian	(Typic) Plinthudults	Yellow podzolic
		b) Malacca	(Petroplinthic?) Haplorthox	Latosol
		Gajah Mati	(Petroplinthic?) Haplorthox	Latosol
		Marang	Oxic Dystropepts	Gray podzolic
		Kedah	(Oxic) Plinthudults	Yellowish brown podzolic
		Seremban	(Oxic) Plinthudults	Reddish brown podzolic
V	Below average (1 000)	*a)* Briah	Tropic Fluvaquents	Low humic gley
		Selangor	Typic Sulfaquepts	Low humic gley
		b) Sungei Buloh	Orthoxic Quartzipsamments	Alluvial
		c) Linau	Typic Sulfaquepts	Low humic gley-bog
		d) Peat[c]	Tropofibrist	Bog

NOTES Only average management standards are considered for higher levels of management standards and modern clones productivity is significantly higher (Chan and Pushparajah 1972)

[a] Data from Chan 1975

[b] Included on the basis of limited data and their close likeness in physical and chemical properties to the ones studied

[c] I must qualify that there are soil variations like soil texture existing within a soil series The physiography of the soil series can also vary e g slope and soil depth These variations influence yield and growth (Chan et al 1972 and 1974) As such the soil series mentioned in this table are the model or standard soil series only Further investigations of such variations on *Hevea* performance will provide the basis for further updating and revision of these recommendations to incorporate any necessary refinements For current practice and purpose it is sufficient if a plantation has its property properly soil-mapped at the series level This is an essential prerequisite for any initial proper management planning

[d] Term in parentheses in classification column denotes suggested new subgroupings

[e] No soil series name has been given to *Peat* in this paper the general grouping of *Peat* is used

age and wind damage (Table 6), hence, an indirect effect on yield (Chan and Pushparajah, 1972).

Productivity Potentials of Soils

A Proposal for a Technical Grouping System of Soil Suitability and Productivity

Soil limitations

The profile characteristics, chemical properties, and physiographic features of the soils studied are discussed elsewhere (Chan, 1975), their classification according to the U S *Soil Taxonomy* is shown in Table 7 A study of the soil data shows that some soils have properties in the desirable range indicated earlier and many in the intermediate range, and that a few have properties that are not suitable for rubber at all The greater the limitations hindering optimal growth and performance of rubber the less suited are the soils for rubber Further, the limitations vary in intensities of hindrance and, through quantitative and semiquantitative assessments of available soil and agronomic data can be graded (*minor*, *serious*, and *very serious*) and scored (arrive at the total point scores of each pedological soil unit, based on the sum total of scores of sixteen principal soil criteria) (Table 8)

Table 8 shows that soil units that are deep have a balanced composition of particle-size distribution, friable consistencies, medium and fine subangular blocky structures that are strong and moderately strong, and good drainage features To wit Paleudults and Haplorthox (excepting the Petroplinthic? subgroup) score the highest (70 to 78 out of 80) Soil units that have a shallow "effective" depth an unbalanced composition of particle-size distribution, and poor drainage conditions and are very firm or very loose in consistency and are compact or structureless in structure score the lowest, namely, Sulfaquepts and Tropaquepts (42 to 55 out of 80) The rest of the soil units, whose properties are in the intermediate range, are intermediate in score

Yield substantivity and the proposal

The above approach and principles towards developing an appropriate soil-suitability technical grouping system for rubber concur with field experience and the yield patterns obtained, as shown in Table 5 and discussed earlier Consequently, a "First Approximation" soil-suitability and productivity technical grouping system for *Hevea* was proposed (Chan et al, 1975) (see Table 9)

Scope for Agromanagement to Improve Yields

The yields discussed hitherto are the mean yields of a particular clone on a particular soil given comparable husbandry Chan and Pushparajah (1972) found, however that when the sampled population is re-sorted to include different levels of agromanagement standards, it improves the yield significantly Table 10, which summarizes their findings shows the ranges in mean yield per year (averaged over the second to fourth year of tapping) for the recommended modern *Hevea* clones, as well as older materials like RRIM 623 and Tjir 1 on contrasting soils The national mean yields obtained are also included for comparison

Large differences in minimum and maximum yields can be observed for the Class I technically grouped soils (Haplorthox and Paleudults) In all instances, the differences exceeded 1,000 kg per hectare per year, and the maximum yields were traced to good upkeep and a high agromanagement standard, whereas the minimum yield points were traced to poor upkeep and a low management standard The data clearly demonstrate that, for maximum exploitation of a planting material on a soil, the best agromanagement inputs are essential

However, although there are considerable economic benefits for the Class I technically grouped soils, the investment of agromanagement inputs for poorer soils may have to depend on the economic returns, as shown in Table 10, where increases ranging from about 200 to 500 kg per hectare per year are experienced between the lowest and highest

Table 10 Minimum and maximum yield trends of clones on contrasting soils (kg/ha year)

Clone	Class I productivity soil[a] Haplorthox and Paleudults			Class IV productivity soil[b] Tropaquepts			Mean yield from commercial registration
	Minimum	Maximum	Difference	Minimum	Maximum	Difference	
RRIM 600	1,214	2,106	892	760	985	225	1,679
GT 1	610	1,830	1,220	787	1,215	428	1,253
PB 5/51	883	1,891	1,008	795	1,044	249	1,262
PR 107	686	1,627	941	597	1,118	521	993
RRIM 623	768	1,777	1,009	890	1,229	339	1,329
Tjir 1	471	1,420	949	690	925	235	969

SOURCE Data from the *RRIM Annual Report* 1972

[a]For RRIM 600 PB 5 51 PR 107 and RRIM 623, Class I soil was the Munchong soil series for the others, it was the Rengam soil series

[b]For all clones, Class IV soil was the Selangor soil series

levels of agromanagement standards for a Class IV technically grouped soil like the Tropaquepts It is likely that the physical limitations of the poorer soils may be overriding factors that markedly reduce the impact of agromanagement to a point where input investment will have to depend on the economics of the situation

Productivity Potentials of Modern *Hevea* Clones on a Class I Soil

The foregoing discussion clearly shows that the maximum exploitation of a planting material, however high its genetic quality, can be fully realized only under the best soil conditions and agromanagement This important fact is further emphasized by another fact that the yield of the modern *Hevea* clones, within a given situation, can be improved by as much as 1,000 kg per hectare per year, given proper husbandry We can infer that the maximum yield potential or the productivity potential of a particular soil-crop situation is a reflection of not only the genetic material but also the soil and its environment and the agromanagement it receives On the basis of this concept, Chan and Pushparajah (1972) computed the productivity potential of some of the most recent *Hevea* clones on Haplorthox, a Class I technically grouped soil (Figure 2)

Prediction of Agromanagement Practices

The "Enviromax" Concept in Selecting Planting Material

The soil-crop studies discussed thus far indicate that the first step towards achieving maximum productivity from a particular locality is proper choice and use of planting material A significant example is the "Enviromax" concept in choosing *Hevea* planting material for a specific locality (Ho et al, 1974, and Chan and Pushparajah, 1972) This concept recognizes the important influence of soils and the environment on the performance of *Hevea* clones The quantifications and mechanics are detailed elsewhere (Ho et al, 1974), but the essence of the concept is (1) to demarcate the rubber-growing areas according to extremes of wind, high incidence of diseases, and main soil units, and then (2) to select the *Hevea* clone by the sieving process to avoid predictable adverse conditions between susceptible clones and inhibitory environmental factors Table 11 summarizes the orders of *Hevea* clone priorities recommended for the technically ranked soils of Classes I, II, III, and IV, Class V is not recommended because it shows more favorable productivity for other perennial crops (Pushparajah and Chan, 1973)

Table 11. Ranking of clones by yield potential on various soil classes

Soil class	Class I clones	Class II clones[a]
Ia	RRIM 600, PR 255, PR 261, GT 1, PR 107, PB 5/51	PB 235, RRIM 703, PB 28/59, RRIM 628, RRIM 701,
Ib	GT 1, RRIM 600, PR 255, PR 261, PB 5/51, PR 107	PB 252, RRIM 623, RRIM 527, PB 217, RRIC 6, AVROS 2037
II and III	RRIM 600, PR 255, PR 261, PB 5/51, GT 1, PR 107	
IV	PB 5/51, GT 1, PR 107	

SOURCE. Data from Ho Chan, and Lim, 1974

NOTE Information about the performance of PR 255 and PR 261 on various soil types is limited They resemble closely RRIM 600 in yield level and habit and are therefore, provisionally ranked after it

[a]Class II clones are ranked on their yield performance in clonal trials, no Class II clone is recommended on Class IV soil

Agromanagement Priorities by Soils

An appraisal of available experimental data and of the current state of agronomic know-how and experience has made it possible to sieve broad patterns of agromanagement priorities required for the common Malaysian soils used for *Hevea* cultivation (Chan et al, 1973) Table 12 summarizes the findings Besides the specific "extra" agromanagement inputs required to overcome principally the physical limitations of the soil, the basic important inputs common to all soils are as follows (1) establishment of a good creeping leguminous cover during the early immature phase of rubber, and maintenance of a light cover during maturity, (2) mulching of young rubber, particularly during the first 2 or 3 years of field immaturity, or allowing legume covers to creep to the base of the rubber and spraying out periodically to ensure a mulching effect, and (3) plowing of soil on steep slopes should be done along the contours and not up and down the hill (plowing should be done only when the soil is at field capacity)

Soil and Foliar-Nutrient Surveys to Diagnose Fertilizer Needs

Because soil chemical properties were shown to be related to the fertilizer needs of *Hevea* (Pushparajah and Guha, 1968) and because of the desire to overcome chemical limitations, Guha and others (Guha, 1969; Guha et al, 1971) evolved the concept of using soil and foliar-nutrient surveys to diagnose fertilizer needs Chan (1971) developed this concept further by substantiating its benefits Differentiation on the basis of clones was introduced later (Pushparajah and Tan, 1972, Chan et al, 1972) The main idea is (1) to use soil surveys to identify homogeneous soil units, soil and foliar-nutrient status, and agromanagement history, and (2) to interpolate these identifications with the results of fertilizer experiments to increase the reproducibility of the results of fertilizer experiments for wider application in the field Although this is the ideal approach, studies concerning soil and foliar-

nutrient data alone have made it possible to compute "guideline" nutrient requirements for the common soil units (Chan et al., 1972) Table 13 gives a summary of the recommended nutrient requirements, which can be used in the absence of a comprehensive soil and foliar-nutrient survey

Possible Uses of Soils for Other Crops

Basic to the objective of achieving maximum productivity is proper use of land resources and in turn proper crop selection for a specific land area For example, studies have shown that the extensive alluvial tracts of Tropaquepts and Fluvaquents in Peninsular Malaysia are least suited for rubber (Chan and Pushparajah 1972) but most suited for oil palm (Ng 1968) and that they are suited not only for cocoa (Kanapathy and Thamboo, 1970) but also for coconuts and for mixed cropping of cocoa and coconuts (Wong, 1972) Subsequently, Pushparajah and Chan (1973) demonstrated and emphasized the need to allocate land resources on the basis of the specific soil requirements of the crop, and not purely on the basis of general land-capability classification Pushparajah and Chan estimate that at least 0 35 million hectares (about 10%) of the land now under cultivation grow rubber on soils that are least suited to rubber, when the same land could be used more profitably by growing other crops like oil palm By identifying the more suitable areas for rubber (Figure 3), Pushparajah and Chan were able to assess that of the 6 4 million hectares demarcated as suitable land for agriculture in Peninsular Malaysia (Lee and Panton, 1971), at least 5 5 million hectares are suitable for rubber (Table 14) Pushparajah and Chan (1973) also made an assessment of the areas suitable for the cultivation of oil palm and other crops Their concept was developed further (Pushparajah et al., 1974) to include climatic and economic considerations as well

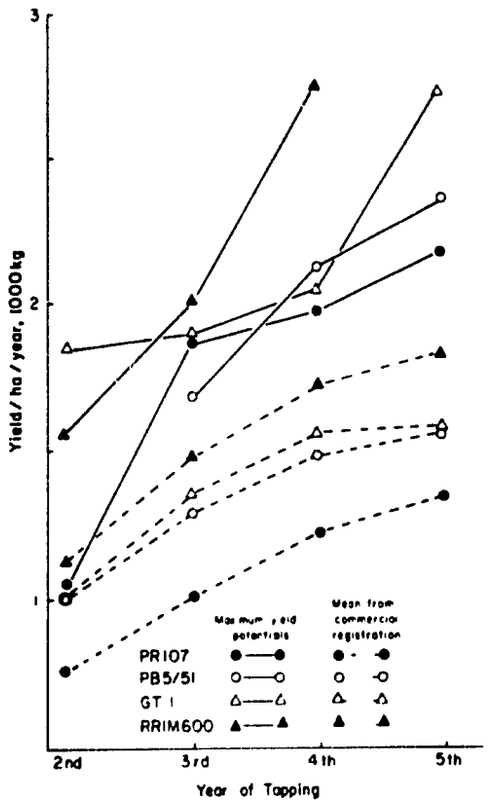

Fig 2 Maximum yield potentials of Class I clones on a Class I soil the Munchong series (Typic Haplorthox)

Progress in Soil Surveys and Mapping

To have efficient technological transfer of research information similar to that reported above, soil surveys at various scales of mapping, for specific objectives have been conducted steadily in the past decade in Peninsular Malaysia (Figure 4) In the optimization of land-resource use either for rubber or for other agricultural crops, reconnaissance soil maps at a scale of 1 inch to 24 miles (or an RF of 1 2 520,000) are available for broad planning (Law and Selvadurai, 1968) For the specific implementation of agromanagement by soil series in the rubber-growing areas semidetailed soil maps at scales of 1 inch to 16 chains (or an RF of 1 12,500) have been made covering approximately 40% (~75% in the estate sector and ~10% in the small-holding sector) of the areas under rubber cultivation in the country Likewise,

Table 12. Soil-capability classes· limitations and specific "extra" agromanagement practices required

Soil-capability class	Soil series	Minor limitation	Serious physical limitation	Very serious limitation	Specific "extra" agromanagement practices
I	a. Munchong, Prang, Kuantan, Segamat b. Rengam, Jerangau, Yong Peng	—	—	—	Contour terracing and planting for slopes > 16%
II	a. Klau, Harimau, Bungor	Moderate drainage conditions	—	—	Extra and split application of balanced fertilizers
	b Serdang	Susceptibility to soil erosion	—	—	Contour terracing and planting for slopes > 16%
	c. Subang	Weak structures within 90 cm Susceptibility to flooding	—	—	For Serdang series, soil-conservation measures, particularly contour planting on 2–8% slopes; if > 8%, terracing or ridging essential; minimal disturbance to existing natural covers on steep slopes, i e , > 16% slopes Proper drainage system for Subang series (see *RRIM Planters' Bulletin No 114*, 1971)
III	Holyrood, Tampoi	Weak structures and sandy within 90 cm	Susceptibility to moisture stress if bare	—	Soil-conservation measures, particularly broad-base terracing (acute "ridging" essential on 3–8% slopes) Extra and split application of balanced fertilizers
IV	a. Batu Anam/ Durian	—	Poor structures Strong compaction, poor permeability, and infiltration	—	Soil-conservation measures, particularly contour terracing/planting and silt pits Where mechanical plowing is practical, plow at proper soil moisture content, as a rule-of thumb guide, if a heavy rain falls, plow 2 to 3 days after the shower When planning planting material, avoid heavy crown clone, if a higher yielder like RRIM
	Sogomana/Sitiawan	—	Imperfect drainage Strong compaction, poor permeability, and infiltration	—	

	Seremban, Apek/ Marang, Kedah, Kulai, Ulu Tiram	—	Steep slopes (Class D) Hard pan within 40 cm of surface	— —	600 is preferred to be used, crown bud with a light canopy (Soong, 1971) Contour planting and terracing necessary
	b Malacca/Gajah Mati/ Tavy	—	Laterite pan close to surface Rock outcrop on surface	—	
V	a. Briah, Selangor, Linau	—	—	Heavy clay, water-logged conditions Permanent water table near surface	For Class V*a* and V*c* soils, deep and proper drainage system, proper outlet drains to remove excess water that may accumulate in the subsoil (see *RRIM Planters' Bulletin No 114*, 1971)
	b Sungei Buloh	—	—	Very sandy and structureless	When planning planting material, avoid heavy crown clone, if a higher yielder like RRIM 600 is preferred to be used, crown bud with a light canopy (Soong, 1971)
	c Peat	—	—	Acid peat layer thicker than 9 inches near the surface Lacks mineral component of soil Permanent water table near surface	For Class V*b* and V*c* soils like the Sungei Buloh series and peat, extra split applications (at amount and even more frequent intervals than for the Holyrood series) of balanced fertilizers

SOURCE. Data from Chan, Soong, Wong, and Chang, 1973
NOTE. For all soils, a good legume cover is essential during immaturity, during maturity, at least some form of cover is required "Extra" practices needed are so noted under agromanagement practice

Table 13 Nutrient requirement recommended for mature rubber on common Peninsular Malaysian soils (in kg per hectare)

Soil series/association	Group 1[a] All clones except Groups 2 and 3		Group 2 RRIM 600 and GT 1		Group 3 Clones susceptible to branch and trunk snap[b]		Groups 1, 2, and 3 All clones	
	N	K_2O	N	K_2O	N	K_2O	P_2O_5	MgO
Rengam/Jerangau	16	94	20	118	8	94	28	10
Munchong/Prang	16	59	20	94	8	59	21	10
Malacca/Gajah Mati/Tavy	20	59	24	94	8[d]	59	21	10
Batu Anam/Durian	20	59	24	94	12	59	21	10
Serdang	16	94	20	118[c]	12	94	21	10
Holyrood	16	141[c]	28	176[c]	12[d]	141	28[c]	15
Selangor	20	—	24	47	12[d]	—	—	—

SOURCE. Data from Chan, Soong, Woo, and Tan, 1972.

NOTE Assumed mean yield is 1,500 kg per hectare, after 1,500 kg per hectare yields, for every additional 1,000 kg per hectare obtained, particularly on the basis of nutrient drainage besides other factors, apply 11 kg of N + 17 kg of K

[a]PB 5/51, in particular the amount of K applied, should be as shown in Group 2

[b]Examples are RRIM 605, 623, and 501

[c]Takes into consideration soil-leaching losses

[d]The levels of N are kept low, although leaf N is low in some cases, to prevent the increase of canopy weight, which, if too heavy, is susceptible to tree damage by windstorms

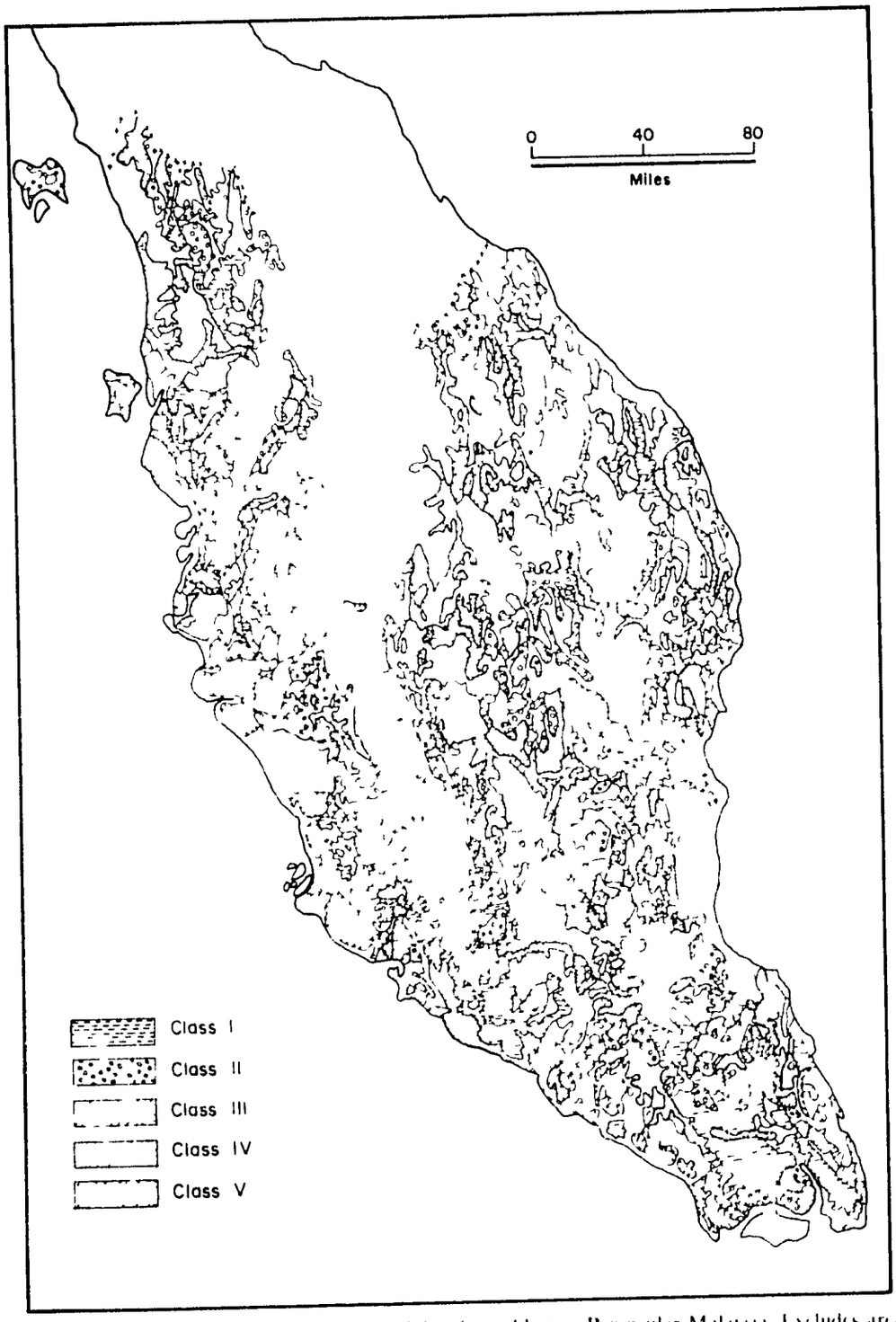

Fig 3 Reconnaissance map of soil suitability for rubber in Peninsular Malaysia Excludes areas now under rice cultivation (Source Pushparajah and Chan 1973)

Table 14 Estimated area by soil-suitability classes for rubber in Peninsular Malaysia

Soil-suitability class	Yield category attainable in kg per hectare	Area in hectare
I	High yielding (> 1,350)	1,843,563
II	Above average yielding (1,250 to 1,350)	945,425
III	Average yielding (1,100 to 1,250)	781,043
IV	Slightly below average yielding (1,000 to 1,100)	1,953,887
V	Below average to low yielding (< 1,000)[a]	880,655
Total		6,404,573

SOURCE Data from Pushparajah Chan, and Ti, 1974

[a] Excludes areas under paddy

semidetailed soil maps of similar scales for some specific areas in the eastern parts of Peninsular Malaysia are now in progress (Paramananthan, 1975)

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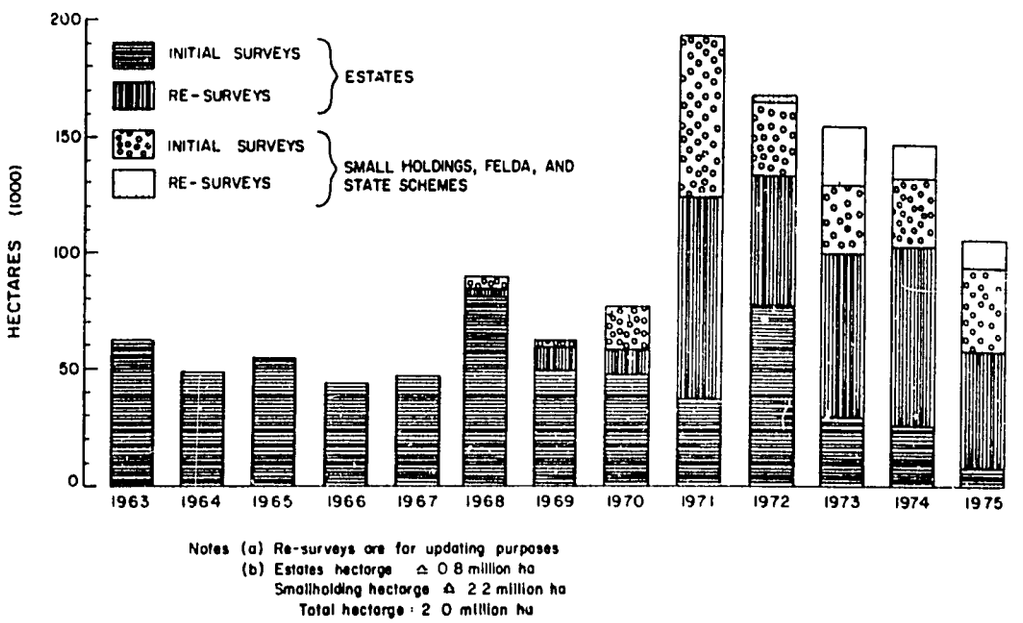

Fig 4 Progress of soil surveys for the rubber industry in Peninsular Malaysia, January 1963 to September 1975

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Use of Soil-Survey Data in Korea: Land Selection for 'Tongil'

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In Korea the reconnaissance soil survey was completed by the end of 1969, but the detailed soil survey is still being carried out Only one-fourth of the total country area has been surveyed in detail to date

A most successful use of soil-survey results has been achieved through a program to select suitable lands for Tongil a newly bred high-yielding rice variety which shows selectivity to characteristics of soils

The reconnaissance soil maps have been successfully used for soils selection The Government's strong desire for the early propagation of Tongil' as a way for the country to become self-sufficient in food and the farmers' enthusiasm toward the advanced techniques of farm management have been important forces that led to the successes in the use of soil-survey results on such a large scale and in such a short time

Soil surveys have been carried out intensively in Korea since 1964 when the Korea Soil Survey Project was initiated under the cooperative efforts of the Korean Government, the Food and Agricultural Organization of the United Nations (FAO) and the United Nations Development Program (UNDP) Men on the Project completed in 5 years the reconnaissance soil survey for the entire country, they also made detailed soil surveys of the priority areas for agricultural development The Institute of Agricultural Sciences (IAS) of the Office of Rural Development (ORD), which was actively involved in the soil survey projects during and after the Korea Soil Survey Project has undertaken the job of arranging the survey results for publication and of completing a detailed soil survey for parts of the country that have not yet been surveyed

The reconnaissance soil maps (scale of 1 50 000) published in 1971 (FAO, UNDP and IAS, ORD 1971), have been released to various organizations to be used for the national land and agricultural development programs The detailed soil surveys have now been completed for 32 Guns (counties) and cities which are equivalent to one-fourth of the whole country Results obtained from detailed soil surveys for the whole country will be completed by 1979

The soil-survey information has been used for various purposes The most extensive uses have been made in the field of agriculture, particularly in the selection of suitable soils for the introduction of 'Tongil,' a newly released high-yielding rice variety

General Background

Agriculture ranks as Korea's most impor-

tant economic activity, it provides the means of living for more than 44% of the population and constitutes the source of about 28% of the total national income

The total acreage of arable land in Korea is about 2 24 million hectares, of which 1 26 million hectares (56% of the total arable land) grow rice, the most important staple food As shown in Table 1, in 1973, Korea produced 4 21 million metric tons of rice, which comprised 58 5% of the total grain production Although this amount was greater than amounts of previous years, rice was still short of demand by around 440 thousand metric tons (Ministry of Agriculture and Fishery, Republic of Korea, 1974)

The achievement of self-sufficiency in food has been Korea's objective for a long time To attain this goal, the Government has focused every effort on many programs improvement of irrigation systems, land consolidations, dissemination of knowledge about the use of fertilizer and agricultural chemicals, and expansion of arable lands by reclamation of coastal and hillside lands Land productiveness has been significantly improved by these efforts But these alone were not enough to boost the yield of major staple food crops beyond a certain level

In the late 1960's, the Office of Rural Development, under close cooperation with the College of Agriculture of Seoul National University and with the International Rice Research Institute in the Philippines, succeeded in breeding 'Tongil,' a new high-yielding rice variety, which is a Japonica-Indica cross The performance tests with this new variety showed that 'Tongil' possesses an outstanding yield potential, leading the conventional varieties by an average increase of 30% From the early 1970's, the Government of Korea wanted to release this particular variety for cultivation throughout the country However, because the high-yielding potential of 'Tongil' seemed to depend on the nature of the soils provided, the Government first had to make selections of suitable soils before it could introduce the new variety To this end, the Government set up a program to investigate the reconnaissance soil survey data to determine the areas suitabl for the cultivation of 'Tongil'

Objective

The objective of the land-selection program was to define the suitability of soils for the cultivation of 'Tongil' and to find such soils on the reconnaissance soil map so that the rural guidance officers could select areas for the introduction of 'Tongil'

How Soils Data Were Used

The selection of suitable soils for 'Tongil had to be preceded by the defining of the suitability itself To do this, the characteristics of soils on which 'Tongil' was cultivated were surveyed in detail And the survey results were interpreted by comparing the performance of 'Tongil' with those of conventional varieties This survey excluded the coarse-textured soils because information already available indicated that 'Tongil' required high soil fertility and that it had lower root activity than conventional varieties even under such unfavorable conditions as heavy soil reduction, low temperature, and nitrogen deficiency (Choi et al , 1974)

Table 1 Rice production, consumption, and import (in 1,000 metric tons)

Year	Production	Consumption	Self-sufficient rate	Import
1969	4,090	4,394	93 1	755
1970	3,939	4,777	82 5	541
1971	3,997	4,362	91 6	907
1972	3,957	4,296	92 1	584
1973	4,211	4,641	90 7	437

Table 2 Relationship between soils and rice yields

Soil	Number of experiments	Yield of unhulled rice (in tons per hectare)		Percentage of yield increase
		Conventional varieties	'Tongil'	
Somewhat poorly to moderately well drained, fine- and medium-textured soils	16	6 11	7 11	16
Somewhat poorly to moderately well drained, moderately coarse-textured soils	12	5 58	6 87	23
Poorly drained, fine- and medium-textured soils	1	6 27	6 80	8

Table 2 shows the relationship between soil characteristics and rice yields (Institute of Plant Environment 1971) Although 'Tongil' outyields the conventional varieties in a wide range of soil conditions it is less adaptable to poorly drained soils than to soils somewhat poorly to moderately well drained The yield-increase ratio of 'Tongil' in poorly drained soil is much lower than in soils that have better drainage conditions 'Tongil' requires more (about 30%) fertilizer than do other varieties and some special managements, such as early transplanting and frequent draining of fields When these facts were weighed against the small increase in yields, the recommendation to grow 'Tongil' on poorly drained soil was considered unreasonable

On the basis of this information about 'Tongil' and the results of soil surveys on experimental fields, the characteristics of suitable soils for the cultivation of 'Tongil' were described (Table 3) (Y Shin, 1975), which in turn led to the suitability grouping of the soils for 'Tongil' (Table 4)

Since it was established, the suitability grouping has been used for the selection of land for 'Tongil' And for the right use of reconnaissance soil maps, rural guidance officers have been trained through lectures and

Table 3 Characteristics of soils suitable for 'Tongil'

Soil physiography	Suitability for 'Tongil'
Soil drainage	Somewhat poorly to moderately well drained
Soil texture	Moderately coarse to fine texture
Available soil depth	More than 50 cm
Permeability	Slow to moderate
Gravel content	Slight to none
Soil pH	4 5 to 7 0
Salinity	Less than 4 millimhos per cm
Accumulation of toxic substances	Slight to none
Irrigation and drainage system	Good
Flood hazard	Slight to none
Land slope	Less than 15%
Ground water table	Lower than 50 cm
Persistence of irrigated water	4 to 6 days

practices to be knowledgeable in the following (1) soil characteristics of each soil group on the reconnaissance soil maps, (2) relationship between the soil characteristics and the performance of 'Tongil', (3) reading of soil maps, (4) area measurement on soil maps, and (5) drawbacks involved in reconnaissance soil maps

Physical and Socioeconomic Accomplishments

The introduction of 'Tongil' has been a great success The farmers' incomes and the country's economy have been affected significantly Self-sufficiency in staple food, long hoped for by Korea, has now become an attainable objective because of the nationwide acceptance of 'Tongil' (Table 5)

The increase of rice production is attributable not entirely to the superiority of 'Tongil' itself, however The correct selections of suitable lands and right managements of soils and water were no less important than the outstanding yielding potential of 'Tongil'

In 1972, encouraged by the high yield of 'Tongil' (49 6% increase over conventional varieties), the Government hastened the introduction of the new variety by planting it in nearly 16% of the total paddy, without paying proper consideration to soil suitability The result was somewhat discouraging when compared with that of the previous year 'Tongil' showed only a 20% increase over conventional varieties Discouraged by this poor return, the Government in 1973 had only 12% of the total paddy fields plant 'Tongil', but this time it gave more care to the selection of suitable lands and more careful field management The results obtained were favorable 'Tongil' gave an average increase of 37 4% in yield above those of conventional varieties

In 1974, when the area for the cultivation of 'Tongil' was expanded up to more than 35% of the total paddy, the Government in the course of planting took full consideration of previous experience In 1975, the Government planned to plant the new variety on 450,000 hectares, which amounted to 37 3% of the total paddy area Judging by the standing of rice in the field, we estimate that the increase of yield by 'Tongil' will not be less than that of 1974

In short, through the successful introduction of 'Tongil' and through its cultivation under right management, not only was the national supply of food production greatly

Table 4 Suitability groups of paddy soils for 'Tongil' by mapping units of soils on the reconnaissance soil map

Suitability group	Managements required	Mapping unit[a] of soils	Area (ha)
Well suited	No special managements are required	Ana, Apa, Fma	463,000
Moderately well suited	Some special managements are required	Anb, Apb, Apc, Fmb	406,000
Poorly suited	Very special managements are required	Apd, Fmc, Fmd	391,000

[a] The mapping-unit codes are explained below
An complex of soils, narrow valleys Ana moderately fine-textured Gleysols and Fluvisols, somewhat poorly to moderately well drained Anb moderately coarse-textured Fluvisols and Gleysols, moderately well to somewhat poorly drained Ap Gleysols, Acrisols, and Fluvisols, alluvial plains Apa moderately fine and fine-textured Gleysols, somewhat poorly drained Apb moderately fine and fine-textured Acrisols, moderately well drained Apc medium-textured Fluvisols with gravels, moderately well to somewhat poorly drained Apd moderately fine and fine-textured Gleysols and Fluvisols, poorly drained Fm Gleysols and Fluvisols, Fluviomarine plains Fma moderately fine and fine-textured Gleysols, somewhat poorly drained Fmb moderately coarse-textured Fluvisols and Gleysols, somewhat poorly drained Fmc medium and moderately fine-textured Salic-Eutric Gleysols poorly drained Fmd moderately fine and fine-textured Gleysols, poorly drained

Table 5 Increase of rice production by 'Tongil'

Item	1971	1972	1973	1974	1975
Area planted (in 1,000 hectares)					
Total	1,190	1 191	1 182	1 204	1 206
'Tongil'	2 75	187 47	139 03	427 40	450 00
Percentage of 'Tongil'	0 2	15 7	11 8	35 5	37 3
Yield (in metric tons per hectare)					
Conventional varieties (A)	3 36	3 21	3 50	3 53	
'Tongil' (B)	5 01	3 86	4 81	4 73	
B/A percentage increase	49 6	20 2	37 4	34 0	
Yield increase by 'Tongil' areas (in 1,000 metric tons)	-	122	182	368	

NOTE Data for 1975 except those for area planted were not ready to be included in this table

increased but also the farmers' economic situations were improved remarkably (see Table 6) (D Shin, 1975) Farmers' net incomes increased by 50 (individual farm) to 250% (cooperative farm) through the cultivation of 'Tongil'

Causes of the Success or Failure

The most significant cause that led to the remarkable successes in the use of soils data in Korea might be the development of the necessity for soils information, along with the appearance of the new high-yielding rice variety 'Tongil,' which has shown obvious selectivity toward the characteristics of soils The correct understanding about the physiological characteristics of 'Tongil' and the readiness of information about soils because of the timely completion of the reconnaissance soil survey have also been important in the successful uses of soils data for the early propagation of 'Tongil'

The farmers' enthusiasm toward the advanced techniques introduced for farm management and toward 'Tongil' has also been

Table 6 Increase in the average rice yield and farmer's income by 'Tongil'

Item	Individual farm		Cooperative farm
	Conventional variety	'Tongil'	'Tongil'
Number of farmers	514	506	113
Yield (in metric tons per hectare)	3 51	4 51	6 20
Yield percentage	100	128 5	176 6
Gross income (in won per hectare)	754,470	935,900	1,281,400
Percentage	100	124 1	169 8
Net income (in won per hectare)	145,430	211,480	500,685
Percentage	100	145 4	348 5

Table 7 Farmers' participation in farm management programs

Activity	Individual farm		Cooperative farm
	Conventional varieties	'Tongil'	'Tongil'
Contact with rural guidance officers (number of times a year)	9 6	28 6	49 3
Listening to the farm school program on the radio (number of times a week)	0 9	5 6	4 4
Participation in farmers' meetings (number of times a year)	3 3	10 7	19 1
Participation in farmers' training (number of times a year)	0 4	4 5	3 8

important, it has made the farmers receptive to accepting the use of soils data As shown in Table 7, the farmers cultivating 'Tongil' have come to feel very positive toward the various extension programs that handle soils problems As a result, they have come to understand the importance of right selection of soils for 'Tongil' and have been very cooperative therefore in the selections of soils

On the whole, the use of soil-survey information for the selection of suitable soils for 'Tongil' has been successful However, there have been some problems in the use of reconnaissance soil maps These maps, which are on a scale of 1 50,000, are too rough for small areas because they do not show areas smaller than 6 5 hectares Because of this limitation, incorrect selections of soils for 'Tongil' were made several times The rural guidance officers using the soil maps have pointed out another problem that these soil maps are difficult to read

These difficulties and problems in the uses of soil maps are expected to be resolved soon The scale of reconnaissance soil maps will be reduced by using the detailed soil maps when the detailed soil survey for the whole country is completed To meet the complaints about the difficulties in understanding the soil maps, more intensive training programs are planned

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Soil-Survey Interpretations for Watershed Development

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Purposeful and practical interpretations are most important in the utilization of soil-survey data An attempt has been made to present efforts made in developing interpretations for land capability units hydrologic soil groups paddy soil groups and irrigation-suitability classes The procedure developed for the delineation of priority watersheds on the basis of relative erodibility of different mapping units and their delivery ratios has also been described Supporting examples have been given from the work carried out in the Matatilla catchment in Madhya Pradesh Illustrations indicating the utility of basic soil-survey data in determining cost benefit ratios of different development efforts have also been given for two areas A and B in north central India Having an overall cost-benefit ratio of 3 5 Area B has greater potential for development than Area A which has an overall cost-benefit ratio of 2 7

Modern soil surveys are designed to provide scientific information about soils their characteristics classifications and delineations of location and extent on suitable maps Each kind of soil is defined in terms of a specific set of characteristics and qualities that can be observed measured and estimated But the ultimate objective of any soil-survey program is utilitarian the practical and purposeful application or interpretation of soil-survey data is for a specific use or for a number of varied uses Aandahl (1958) defined soil-survey interpretations as "the organisation and presentation of knowledge about characteristics, qualities and behaviour of soils as they are classified and outlined on maps"

Basis for Interpretation

The use potential of a soil is governed by a unique set of characteristics and qualities *Soil characteristics* refer to such directly observable features as soil color, texture, structure, and the like, whereas *soil qualities* imply such properties as fertility, erosion hazard permeability and the like that are estimated or inferred

A particular soil property or quality may be desirable for a specific purpose that may prove deterrent for another purpose For example, somewhat excessively or excessively drained soils are rated very low in their suitability for paddy cultivation but are rated best suited for having untreated steel pipes laid out or for filter fields for septic tanks Soil-survey interpretations, thus, are based on the knowledge of soil properties stemming from experience and research findings

The data of research findings from laboratories, from greenhouse trials, or from field plots on a particular soil, qualified under an accepted system of classification, can be successfully extended for similar soils

occurring under identical habitat and environment Correlations based on a single soil property or quality, howsoever promising they may seem in a particular area, often fail when tested in larger areas It is the entire soil system, with the full spectrum of complex and interrelated soil properties, that should form the basis of a sound interpretation system

Soils being integrant of an ecosystem, interpretations are incomplete or invalid unless associated land characteristics and climatic settings are taken into account, particularly when the interpretations concern growth and development of plants The amount, distribution, and intensity of rainfall and the number and distribution of wet months in a year dictate the choice of crops or timber species for a particular kind of soil Soil-survey interpretation for agriculture, forestry, or pastures have to rest on an orderly integration of soil characteristics, land features, and climatic conditions

Level of Abstraction

The scope and extent of interpretations are governed largely by the level of abstraction of soil-mapping units A generalized soil map can be translated only for broad land-use planning to reveal broad limitations, restrictions, or hazards for use relative to specific areas Wider ranges of interpretations, as are required for any operational development programs, are possible only when the individual mapping units are narrowly defined

The watershed development program under the Centrally Sponsored Scheme of Soil Conservation, of the Government of India, involves soil-conservation works including the structures, protection, management, and development of agricultural lands, woodlands, and pastures to combat erosion and counteract premature siltation in the dam reservoirs to enhance irrigation and power potential Ultimately, all-round development of the area is envisaged

The major aspects constituting agricultural development are the development of suitable cropping patterns matching soil potentialities and available irrigation facilities, maximum utilization of rainfall, efficient use of available irrigation potential, reduction in velocity and amount of runoff, and safe disposal of excess water

Soil surveys by the All India Soil and Land-Use Survey (Department of Agriculture) are designed, therefore, to provide both cartographically and categorically detailed soil maps The individual mapping unit is a phase of a soil series Each mapping unit on the map (Figure 1) represents a segment of the land homogeneous in respect to the following soil depth, number, kind, arrangement, and sequence of soil horizons, soil horizonal characteristics, parent material texture of the surface soils, slope gradient, erosion, stoniness, gravelliness, salinity, and alkalinity

Delineation of Priority Watersheds

The broadest level of abstraction is used in the methodology devised for the determination of highly eroding natural entities of River Valley Project catchment areas for soil-conservation programs This method (Demarcation of Priority Watersheds in the Catchments of River Valley Projects) was progressively developed by the All India Soil and Land-Use Survey Organization of the Department of Agriculture to cope with the stupendous task of handling 27 river valley catchments, involving a total area of about 64 million hectares

Interpretative groupings of the erosion-intensity units form the basis of the whole system The composition of the units reflects a unique set of soil and land factors that have decisive bearing on soil erosion Phases of soil families expressing soil depth, textural sequence in the profile, soil reaction, infiltration, permeability, and erodibility are taken into account, along with others such as land form and slope gradient, vegetal cover, cover conditions (stoniness, rockiness, etc), and land use, and observable features of soil erosion and soil-conservation measures, if any This is exemplified in the ero-

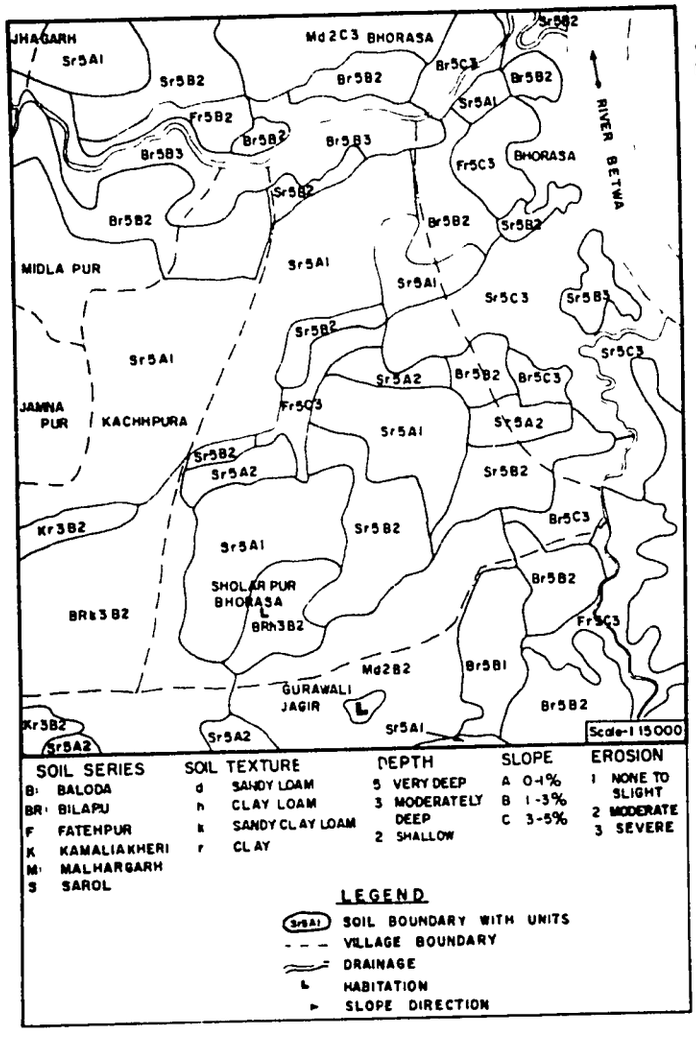


Fig 1 Soil map of MH6 and MH7 watersheds in Matatilla RVP catchment

sion-intensity legend for the Matatilla catchment area (Madhya Pradesh) shown in the Appendix

The erosion-intensity units are assigned weightage values suggesting relative potential-silt detachment Weightage value is arrived at by considered judgment on the composite effect of different attributes of an erosion-intensity unit in inducing silt yield

The sediment yield index (SI) implying the relative silt yield in a watershed is computed as follows

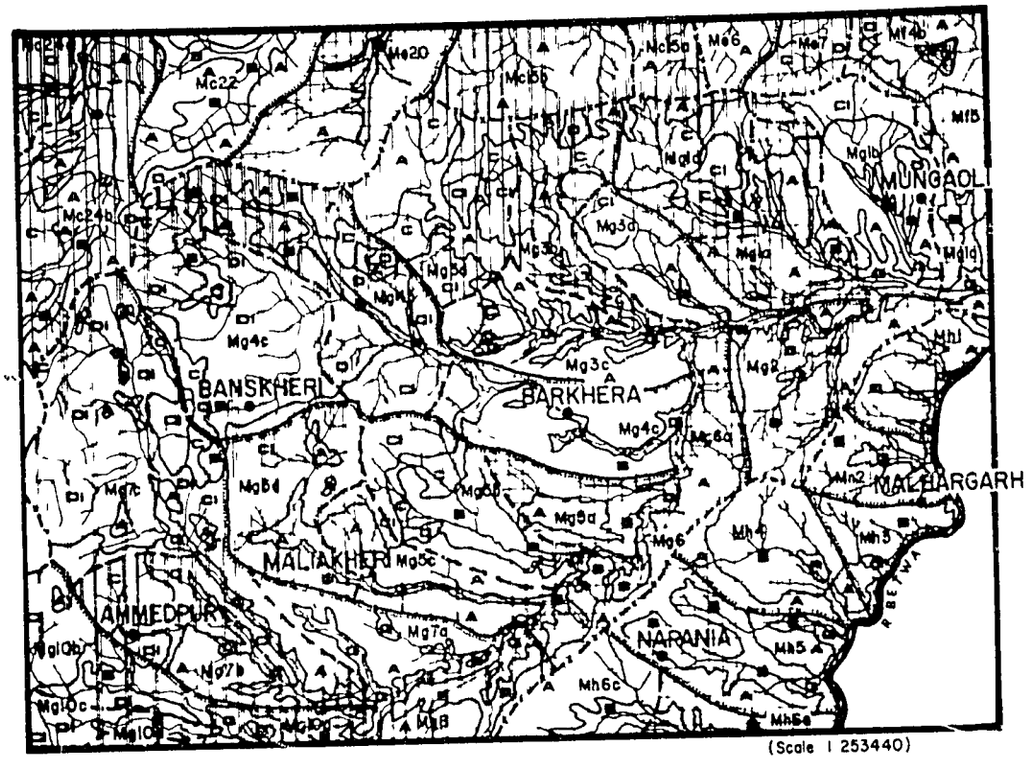
$$SI = \frac{\text{Summation } (UA \times V \times DR)\ 100}{WA}$$

where UA = area of erosion-intensity unit, V = weightage value, DR = delivery ratio, and WA = area of a watershed

The delivery ratio implying the relative quantity of detached silt yield that reaches the storage reservoir at the dam site is adjudged in consideration of both the soil and watershed characteristics A maximum delivery ratio is assigned to each of the map-

Table 1 Soil-mapping units, their descriptions and interpretations for varied uses in the MH6 and MH7 watersheds Matatilla catchment, Madhya Pradesh India

Soil unit	Description	Land-capability unit	Soil-irrigability class	Land-irrigability unit	Paddy soil group	Hydrologic soil group
Br5B1	Baloda clay very deep (above 90 cm) very gently sloping (1-3%) none to slight erosion	II s-1	B	2 st	2	D
Br5B2	Baloda clay very deep (above 90 cm), very gently sloping (1-3%), moderate erosion	II es-1	B	2 st	2	D
Br5B3	Baloda clay very deep (above 90 cm) very gently sloping (1-3%) severe erosion	III es-2	B	4 st	2	D
Br5C3	Baloda clay very deep (above 90 cm) gently sloping (3-5%) severe erosion	III es-2	B	4 st	2	D
BRh3B2	Bilharu clay loam moderately deep (23-45 cm) very gently sloping (1 3%) moderate erosion	III es-2	C	4 st	2	B
BRk3B2	Bilharu sandy clay loam moderately deep (23-45 cm), very gently sloping (1-3%) moderate erosion	III es-3	C	6 st	2	B
Br5C3	Fatehpur clay very deep (above 90 cm), gently sloping (3-5%) severe erosion	III e-1	B	4 st	2	B
Kr3B2	Kamilakheri clay moderately deep (23-45 cm), very gently sloping (1-3%) moderate erosion	III es-3	C	2 st	3	C
Kr3B3	Kamilakheri clay moderately deep (23-45 cm) very gently sloping (1 3%) severe erosion	III es-3	C	2 st	3	C
Md2B2	Malhargarh sandy loam shallow (8 23cm) very gently sloping (1 3%) moderate erosion	IV es-1	E	4 st	4	C
Md2C3	Malhargarh sandy loam shallow (8 23 cm) gently sloping (3-5%) severe erosion	IV es-2	E	4 st	4	C
Sr5A1	Sarol clay very deep (above 90 cm) nearly level (0-1% slope) none to slight erosion	II s-1	B	2 s	1	D
Sr5A2	Sarol clay very deep (above 90 cm) nearly level (0-1% slope) moderate erosion	II es-1	B	2 s	1	D
Sr5B2	Sarol clay very deep (above 90 cm) very gently sloping (1 3%) moderate erosion	II es-1	B	2 st	2	D
Sr5B3	Sarol clay, very deep (above 90 cm) very gently sloping (1-3%) severe erosion	III es-2	B	4 st	2	D
Sr5C3	Sarol clay very deep (above 90 cm) gently sloping (3-5%) severe erosion	III es-2	B	4 st	2	D



PRIORITY CATEGORIES

Very High	SI	>	1500
High	SI	1001 –	1500
Medium	SI	600 –	1000
Low	SI	301 –	600
Very Low	SI	<	301

LEGEND

Sub-Catchment Boundary
Watershed Boundary
Sub-watershed Boundary
Erosion Intensity units
Drainage

Fig 2 Part of Matatilla RVP catchment showing delineations of priority watersheds (see appendix, pp 83 84, for descriptions)

ping units on the basis of soil characteristics that include surface texture soil reaction, and slope A delivery ratio of 80 assigned to a particular mapping unit means that 80% of the total detached material is likely to reach the reservoir provided it enters into a main stream at a reasonable distance from the reservoir However, the maximum value is proportionately reduced in different parts of the catchment in view of the following physiographic position, relief-length ratio, drainage density, proximity of the active stream, land use, soil-conservation measures implemented (if any), and the distance from the reservoir and the occurrence of depositional areas (such as lakes and ponds) in the watershed The ranges of the delivery ratio used in the different parts of the Matatilla catchment area are given for each of the mapping units in the Appendix

Figure 2 illustrates a part of the priority-delineation map for the Matatilla catchment

Table 2 Differentiating morphological characteristics of the soil series in the Matatilla catchment, Madhya Pradesh, India

Soil series [a]	Physiography and slope	Effective depth (cm)		Color (moist)	Texture	Structure	Rock fragments, iron, manganese, mineral nodules	Special features	Parent material
Baloda fine clayey, montmorillonitic, calcareous, hyperthermic Typic Chromusterts	Mesitas and shallow broad valleys very gentle slopes (1-3%)	Very deep (> 150)	I [b]	Dark grayish brown (10YR 4/2-3/2)	Clay	Weak medium, granular	Calcium carbonate concretions abundant throughout	Intersecting slickensides and pressure faces	Basalt
			II [b]	Pale brown-dark brown (10YR 4/3-3/3)	Clay	Moderate, medium subangular blocky to massive	—	Very deep and wide cracks on drying	—
Biharu, fine loamy, mixed hyperthermic Typic Rhodustalfs	Hummocks, very gentle slopes (1-5%)	Moderately deep (22 5-35)	I	Dark brown (7 5YR 4/4)	Clay loam	Moderate fine, crumbly to weak, fine, subangular blocky	Ferruginous concretions increase with depth	—	Ferruginous sandstone
			II	Reddish brown (2 5YR 4/5)	Sandy clay loam	Moderate, medium granular	—	—	—
Fatehpur fine clayey, montmorillonitic, hyperthermic Typic Ustochrepts	Alluvium colluvium, undulating, gentle slopes (3-5%)	Very deep (> 150)	I	Grayish brown (10YR 4/2)	Clay	Moderate, medium, subangular blocky	Calcium carbonate concretions increase with depth	Pedologic discontinuity abrupt soil boundary	Alluvial
			II	Brown (10YR 5/3)	Silty clay loam	Moderate, medium, subangular, blocky	—	—	—

Kamilakheri fine clayey montmorillonitic, hyperthermic Vertic Ustochrepts	Foothills, very gentle slopes (1-3%)	Moderately deep (22 5-38)	i	Dark grayish brown (10YR 4/2-3/2)	Sandy clay	Weak, medium granular to subangular blocky	Reddish greenish weathered parent material with lime in pockets	Cracks on drying	Basalt
			ii	Variegated colors of soft powdery saprolite	–	–	–		
Malhargarh coarse loamy, mixed hyperthermic Lithic Ustorthents	Erosional remnants, undulating slopes (1-5%)	Shallow (< 8)	i	Dark brown (7 5YR 4/4)	Sandy loam	Weak, fine granular		—	Sandstone
			ii	Weak red (2 5YR 4/2)	Weathered parent material		Sandstone	–	—
Sarol very fine clayey, montmorillonitic, hyperthermic Typic Chromusterts	Mesitas and shallow broad valleys, very gentle slopes (1-3%)	Very deep (> 150)	i	Very dark gray brown (10YR 3/2)	Clay	Moderate medium granular	Few calcium carbonate concretions	Intersecting slickensides and pressure faces	Basalt
			ii	Very dark gray brown (10YR 3/2)	Clay	Weak to moderate medium to strong, subangular to angular blocky	—	Very deep and wide cracks on drying	—

[a] Source U S *Soil Taxonomy* (USDA 1975)
[b] Read surface (i) and subsurface (ii) data horizontally through the rest of the table

Table 3 Criteria for classifying soils into paddy grouping

Soil property	Suitability grouping			
	Very good	Good	Fair	Poor to unsuitable
Texture	Fine	Fine to moderately fine	Medium coarse	Coarse
Depth in cm	Deep to very deep, >50	Deep to very deep, >50	Moderately deep to deep, 20 to 50	Shallow to very shallow, <20
Salinity in mmhos	<4	4 to 8	8 to 16	>16
Exchangeable sodium percentage	<15	<15	<15	>15
Puddling qualities	Good	Good	Fair	Poor
Permeability	Very slow to slow	Very slow to slow	Moderately slow to moderate	Moderately rapid or more
Slope percentage	0 to 1	1 to 3	1 to 3	3

Land-Capability Groupings

The land-capability classification developed by the USDA is one of the earliest interpretative groupings introduced in the soil-survey program of India Until very recently, it was the only soil-survey interpretation attempted in most of the standard soil surveys in India The level of interpretation attained was up to the subclass level Interpretations are now attempted up to the capability unit, synonymous with management unit implying edaphologically similar subclasses of soils that are alike in their specific management requirements and responses to treatments

A system of soil-suitability classification developed by Beek, Bennema, and Camargo (1964) is comparable with the land-capability classification but reflects much broader abstraction

Table 1 gives the translation of soil-mapping units (phases of soil series) into capability units for parts of MH6 and MH7 watersheds of the Matatilla catchment, Madhya Pradesh. Figure 1 gives the basic soil map, Table 2 shows the differentiating characteristics of the soil series

Other Interpretative Groupings

Paddy Soil Groupings

The cultural requirements of paddy crops are more specific than those of most of the normal arable crops The success of the wetland paddy depends on the capacity of the soil to hold water on the surface This requirement, which is somewhat at variance with that of the most arable crops, limits the scope of adoption of the land-capability classification to ascertain the relative suitabilities of the soils for paddy To overcome this limitation imposed on the stipulations of land-capability classification, paddy soil groupings are proposed as adjuncts to the land-capability system (Table 3)

The classification rests predominantly on soil characteristics and qualities that control water retention on the soil surface and in the soil profile Interpretations of soil units for paddy soil groupings for the Matatilla catchment are given in Table 1 It may be clarified that the most limiting property decides the paddy soil groupings For example, a very deep and fine-textured soil that has very

slow permeability on a 4% slope would be considered poor for paddy cultivation because of the limitation imposed by the slope Four classes are being used in India Further refinements on the basis of new findings are possible

Hydrologic Soil Groups

Hydrologic soil groups are developed to estimate runoff potential of the different soils on the basis of properties that are directly or indirectly related to soil-water relationships Such properties include soil depth, number, characteristics, and thickness of different horizons in a profile content and type of clay, the infiltration rate and permeability The methodology is fully described in an earlier publication (Ministry of Agriculture Soil Conservation Division 1972), wherein hydrologic groupings for over 200 important soil series of India are furnished This information is an important parameter in hydrologic and sedimentation studies of watersheds

There are four hydrologic soil groups (1) hydrologic soil group A, characterized by low runoff potential (2) hydrologic soil group B by moderately low runoff potential, (3) hydrologic soil group C by moderately high runoff potential and (4) hydrologic soil group D by high runoff potential Interpretations of taxonomic units of the Matatilla catchment into hydrologic soil groupings are given in Table 1

Irrigability Classification

The irrigability classification makes possible the prediction of soil behavior under irrigated conditions and the estimation of land suitability for irrigation This classification system adopted for India has been described and discussed in the *Soil Survey Manual* (Soil Survey Staff, 1970) Further elaborations of class criteria are made by Rege, Bali, and Karale (1974) Following the criteria proposed by Rege and coworkers, Table 1 shows the soil-irrigability and land-irrigability classes, as estimated from the soil map (Figure 1) for parts of the MH6 and MH7 watersheds in the Matatilla catchment, Madhya Pradesh

Soil Surveys in the Planning and Implementation Processes

In addition to proper utilization of a particular piece of soil and land according to its capabilities and needs, the basic facts obtained from different types of soil and land-use surveys provide an authentic and scientific inventory for decision-making by planners and program implementers, who keep in view other parameters of agricultural development, such as technical, financial, and socioeconomic aspects The basic soil data are important specifically in selecting land areas according to their responsiveness to different development programs, to the effectiveness of alternative treatments, and to possible cost-benefit ratios

The delineation of priority watersheds for effective minimization of silt yield has already been illustrated Further deductions are possible from various interpretation units to compute cost-benefit ratios in executing projects In watershed treatment and in effective control of damage or deterioration, reduction in unit silt yield per unit area per unit of investment could be suitably determined For example two identical silt-yielding watersheds may need different magnitudes of costly structural treatments and cheaper vegetative measures or their combinations Watersheds having a more promising cost-benefit ratio could merit preferential implementation of the program

For agricultural development programs, basic soils and land data could be processed to determine quantitatively the problem areas, treatment needs, costs of implementing treatments on various soil and land types, additional production benefits, and other advantages Examples given in Table 4 are from a report by Coover, Roberts, and Bali (1970), they relate to Area A and Area B in north central India, each having an annual rainfall of about 750 mm The physical data

Table 4. Soil data of Areas A and B

Description	Area A	Area B
Total geographical area	373,610 hectares	354,480 hectares
Deep-to-very deep soils	13 8%	33 1%
Shallow-to-moderately deep soils	86 2%	66 9%
Irrigable Class I and Class II lands	12 9%	30 7%
Area under rain-fed crop lands	37.6%	55 4%
Area under grasslands	59 3%	40 3%
Class VI lands under cultivation	51,460 hectares	35,680 hectares
Total project-implementation costs	Rs 42 40 million	Rs 49 63 million
Rain-fed crop lands	Rs 30 60 "	Rs 41 97 "
Grasslands	Rs 11 80 "	Rs 7 66 "
Total annual costs	Rs 7 38 "	Rs 8 64 "
Crop lands	Rs 4.82 "	Rs 6 93 "
Grasslands	Rs 2.56 "	Rs 1 71 "
Per hectare	Rs 20 95 "	Rs 26 30 "
Total annual benefits	Rs 20 06 "	Rs 30 49 "
Crop lands	Rs 12 14 "	Rs 25 06 "
Grasslands	Rs 7 92 "	Rs 5.43 "
Per hectare net	Rs 36 00 "	Rs 66 58 "
Cost-benefit ratios		
Whole area	2 7	3 5
Crop lands	2 5	3 6
Grasslands	3 1	3 2

and current crop yields for the two areas were determined by surveys Improved yields, costs and benefits were estimated for each soil unit in each area and summed to give the totals shown

It is apparent that, on the basis of unit cost and benefit, Area B has greater potential for development of rain-fed crop lands and grasslands than Area A. Further, Area B has more potential irrigable lands and fewer problems of land-use adjustment

Although data generated by soil surveys are so vital to rational processes of planning and implementation of agricultural development programs, the uses made of soil surveys are limited and few The main reason for this lacuna is unavailability of soil-survey data in advance It is, therefore, essential that soil surveys should be given proper and due recognition and adequate financial support. The expenditure for soil surveys should be regarded as pre-investment toward optimum and economic agricultural development

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Appendix 1
Erosion-intensity mapping legend for the Matatilla catchment, Madhya Pradesh[1]

Symbol	Description	Weightage/Delivery Ratio
Basalt Landscape		
A	Very gently to gently sloping broad intermesital valleys and plateaus, grayish brown very deep (occasionally deep and moderately deep), fine-textured, cracking soils mostly cultivated, showing evidence of moderate sheet and rill erosion, few gullies	25 / 80-40
B	Gently sloping stream banks, grayish brown deep (occasionally very deep), fine-textured cracking soils, mostly cultivated, moderate and severe sheet, rill and gully erosion	30 / 90-40
C	Very gently to moderately sloping, slightly undulating uplands, grayish brown (occasionally reddish brown), very shallow and shallow, fine-textured, stony soils, shrubs and grasses, moderate erosion	15 / 40-20
C1	Moderately to moderately steep sloping (occasionally gently sloping and steeply sloping) hillocks, dark reddish brown (occasionally very dark grayish brown), very shallow to shallow moderately fine and fine-textured stony soils, medium forest vegetation, slight sheet and rill erosion	16 / 40-20
D	Gently to strongly sloping isolated, subdued hillocks, with lateritic cappings, reddish brown (occasionally grayish brown), moderately fine-textured, gravelly soils, shrubs and grasses, moderate erosion	14 / 30-10
D1	Moderately to moderately steeply sloping (occasionally steeply sloping) hillocks, reddish yellow and yellowish red (occasionally dark reddish brown), very shallow to shallow, moderately fine-textured, gravelly soils overlying laterite, exposed rock at places, medium forest vegetation, slight sheet and rill erosion	15 / 30-10
Granite Landscape		
E	Very gently to moderately sloping, undulating uplands and moderately to strongly sloping, subdued hillocks, reddish brown, shallow (occasionally moderately deep and very shallow) moderately coarse-textured soils, predominantly under grasses and shrubs, moderate erosion	13 / 30-10
F	Moderately to strongly sloping hillocks, reddish brown and yellowish brown, very shallow, moderately coarse-textured, stony soils, rock outcrops common, medium forest vegetation, part of the area (approx 50%) protected by enclosures, slight erosion	12 / 30-10

G	Gently to strongly sloping, upper pediment back slope; exposed rocks surface occasionally with only a very thin cover of coarse-textured gravelly soils	11 / 30-10
H	Gently sloping, lower pediment back-slope, reddish brown, shallow (occasionally moderately deep) coarse and moderately coarse-textured, bouldery and stony soils; shrubs and bushes, slight erosion	12 / 30-10
I	Very gently to gently sloping, pediment foot slopes, reddish brown, moderately deep and occasionally deep, moderately coarse to moderately fine-textured soils, under cultivation, moderate erosion	15 / 50 20
J	Nearly level toe slopes, grayish brown, very deep, fine-textured, cracking soils showing hydromorphic influence in the lower layers, under cultivation, moderate erosion	16 / 80-30
K	Gently to strongly sloping, undulating lands bordering stream courses, a complex of reddish brown and grayish brown, very shallow and moderately deep and deep, moderately coarse- and fine-textured soils, interspersed with rock outcrops, partly cultivated, moderate erosion, occasional gullies	18 / 80 50
L	Steep to very steeply sloping irregular hillocks (granite-quartzite dykes), yellowish brown and reddish brown, very shallow and shallow, coarse-textured, gravelly skeletal soils, shrubs and forest vegetation, moderate to severe erosion	12 / 40 10

Sandstone Landscape

M	Moderately steep to very steeply sloping hillocks, reddish brown, very shallow and shallow, coarse-textured, skeletal soils, moderately dense forest vegetation, mostly protected by enclosures, none to slight erosion	13 / 30-10
N	Very gently to gently sloping upland (structural terraces), reddish brown, shallow (occasionally moderately deep), moderately coarse-textured soils, shrubs and grasses, slight erosion	12 / 40-10
X	Nearly level to gently sloping foot hills, reddish brown to grayish brown, very deep (occasionally deep), fine-textured soils, dense, bushy vegetation, slight erosion	15 / 50-20
P	Level to gently sloping valley lands, grayish brown, very deep, fine-textured cracking soils, mostly cultivated, moderate erosion, with occasional gullies	20 / 80-50
Q	Gently to moderately sloping and rolling wastelands along streams and rivers, yellowish brown, deep and very deep, highly calcareous, fine-textured, alluvial soils, sparse shrubs, severe gully and stream-bank erosion	35 / 90-50
Q1	Undulating and rolling lands along the stream courses, yellowish brown, very deep, moderately fine-textured, calcareous soils, medium bushy vegetation severe sheet and rill erosion	30 / 90-50
R	Strongly to very steeply sloping isolated small hillocks, dark yellowish brown and dark reddish brown, very shallow and shallow, coarse-textured soils, rocks exposed at several places, mostly barren, slight sheet erosion	14 / 30-10

[1]This appendix describes the soils shown in Figure 2

Contribution of Soil-Survey Interpretation in Land Appraisal

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Soil-survey interpretation is concerned with understanding and explaining the practical significance of soil differences recognized and mapped by a soil survey It is not land classification since this includes other environmental and socioeconomic factors

Most soil-survey interpretations are made in terms of general capability classifications, which have several weaknesses including their nonspecificity regarding crops and the absence of levels of management information Interpretations that are expressed as soil suitabilities for specific forms of agriculture are more useful, but the specific agronomic information that should form their basis is often lacking and they can serve only the broadest planning purposes Where these are combined with adequate agronomic information, they are of great value The same can be said for engineering interpretations of soils that have reached a high level of accuracy and usefulness in the United States

There is a growing conviction that interpretations need to be specific about purpose and site to provide the needed basis for immediate development Limitations of soil units for specific purposes based upon soil characteristics that are spatially uniform within the unit may be the most useful form of soil-survey interpretation for the future The soil characteristics selected as diagnostic should be reasonably stable unless deliberately modified by man When they have been well selected they can provide the basis for single-factor maps A wide variety of such maps can be invaluable to the planner

The environmentalists, hysterical and otherwise, have created awareness of the need to husband the earth's land resources A need for conservation in the wisest sense, involving maximum effective use of land and a slowing—if not even a reversal—of the trend of deteriorating land qualities The urgency of this need, which we now appreciate, focuses attention on our capacity to apply existing scientific knowledge Many problems remain, and the purer forms of research must continue, but there is immediate necessity to make use of what we already know no matter how inadequate it may sometimes seem This is what soil-survey interpretation is all about —the application of existing knowledge to guide the acquisition of soils data and to gain an understanding of these data for the wise use of soils

More prosaically, soil-survey interpretation is concerned with understanding and explaining the practical significance of soil differences recognized and mapped by a soil survey Vink (1960) pointed out that soil is the one environmental factor that is both stable enough to form a base for land classifica-

tion and, at the same time, flexible to man's influence More recently, however, Vink (1975) has also stressed that, although it is occasionally acceptable to regard the results of soil surveys as the most essential part representing all other land resources, the approach is one-sided and in several instances has proved disappointing because data on other aspects of land and human resources were lacking In 1962, Kellogg wrote " it is highly important to distinguish clearly between soil-survey interpretations and land classification" Since then other authors (Mahler et al, 1970, Maletic and Hutchings, 1967, Smyth, 1972) have stressed the essentially contributory role of soil-survey interpretation in land classification, and the greater complexity of the land concept has been fully recognized in an international discussion of the FAO Framework for Land Evaluation (Brinkman and Smyth, 1973)

To date, however, although conscious effort seems to have been made in many countries, it seems insufficient to interpret soil surveys in ways specifically suited to integration with other environmental studies Traditionally, soil-survey interpretation has been seen as a source of planning advice in its own right To achieve this aim, it is usual for assumptions to be made regarding the following the uniformity of other environmental factors, the feasibility of inputs, the expected levels of management, and the availability of markets, access, and other factors that a soil survey would not normally explore These assumptions seriously prejudice the practical value of the interpretations since they relate to variables of great significance in land-use planning

It might be thought that the present trends towards interpretative land classification (land evaluation) by multidisciplinary teams would eventually overtake soil-survey interpretation, leaving the latter with no role to play This does not seem likely because the validity of land classifications relating to very precisely defined objectives is short-lived, especially the land classifications that have quantitative economic bases, which were advocated by the international discussions reported by Brinkman and Smyth, 1973 Continual effort would be necessary to keep these classifications up-to-date, therefore, and from time to time, new use options would doubtless require evaluation In either case, there would be a need to reexamine the basic environmental data, and this would be much assisted by the availability of interpreted information on the more stable soil characteristics

It is in this context that this paper attempts a brief review of the art and the directions in which soil-survey interpretation might desirably go

Soil-Survey Interpretation Today

FAO (1974) and Vink (1975) provide recent and fairly comprehensive and internationally oriented accounts of land-appraisal methodology including aspects of soil-survey interpretation Here only a superficial and subjective view can be given

Much of the world's effort in soil-survey interpretation finds expression in some form of capability classification, and the doyen of these is, of course, the Land Capability Classification of the Soil Conservation Service of the U S Department of Agriculture (Klingebiel and Montgomery, 1961) This eight-class system is too well known to require description Despite its name, it is a classification of soils rather than land, for, by assumption, only permanent soil characteristics and climate are taken as determinants Variants of this U S system have appeared in nearly all countries, and have been adapted to a greater or lesser extent to meet local conditions, particularly in respect to the limitations diagnostic of subclasses These classifications have proved their worth in contexts of broad planning, particularly in making broad assessments of the usefulness of land in terms of agricultural versatility The full potential of the system has scarcely been exploited outside the United States, however, where, on the one hand, classification at the capability-unit level (rarely used elsewhere) assists preparation of individual farm plans and, at the other extreme, the system has been used as a basis for a national conservation-needs inventory

Shortcomings common to the various general capability classifications include

1 A confusion of interpretative objectives, some of which may be in conflict (e g , relative suitability for cultivated crops decreasing choice of crops, increasing limitations to cultivation, especially erosion hazards, increasing input requirements, and actual recommendations for kinds of use) Frequently, it is impossible to identify which considerations have contributed to the class designations
2 No clear indication of the specific crops or management inputs that are the principal concern of the classification Increasing limitations are understood to narrow the range of suitable crops, but the crops excluded are rarely stated
3 No adequate provision for locally important crops, such as wet-land rice or pasture that differ in their optimum requirements from wheat, maize, and other row crops which usually, but not necessarily appropriately, constitute the norm

In some countries, development of more specific capability classifications has been attempted For example, in Canada the soil-capability classification relates solely to agriculture (McCormack, 1971) Forestry has also been excluded from consideration in Ghana, where the capability classification focuses on mechanized and hand cultivation for crop and livestock production (Obeng, 1968) In Ireland, in addition to a general soil-suitability classification that has only six classes but is otherwise similar in principle to the U S system, a separate classification is used, which groups soils into five use ranges These ranges refer to the uses to which the soils are suited under normal management and fertilizer practice and extend from wide to extremely limited (Gardiner in FAO, 1974) This extract from the general system is of considerable interest since its meaning is unencumbered by other ideas The use range could be especially valuable in planning situations that involve competition for the use of agricultural land

Another major form of interpretative expression is the suitability assessment of soils for specific crops or for specific kinds of agricultural enterprise, such as mechanized arable farming or market gardening Quite often these assessments are the outcome of soil surveys undertaken for a specific purpose, examples are the various surveys to identify soils suited for cocoa in West Africa and Latin America, for coconuts on Christmas Island (Jenkin and Foale, 1968), or for oil palm in Gambia (Hill, 1969) At other times, the assessments are included in the findings of surveys having a more general purpose, a notable example being the wide range of crop-suitability interpretations developed in the FAO-assisted soil surveys in Pakistan and Bangladesh (FAO, 1971)

Commonly these soil-suitability assessments are expressed in simple three- or four-class classifications, and, in theory, the soils are rated in terms of limitations specific to the enterprise in question In practice, subjective observation and experience play an important part because, as Vink (1975) points out, specific information about soil requirements of crops still tends to be vague and difficult to find Understandably, the suitability interpretations themselves are often vague and so lacking in information about the farming context to which they are intended to apply that they can serve only the broadest of planning purposes

In the United States, the Soil Conservation Service has developed a standard format for the computer storage of soil-survey interpretation data relating to each established soil series These data include predictions of yield (under a high level of management) for each of the more important crops grown on each major phase of the series These predictions may be thought of as a form of quantitative suitability assessment The data sheets also include detailed interpretations, phase by phase, of woodland suitability and recreational possibilities These interpretations, relating as they do to central concepts of soils at the phase level, are well suited to contribute to true interpretative land classification on specific sites, despite the assumptions

about management that are at the base of the surveys themselves. Unfortunately, the development of survey interpretations calls for a highly developed soil taxonomy and a fund of other environmental information, to which most other countries can now only aspire

Another area of soil-survey interpretation in which the U S Soil Conservation Service has taken giant strides relates to engineering uses (USDA, 1971) The data sheets for established soil series, referred to earlier, include assessments of soil limitations (slight, moderate, severe) for five aspects of sanitary facilities (septic tanks, lagoons, and various land-fills), for five aspects of community development (excavations, various buildings, and streets), and for lawns, landscaping, and fairways Comments on seven aspects of water management are provided, and the separate phases of the series are also evaluated in four classes (good, fair, poor, unsuited) as source material for road-fill, sand, gravel, and topsoil

Evaluations of soil as source materials for construction have special significance in that they represent perhaps the only aspect of soil interpretation that is truly independent of other environmental factors—at least at the site where they are mined At the same time, it is worth noting that the engineering character, even more perhaps than the agricultural character, of a specific site may be critically dependent on the nature of adjacent sites, particularly with regard to moisture properties

Recognition of hazards associated with specific soils is an especially valuable form of interpretation The hazards might be of a physical nature (instability, slumping, etc) or connected with soil pests (such as nematodes), diseases (notably root rots), or pollution The immediate and obvious value of these interpretations, in common with engineering interpretations, has the very practical advantage of attracting interest and financing for soil surveys

Some soil surveys in France are presented in terms of maps designed to give a visual impression of some of the most significant, partially interpreted characteristics of the soils (e g , slope, shallowness, waterlogging, and salinity) The aim is to produce a relatively long-lasting document that will be informative to a wide range of people having different interests, although the needs of agriculture remain in the fore (Boyer in FAO, 1974) This approach clearly has possibilities for contribution to the interpretation of land

Finally, but by no means least important, reference must be made to parametric methods of soil-survey interpretation These methods involve assigning numerical values to soil (and sometimes site) variables and manipulating these values mathematically to derive a predictive index of productivity, often expressed as a percentage of an optimum yield The principles, advantages, and drawbacks of the major parametric methods have been summarized recently by Riquier (in FAO, 1974) The methods have been particularly favored in the Eastern European countries (Teaci and Burt, FAO, 1974) Although it is questionable whether these methods are much less subjective than traditional comparisons, with further development, they do offer possibilities of assisting the injection of soil and other environmental data into the interpretation of land

More Effective Use of Soil Survey

Planning the Objectives

Concern for the practical application of soil-survey findings demands that we examine more closely the requirements of the ultimate users—the farmers, land planners, engineers, and others Recent attempts to do so lead to the growing conviction that interpretations must be specific as to purpose and site if they are to provide the needed basis for immediate development (Brinkman and Smyth, 1973) This implies a clear departure from the vague and sometimes confused interpretations discussed in the previous section Indeed, there is already impatience, especially amongst investment agencies and aid donors, for information that will serve implementation rather than further broad planning

Broad land-resource knowledge is, nevertheless, a most desirable background for in-

tensive, specific studies How else can one be sure that the most appropriate area has been chosen for costly intensive work? How else can one hope to extend with confidence the experience of the pilot area to the surrounding country--surely the very essence of development work? The solution to this dilemma would seem to lie in ensuring that a reconnaissance survey is performed to clear cut objectives and that it gives way to more intensive phases of study, each with carefully refined objectives as soon as the most appropriate areas can be identified There is no reason in principle why the various phase of survey should not overlap Thus, semidetailed studies may have identified project areas and given way to various intensive preimplementation studies before the reconnaissance is completed

What is most important, however, is the sound development of objectives before and during each phase of survey To quote once more from Kellogg (1962) "Planning good soil survey interpretations, like planning good research depends first of all on a clear statement of the critical questions" If the right questions are to be asked and answered in the final stages of the study, they must be developed through formulation and refinement and if need be through change of objectives brought about by close and continuing consultation with all parties concerned in the development

The formulation of objectives involves much more than soil-survey interpretation Indeed in most instances, it is to be hoped that soil survey itself will form only part of an integrated study Nevertheless, soil-survey interpretation is certainly involved, and this implies that, in a survey, it is never too early for interpretation to begin

The Choice of Interpretative Criteria

Every young soil surveyor is told that he should gather every scrap of information that he can while in the field because it costs so much to put him there and he may never pass that way again Within reason this is sound advice, but the volume of data collected can be suffocating, especially when it is augmented by laboratory analysis and the results of field tests The selection and simplification of these data for practical presentation have always been important aspects of soil-survey interpretation They seem likely to become more important if soil surveys are to be interpreted to provide specific, and preferably quantitative, inputs to land classification, rather than generalized capability or suitability groupings that can conceal a wealth of unexplained complexity

Present evidence suggests that the interpretative inputs that soil survey can best provide will be expressed in terms of limitations for a given objective associated with classified kinds of soil (recognizing, of course, that what is a limitation for one use can be a positive advantage for a different use) The limitations might be single soil characteristics (e g content of stones) or interpreted combinations of soil characteristics (e g , sequence of textural horizonation), but they could not, in themselves, have the complexity of land qualities (e g , availability of soil water, hazard of salinity), as described by Beek and Bennema (1972), since many land qualities are influenced by the character of adjacent lands and depend, therefore, upon unique location An understanding of the characteristics of the soil (or soils) involved is essential, of course, for the a sessment of land qualities, and this could well be the main contribution of soil-survey interpretation in the future--a tool of the land-evaluation specialist rather than of the land-use planner

In the selection and rating of significant soil limitations, many questions still remain unanswered The problems involved have been closely studied by the authors of parametric interpretative classifications, but their interest has been directed primarily to the relation between measurable soil characteristics and crop performance Mathematical methods of principal component analysis show excellent promise of being able to establish these relationships objectively and of indicating in a given instance which characteristics are most significant

This is only part of the problem, however To contribute to land evaluation, the soil

characteristics selected as diagnostic must be reasonably stable unless deliberately modified by man. Furthermore, if we are to use soil maps as a basis for interpretation, the distribution of the chosen diagnostic characteristics must be reasonably uniform within each mappable unit In fact, in an agricultural context, in choosing diagnostic soil characteristics, one must consider each characteristic in terms of relevance to crop performance, susceptibility to quantification and rating, stability with time, uniformity of distribution in relation to mappable units, and response to improvement

The last consideration may have little bearing on assessing the present status of soil and land, but it is vital to assessment of land potential and the prospects of change, with which land evaluation must be increasingly concerned

This list of considerations strengthens the view that the best choice of diagnostic soil characteristics must be decided locally, for the best choice depends not only on the development objectives in view and on the physical characteristics of the area but also on the intensity of the study For example, average values for characteristics that have very high spatial variability (e g, many chemical characteristics) may be diagnostically useful in interpreting reconnaissance surveys but could be highly misleading if applied to soil units in a detailed study Characteristics of moderate spatial variability (e g, microtopography), on the other hand, are likely to be diagnostically more useful in detailed than in small-scale studies

The apparent need for a fresh choice of diagnostic criteria in each new situation casts doubt on the possibilities of complete success for any universal parametric system

Having selected the diagnostic criteria that appear to have relevance to a number of interpretative purposes, I feel that there could be merit in presenting these individually in the form of single-factor maps Computer mapping can reduce to reasonable proportions the time and cost of producing a wide variety of such maps, which would then be basic tools of the land classifier

These single-factor maps would differ from those that were made in the infancy of soil survey in that they would normally be derived from, and would remain equatable to, basic soil maps depicting units classified in a taxonomic classification and possessing, therefore, all the potential advantages of correlation Occasionally, of course, single factors of high practical significance can and should be mapped separately if their distribution appears unrelated to the boundaries of taxonomic units (Hansell and Wall, 1974)

As a final point, I might mention that the emphasis placed on single soil characteristics, or simple combinations of soil characteristics as diagnostic in interpretation has implications for the requirements of soil description If an interpretation is to have relevance to a soil unit as a whole, it must be based on characteristics that pertain to all, or nearly all, parts of that unit We are all conscious that the "typical" profile of a soil rarely occurs—the "type" profile tends to be the one that departs least seriously from the theoretical norm This places great importance on preparing a summary description of the modal profile, which includes reference to all characteristics believed to typify the soil unit as a whole Emphasis must also be placed on describing the range of characteristics, especially in terms of horizon thickness, that are anticipated within the unit Both of these provisions are foreseen in the widely used methods advocated by the *U S Soil Survey Manual* and by the *FAO Guidelines for Soil Description*, but they are generally accorded lesser importance than the detailed description of a type profile, and they are sometimes even omitted

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PART III:
USE OF SOIL-RESOURCE DATA IN LAND-USE PLANNING

Techniques for Displaying Soils Data

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Soil-survey reports are the most useful source of land-resource information available Complete land-resource inventories which might contain several hundred data, are usually too time-consuming to compile and experience shows that much of the information gathered is never used Land-use planning is an interactive process that benefits from the early display of existing data

Methods of displaying land-resource data have a strong influence on the acceptance of the data Interpretative overlay maps are effective inexpensive and easy to prepare using resource maps and criteria tables developed by professionals Electronic computer displays can be very effective but they are expensive to develop and certainly not essential to good land-use planning

A soil map of Gallatin County published in 1931 provided a satisfactory base for soil-survey interpretations and land classification 40 years later Methods used in displaying the interpretative data include color-coded soil-limitation maps overlay maps showing composite soil limitations for several complementary uses black-and-white maps for newspaper use interactive overlay techniques integrating soil geological climatic land-use and social and economic factors the shaded-window technique three-dimensional models and computer graphics The determination of the costs required to overcome soil limitations is a highly effective type of soil-survey interpretation

These interpretations can be made for and used by planning commissions state and local authorities and agencies citizen and community associations realtors and other land-related businesses professional groups, schools and universities recreational groups and the general public through the news media

The effectiveness of these interpretations can be judged from their application, by the level of user interest as determined by surveys, and by the demand generated for the basic soil-survey reports from which the interpretations were made

Every nation, region state, and farm has a unique assemblage of natural resources soil and rocks, water and air plants and animals These together with social, economic, and human resources determine current and potential land use Every land area has comparative strengths and weaknesses Land planners seek information on land capabilities and limitations (Bartelli et al, 1966, McHarg, 1969) Base-line data describe *what is*, and they are used to predict *what can be* Results are displayed so audiences visualize the distribution of resources and sense the land's potential

Planning goals should be based upon inventories of resources and upon economic analysis of the production potential for scarce commodities Reports in which the

soils are classified, mapped, and evaluated according to standard procedures are indispensable inventories

This paper, based on our experiences in Montana, describes techniques used to deliver soil-survey data to land planners, decision makers, and the general public

Background

The need for land planning is felt at all levels from individual farmers to the authors of national land-use policies In the United States, federal and state laws require impact statements for public review before major changes are made in the use of public lands Land-use plans and impact statements are prepared prior to many developments ranging from highways and airports to dams and housing projects Most laws require some kind of land-resource inventory to establish conditions before development The inventories are interpreted to answer questions about management alternatives, development consequences, social, economic, and cultural benefits and costs, and preservation of unique land areas

World food shortages have brought renewed commitments to all-out food production and to agricultural development A national assessment of prime farm lands is being conducted under the land-inventory and land-monitoring program of the U S Soil Conservation Service Elsewhere questions are asked about land potential for crop varieties, cropping systems, and alternative urban land uses Basic land-resource inventory data are needed to deal with all of these questions

Conflicting land uses, especially in urban areas and their rural fringes, have increased the demand for land-use plans Ian McHarg and Phillip Lewis, renowned planners, agree that few, if any, inputs to a plan are more important than a soil-resource inventory A checklist developed at Montana State University lists 1,400 particulars that might be included in a land-resource inventory (Plantenberg et al , 1974) Nearly one-fourth (330) of these are given or can be estimated from soil-survey reports. No other commonly available source of information is as useful

Need for Soil Data in Land-Use Planning

In response to demands for soils- and land-use information, agricultural experiment stations and cooperating federal agencies in the USDA have initiated regional research projects Ten western states are studying Soil Interpretations and Socioeconomic Criteria for Land-Use Planning he investigators recognize the need to (1) document impacts of urban encroachment on rural lands, (2) identify and organize soil data and interpretations for present and potential clientele, and (3) evaluate the adequacy of present data and develop new data, interpretations, and procedures to overcome soil limitations General soil maps (1 1,000,000 and 1 250,000) have been developed by several states as part of this effort Hawaii is evaluating soils for specific crop requirements to rate land for agricultural potential Colorado is developing land-opportunity and land-limitation maps

Ten north central states are cooperating in a research project called Soil Landscape Characteristics Affecting Land-Use Planning and Rural Development General soil maps (1 250,000) are being prepared Additional land-resource information (geology, topography, ground water) has been added to soil-survey information for better soil-landscape interpretations Computer graphic display systems for developing interpretative data and maps are being examined as are remote sensing techniques for characterizing soil-landscape units and for detecting soil limitations Developing more effective methods of disseminating data and interpretations is a major goal of these projects

The American Society of Agronomy (ASA) will publish a monograph to meet demands for soil data in land-use planning Topics considered include principles of land-use planning, data bases (emphasis on soils, plants, and water), modern mapping and reporting methods, remote sensing, data

presentation, land-information systems, and major sections on planning for cultivated and range lands, forest and woodlands, metropolitan land, recreation areas, transportation systems, and waste-disposal areas

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 is often needed about climate water, and other land resources Dr Rudy Dudal Director of Soil Surveys for FAO and Executive Secretary of the International Soil Science Society stated that present soil surveys are inadequate to define land potential The most difficult task of all is the integration of basic land-resource data with information on social economic and human resources

We are studying similarities of barley research stations on a worldwide scale Cluster analysis methods were applied to data from questionnaires returned from 122 locations The data included 53 climatic factors Eight North American groups contained soils remarkably similar according to *Soil Taxonomy* (USDA, 1975), but unfortunately not all soils of world centers could be classified

Soil data are needed for land-use planning *now* for many different purposes, in different scales, for different kinds of displays Land-use planning can never be complete, comprehensive, or perfect It is an iterative (cyclic) process that should begin by effectively displaying information that is already available Better data will always be needed, but displays of current information show which new details are most critical and which inventories most inadequate Our experiences with land-resource inventories show that much information is gathered that is never used Early attempts to deliver the facts already in hand will help prevent this waste and point inventory work in more productive directions

Display Examples

A soil map of Gallatin County, Montana, was published in 1931 (DeYoung and Smith, 1931) Hundreds of reports remained on shelves until 1970 when a supplemental report (Soil Conservation Service and Montana Agricultural Experiment Station Staff, 1971) was prepared in which the use capabilities 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 soil limitations green yellow, and red for slight, moderate, and severe, respectively Each map (half a square meter) cost $3 50 for materials, and was prepared in about 8 hours by nontechnical help 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 and 35-mm slides were used to illustrate soil limitations and related land-use problems The investment per monolith was about 8 hours of labor and $10 for materials

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 soil limitations sometimes prevents 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 colored maps and were reduced photographically for publication in newspapers Most

newspapers accept maps that accompany short articles on soils and land use and publish them without cost For example, we converted a county land-ownership map from color to black and white using about 8 hours of labor, $10 for materials, and $8 for photographic reductions The map was published free and reached 8,000 people A colored map would have cost $240 just to prepare for printing Publication in color is 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 This kind of interdisciplinary study technique that can be demonstrated with overlay maps at a seminar cannot be shown in this paper

The shaded window-display technique uses transparent overlay maps in which constraints for a particular land use are indicated in shades of red, using color films Each map is made in about 8 hours and costs $6 for materials This technique is demonstrated on a world map (Figure 1) The map is a composite of four overlays representing constraints on dryland barley production imposed by (1) soil, (2) precipitation, (3) evapotranspiration, and (4) growing season Areas that appear darkest red (black in Figure 1) have the greatest limitation for the production of dryland barley Clear areas or *windows* are areas where dryland barley is expected to thrive and where, in fact, most world barley-breeding centers are located This crude technique indicates a band through central Africa where barley would appear to thrive but where barley varieties are not being developed If this area continued to appear as a window after many additional land-resource overlay maps were added, then the land would certainly seem to have potential for barley production We are not recommending that barley should be

Fig 1 Composite of transparent overlay maps showing shaded areas that have environmental constraints for barley, imposed by soil, precipitation, evapotranspiration and growing season Darkest areas have greatest limitation.

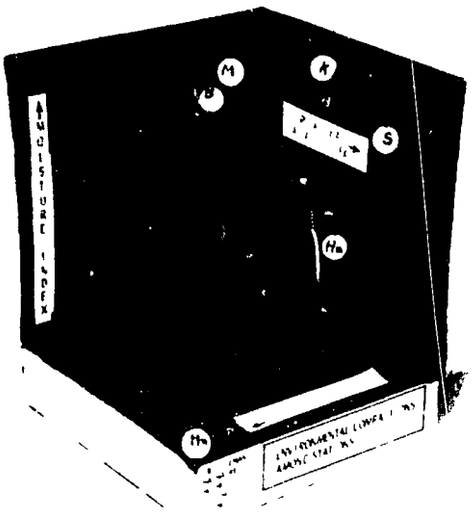

Fig 2 Model of environmental differences among Montana Agricultural Experiment Stations

produced in this area, however, because social, economic, and human considerations such as capital requirements, markets, health, transportation, education, and ownership were not evaluated These constraints are more difficult to evaluate than land-resource constraints

Three-dimensional models can also be constructed to demonstrate environmental differences between land areas Figure 2, a photograph of such a model, shows environmental differences among agricultural experiment stations in Montana The ball labeled *Hu* represents the site that is environmentally the most different from other sites It would be risky to extend experimental results from here to other stations without further testing Two sites that appear near the same point in the model could exchange research results with some confidence that their environments are alike Materials in the model cost less than a dollar

Electronic computers can save time when help is scarce We record data in the field on mark-sense forms Computers write descriptions of soil pedons and mapping units and rate soil limitations as slight, moderate, or severe for many potential uses (Decker et al., 1975) The ratings are based upon criteria previously developed by the Soil Conservation Service and others The results appear as typewritten descriptions and tables, not as computer graphic displays and maps (A report on this automated data-processing system was given to participants in the seminar) Those who wish may have a small packet of trial mark-sense forms processed at cost (about $2 per pedon) at Montana State University Note, however, that the interpretative criteria are developed for Montana and cannot be applied directly to land in other areas

Future efforts to communicate ideas about land potential to decision makers will certainly use more composite constraint-overlay maps But overlays have some limitations Eventually, computers may be used to make individual soil-constraint maps as well as composite maps printed by the computer in which each component map is, in a sense, weighted according to its importance The importance of each map (soil, climate, present land use, etc) would be previously assigned by experts

Land information systems will eventually incorporate computer graphic displays, remote-sensing from high-elevation aircraft and satellites, computer data-processing systems, and systems-analysis techniques Integrated land-capability maps will appear on television monitors Planners will simulate future land uses for decision makers The audience will participate by changing the criteria used for evaluating the land resource or by changing any assumptions about future prices, populations, and the like 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 outputs are rare

Audiences

The following list of audiences illustrates the range of public interests in soil-resource data for land-use planning No overt efforts were made to call attention to the data

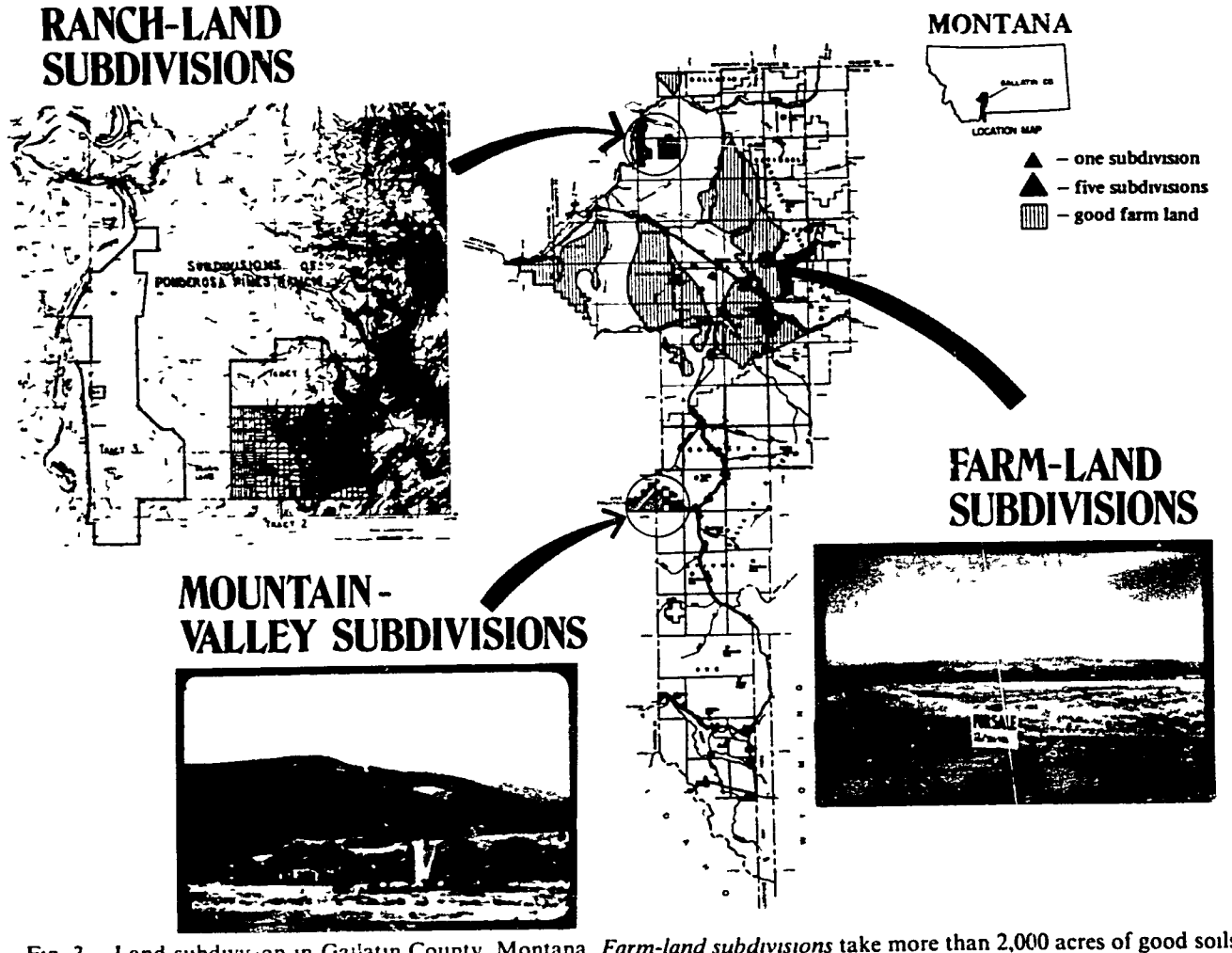

Fig 3 Land subdivision in Gallatin County, Montana *Farm-land subdivisions* take more than 2,000 acres of good soils out of production *single-ranch subdivisions* cut 13,000 acres into 950 lots, with little consideration for land capabilities, and *mountain-valley subdivisions* use land for recreation and retirement homes (Source Gallatin Canyon Study Team 1974)

and interpretative maps One presentation seemed to lead to another During the past 3 years, over 150 presentations were given by staff of Montana State University's Plant and Soil Science Department, the Agricultural Economics Department, the Cooperative Extension Service and the Soil Conservation Service

University classes in Soil Science, Architecture, Real Estate, Economics, Earth Science, Geography, Recreation Area Management and Planning—Montana, Idaho, and Washington
Soil Science Society of America—Laramie, Wyoming
Planning Division, Canadian National Park Service—Calgary
Interregional Resource Economics Committee—Chicago
Citizens Conference on Taxes—Manhattar, Kansas
Division of Agriculture Institute of Canada—Calgary
Planning associations—three Montana counties and Tucson, Arizona
Montana State Cooperative Extension Staff—Bozeman
Private land resource consultants
County commissioners and city-county planning boards—six counties
Realtors Association—Gallatin County
Soil Conservation Service training meetings—six Montana cities
Kellogg Extension Education Program —Cooperative Extension Service, Montana
American Institute of Industrial Engineers—Western Student Conference
Statewide County Planning Workshop —Montana
Center for Industrial Development—Montana State University
Environmental Quality Workshop—Montana College of Mines and Geology, Butte
New Mexico Chapter of SCSA—Las Cruces
National meetings SCSA—Hot Springs, Arkansas
Western Regional Planning Association of Montana and Department of Natural Resources and Conservation —Missoula, Montana
Gallatin Sportsman's Association—Bozeman, Montana
Farm Bureau—Wheatland and Park Counties, Montana
Montana Art Education Association
State Rural Areas Development Committee—Montana
State Departments of Natural Resources, Lands, and Fish and Game —Montana
Montana Soil Scientist Workshop for Federal and State Agencies
Montana Wilderness Association
Department of Film and Television—Montana State University
Forest Service—Gallatin National Forest
Gallatin County Fire Council
Crow Indian Reservation—Bighorn County, Montana

Presentations were directed toward officials at the county level and to the general public Most audiences were unaware of the comparative advantages and disadvantages that are characteristic of their land resources They could not clearly visualize the geographic distribution of resources and were not fully aware of current land-use changes and their implications Many oppose land-use planning by state and federal agencies

A pictorial bulletin was published to increase public awareness of development impacts upon land resources, land use, and the future of Gallatin County in southwestern Montana (Gallatin Canyon Study Team, 1974) Figure 3 is from that bulletin

A 35-mm slide series and narrative entitled "Land Use and Abuse in Montana" was produced for the Cooperative Extension Service This was used as lead-off material for nine regional land-use conferences sponsored by a broad spectrum of interest groups both private and public, rural and urban

A workshop on county resource inven-

tories and land-use problems was conducted at Montana State University for county commissioners and planning board members from throughout the state This workshop reaffirmed the conviction that much useful information about county resources remains unused because (1) potential users are not aware of its existence and (2) the information is in relatively unusable form

Workshop participants and others have urged the preparation of a County Resource Inventory Handbook that (1) gives sources of information, (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 county resource data for selected uses (i e , roads, schools, waste disposal, agriculture), and (4) explains how overlay maps can be prepared for public meetings The handbook will have sections on geology, topography, climate, soils, water, vegetation, wildlife, land ownership, land use, population characteristics, business levels, taxes, and public services It will not tell how to do land-use planning The handbook will describe how general land-resource information that is already available in files can be assembled for county-resource analysis

Further soil-resource interpretations are needed in Montana in the following areas 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, wilderness protection, barley and alfalfa production, definition of carrying capacity for land, route selection for transportation systems and utility corridors, planning of and implementing strip mine reclamation, home-site selection, ground truth for remote sensing, and saline-seep identification

Each audience representing a specific interest needs specific interpretative criteria and specific maps showing soil-resource capability All can rely upon the same basic soil data if standard methods of classification and mapping are used.

Effects on Decision-Making

Maps of soil resource capabilities and constraints influence land-use decisions However, this is hard to document because decisions are seldom made on the basis of a single factor To identify the most influential factor is often impossible

Few, if any, regional planning efforts in the United States have been as successful as that in southeastern Wisconsin Much of the latter's success has been attributed to the standard soil-survey and land-use interpretations that were made available before land-use plans were developed

A few Montana counties have prevented subdivision of agricultural land of high quality The influence of soil-resource maps presented at public meetings and in newspapers is hard to measure

In a formal evaluation of statewide county workshops on planning and regulation of land use, presentations about the use of soils information in planning were ranked by participants as 6 38 on a scale of 1 to 7 (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 on 12 presentations about various aspects of land-use planning A total of 107 requests have been received for information about methods of producing overlay maps that show constraints of soils and other natural resources

Suggestions to Increase Use of Soil Inventories

1 Recognize that land planning is an iterative (cyclic) process that is never complete and is always tentative, more accurate information will always be needed Do not delay the first attempt

2 Select a base map scale that fits the needs of the user Large-scale maps, detailed enough for farm planning, are too large for county or regional land-resource evaluations

3 Deliver soil maps in terms of the user's needs For example, soil names like Quartz-

ipsammentic Haplorthox mean much to some soil scientists, but cotton growers are more interested in overlay maps showing the potential of this soil for cotton production

4 List the criteria used to evaluate resources and explain them to the audience

5 Display soil-resource information required by land-use laws Audience interest is automatic, and use of the data is assured Some states require soils maps showing suitability for proposed residential areas

6 Deliver soil-resource information on time Development projects frequently proceed through the planning stages on a strict time schedule Decisions are made on the basis of the information in hand

7 Make maps that are colorful, easy to understand, and hold audience attention

8 Include key reference points on all maps Familiar roads, rivers, and towns give a feeling of being present on the land

9 Be willing to take a leading role Many soil scientists have multidisciplinary training and experience in the interpretation of soil-resource data for agricultural development and other purposes

10 Be ready to share maps and other displays once they are prepared Move on to inventory new areas, reevaluate interpretation criteria, and develop even better data displays

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Land-Use Planning in Karnataka, India

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The use of soils data in land-use planning for Bangalore, Karnataka, is discussed a general background of its soils, the recommended land-use practices for the Bangalore district, and the two specific sites chosen, one for transferring agricultural technology to dryland farming regions and the other for testing the validity of the land-use plan's recommendations for horticultural crops Also discussed are the usefulness of land-use plans, the main objectives, use, and interpretation of soils data, the cooperation between soils and planning agencies, and factors responsible for success or failure The case study is illustrated with appropriate soil maps and land-use plans to substantiate the results achieved

Food needs of the world in general and any country in particular cannot be met successfully unless adequate efforts are put forward to increase the productivity per unit of land Whereas a high level of productivity has been achieved in temperate regions, a breakthrough is yet lacking in tropical regions despite the report of the *green revolution* for crops like wheat and rice in certain parts of Asia and a few other countries Such advances are possible provided proper technology is developed and made available It is in this regard that soil classification and land-use planning play vital roles, they provide the basic data for planning and transferring agricultural technology to achieve satisfactory results of development They should, therefore, receive immediate attention in the tropical countries

The tremendous potential inherent in tropical soils is well known it may be possible to double or triple the crop yields of these soils without causing deterioration to them But socioeconomical and technical problems pose certain difficulties in the implementation of the agricultural development program It is not only the soil scientists who are involved in such an effort but also those holding responsibility for national resource planning and development

It is, therefore, very appropriate that opportunities are provided for soil scientists, agronomists, technologists, program planners, and the like from different parts of the world to pursue the following objectives to discuss the various problems about land, to report their experiences, to contribute to the exchange of new thoughts and ideas, and to learn about the practical usefulness of soil maps and soil-survey interpretations in interrelating research studies on soil, water and crop management in tropical areas, preparation of land-use plans, and implementation of large-scale development programs for agricultural production

Keeping the above objectives in view, I will describe a case study from India, taking two specific examples from Bangalore, lo-

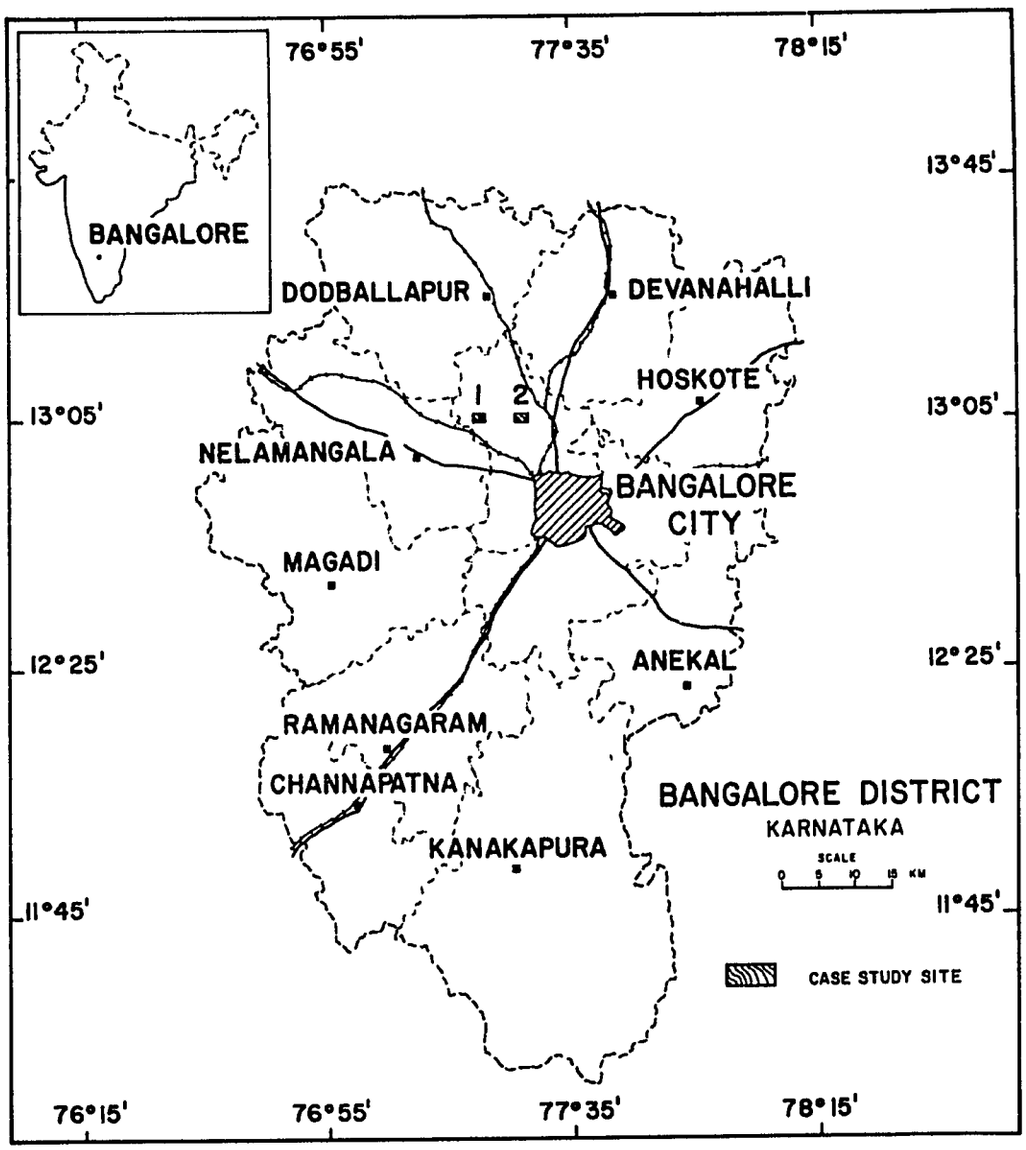

Fig 1 Location of Bangalore district and of case study sites

cated in South Karnataka State The case study demonstrates the soil survey's extent and the manner in which the soils data collected during the soil survey have been used to evolve a rational land-use plan. I shall first describe as background the generalized soil map and land-use recommendations available for Bangalore

Background and Conditions prior to Planning

Bangalore is one of the most advanced and populated districts of Karnataka State, located in the Peninsular Region of India (Figure 1) It has a population of about 3 5

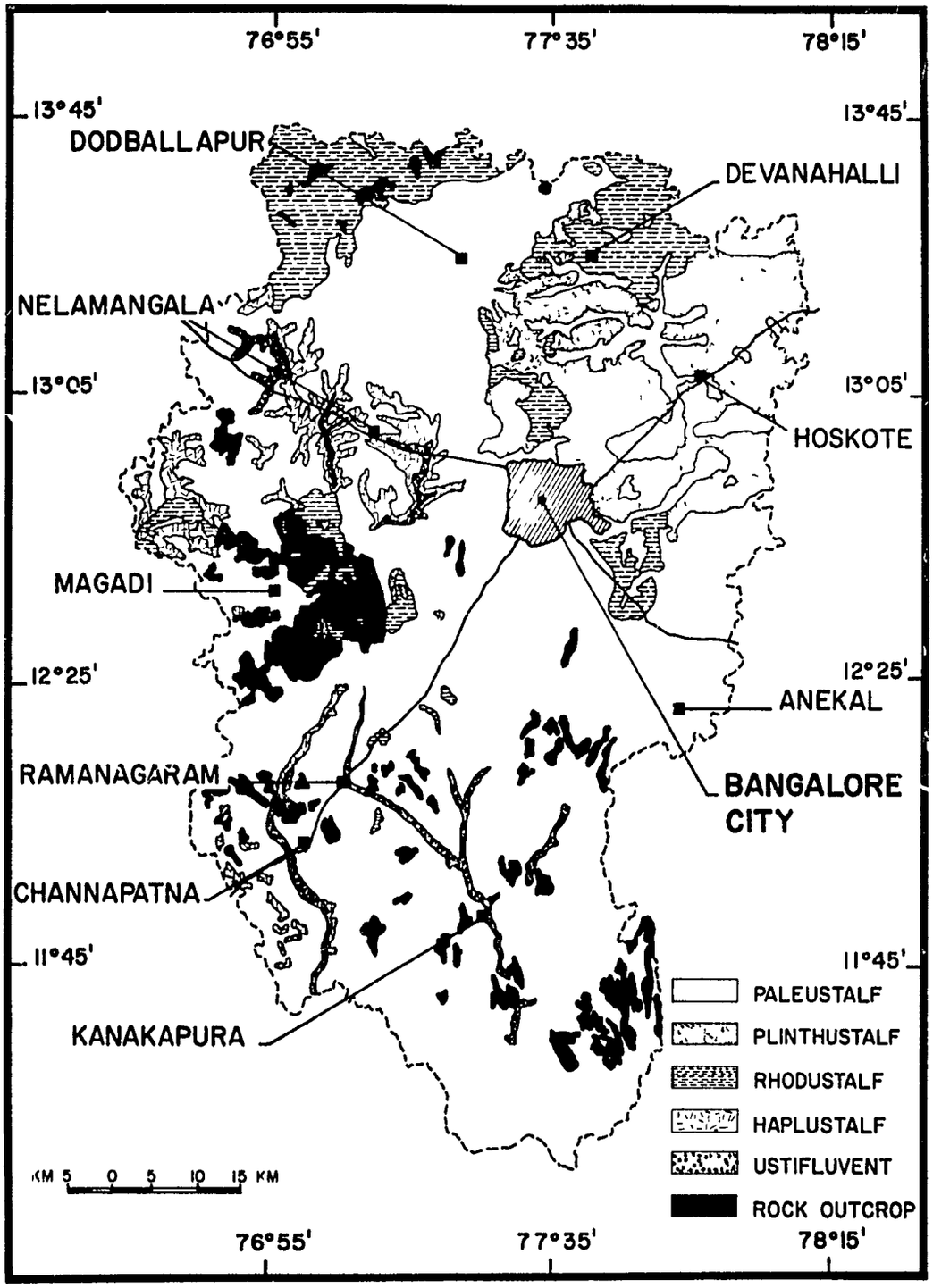

Fig. 2 Generalized soil map of Bangalore district

million distributed in 2,478 villages and 22 towns, including Bangalore city The average population density is 309 per km², Bangalore city itself has 2,408 per km² The district is 136 km long, north-south and 80 km wide, east-west, comprising a total area of 7,894 km² spread over 11 taluks (*Taluk* is an administrative unit) The sites selected for the case study are in Bangalore north taluk Figure 1 shows the location of the district and the sites of the case study

The central, northern northeastern and eastern parts of the district are open lands characterized by a topography that is undulating to gently sloping The low-lying areas and valleys are covered by a network of tanks In the extreme north and west are broken chains of rocky hills The altitude ranges from about 617 m to 1,517 m above mean sea level

The climate is warm and semiarid with a mean annual precipitation of about 790 mm that is fairly distributed over 7 months in the year The mean maximum temperature ranges from 30° to 32°C during April and May, and the mean minimum temperature is 16°C during November and December The major portion of the rain is received during the southwest monsoon which breaks by the end of May or early June

The geology dates back to the Archaeans which consist of the oldest rock formations The most common Archaean rock is gneiss lacking uniformity in structure and composition The common gneissic rock types are light-to-dark-gray biotite gneiss that vary in structure texture and relative abundance or scarcity and mode of deposition of ferromagnesian minerals Overlying the gneissic rocks are extensive areas of laterites, whose probable age is Tertiary

Of the total geographical area of 789,400 hectares, nearly 43% is under cultivation and the remainder is forest, pasture, current and other fallows, cultivable waste, and the like The cultivated area is of three types wet, garden, and dry The wetlands consist of such crops as paddy, sugarcane, and ragi, irrigated by canals under an assured supply of water from tanks and wells The garden lands are irrigated mostly by wells and confined to valleys In the drylands, ragi, groundnut, pulses, castor, tobacco, and the like are raised In the suburbs of Bangalore, where water and marketing facilities are available, large areas are being converted into grape gardens, flower gardens, and orchards A number of agricultural estates have been established in recent years to grow vegetable and commercial crops

Forty-two soil series and series associations established in the final correlation during the reconnaissance soil survey of the Bangalore district, classified at the great group level, are shown in the generalized soil map in Figure 2 These consist of Plinthustalfs Paleustalfs, Haplustalfs, Rhodustalfs and Ustifluvents Inclusions to the extent of 5 to 10% of other groups that cannot be delineated separately because of limitations in the scale of the map are not uncommon Such a map (1 0 5) should serve for purposes of district-level planning

The laterites and lateritic soils classified under Plinthustalfs are derived from the weathering of granites and granite gneiss rocks The soils are deep to very deep, well drained, fine textured and friable The color of the surface horizon ranges from 7 5 YR to 5 YR in hue, 3 to 4 in value and 4 to 6 in chroma, the subsoil ranges in chroma from 4 to 6 The profile contains mottles of variegated colors and ferruginous rounded gravel Plinthite is observed at lower depths The soils are acidic with medium base saturation The water table is located at depths below 10 to 16 m

The red gravelly, red loamy, and red sandy soils classified under Paleustalfs, Haplustalfs, and Rhodustalfs are derived from the weathering of pink and gray granites, granite gneiss, and gneissic granite rocks The soils are moderately deep to very deep, coarse to fine textured, and well drained The color ranges from 7 5 YR to 2 5 YR The profile contains quartz gravel having an argillic horizon Clay skins are present Soils generally occur on slopes at 1 to 10% and are susceptible to severe sheet erosion

The alluvial soils classified under Ustifluvents are confined to the flood plains of the

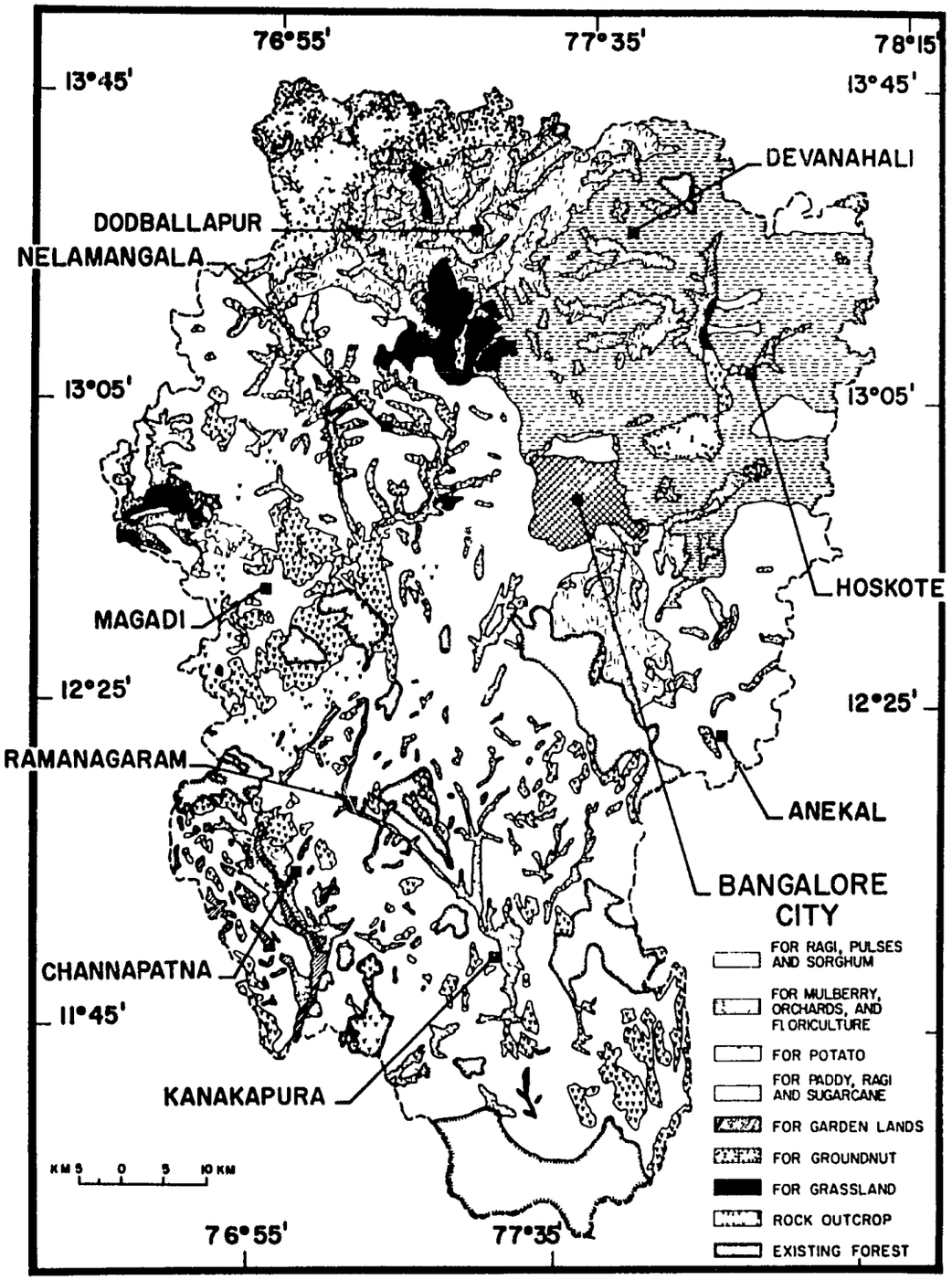

Fig 3 Suggested land use plan for Bangalore district

rivers The soils are deep to very deep, coarse-to-medium-textured, and stratified The color of the surface and subsoils ranges from 7 5 YR to 10 YR in hue, 4 to 5 in value, and 4 to 6 in chroma The water table is met at depths below 5 to 10 m

Objectives of the Land-Use Plan

The purpose of soil survey is not attained unless a suitable land-use plan is projected on the soil map Such a plan for the district as a whole is illustrated in Figure 3 Because quite a vast area in the district is suitable for dry crops only, land use cannot be changed drastically in such areas Intensification of agriculture by a proper selection of crops, varieties, supply of inputs like good seeds, application of fertilizers adoption of plant-protection measures dry farming techniques, and soil- and water-conservation practices will go a long way in increasing crop yields Soils that qualify for the above land use as well as those that are recommended for irrigation farming, garden lands, orchards flowers and vegetables and commercial crops like potato and mulberry are delineated in the land-use plan

The objectives in site 1 of the case study are to investigate and map the land-form units and their associated soils, to assess the potential for dryland farming, and to suggest ways and means of developing improved agricultural technology for the rainfed areas with special reference to the soils existing in the farm and those representative of the soils occupying extensive areas in the district

Site 2 is mainly concerned with the intensification of research for the improvement of horticultural crops like fruits, vegetables, and ornamental plants In the land-use plan, therefore, suitability of soils for horticultural crops and all management needs are highlighted The land-use plans based on land-capability classification indicating the suitability of different soils units under high, medium, and low levels of inputs thus provide a sound basis for the establishment of cropping systems, irrigation systems, and major engineering and agricultural developments

How Soils Data Were Used

A detailed soil survey of site 1 comprising about 33 hectares was carried out by using a base map on a scale of 1 500 The soil series mapped is correlated with the series established in the reconnaissance survey of the district The Hoskote series consists of reddish brown laterite soils and of very deep, moderately well-drained, fine loamy soils occurring on lands nearly level to gently sloping The texture of these soils ranges from an *Ap* horizon, 7 to 15 cm thick and sandy loam to sandy clay loam, to a *B* horizon, 83 to 112 cm thick, becoming finer with depth The subsoil, which becomes hard when dry, acts as a hardpan and restricts root penetration and water infiltration Root penetration is limited to 30 to 35 cm and at places only 15 to 20 cm The soil reaction is strongly acidic along the profile depth

The mapping units are as follows

1 Hoskote sandy loam, very deep on 0-to-1% slope, moderately eroded	0 51 hectare
2 Hoskote sandy clay loam, very deep on 0-to-1% slope, moderately eroded	9 78 hectares
3 Hoskote sandy loam, very deep on 1-to-3% slope, slightly eroded	6 59 hectares
4 Hoskote sandy clay loam, very deep on 1-to-3% slope, moderately eroded	10 12 hectares
5 Hoskote clay loam, very deep on 1-to-3% slope, moderately eroded	4 92 hectares
6 Miscellaneous (rock outcrops, etc)	1 00 hectare

In soils of the above type, the main problem is how best to maximize the soil moisture storage under dryland farming conditions. The amount of water entering the soil is a function of the rate of infiltration, soil-surface conditions, vegetative cover, and land slope, all of which can be modified to retain most of the rainfall on the ground surface for long periods All cultural practices that reduce runoff and erosion result in the increased storage of soil moisture

The crops proposed for the soils mentioned above (site 1) are mainly ragi, minor millets pulses like *Dolichos lablab*, horse gram, cowpea, and soybean, and oilseeds like groundnut, sesamum, niger, and castor The limitations for growing crops include the following lack of assured and proper distribution of rainfall during the growth cycle, moderate-to-severe susceptibility of the soil to erosion, shallowness of the rooting zone, the soils' tendency to form a hard crust on the surface, hard, compact subsoil, low fertility status, and poor soil structure

Soils data have thus been useful in understanding the real problems and in planning the following appropriate management practices for the aforementioned mapping units

1 Shifting sowing to the first week of July or a little later by utilizing the first peak of showers during May for preparatory cultivation The duration of crop varieties should not exceed 120 days This will cut short the incidence of drought considerably
2 Contour bunding, about 90 m apart on a 1% slope and 75 m apart on a 1-to-3% slope
3 Deep plowing at least once in 3 years to disturb not only the crust on the surface that obstructs the intake of water but also the subsoil that is hard and compact, and application of libe al doses of farmyard manure to improve soil structure
4 Stubble mulching to leave the field in a rough condition immediately after harvest and to reduce evaporation
5 Collecting runoff in farm ponds and utilizing the water for one or two light irrigations for limited areas during the drought period
6 Liming of soils in view of their being strongly to moderately acidic

A detailed soil survey of site 2 (about 25 hectares) for the case study was carried out by using a base map on a 1 600 scale Three soil series were mapped The Tyamagondalu series consists of soils reddish brown to yellowish red derived from fine-to-coarse-grained granites, very deep, loamy soils in the surface, moderately well drained to well drained, with a good argillic horizon having abundant clay skins The Mutkur series comprise soils reddish brown to yellowish red and deep to very deep soils of fine clayey texture, somewhat poorly drained The Arkavati series consists of stratified reddish brown and noncalcareous alluvium, very deep, well drained, and textured coarse loamy to fine loamy

Mapping units indicate that about 11 4 hectares consist of lands level or nearly level whose soils are of the Tyamagondalu and Arkavati series They are very deep soils, textured sandy loamy to sandy clay loamy, slightly to moderately eroded, and slightly acidic to neutral Their clay content increases with depth, and they are low in organic matter, the available P_2O_5 and K_2O being low to medium Given proper application of fertilizers, the soils are best suited for vegetables, banana, papaya, and grapes

A small area of 0 64 hectare consists of lands nearly level to gently sloping whose soils are also of the Tyamagondalu and Arkavati series They are very deep soils, sandy loamy to sandy clay loamy and are slightly to moderately eroded They are neutral in reaction A part of this area is already under mango cultivation and can be extended to the adjoining area also Applications of farmyard manure and suitable fertilizer mixtures are recommended

Another area of 2 53 hectares consists of nearly level to gently sloping lands of very deep, sandy loam soils of the Arkavati series, slightly eroded The soil conditions are suited for banana cultivation and for other fruit-plant collection

The remaining 4.37 hectares consist of gently sloping lands having very deep, sandy loam soils of the Mutkur series, slightly to moderately eroded. The soils' pH is on the acidic range and their clay content increases with depth. The soils are low in organic matter, the available P_2O_5 and K_2O being very low to low. These soils are recommended for fruit trees like guava, banana, litchi, and pineapple. Application of liberal doses of organic manure and suitable fertilizer mixtures is recommended in addition to 2,500 kg per hectare of dolomite or $CaCO_3$ as a soil-amelioration measure to raise the soil pH.

The soil map has thus been used to demarcate areas for different fruit crops, vegetables, and the like and to define the management practices for them.

Cooperation between Soils and Planning Agencies

The soil survey of sites 1 and 2 described above was carried out by the National Bureau of Soil Survey and Land Use Planning, Regional Centre, Bangalore. Site 1 is one of the fifteen main centers in operation under the All India Coordinated Project for Dry Land Farming, selected on the basis of agroclimatic and soil conditions and availability of research facilities. The layout, designing of experiments, follow-up of the land-use plan, and the like have been done in mutual consultation by taking advantage of the soil map. The Regional Soil Correlator, as one of the members of the Coordination Committee, discusses program implementation, progress of work, and results achieved. The Chief Scientist acts as coordinator.

Site 2 is the headquarters of the All India Coordinated Research Project for grapes, banana, mango, pineapple, papaya, and guava. Moreover, it is the main center for vegetable crops and floriculture. The Director of the Institute of Horticultural Research and other scientists concerned with the above projects have planned the experiments according to the land-use plan supplied. They consult the Regional Soil Correlator during different stages of experiments for sampling of soils, their analysis, and interpretation of data.

Examples of the Plan

The soil- and land-use plans of sites 1 and 2 selected for the case study are given in Figures 4 and 5.

Case study site 1 is situated 8 km north of the University of Agricultural Sciences, Hebbal Campus, near the village of Tinnalu. The physiography consists of lands nearly level to gently sloping, with slope gradients ranging from 1 to 3%. Relief is subnormal. Elevation ranges from 920 to 931 m above mean sea level. The drainage pattern is dendritic; the north and extreme northwest parts have an eastward drainage, whereas the south central portion drains toward the pond. The soils are moderately well drained; runoff during the rainy season being quite appreciable. The mapping units of the Hoskote series delineated on the basis of variations in texture, slope, and erosion are indicated in the plan.

Case study site 2 is located about 25 km north of Bangalore within the revenue limits of the village of Arvarakhandapura. The physiography consists of lands nearly level to very gently sloping, with slope gradients ranging from 1 to 3%. The relief is subnormal, and approximate elevation is 863 m above mean sea level. The site is drained by the Arkavati river, which flows along the western boundary. The uplands of the northern and northeastern portion are excessively drained to well drained. Lowlands in the southern portion are nearly level to gently sloping, moderately well drained, and imperfectly drained.

Three soil series are mapped showing variations in soil type, soil depth, slope, and erosion. The suitability of the soils for growing various horticultural crops is also projected in the plan.

Usefulness of the Plan

The usefulness of the land-use plan,

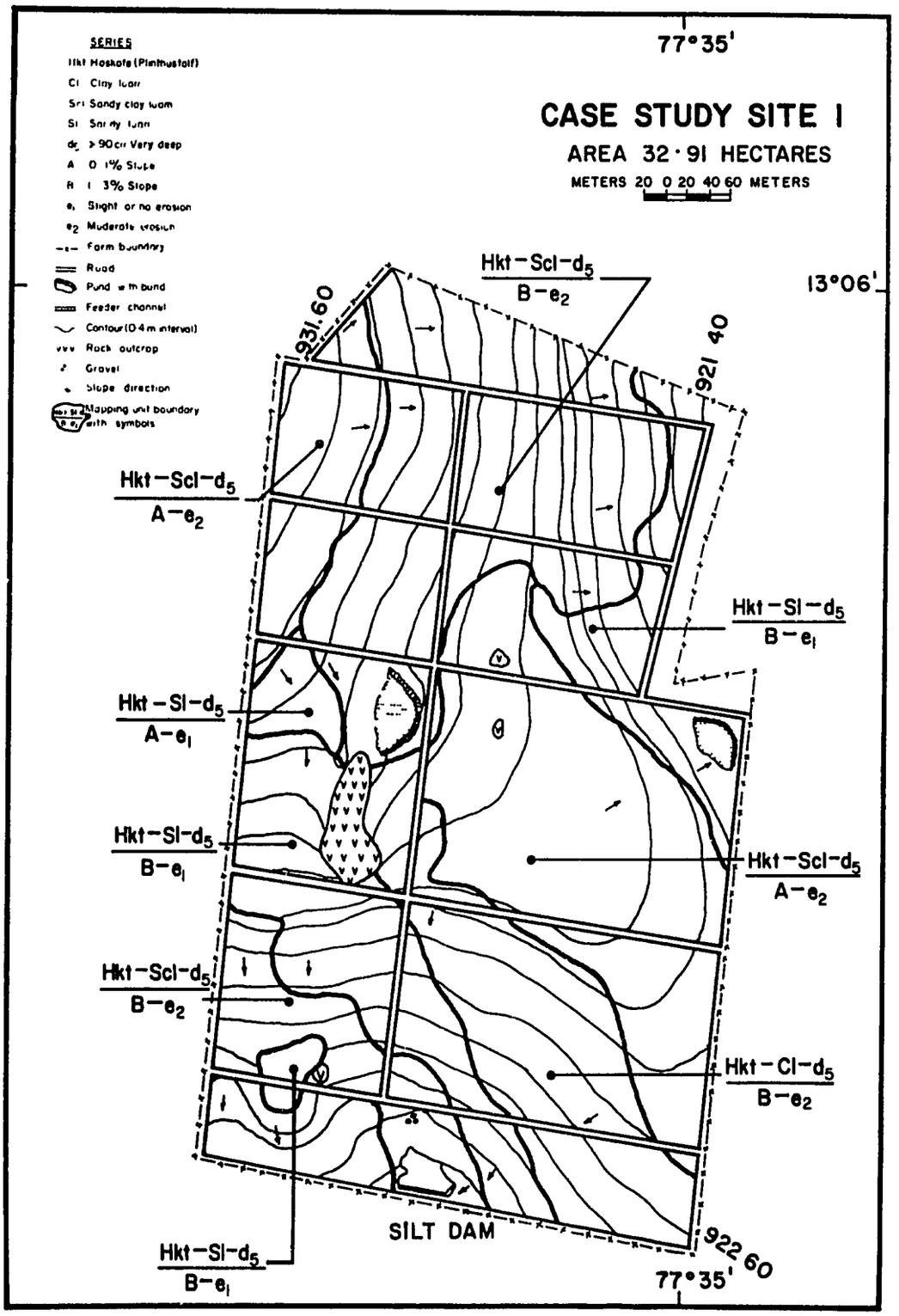

Fig 4 Soil- and land-use plan of case study site I near the village of Tinnalu

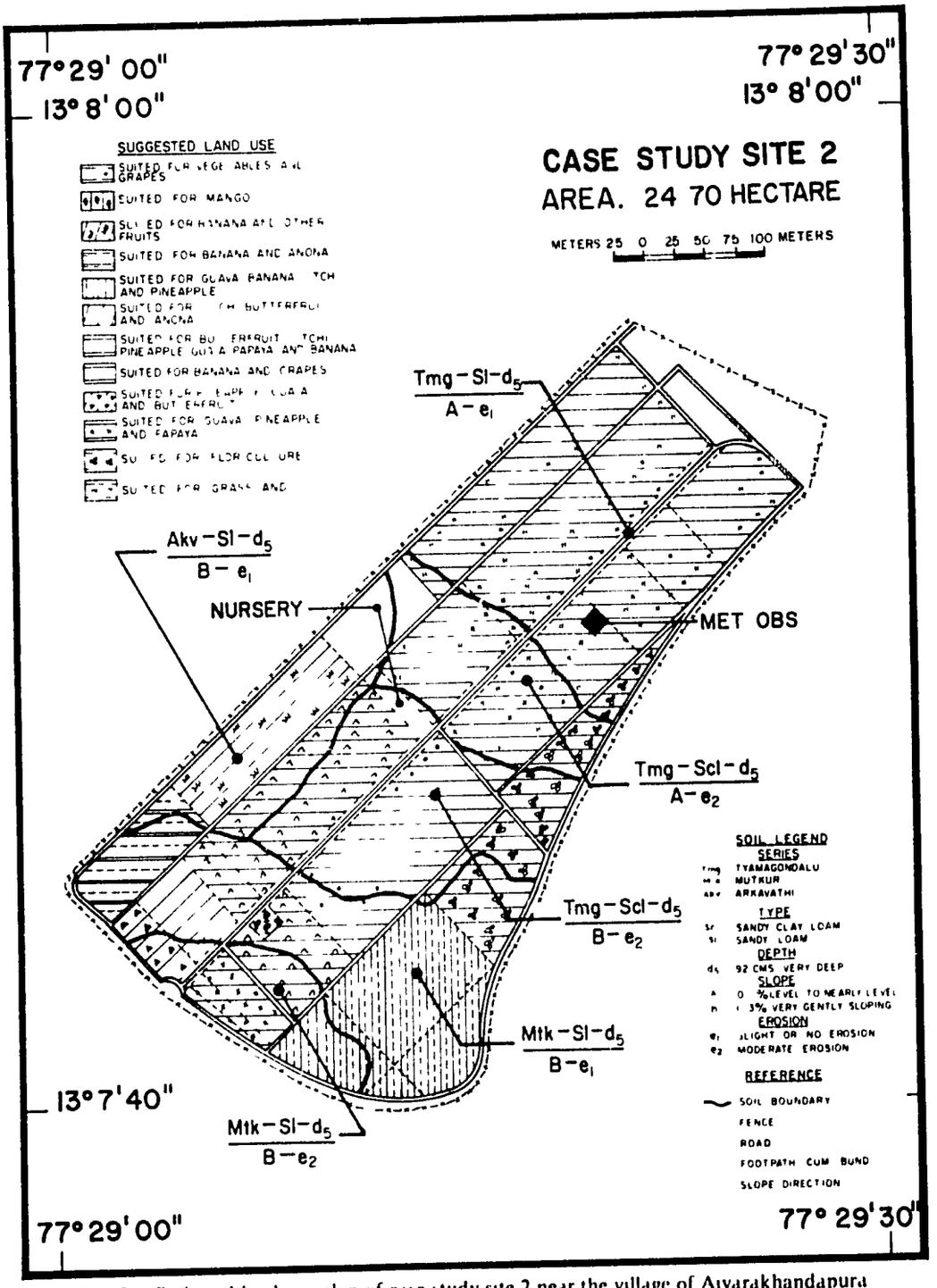

Fig 5 Soil- and land-use plan of case study site 2 near the village of Aivarakhandapura

Table 1 Effect of soil management practices on crop yield

Crop	Year	Crop yield (in quintals per hectare)	
		Without recommended management practices	With management practices
Ragi	1972-1973	9 5	20 0
	1973-1974	9 5	19 0
Hybrid maize	1972-1973	16 0	34 0
	1973-1974	15 0	27 0
Sunflower	1972-1973	5 0	8 2
	1973-1974	5 0	8 0
Cowpea	1972-1973	4 0	6 0
	1973-1974	4 0	8 0

prepared by utilizing the soil-survey data for which a reference has been made earlier, is clear from the nature of experiments that are included in the technical program drawn up for the development of site 1 Studies on cropping system and crop intensity were made to examine the possibility of raising the crops successfully during July through November when there was practically no moisture stress Given proper agronomic management of crops and fertilizer application, cowpea could be grown as early as kharif crop to be followed by ragi Certain intercropping systems in ragi and maize were also possible and remunerative Further studies on suitability of different crops for early sowing in May and their influence on transplanted ragi, suitability of different crops for sowing after cowpea, management of transplanted ragi after cowpea crop, and intercropping in ragi and maize will confirm the beneficial results of such practices

Where crop duration and varieties are concerned, although the monsoon is normally expected by July, at times it may be delayed to the middle of August, affecting the whole operation of seeding and shortening the growing period Crops and varieties have to change with the changes in rainfall each year This leads to the necessity of identifying ragi varieties according to time of sowing, performance of crops grown in September, ratoonability of different crops, and the like

Though contour bunding is a recommended practice for soil conservation, uniform distribution of water becomes difficult For efficient management, contour border strips have proved the best though quite expensive Other land-shaping methods have to be examined and tillage methods worked out for better moisture conservation

Runoff water stored in farm ponds for protective irrigation is often lost because of excess seepage, especially in areas of red and laterite soil To reduce the seepage loss,

Table 2 Average crop yields from cultivator's farm and case study site 1

Ragi variety	Cultivator's farm (quintals per hectare)	Site 1 (quintals per hectare)
PR 202	20 to 25	45
Poorna	18 to 20	31
RHO-2 (Shakti)	20 to 25	38

lining of farm ponds is essential Studies that tested the different lining materials showed that the one with clay + NaCl + Na_2CO_3 was the best and most effective in controlling seepage losses

Mulching was not found beneficial for normal kharif crops But it is likely to be useful for double cropping or for late-duration crops like hybrid cotton

Table 1 shows the results of experiments conducted with and without recommended practices for dryland farming on some of the crops

Yields obtained in case study site 1 as against the cultivator's farm average are given in Table 2

While the land-use plan for site 2 was being carried out, the existing old plantations of mango, sapota, and butter fruit were not disturbed Vegetables suggested for soils of the Tyamagondalu series were not cultivated Instead, germplasm of 200 grape varieties was planted, the fertilizer trials were carried out with nitrogen phosphorus and potassium on the Tyamagondalu series to study their effect on the growth yield quality, and papain content of papaya and a variety of coorg honeydew melon Results for the number of fruits per plot were highly significant The best fertilizer combination that resulted in the greatest number of fruits was 250 g N, 250 g P_2O_5 and 500 g K_2O per plant

Experiments were conducted to study the effect of a spacing-cum-fertilizer trial on banana (robusta variety) using spacings 8 ft by 8 ft and 8 ft by 6 ft and the following fertilizer treatments 90 g, 180 g, and 270 g of N, 36 g, 72 g, and 108 g of P_2O_5, 225 g, 250 g, and 765 g of K_2O Plants were given a basal dose of 15 kg of farmyard manure and 0 5 kg of dolomite The banana yield was significantly influenced by the levels of N, P, and crop density 180 g of N per plant yielded 44 23 tons per hectare, whereas 108 g of P_2O_5 per plant gave 44 39 tons per hectare The response to a high level of P could be due to low content of P in the experiment plot, as observed from soil-analysis data at the start of the experiment Closer spacing resulted in higher yields compared with wider spacing because of the greater number of plants per unit area

A spacing-cum-fertilizer trial on the pineapple variety kew in the Mutkur series, using 3 population densities and 27 treatment combinations of N, P, and K showed that the effect of N was significant only in closer and medium spacings The effects of P and K were significant in medium spacing The combined effects of N, P, NK, and PK were significant in medium spacing for fruit weight with crown and in closer spacing for crown weight Total yield increased with higher population density The mean yield in tons per hectare increased from 43 to 70 in medium spacing and from 43 to 77 in closer spacing

Significant Factors for Success or Failure

The case study of the two sites described above is a good example of cooperation and coordination between the National Soil Survey Organization and the user agencies to utilize the land-use plans for planning and experimentation The results achieved so far are quite encouraging The success may be attributed to the following

1 Recognition of the importance of a basic soil survey and soil map prior to the initiation of development work on the sites,
2 Designing a proper layout according to the mapping units,
3 Choice of experiments suited to the problems and potentialities of the soils,
4 The soil series being typical and representative of vast areas in the district

Further success of the practices in site 1 depends upon evolving suitable crop varieties for different times of sowing This, supplemented with supporting researches in the areas listed below, will go a long way in carrying the results to larger areas suitable cropping system and crop intensity, efficient crop management, fertilizers to increase pro-

duction; and evaluation of crop varieties.

Where site 2 is concerned, although our experiments were limited to only some horticultural crops, broad recommendations indicated in the land-use plan regarding choice of crops on specific soil types based on the soil map have yielded some promising results. But there are some obstacles with horticultural crops, which, unlike other agricultural crops, present difficulties where large-scale testing is concerned Fruit trees, unlike other agricultural crops, take time to establish and produce the desired yields Until the orchards reach an advanced stage, proper attention needs to be paid toward management. Hence, although good results are expected to be achieved from the land-use plan's recommendations, their application on a wider scale might not be easy and require more time These are some of the limiting factors

ACKNOWLEDGMENTS The experimental data relating to case study site 1 were supplied by the Chief Scientist of the All India Coordinated Project for Dry Land Farming, Hebbal (Bangalore) main center Data concerning the horticultural crops in case study site 2 were supplied by the Director of the Institute of Horticultural Research, Bangalore Their assistance is gratefully acknowledged

Interpretation of Small- and Large-Scale Soil Maps for Arid and Semiarid North Indian Plains

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Small-scale (1 250,000 to 1 63,000) and large-scale (1 13,500 and 1 7,920) soil maps can be used for land-use planning in the arid and semiarid regions of the north Indian plain To be useful, small-scale maps need to include indications of soil textural variations Large-scale soil maps are necessary to show what crops can be grown in different subdistricts of the regions, and how many irrigations are needed during the cropping cycle In rain-fed farming in the driest parts of the region crop growth is possible only on sandy soils because of the rapid infiltration of rainfall, without subsequent evaporation loss caused by upward capillary movement Under irrigation textural differences are important because of their influence on available moisture capacity and on the number of irrigations needed during the cropping cycle In wetter areas, the moisture-holding capacity determines what crops can be grown in rain-fed farming Finer-textured soils which have generally higher moisture-holding capacities, can be used for longer-duration crops like sorghum and maize in the wettest areas and pearl millet and oilseed in the intermediate rainfall areas Coarse-textured soils in the same circumstances can only be used for short-duration drought-tolerant crops like kidney beans

Crop yields are influenced by soil properties, weather conditions during the growing season, and management practices In any given area, soils vary in their characteristics, even though weather conditions remain the same Since soil moisture regimes are only partial functions of climate, and thus in any given landscape with the same climate, adjacent soils may have different moisture regimes (USDA, 1970), efficient crop production calls for the application of agrotechnology based on the productive capacity of the soils of an area That is, the suitability of a particular crop to a particular soil and the adaptability of a soil to a crop become important Many low-yield environments for rice or wheat may constitute high-yield environments for pulse or oilseed crops (Swaminathan, 1973)

As Robertson et al (1968) have stated, if one looks for primary production, one should ask about water resources But in arid and semiarid agriculture, scanty rainfall is implied For India, agricultural land use of arid and semiarid soils holds a special significance for primary production, though this may not be so for countries where concepts on interpretation of soil maps are developed and used on the assumption that there are adequate resources Thus an appraisal of water resource in relation to soil is necessary for India Obviously, rational interpretations of soil maps and statements on the suitability of named soils for agricultural use assume considerable importance In this paper, we will present the interpretation of

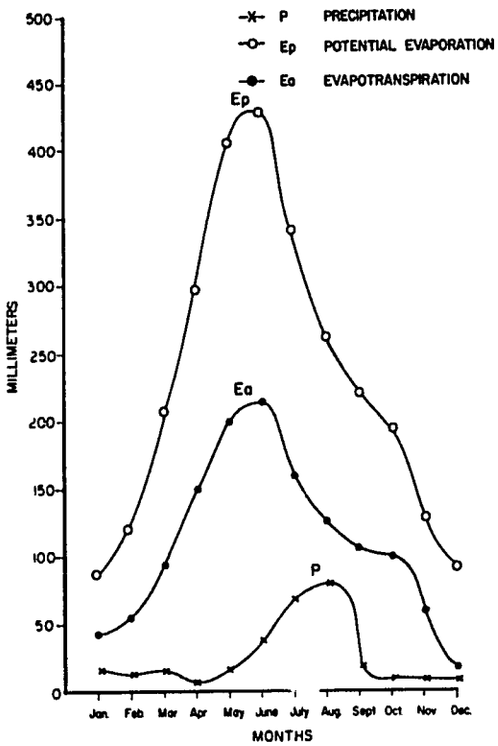


Fig 1 Monthly distribution of precipitation, potential evaporation, and evapotranspiration in the Ganganagar-Rajasthan Canal area

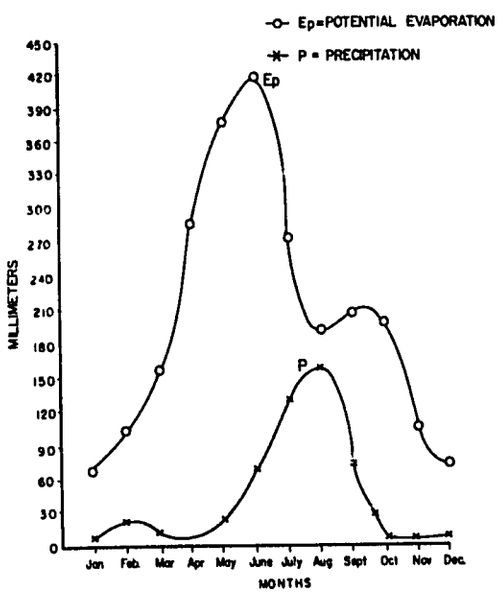


Fig 2 Monthly distribution of precipitation and potential evaporation in Hissar

small-scale and large-scale soil maps of parts of the arid and semiarid north Indian plains for agricultural use.

Small-Scale and Large-Scale Maps

The utility of a soil map is based on the principles that (1) soils differ in their behavior to use, (2) soils differ in their characteristics within a given subclimatic environment, (3) the crop yield depends on the interaction between soil characteristics and the combination of management practices, and (4) although soil characteristics remain relatively stable, management practices are subject to change with technological development Soil maps, thus, will be the basis for interpretation of soil behavior Requier et al (1970) have stated that the maps may be on a small scale, sometimes covering an entire continent, or on a large scale, intended, say, for a particular farm Their opinion is too broad to enable one to comprehend an appraisal of an interpretation of a small-scale map The taxonomic level of mapping determines the precision of a description of soils, and a less precise statement of a great soil group than of a soil series is possible The precision about soils that a soil map and a memoir can provide decreases with the inclusiveness of the profile classes defined and with the complexity of the mapping units (Bie and Beckett, 1970)

Information about present land use will be important, since it can identify specific crop areas and yield potentials of soils in relation to immediate and future projections of the soil maps Land use in the arid and semiarid plains is more intensive in India than in many other countries Certain relationships between land use and soil units may thus be expected for India The small-scale maps used in this paper are reconnaissance soil maps on a scale of 1 50,000 or 1·63,000, giving descriptions of named taxonomic units at the series level or association of soil series They were prepared through reconnaissance soil surveys using air photographs or topographic maps as the base They indicate inclusions and identify phases

of surface texture, erosion, slope, and the like These maps may be generalized and abstracted to produce maps for the district, state, and country levels for their planning

Large-scale maps were prepared by using a 1 8000 scale or larger-scale cadestral maps as the base and by having observations at regular intervals to separate phases of soil series so necessary for village- and farm-level planning, reclamation, and the like

General Information of the Area under Study

The area under study may be defined broadly as the arid and semiarid parts of the north Indian Indo-Gangetic plains lying between the Iso-hyet lines 20 and 80 cm, falling within 27 to 32° latitude N and 72 to 80° longitude E During the upheaval of the Himalayas, a syncline was formed between the Peninsula of India and the Siwalik hills The alluvium filling of this depression, dating back to the Pleistocene age, is estimated at 90 to 400 meters, and the sedimentation is still going on much of the alluvial sediments has originated from the Siwaliks and consists of clays, silts, and sands This part of the alluvial plain appears to have been built up by the activities of the rivers Ghaggar, Saraswati, Chautang, Sutlej, and an eastern branch of the Indus, all of which previously drained into Rann of Kutch There are obvious differences in the age of the deposits, the younger being mainly confined to the vicinity of the channels of today The occurrence of sand dunes and sandy plains is due to the advancement of the desert sands of the Thar, as the rivers filled up or shifted their course in the recent past (FAO/UNDP, 1971)

Climate is arid and semiarid in the southwestern limit of the old flood plains of Ghaggar and its tributaries (Anupgarh Shakha of the Rajasthan Canal area), semiarid in the alluvial plains and mid-southeastern part (Hissar tehsil), and semiarid and subhumid in the central part of the alluvial plains (Patiala tehsil) (*Tehsil* is an administrative subunit of a district, a district is an administra-

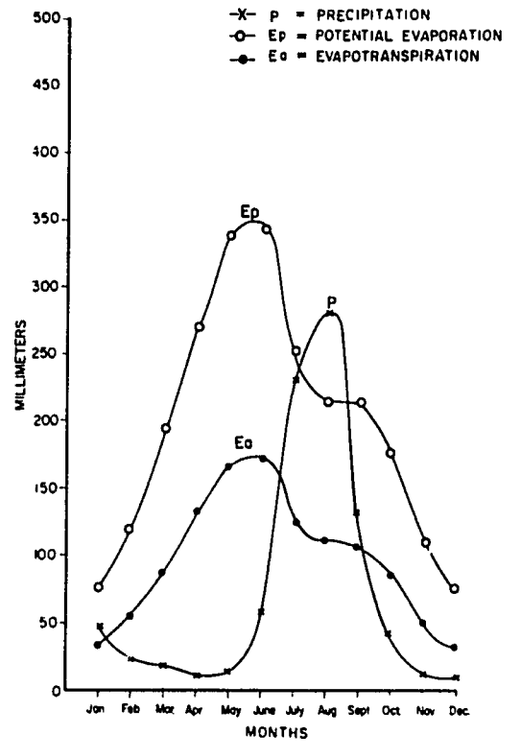


Fig 3 Monthly distribution of precipitation, potential evaporation, and evapotranspiration in Patiala

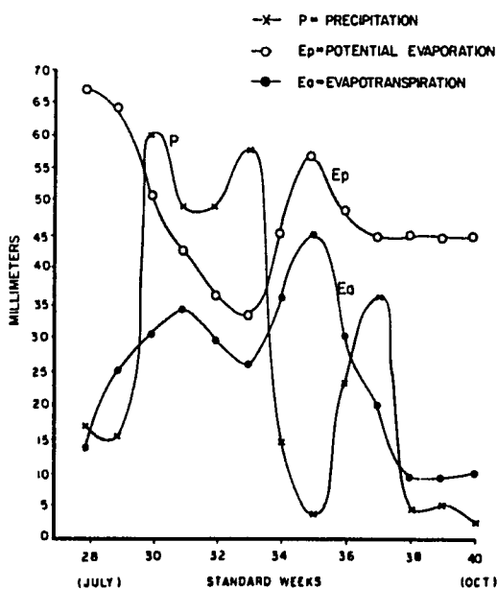
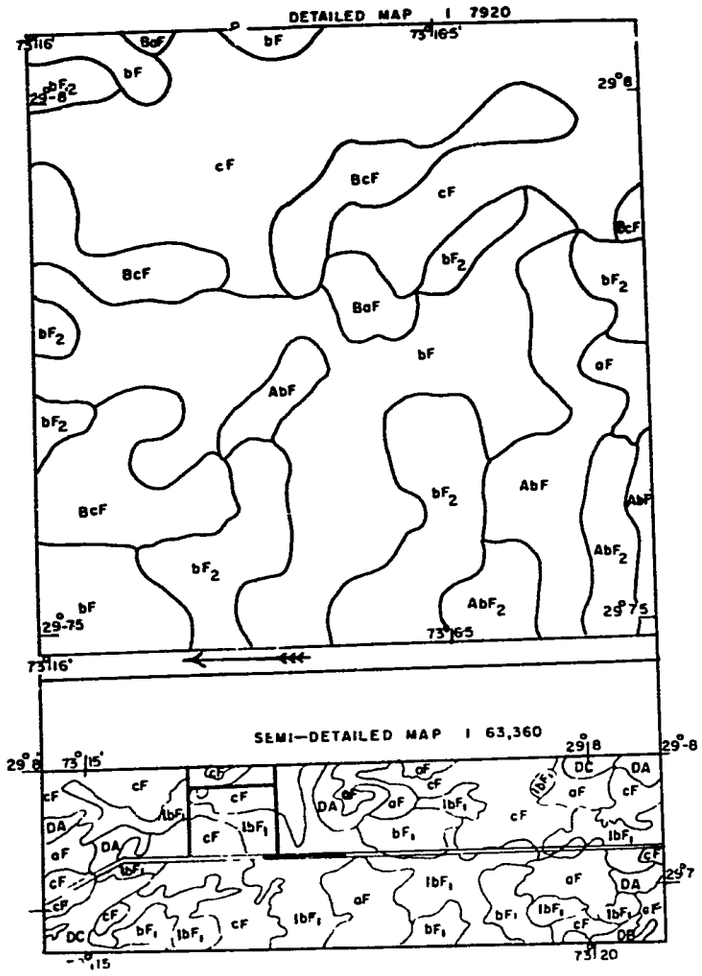


Fig 4 Weekly distribution (in kharif) of precipitation, potential evaporation, and evapotranspiration in Hissar



Symbol	Description
aF	Dominantly fine sand to loamy fine sand to 150 cm mixed Typic Torripsamments
BaF	Same as *aF* except a fine sandy loam to silt loam surface texture
bF	Dominantly fine sandy loam to silt loam to 150 cm coarse loamy, mixed Typic Torrifluvents
AbF	Same as *bF* except with a fine sand to loamy fine sand surface texture
bF_1	Same as *bF* except with a clay loam to clay strata below 75 cm depth, coarse loamy over fine loamy, mixed Typic Torrifluvents
IbF_1	Same as bF_1 with sand to loamy fine sand over a burden 15 to 45 cm
bF_2	Same as *bF* except with a clay loam to clay strata below 75 cm depth, coarse loamy over fine loamy, mixed Typic Torrifluvents
AbF_2	Same as bF_2 except with a fine sand to loamy fine sand surface texture
cF	Dominantly clay loam to clay to 150 cm clayey, illitic, Typic Torrifluvents
AcF	Same as *cF* except with fine sand to loamy fine sand surface texture
BcF	Same as *cF* except with a fine sandy loam to silt loam surface texture
DA	Undifferentiated sand dunes of fine sand to loamy fine sands < 1 m in height over flood plain units
DC	Fine sand to loamy fine sand to 150 cm mixed Torripsamments

NOTE Soils of the flood plain are highly stratified, calcareous, and variable saline-sodic All the soils are hyperthermic

Fig 5 Soil maps of a part of the Anupgarh Shakha area, Rajasthan Canal Project (Source FAO and UNDP, 1971)

tive unit of a State comparable to a *country* in the United States) Figures 1, 2, and 3 show the monthly distribution of relative climatic data in these three areas, Figure 4 shows the weekly data for Hissar tehsil

The soils of the tract are developed over alluvium They vary in their texture from fine sand to clays and are generally calcareous, though noncalcareous soils are also mapped, especially in the Patiala area Vertical and horizontal textural variations are common The whole of these plains needs more intensive field observation in terms of mapping, both small-scale and large-scale, than is commonly recognized

In the agricultural use of these lands there is variation in both the intensity and selection of crops In the arid part most of the land is used for grazing, especially the low and medium dunes and coarse-textured flood-plain soils which have thin grass vegetation Small areas of less undulating sandy soils are used to cultivate rain-fed kharif season crops (*Kharif* refers to the season from June through October) They are bajra (*Pennisetum typhoideum*), or pearl millet, moth (*Phaseolus comitifolius*), or kidney beans and til (*Sesamum orientale*), or gingelly In winter taramira (*Eruca sativa*), or rocket salad, is grown In the Hissar tehsil, 87% of the area is cultivated, 45% of which is under canal and tubewell irrigation A variety of kharif crops like bajra, paddy (*Oryza sativa*), maize (*Zea mays*), cotton (*Gossypium* spp), and pulses is grown Gram (*Cicer arietinum*), wheat (*Triticum aestivum*), and mustard (*Brassica* spp) are important rabi crops (*Rabi* refers to the season from November through March) In the Patiala tehsil, more than 88% of the area is under cultivation, of which about 55% is under irrigation and about 38% is double-cropped Important kharif crops are paddy, maize, and fodder jowar (*Sorghum vulgare*) Wheat accounts for about 82% of the rabi crops, gram, barley, and lentil, for 13 to 14%

Soil Maps

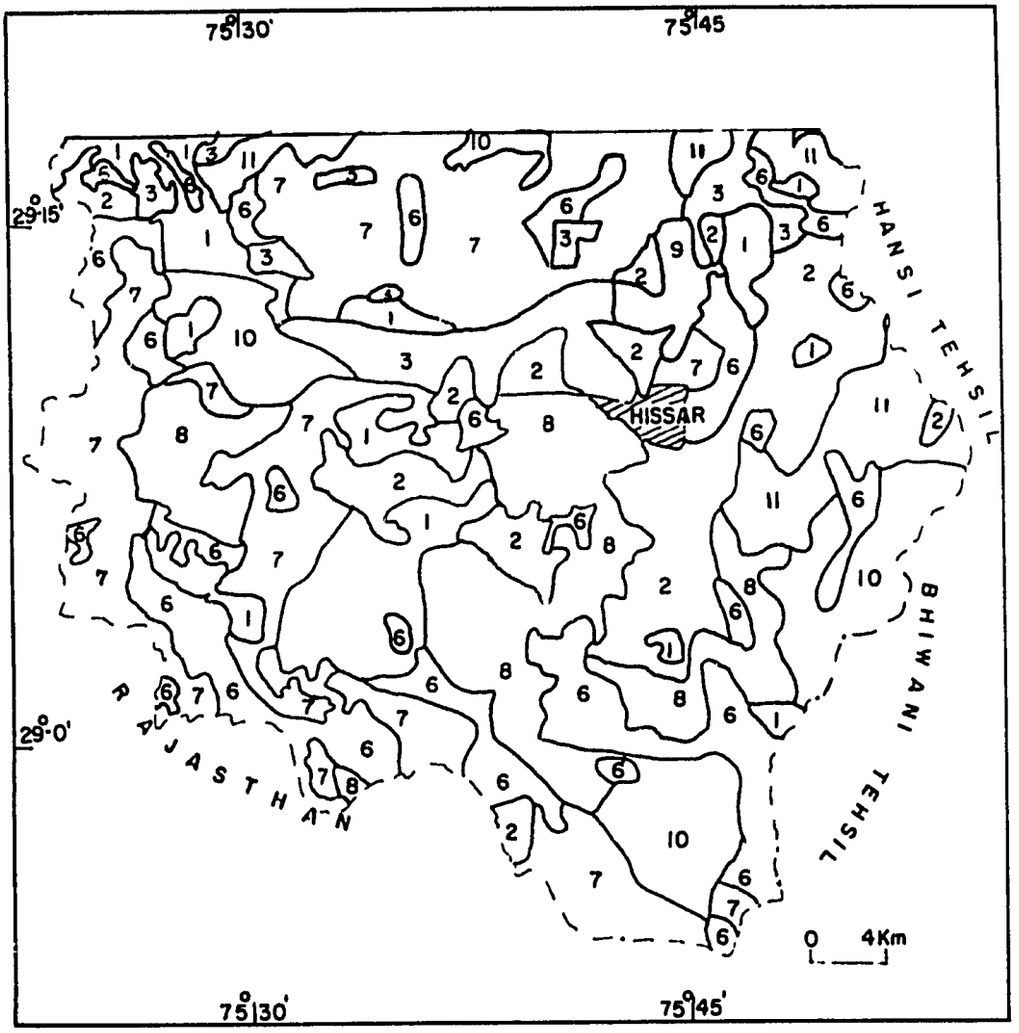
Figures 5, 6, 7, and 8 represent the reconnaissance and detailed soil maps of representative areas Figure 5 refers to a part of the old flood-plain soils of the Rajasthan Canal area (FAO/UNDP, 1971) The map carries essential descriptions and soil classification of the different units, the semi-detailed soil map delineation of such units on the map includes 50 to 70% of the indicated taxonomic units The rest are inclusions of other flood-plain mapping units Consequently, the mapping-unit symbols used for these flood-plain soils approximate the soil conditions indicating the irrigation-development problems of the delineated area Note, however, that although the mapping units only approximate the soil conditions the identification of units is specific and the recommendations on the basis of present knowledge are also specific The delineation of mapping units shown in the detailed soil map is estimated to be 90% accurate

Figure 6 is a reconnaissance soil map of the Hissar tehsil, its mapped units include up to 20 to 30% of other taxonomic units Figure 7 is a part of the reconnaissance soil map of the Patiala tehsil in Punjab and Figure 8 refers to a part of the detailed soil map of the Sanaur Village in the Patiala tehsil

The monthly rainfall and potential evaporation distribution in the Ganganagar-Rajasthan Canal area (Figure 1) clearly indicates large moisture deficits in all the months However, even under such moisture deficits, crops like bajra and moth are grown on the sandy soils, even though their yields are low It is obvious, then, that soil texture greatly influences crop growth Of the textural variations shown in Figure 5, the significant ones are as follows

aF Dominantly fine sand to loamy fine sand, with available moisture capacity of about 35 mm per 60-cm profile (Available soil moisture was estimated according to the method given in Report of Coordinated Scheme for Irrigation Research, Haryana Agric Univ , 1970)

bF Dominantly fine sandy loam to silt loam, with available moisture ca-



Symbol	Series	Description
1	Talwandi	Very deep, calcareous, aeolian sandy loam, control section on gently sloping lands, mixed Typic Camborthids
2	Juglaon	Very deep, calcareous, loam to silt loam, control section on gently sloping lands of alluvial plains, mixed Typic Ustochrepts
3	Hissar	Very deep, calcareous clay loam to silty clay loam, control section on level lands of alluvial plains, mixed Typic Ustochrepts
4	Tohana	Very deep, calcareous, silty clay to clay, control section on level concave slopes of alluvial plains, Illitic Udic Ustochrepts
6	Thaska-Banra	Very deep, calcareous and noncalcareous, aeolian fine sand to loamy sand, mixed Typic Torripsamments
7	Thaska-Talwandi	
8	Talwandi-Juglaon	
9	Talwandi-Hissar	
10	Juglaon-Hissar	
11	Tohana-Hissar	

NOTE Association 5 is in other parts of the tehsil, inclusions of other series up to 20 to 30% are common

Fig. 6. Partial reconnaissance soil map of Haryana in the Hissar tehsil.

pacity of about 60 mm per 60-cm profile

cF Dominantly clay loam to clay, with available moisture capacity of about 160 mm per 60-cm profile

Dc Fine sand to loamy fine sand of the dune area, with available moisture capacity of about 25 mm per 60-cm profile

Under dryland agricultural conditions some crop growth is possible only in sandy soils that have high infiltration without subsequent evaporation loss caused by upward capillary movement Black (1968) has stated that where rainfall is not sufficient to fill soils of all textures to capacity the amount of water available to plants may be determined not by the capacity of the soils but by other properties such as the rate of infiltration and the rate of evaporation Soils of coarse texture are usually superior to those of fine texture in these aspects Thus, whereas soils of coarse texture are considered to be droughty in humid regions soils of fine texture are droughty in dry regions

In other soils that are finer and slower in infiltration, the moisture is lost by evaporation even before it is infiltrated Further, what little is infiltrated may be lost by capillarity Salinity is common in these soils

Textural differences become important also under irrigation because of available moisture capacity Table 1 gives data on available water capacity moisture deficits for kharif and rabi seasons, and the number of irrigations needed for a bajra crop in kharif and wheat in rabi (Moisture deficit was calculated on the basis of precipitation and estimated actual evapotranspiration as outlined in fech Series 2, Ministry of Agric, 1970) It is apparent that the soils vary considerably in their available moisture capacity, the number of irrigations required also varies to satisfy the same moisture deficit

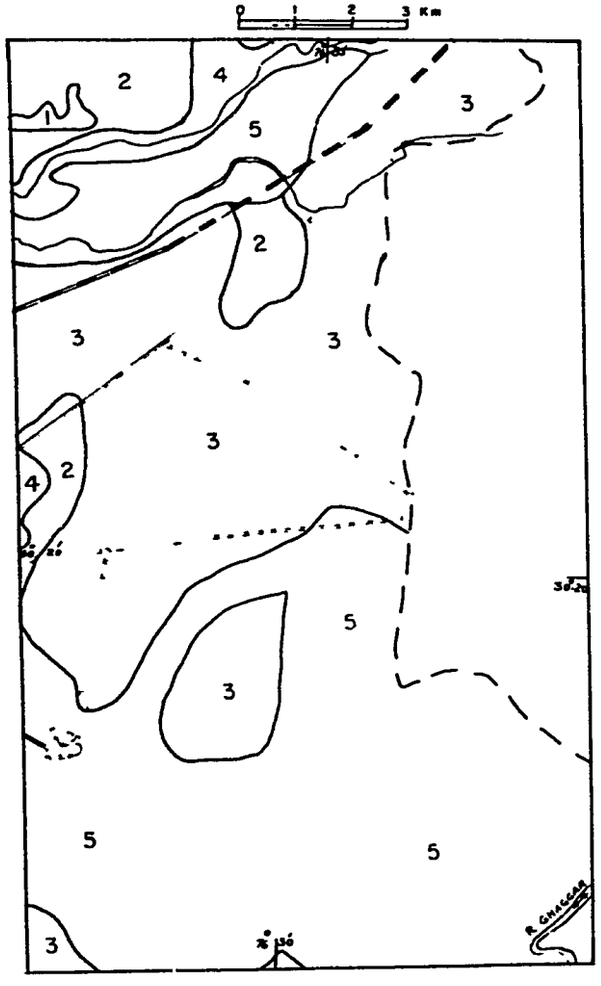
As indicated earlier the soil map in Figure 5 helps in identifying the taxonomic units, and their delineations invariably include taxonomic units other than the named ones A large-scale soil map of a part of the semidetailed survey area parcels out the different taxonomic units that vary widely in their moisture capacity

The monthly rainfall and potential evaporation distribution at Hissar (Figure 2) indicates that potential evaporation exceeds precipitation in all the months of the year The weekly distribution data (Figure 4 and Table 2) on precipitation and potential evaporation for the standard weeks (28th to 40th weeks) falling between July and October show that the moisture is in excess of potential evaporation between the 30th week and the 34th week It is well known that the actual evapotranspiration is less than potential evaporation (also shown in Figure 4 and Table 2) It may be stated then that there is net surplus moisture to meet evapotranspiration demands between the 30th week and the 41st week (Table 2) But the utilization of surplus moisture depends upon the available moisture capacity of the soils

The soil map in Figure 6 indicates the textural variations in Hissar The available moisture capacity of the mapped units is as follows

Thaska series	Sandy soils with available moisture capacity of about 48 mm per 60-cm profile
Talwandi series	Coarse loamy soils with available moisture capacity of about 58 mm per 60-cm profile
Juglaon series	Fine loamy soils with available moisture capacity of about 68 mm per 60-cm profile
Hissar series	Fine loamy soils with available moisture capacity of about 84 mm per 60-cm profile
Tohana series	Fine clayey soils with available moisture capacity of about 160 mm per 60-cm profile

Since the soils of Tohana and Hissar series can retain almost all the surplus moisture, rain-fed crops like jowar, bajra, kharif pulses, and oilseeds do not usually suffer from moisture stress In the soils of the Juglaon series, a moisture deficit is marginal but is apparent in October Therefore, only crops that mature in less than 100 days, such as pearl mil-



Series Association	Description
1 *Fatehpur-Samana* aeolian soils on dune slopes and interdunal flats	Fatehpur· sandy surface over loamy fine sands, Typic Ustipsamments Samana sandy loams, Typic Ustochrepts
2. *Samana-Vijalpur*· soils of the interdunal flats	Samana as above Vijalpur sandy clay loam (fine loamy), calcareous, Typic Ustochrepts
3 *Patiala-Urdan-Bahadurgarh.* soils of the old flood plains	Patiala occasionally stratified at lower depths, silty clay to clay (fine clayey), calcareous, Typic Ustochrepts Urdan silt loam to clay loam (fine loamy), Typic Ustochrepts Bahadurgarh clay loam to silt clay loam (fine loamy), calcareous, Typic Ustochrepts
4 *Todarpur-Chataihra* soils of the old flood plains	Todarpur silt loam to clay loam (fine loamy), calcareous, Fluventic Ustochrepts Chataihra silt loam to silty clay loam (fine loamy), calcareous, Typic Ustochrepts
5 *Sanaur-Julkan-Bahadurgarh* highly variable soils of the Ghaggar Plains	Sanaur stratified, dominantly loamy sands, calcareous, Typic Ustipsamments Julkan stratified, dominantly silty loams (coarse silty), calcareous, Typic Ustifluvents Bahadurgarh as above

NOTE. Very deep, hyperthermic, mixed mineralogy is common

Fig 7 Partial reconnaissance soil map of Punjab in the Patiala tehsil

let, sesamum, and legumes, are grown Because the soils of Talwandi and Thaska cannot hold surplus moisture and start showing a deficit from September, they support only short-duration and drought-resistant crops like moth (kidney beans) For a crop under irrigation like bajra, the Juglaon, Talwandi, and Thaska soils may need 1 to 2 irrigations (Table 1)

The rabi season's moisture deficit is estimated as 150 mm Hence no crop is grown in the rabi season without irrigation Because of the differing available moisture capacities of the soil series, the frequency of irrigation also varies the Thaska soils need 3 to 4 irrigations for a crop like wheat, whereas the Tohana soils need only 1, the other soils need 2 to 3

The monthly rainfall and the potential and actual evapotranspiration distribution at Patiala (Figure 3) clearly indicate that there is a moisture surplus between July and September The moisture stored during these months can be utilized in subsequent months, but this depends on the taxonomic units (Figures 7 and 8) Below are three representative taxonomic units mapped in the area, they illustrate the differences in texture and available moisture capacity (Table 1)

Sanaur series	Dominantly loamy sand with available moisture capacity of about 20 mm per 60-cm profile
Daun series	Dominantly sandy loam to loam with available moisture capacity of about 71 mm per 60-cm profile
Bahadurgarh series	Dominantly silty clay loam with available moisture capacity of about 130 mm per 60-cm profile

The soils of the Daun and Bahadurgarh series retain enough moisture to support most of the kharif crops without irrigation The light-textured Sanaur soils show a marginal deficit of about 24 mm, hence these soils are used for growing crops like bajra, pulses, and oilseeds In the rabi season, the moisture deficit for a crop like wheat is estimated to be about 158 mm, hence irrigation is necessary The frequency of irrigation, however, depends on the taxonomic unit Thus the Sanaur soils need as many as 7 to 8 irrigations, whereas the other soils require only 1 to 2

The Reconnaissance Soil Map (Figure 7) shows the distribution of soils as series associations Association No 5 represents the highly variable soils of the Ghaggar plains The detailed soil map of Sanaur, representing Association 5 (Figure 8), parcels out taxonomic units varying widely in textural families and available moisture capacity Other soil units consisting of the Fatehpur and Samana series are expected to behave like Sanaur in moisture characteristics Soils of the Patiala, Urdan, and Todarpur series would be similar to the Bahadurgarh series, whereas the Vijalpur series is similar to the Daun series in moisture characteristics

General Discussion

There is wide variation in rainfall in the three areas of the plains under study Soils within the different areas vary in texture and available moisture capacity Naturally, agricultural use of the soils also differs In the arid part of the plain in Rajasthan under dryland conditions, agriculture is practiced to a small extent and is confined to sandy or coarse-textured flood-plain soils Crops grown are drought-resistant, and their yields are low Gupta and Prakash (1975) have also observed that in this part of Rajasthan, the sandy soils alone are used for crop production under rain-fed conditions Under dryland agriculture in semiarid Hissar, a variety of crops are grown, bajra being a dominant kharif crop In Patiala, where rainfall is higher, more crops are grown maize, bajra, as a minor kharif crop, and paddy, under irrigation In rabi, although under-irrigation wheat is the important crop in all the areas, gram takes a dominant place in Hissar, though wheat predominates in Patiala

In Hissar, the rainfall data taken on the basis of weekly distribution show surplus moisture periods in the kharif period Soils vary in their capacity to sustain crops because of the variable available moisture capacities Weekly distribution data of rainfall

Table 1. Moisture characteristics and irrigation requirements of different soil units

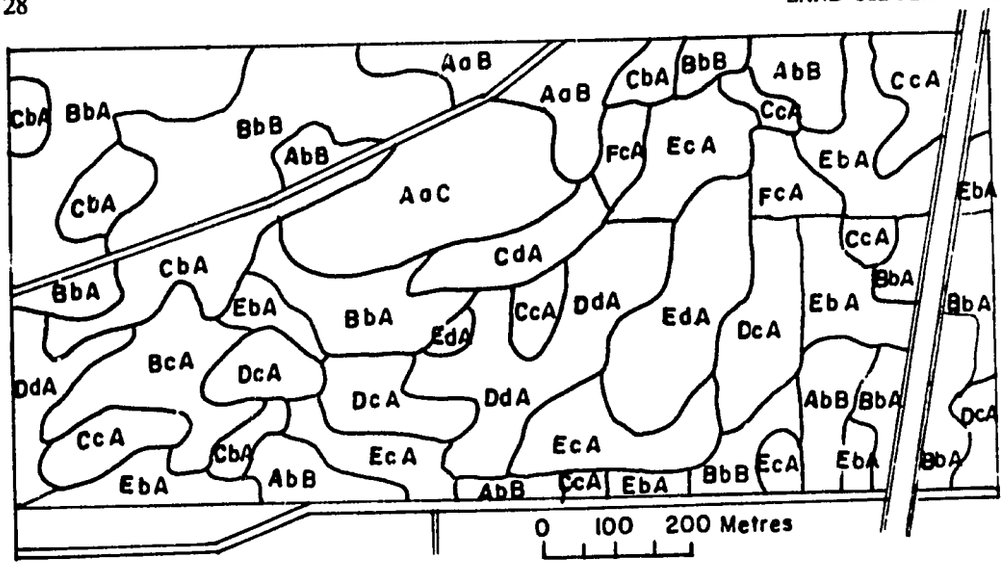
Soil unit	Available moisture in mm/60 cm	Net moisture deficit (–) or surplus (+) in kharif (mm)	Number of irrigations for bajra or maize	Moisture deficit in rabi (mm)	Number of irrigations for wheat
Anupgarh Shakha of the Rajasthan Canal area[a]					
aF: sandy	35	–302	7 to 8	238	6 to 7
bF fine loamy	60	–302	4 to 5	238	3 to 4
cF clayey	160	–302	—	238	2
Hissar tehsil					
Thaska· sandy	48	–34	1	150	3 to 4
Talwandi coarse loamy	58	–24	1	150	3
Juglaon fine loamy	68	–14	1	150	3
Hissar· fine loamy	84	3	0	150	2
Tohana clayey	160	9	0	150	1
Patiala tehsil[a]					
Sanaur *A*, sandy	20	–24	1	158	7 to 8
Daun *B*, fine loamy	71	27	0	158	2 to 3
Bahadurgarh *D*, fine loamy	130	+86	0	158	2

NOTE. Moisture deficit for the Rajasthan Canal area and for Patiala is for 4 months in kharif (July to October) and 5 months in rabi (November to March), for Hissar, standard weeks 28th to 41st (July to October) for kharif and 47th to 52nd and 1st to 13th (November to April) for rabi

[a] *aF, bF, A, B,* and *D* are symbols corresponding to those used in Figures (soil maps) 5 and 8

Table 2 Weekly distribution during kharif of precipitation, evaporation, and evapotranspiration in Hissar

Week of the year	Precipitation	Potential evaporation	Actual evapotranspiration	Cumulative surplus or deficit (-)	Soil series at a soil depth of 60 cm (moisture status in mm)				
					Tohana	Hissar	Juglaon	Talwandi	Thaska
28th	17 5	67 9	13 6	3 9	3 9	3 9	3 9	3 9	3 9
29th	16.5	64 1	25 6	-5 2	-5 2	-5 2	-5 2	-5 2	-5 2
30th	60 2	52 5	31 5	23 5	23 5	23 5	23 5	23 5	23.5
31st	49 1	43 2	34 6	38 0	38 0	38 0	38 0	38 0	38 0
32nd	48 8	36 3	29 0	57 8	57 8	57 8	57 8	57 8	48 0
33rd	58 7	32 9	26 3	90 2	90 2	84 0	68 0	58 0	48 0
34th	14 0	45 5	36 4	67 8	67 8	61 6	45 6	35 6	25 6
35th	2 9	57 4	45 9	24 8	24 8	18 6	2 6	-7 4	-17 4
36th	23 6	49 8	29 9	18 5	18 5	12 3	-3 7	-13 7	-23 7
37th	36 4	45 9	18 4	36 5	36 5	30 3	14 3	4 3	-5 7
38th	4 1	46 2	9.2	31 4	31 4	25 2	9 2	-0 8	-10 8
39th	4 7	44 5	8 9	27 2	27 2	21 0	5 0	-5 0	-15 0
40th	0 8	49 0	9.8	18 2	18 2	12 0	-4 0	-14 0	-24 0
41st	0 2	47 5	9 5	8 9	8 9	2 7	-13 3	-23 3	-33 3
Total	337 5	682 7	328 6						



Series	Symbol	Description
Sanaur	A	Very deep, excessively drained, finely stratified, dominantly loamy sand in 25 to 100 cm
	AaB	Same as *A* with loamy sand surface on a 1-3% slope
	AbB	Same as *A* with sandy loam surface on a 1-3% slope
	AaC	Same as *A* with loamy sand surface on a 2-5% slope
Daun	B	Very deep, well-drained, highly stratified, dominantly sandy loam to loam in 25 to 100 cm, calcareous
	BbA	Same as *B* with sandy loam surface on a slope $<1\%$
	BcA	Same as *B* with loam surface on a slope $<1\%$
	BbB	Same as *B* with sandy loam surface on a 1-3% slope
Julkan	C	Very deep, well drained, highly stratified, dominantly silt loam in 25 to 100 cm, calcareous
	CbA	Same as *C* with sandy loam surface on a slope $<1\%$
	CcA	Same as *C* with loam surface on a slope $<1\%$
	CdA	Same as *C* with silty clay loam surface on a slope $<1\%$
Bahadurgarh	D	Very deep, moderately well-drained, finely stratified, dominantly silty clay loam in 25 to 100 cm, calcareous
	DcA	Same as *D* with loam surface on a slope $<1\%$
	DdA	Same as *D* with silty clay loam on a slope $<1\%$
Kapuri	E	Very deep, moderately well drained, stratified, silty clay loam over loam or sandy loam in 25 to 100 cm, calcareous
	EbA	Same as *E* with sandy loam surface on a slope $<1\%$
	EcA	Same as *E* with loam to silt loam surface on a slope $<1\%$
	EdA	Same as *E* with silty clay loam surface on a slope $<1\%$
Devigarh	F	Very deep moderately well-drained, stratified, dominantly silty clay loam to silty clay in 25 to 100 cm
	FcA	Same as *F* with loam surface on a slope $<1\%$

Fig 8 Partial detailed soil map of the Sanaur village in the Patiala tehsil

in similar areas will be useful in correlating the relationship existing amongst soil, moisture, and crop The existing land use throws light on the soil-moisture characteristics with reference to crop growth Agricultural land use gives a different picture for Patiala, where there is enough rainfall to produce different crops and where generally maize is preferred to bajra

The number of irrigations needed for soils varies according to the stored soil moisture and the available moisture capacity Although the number of irrigations given in Table 1 is calculated on the basis of available moisture capacity in practice more irrigations are needed because irrigation is given before the crop reaches the wilting stage In the case of reclamation again soils vary in their response to measures like time and amount of leaching required It is common knowledge, for example that soil salinity is highly variable in any given area in these plains, soil texture is also variable Hence tying salinity conditions to texture is very important Should soils be mapped with this point in mind, effective recommendations on reclamation would be possible

In rabi season crops like wheat, mustard, and gram are grown in the Tohana and Hissar soils, though their moisture deficit is apparent This anomoly may be due to the contribution of moisture from dew and from internal condensation within the soil profile during the growth period It is also probable that wheat may withstand greater stress than is generally understood (Richards and Richards 1957) Gram and mustard are more tolerant of drought than is wheat

Small-scale soil maps and the memoirs separate soil series associations and provide statements on soil series phases, these can be used for preparing large-scale maps In a given subclimate, textural variations need to be separated out (soil series association) in the small-scale maps so that interpretation can be made for growing crops and for cultural practices It is not adequate to consider only the accessory characteristics that is, organic matter base status and salinity as has been mentioned in *Soil Taxonomy* (USDA 1970) Small-scale maps should help in delineating potential and problem areas for broad-level planning and research needs, whereas large-scale maps should provide the basis for the application of research findings

It may be concluded that soil mapping for land evaluation in our country should take into account rain-fed agriculture, high-intensity land use small holdings, and low to high level of management

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Land Evaluation for Agricultural Land-Use Planning

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The principles of modern land evaluation are described in terms of land utilization types, such as maize or timber production, land attributes, such as the nature of the soil and vegetation, qualities of land attributes, such as soil response to fertilizer or the yearly production of natural vegetation, and the land characteristics upon which these qualities depend, such as the organic matter of the topsoil or the dominant species in the vegetation The interaction between one land utilization type and others in the surrounding areas is emphasized The interaction between a land utilization type and the land unit is also emphasized, because permanent reconstruction of the land unit may occur

Physical land evaluation is seen as a multidisciplinary exercise involving many types of specialists In any final report on physical land evaluation, it is almost always necessary to specify in detail the management levels assumed in the study In fact in all physical land evaluations, cost-benefit ratios of the recommended land evaluation types or improvements are always implied Socioeconomic studies can follow a physical land evaluation, but much can be gained by having the two sets of studies operate simultaneously They can assist each other in adjusting to the realistic possibilities of a particular sit iation

Procedures for carrying out physical land evaluations with and without major improvements such as irrigation and with and without accompanying socioeconomic studies are described and presented in diagnostic form

Land evaluation is as old as man choosing parts of the land for his private purposes Although land evaluation as a systematic approach is younger, it already has a long history, especially in relation to taxation, a subject that today interests different governments

However, the interest of those who study natural resources and soils is directed strongly towards land evaluation for better land use, that is, agricultural land use or other uses (Bartelli et al, 1966) This paper will focus on land evaluation for agricultural land use, which can serve as a tool for agricultural development The importance of land evaluation for better agricultural land use has received greater impetus of late, because it has become increasingly clearer that an efficient land use that does not degrade the land resources can be obtained only when the land conditions or ecosystems with all the detail germane to the use in question are well known

Different disciplines in the field of natural-resource investigations have developed systems for physical land evaluations, and two such disciplines have already established a certain tradition namely, the foresters and the pedologists The foresters, dealing with wood production, nature preservation, and environmental control, may choose land units on the basis of geographical nat-

ural vegetation units (if present) (see also Bennema and van Goor, 1975), the pedologists will choose land units on the basis of soil units with phases

Although land evaluation based on soil units is sometimes known as soil-suitability classification, I do not see any principal difference between a soil-suitability classification and a physical land evaluation, at least not for areas in which the main differences for physical land eva ation can be connected with the soil units and 'eir phases

Steele (1967) has reviewed the system of soil-suitability classification and also soil-survey interpretation in general There are two internationally known systems of soil-suitability classification, both were developed in the United States where they have been used extensively (1) the capability classification of the USDA, Conservation Service (Klingebiel and Montgomery, 1961), and (2) the land evaluation of the Bureau of Reclamation (U S Dept of Interior, 1953, Maletic and Hutchings, 1967) The latter, a complete system or approach to land evaluation, has been developed principally to evaluate the irrigation possibilities of development projects in the United States The soil capability system was designed initially as a tool to curb the spreading soil erosion in the United States, but it has had a wider application Both systems have been used outside the United States with many adaptions (see example in Olson, 1974)

Another approach, based on the concept of Storie indexes (Storie, 1937), is now known as the parametric system (see examples in Riquier, 1974, Boyer, 1974, Teaci and Burt, 1974, Garbrouchev et al , 1974, Sys 1975, Soepraptohardjo and Driessen, 1975) The paramet system has a direct bearing on a part of land evaluation, namely, the determination of yield potentials The contribution of Wishmeyer and Smith (1965) for the determination of erosion susceptibility of land is of the same kind

The question may arise why renewed attention, time, and effort are now given to the principles of land evaluation Are the existing systems inadequate to serve the different purposes of any land evaluation? Most land-evaluation systems in use now serve their purpose well, at least the purpose for which they were designed initially However, the purposes are, as noted earlier, always limited Meantime, we have become more and more aware that land evaluation, were it to see world-wide use, has to deal with many different situations (purposes)

Purposes may vary greatly, or the utilization types for which the land evaluations have to be made may be quite different ones For example, to sort out broad land-use possibilities may be one purpose, to obtain detailed information needed for land-use possibilities and for possible adaptions of the utilization types to local land conditions may be another purpose

Many land evaluations have to be made for utilization types not only because so many different products are involved—products often having different ecological requirements -but also because the level of agricultural management varies so much throughout the world

Till a short time ago, land evaluation was much more concerned with the development of modern medium- to large-scale agriculture than with the development possibilities of the traditional farming of the small holders in tropical countries Land evaluation was also not well equipped to deal with the development possibilities of agriculture of the small holders, because only very little of the agricultural research done then was oriented toward this problem Moreover, land evaluation itself was often concerned more with obtaining information about land suitability than with obtaining information about the possibilities of adjusting present land uses to land conditions (land-condition information is of special interest to the small holder)

Specialists dealing with land evaluations are much concerned that planning of rural land use often proceeds without enough information and that when information is available it is not fully used There are many examples of agricultural development planning that went wrong because basic data about the environment were either missing or wrongly interpreted It is disappointing to

see how planners often give thoughts to designing development plans for lands on the basis of very little information, whereas a good integration of natural-resource data could have resulted in a valuable plan

That this integration is sometimes lacking is not only the planners' fault, it is also the fault of the specialists dealing with the natural resources The environment is very complex, but the numerous data of many different characteristics the specialists collect may have meaning for the specialists but not for the planners The planners must be presented with data that can be readily understood and used Unfortunately, however, in the past, data were presented in forms unintelligible to the planners, who consequently often made their own simplified model of the environment without using the data provided by the specialists about all the intricate conditions of the environment

Models of the environment to be used have to be simplifications, but the simplification should be sought more in a synthesis of the relevant data than in a suppression of basic data Thus, the construction of such models can be seen as one aim of land evaluation

The new attention to land evaluation is given not so much to design a fixed system but more to study the principles and concepts on which any system can be based, or, in other words, to construct a general framework The procedures and concepts of soil surveys and soil classification have been subjects of thought and discussion for a long time, and they are becoming better understood However, until recently, little attention was given to the principles of land classification If the general principles are better understood, it will be easier to generate adequate systems for any situation

I was confronted with these general principles for the first time while designing, together with Mr Beek and Mr Camargo, a soil-suitability classification for Brazil, taking into account different management levels The documents by Beek et al (1964) and Beek and Bennema (1972) and that edited by Mahler (1970), dealing with the suitability for irrigation in Iran, together with the already widely used systems of land evaluation, formed the main basic material for the experts' consultation organized by the FAO in Wageningen (Oct, 1972), which dealt with the principles of land evaluation Consensus on these principles among the participants was wider than expected (see the summary of the meeting "Land evaluation for rural purposes," Brinkman and Smyth, ed, 1973) The main documents were published by the FAO (Approaches to land classification, Soils Bulletin 22, 1974, see also FAO 1975, 1976, Vink, 1975, and Beek, 1975*b*)

General

The subject of this paper is land evaluation for agricultural use, *agricultural use* being understood in its broadest sense to include cropping, horticulture, forestry, ranging, and the like

Land offers different possibilities for different kinds of land-utilization types, and it is necessary to start a land evaluation with broad definitions of the relevant land-utilization types for which the suitability is being estimated Land-utilization types can be defined in terms of the so-called key attributes, that is, the diagnostic criteria important for the land evaluation Examples of such key attributes are type of produce, labor intensity, capital intensity, farm power, farm size, and farmer's level of know-how

The use of the land may change the conditions of the tract of land being used, and it may lead to degradation of that tract It might also have an impact on a wider area But since a marked degradation of the environment is unacceptable, land evaluation must take environmental control into account

Land suitabilities for defined uses and the impact of the uses on the environment are determined by land conditions—in other words, by the qualities of the attributes of the land (not to be confused with key attributes of land-use types) (see Kellogg, 1953 and 1961) Vegetation and soil are examples of land attributes Yearly production and food value are qualities of the natural grass

vegetation, soil fertility and response to fertilizers are soil qualities

Land qualities are in turn based on characteristics or properties of the attributes, dominant grass species of the natural vegetation and organic-matter content of the topsoils are examples of land characteristics From the foregoing it follows that land evaluation has to deal with (1) utilization types, (2) environmental control, (3) land qualities and land characteristics, (4) land units and management units, and (5) land-suitability classification Land evaluation may be based on physical aspects of the land only (physical land evaluation), or it may include full social and economical considerations (socio-economic land evaluation)

Basic Principles

In this section I will present some important components of land evaluation and related principles

Dealing with the Utilization Types

The feasibility of a certain land-utilization type, as a part of an agricultural enterprise, depends on social, economical, and political conditions, in addition to land conditions

It is necessary, at the beginning of a land evaluation, to define relevant alternative land-utilization types, the relevancy being based on social, economical, and political considerations, taking further into account the present land use as well as the overall physical conditions of the regions The utilization types should be defined in terms of diagnostic criteria, which have a marked influence on the performance of the land (key attributes) From the diagnostic criteria follow the requirements of the land-utilization types

However, it is neither necessary from a social, economical, and political standpoint nor desirable from an effective land-evaluation standpoint to define the relevant alternative land-utilization types in great detail at the beginning of the land evaluation (Beek, 1975*a* and 1975*b*) The elaboration of the land-utilization types, if desirable, should be made during the evaluation The details should be defined in such a way that they match as much as possible the land conditions, management specifications for each kind of land unit may be given also This matching of use and land conditions is particularly important in detailed high-intensity land evaluations, though somewhat less important in broad low-intensity land evaluations One result obtained from the matching (besides the indication of suitability) is the description of land-utilization types adjusted to local land conditions These adjusted land-utilization types can be considered as variations of the broadly defined land-utilization types

The matching described in the paragraph immediately before this one deals only with the adjustment of the land-utilization types to local land conditions, but in high-intensity studies, it may also include adjustments to economic and social conditions Studies of the economical and social parameters of the area will then run parallel to the study of the environment and of the technical possibilities and can become integrated during the adjustment of the land-utilization types (parallel procedure of Beek) This is contrary to the procedure in which a physical land evaluation is made first and then a social and economical analysis (two-stage procedure)

An agricultural enterprise may often include more than one land-utilization type These might be uses that are largely *independent*, and their suitabilities are then estimated separately There are, however, land-utilization types in an agricultural enterprise that are *dependent* on each other, the final suitability of one kind of land use in such an enterprise can be estimated only as an integral part of the total land-utilization types included in the enterprise The suitability for the single land-utilization type should be evaluated separately first, then later integrated for the final evaluation In the preparation of the final evaluation, special attention should be paid to the weight to be given to each use in the enterprise and to the influences of the different land-utilization types

on each other (Bennema and van Goor, 1975).

Different cases of the dependency of utilization types within one enterprise can be recognized. e g, multiple uses, alternating uses, compound uses, and associated or allied uses

The identity of the disciplines and the extent to which they are involved in certain land evaluations depend on the kind of utilization types and on the level of generalization of the land evaluation It is clear for example that in the land evaluation for forestry, foresters and other forestry specialists will be important team members, they may form the whole team In physical land evaluations for utilization types, which include land irrigation as a major improvement, a drainage specialist or a hydrologist and a soil scientist and an agronomist may form the team In a physical land evaluation for nonirrigated farming, a soil scientist and an agronomist may be sufficient If only an evaluation is needed for a defined utilization type, and not the description of the adjustments to local land conditions, a soil surveyor or a land-evaluation specialist could conduct the work alone He should collect any information missing by consulting specialists of other disciplines If a socioeconomical land evaluation is made as a parallel procedure (see fourth paragraph in the discussion of utilization types), an economist and a sociologist will be important team members In the two-stage procedure, they will form a team on their own and use the results of the physical-resource team

The land qualities to be surveyed or studied in the investigation of natural resources and the extent of detail of the survey and study depend also on the kind of utilization type and its requirements and on the level of generalization of the land evaluation

Dealing with Environmental Control

The use of a tract of land should avoid strong degradation of the land This should be taken into account in the adjustment of land-utilization types to the land conditions, it should also be expressed in the suitability of a tract for the pertinent use

The impact of land use on the environment as a whole can be studied only in terms of land use of a wider area Environmental impact studies should follow the land evaluation at a later stage as a check on recommended land use (Vink, 1975)

Dealing with Land Qualities and Land Characteristics

The suitability of land for a certain use depends on the potentials or possibilities of

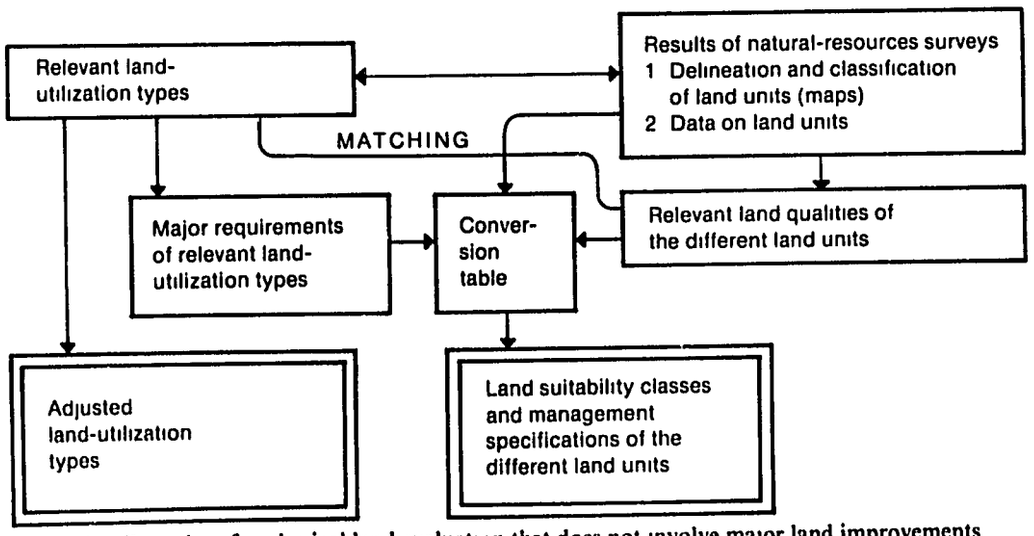

Fig 1 Procedure for physical land evaluation that does not involve major land improvements

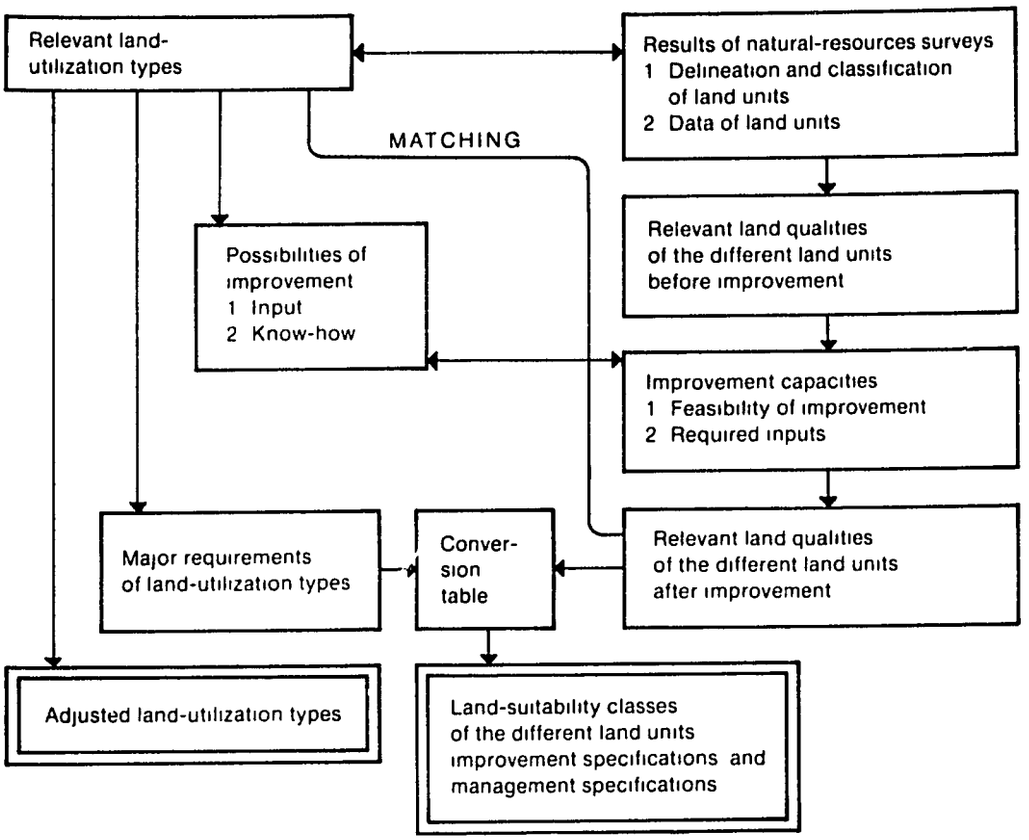

Fig 2 Procedure for physical land evaluation that involves major land improvements

the land in relation to management, conservation, production, and major improvements These potentials can be estimated only in relation to defined utilization types They depend on the so-called land qualities

Land qualities clearly distinct from most other land qualities in their influence on land suitability for a specific land-utilization type can be used as diagnostic criteria (assessment factors in land evaluation) Land qualities can be related to either the direct use of the land or the possibilities of major improvement of the land conditions (improvement qualities) The land qualities related to the direct use include ecological qualities pertinent to plant and animal growth and management qualities Examples of ecological qualities for crop growth are availability of nutrients, oxygen (for roots), water, and radiation energy, risks of damage by hail, storm, and inundations, and temperature regime Important management qualities include possibility of mechanization, accessibility of different parts of the farm, and the possibilities of successful conservation methods The values for the qualities are independent of the use

Normally, a different set of qualities is relevant for different broad uses However, being important for more than one use, a quality may be a member of different sets It is said then to have different *critical* values for different uses Thus the same value has a different meaning for different uses

It is not necessary to use land qualities if only the production levels have to be deter-

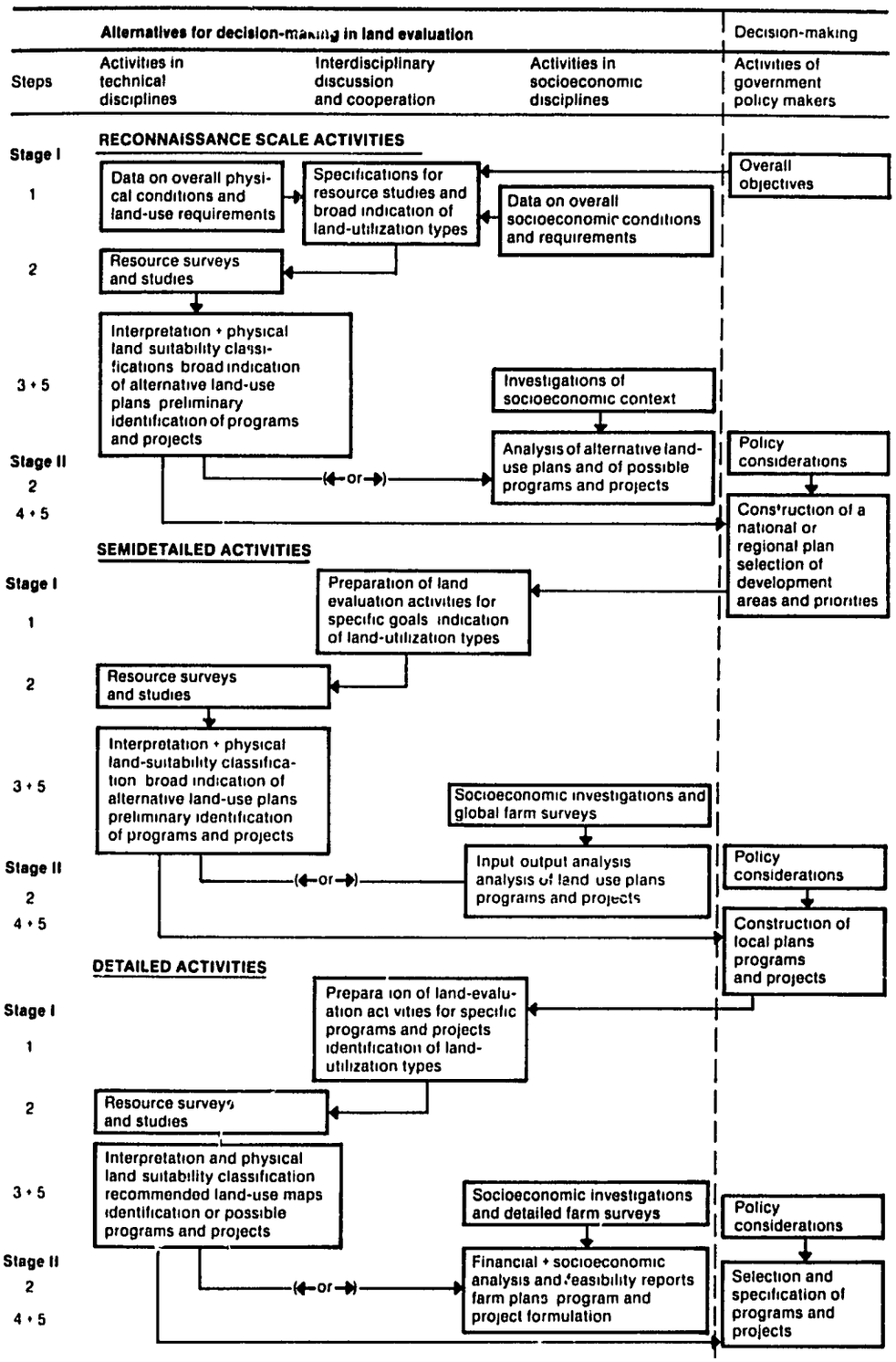

Fig 3 Two-stage procedure for land evaluation in land-use planning

mined for specific produce and specific utilization types These production levels can be found by direct measurements of production potentials or by use of the relation of yield and local land characteristics for regionalization Values are thus assigned to the land characteristics after an empirical assessment is made on the basis of assumed correlations between measured yields and relevant land (soil) characteristics

Land qualities must be used however when in addition to the expected yield, the adjustments of the land-utilization types to the land conditions and to the management specification have to be described Here values are assigned to the land qualities on the basis of the expression of these qualities by the natural vegetation indicator plants land use, crop growth (during the whole growing period), crop yields and known crop hazards From the underlying land characteristics models (e g for water availability showing water balance) can be used Note that the influence of a particular land characteristic on the value of a land quality depends on the whole set of land characteristics The meaning of *soil depth* for example in a climate without a dry period is quite different from that in a climate with a dry period (this also holds for parametric methods, which should therefore be applied to smaller regions)

In sets of qualities related to agriculture, characteristics and qualities of soil and of climate always play a role Characteristics and qualities related to other land attributes are important (sometimes all important) in some, but not all, agricultural land use

There are many different soil qualities and soil characteristics some are related to the performance of plant and animal, others are related to the management of soils, and there are those relevant to the resistance of land to degradations and those relevant to possibilities of improvement Soil qualities and soil characteristics often show a strong variability within a short distance Many of these qualities are surveyed especially for a specific land evaluation

Dealing with Land Units and Management Units

Values of pertinent land qualities and characteristics are assigned normally to *land units* For forestry and for grazing, *geographical vegetation units* may be used as land units, whereas in land evaluation for agricultural use in a strict sense, *geographical soil units* with phases are used as the base for land units

Soil units are classified mostly by their dominant soil profiles or pedons, based on the inherent characteristics of the pedons Soil classification on a world-wide base (Soil Taxonomy 1975) makes it possible to organize the knowledge about soils in an orderly manner also on a world-wide base The study of benchmark soils is hence a powerful tool It is possible to use this increasing pool of knowledge for land evaluation For the classification of the soil units, the Soil Taxonomy or another system is used to the extent that it can be easily translated in the classification of Soil Taxonomy for higher levels of classification (see for example the legend in the Soil Map of the World by FAO UNESCO) It should be realized however, that soil units belonging to the same class of a classification system do not necessarily have the same qualities in relation to a projected use It is often necessary to add phases to these classification units the most important phases in tropical areas being those related to topography ecological zone, and land-use history

Land units having values of land qualities that result in about the same performance for a pertinent use may be grouped together Such technical groups are called *management units*, a name used by the USDA Soil Conservation Service in their land-capability classification The constraints in one management unit are caused by the same qualities and the suitability class for all the members (land units) of this group is also the same Beek (1975*b*) points out also that a convenient grouping can be made of land units for which the main constraints are due to the same qualities and for which the same kind

of management is foreseen without having necessarily the same suitability (due to lower yields). These groups could be used to advantage in describing management specifications

Land units belonging to one management unit have much in common for a specific use, this does not mean that all these land units are exactly the same in their performances They are considered to act the same on a certain (relatively low) level of generalization General management specifications can be made for management units, but the practical elaboration of these specifications often has to be based on the land units and even on the individual tracts of lands The same, but to a lesser extent, holds for the detailed adjustment of the land-utilization types

For certain uses, a combination of land units sometimes can be handled as if it were one unit *(compound land unit)* This means that a management unit may consist of compound land units Such is the case with grazing, which uses wet bottomlands in the dry season and uplands in the wet season

Management units are always made for a specific kind of use Different uses may need different groupings This applies also to the management units of the capability classification of the USDA Soil Conservation Services These management units are valid only for uses that are in accordance with the assumptions on which the capability classification is based, therefore, they should not be applied to uses different from those meant in the assumptions The management units of this system are sometimes misused

The Land-Suitability Classification

The land suitability for a utilization type is determined by a specific set of land qualities The important influence of a land quality on the suitability for a specific land-utilization type is the influence on cost and on benefits in particular, the cost/benefit ratio, next in importance, negatively or positively, is the influence on environmental control

The influence of land quality on the cost/benefit ratio is only implied in the physical land evaluation, it is made explicit in the socioeconomic land evaluation The influence of a land quality on the cost/benefit ratio depends on the value of that quality and on the kind of utilization type The same values of one quality therefore normally have other meanings for different uses

Land evaluations or land-suitability classifications can be made on different levels of generalization

1 Physical land evaluations that indicate land suitability for broadly defined land-utilization types
2 Physical land evaluations that, in addition to indicating land suitability, describe the adjustments to local land conditions and the management specifications
3 Socioeconomic land evaluations resulting from an integrated parallel process or from a second stage following a physical land evaluation The socioeconomic land evaluation takes into account not only the local land conditions but also the local economical and social conditions

Land evaluations for utilization types for which major improvements play a role will have as extra output the description of (1) the relative cost or costs of the improvement works, (2) the improvement specification, and (3) the expected success of the improvement in terms of the values of the land qualities after the improvement It should be noted that improvement may have a positive effect as well as a negative effect on certain land qualities (e g , with irrigation, the positive effect is the better availability of water, the negative effect is the increase in salinization hazard)

Procedure

Land-evaluation procedures depend on the purpose of the evaluation Figures 1 and 2 show the broad outline of a procedure for physical land evaluations where adjustments are made of the land-utilization types to the local land conditions Figure 1 refers to a procedure that does not involve major land

improvements, Figure 2, to one that does involve major improvements The procedure is as follows

1 Define the socioeconomic and politically relevant land uses, taking into account present land use and the overall land conditions
2 Indicate for which areas, regions, or subregions these utilization types are relevant and for which they are irrelevant This is to reduce subsequent work load that is, investigate only those suitabilities of certain land-utilization types that are of interest for the specific area
3 The kind of land qualities, major characteristics and improvement possibilities to investigate follow from the second step
4 If major improvement is foreseen a special study about the improvement possibilities is needed which in certain cases may be the most important and most time-consuming part of the evaluation The study will result in a description of the easiness (or costs) of the improvement works, specifications about the way it should be carried out, and the expected values of the land qualities affected
5 Use the values of the ecological and management qualities to adjust land uses to land conditions This may affect, for example, the kind of machinery to be used and the percentages of rotational crops to be planted
6 The values of the qualities relevant to the efficiency (costs) of management and those related to the yield potentials or the yield potentials themselves will be the base for the suitability classification
7 The study should be completed with a description of management specifications

A full socioeconomic study could follow these physical land evaluations, which would show the suitability for alternative land-utilization types A simpler economic study is possible by using some simple parameters price of products, price of labor, and estimated investment without optimalizations (Vink, 1960 for practical application see also FAO, 1971)

The procedure described is the two-stage procedure In a parallel procedure, the socioeconomic data are used together with the data about the environment for the adjustment of the utilization types both to the land conditions and to the socioeconomic conditions Examples of socioeconomic conditions are land-tenure conditions, labor shortages, marketing possibilities, and credit

Figure 3 shows the role of land evaluation as a two-stage procedure in land-use planning (see also Beek, 1975*b*) The activities are divided into three phases the reconnaissance scale the semidetailed and the detailed The land evaluation in the first phase is the physical land evaluation mentioned earlier that does not involve adjustment to local land conditions, the evaluations in the second and third phases do involve adjustments to the land conditions

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PART IV:
USE OF SOIL-RESOURCE DATA IN REGIONAL AND NATIONAL DEVELOPMENT

Soils Data for Agricultural Development in Ghana

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A soil map of Ghana on a scale of 1 1,500,000 has recently been completed with a legend interpreted in terms of the U S -French classifications and the FAO/UNESCO soil map units The intention is to help Ghana draw upon overseas experiences in soil use Soil-suitability maps have also been compiled for mechanized and nonmechanized agriculture, food crops, import-substitution crops, export crops, and livestock development These maps and subsequent detailed surveys greatly help in the efficient and rapid selection of areas for agriculture The soils work has assisted in a 36% increase in maize production and a 44% increase in rice production in the Operation Feed Yourself and Industries programs Soils data have also been successfully applied to agricultural development by regional development corporations in the Central, Ashanti, Volta, and Brong-Ahafo regions The development of soil science extension services within the National Soil Research Institute has increased the use of soils data by private industry and small-scale indigenous farmers

Agriculture plays a very important role in the economic development of Ghana It is, therefore, essential for the country to develop a sound program to ensure continuous high production of arable, pasture, and tree crops on existing small cooperative and state farms and to develop virgin lands capable of economic production

Such a sustained and increased agricultural production effort, however, cannot be achieved without a nationwide program of mapping and classifying the soils of the country as rapidly and as cheaply as possible to obtain needed information about potential arable, irrigable, pasture, and forestry lands

The development of a soil survey in Ghana began some 30 years ago, when the cocoa industry was first threatened by swollen shoot disease and capsid attack, whereby it became necessary to find out whether soil factors were responsible for such virus and pest infestations Although no useful conclusions about these infestations could be drawn from the soil surveys of cocoa-growing areas, valuable data were obtained on general soil-crop relationships The project was expanded, therefore, to cover the whole country and entrusted to an independent soil and land-use survey organization, which has grown to become the Soil Research Institute of Ghana

The Institute as now constituted is charged by the Government (1) to take an inventory of the soil resources of the nation through organized Regional Detailed-Reconnaissance Soil Surveys to delineate on maps of suitable scale broad areas considered suitable for agricultural development, (2) to conduct ad hoc Detailed and Semidetailed Soil Surveys of areas earmarked for immediate agricultural development by the Government, quasi-government, large agricultural concerns, and indigenous small-scale farm-

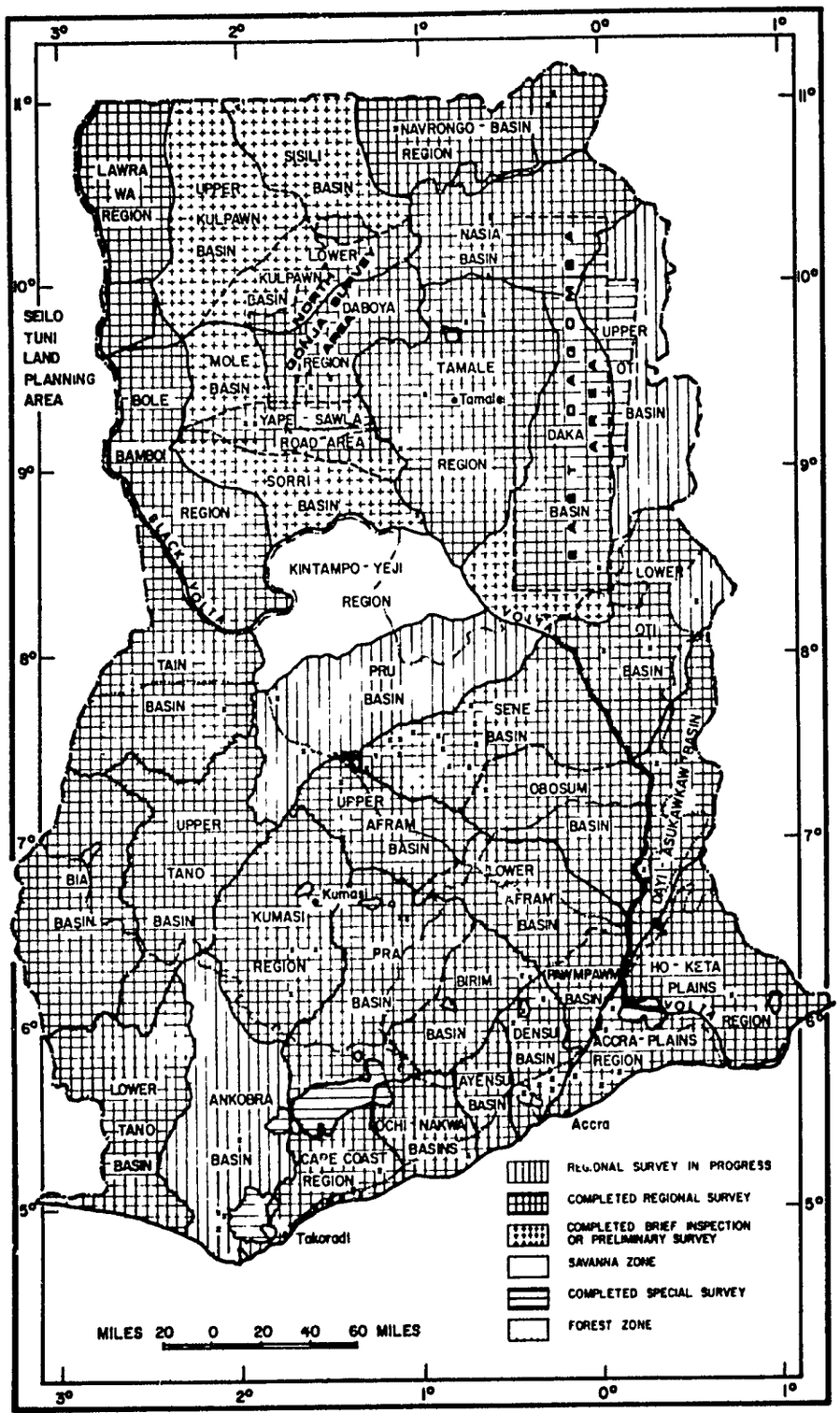

Fig. 1. Progress of soil surveys up to January 11, 1975. (Source: Soil Research Institute [CSIR])

ers, and to evaluate such areas in terms of the suitability of existing soils for the type of agriculture envisaged; (3) to advise ways and means of improving the fertility status of indigenous soils to increase substantially crop and livestock production in the country; and (4) to recommend effective measures to be undertaken to control erosion and conserve the soil resources of the nation

In pursuance of the above objectives, the Institute has established, aside from its administrative division, six main specialized research divisions not only to be able, as soon as practicable, to compile the necessary soil resources data but also to recommend effective measures necessary for the efficient management of indigenous soils, to make them as productive as possible These divisions are: (1) Soil Genesis Survey, and Classification, (2) Soil Chemistry and Mineralogy, (3) Soil Fertility, (4) Soil Conservation and Erosion Control, (5) Soil Microbiology, and (6) Soil Physics

Application of Soils Data to the Development of Agriculture in Ghana

General

The divisions of the Soil Research Institute whose results have been successfully used in the national and regional agricultural development of Ghana are the Soil Genesis, Survey and Classification Division, the Soil Fertility Division, and the Soil Conservation and Erosion Control Division

The programs in the Division of Soil Genesis, Survey, and Classification have had, and continue to have, by far the greatest impact on the improvement of crop and livestock production in the country These programs are executed under two major types of soil surveys, namely, *regional* and *special project* soil surveys For the regional soil surveys, the country has been divided into 37 soil survey regions, the boundaries of which more or less coincide with the different drainage basins (see Figure 1) For these surveys, the detailed-reconnaissance and the photoanalysis and interpretation methods (Obeng et al, 1962) are employed The mapping unit for the regional soil surveys is the soil association Aside from the soil-association map, maps dealing with relief and drainage, vegetation and present land use, miscellaneous information, and generalized land capability (Obeng, 1972) are produced on a scale of 1 250,000 To date, 33 maps have been completed of the 37 soil survey regions

For the special project soil surveys, smaller areas earmarked for immediate agricultural development are surveyed in detail, the soil series is the mapping unit on a scale of either 1 7,920 or 1 6,250 Since the establishment of the Institute some 30 years ago, surveys of over 500 of such project areas have been completed and the results have been published in the form of technical reports and miscellaneous papers

Application of Soils Data in National Agricultural Development

From the enormous data accumulated from the regional and special project soil surveys, it has been possible to compile an up-to-date soil map of Ghana on a scale of 1 1,500,000 with a legend in which equivalent soil groups in the USDA, French, and FAO systems have been included It is hoped that such a comprehensive legend will facilitate the correlation of indigenous soil groups and those similarly developed in other tropical areas so that Ghana can readily draw from experiences elsewhere in the practical utilization of existing soils

In addition to the current soil map of Ghana, series of soil-suitability maps have been compiled showing areas considered suitable or unsuitable in terms of the following mechanized or other cultivation practices, or both, food crops, import substitution crops, export crops, and livestock development These maps, along with further detailed ground investigations, have greatly helped in the efficient and rapid selection of areas across the country for large-scale and small-scale efficient cultivation of a wide variety of climatically suited cash and food crops under the Government's current "Operation Feed Yourself and Industries"

(O.F.Y.I.) programs.

In the O.F.Y I programs started early in 1972, the Government of Ghana seeks to give practical expression to her avowed policy (1) of producing adequate food to feed the nation and raw materials to feed her industries, and (2) of promoting export crops to earn foreign exchange, so that Ghana may become solvent and be in a position to purchase those essential items that she would otherwise have imported

To stimulate as much interest in the programs as possible, the Government has made and is making available all the necessary farming inputs at highly subsidized rates Credit facilities and soil surveys are now readily available to peasant farmers, as well as all those engaged in farming as a business or as an off-duty pastime operation, to a measure unprecedented in the history of Ghana Mechanized cultivation services, improved planting materials, and fertilizers are also available at greatly subsidized rates

Use of Soils Data in Food-Crop Production

The main food crops of the O.F.Y.I. programs are maize, rice, millet, guinea corn, yam, groundnuts, cassava, plantain, cocoyam, and vegetables Soils data obtained from the Detailed-Reconnaissance and Special Project Soil Surveys enable the delineation of areas across the country considered suitable for extensive cultivation of food crops, as shown on the map about soil suitability for food-crop production in Ghana. Such soils data have helped not only in expanding the acreage under cultivation nationally but also in causing significant increases in the yields of maize and rice, to such an extent that Ghana is now self-sufficient in the production of these two grain crops (Table 1)

Maize

Based on soils data, we have been able to delineate several hectares of soils that are level to near level, upland, red to brown, well to moderately well drained, and medium-textured, the soils within the Savannah and the Forest-Savannah Transitional Zones of Ghana have been especially delineated for extensive cultivation of maize These soils have a near neutral pH within the A horizon, becoming acid with depth, they are moder-

Table 1. Land area and production of import substitutions and food crops in Ghana, 1971–1974

Crop	1971	1972	1973	1974
Area (in 1,000 acres)				
Groundnut	242	226	259	273
Oil palm	274	280	308	—
Rice	150	153	164	164
Maize	997	960	1,001	1,045
Production (in 1,000 long tons)				
Groundnut	100	89	120	104
Oil palm	685	700	770	—
Rice	54	56	61	71
Maize	378	396	431	468

ately fertile and are mostly Savannah Ochrosols (Brammer, 1962) and Acrisols (FAO/UNESCO, 1974) These efforts, aided by the Government's massive support under the O F Y I programs, have resulted in tremendous increases in the yield of maize, far surpassing the amount produced under the peasant system (Table 2) the maize production in 1972 showed a 36% increase over that of 1971 A typical example of a successful maize farm, which was given a detailed soil survey to lead to efficient planning of the cultivation pattern, is Ejura Farms, Ltd , a joint venture between Ghana and the United States in the form of a highly mechanized farm within the Forest-Savannah Transitional Zone, covered predominantly by nongravelly Savannah Ochrosols (Brammer, 1962) or Acrisols (FAO/UNESCO, 1974)

Rice

Soils data have also been much used to boost rice yields in Ghana For example, on the national level there was a 44% increase in rice production in 1972, the first year of the O F Y I programs Most of the rice in Ghana is grown within the Interior Savannah Zone, along the extensively level, poorly to very poorly drained, grey, moderately to heavy-textured alluvial soils (Obeng, 1968) of the white and red Volta valleys Typical areas where significant increases in rice yields have been achieved are within the Nasia flats, where the Nasia Rice Company, a subsidiary of the National Investment Bank, has extensive rice farms

General Food Crops

Because of proper selection of soils for such crops as plantain, cocoyam, yams, and vegetables, the production of these crops also saw a general increase These crops are grown on farms of the Food Production Corporation and on small-scale indigenous farms Under the O F Y I programs, funds were made available to the Soil Research Institute to conduct soil surveys especially of small-scale indigenous farms, free of charge Because several farmers took advantage of this, there was a general improvement in the selection of farms for the various food crops

Table 2 Yields of crops under the peasant and improved systems

Crop	Yield (in pounds per acre)	
	Peasant system	Improved system[a]
Guinea corn	600	1,000
Early and late millet	600	800
Maize	806	1,500
Groundnuts	419	1,200 (shelled)
Rice	905	2,000
Cowpeas	226	500
Cotton	500	1,800
Tobacco	500	1,000
Yams[b]	2 tons	4 to 5 metric tons

Sources Agricultural Census, 1963, Ghana Annual Reports, Research Stations

[a] The improved system includes areas that have detailed soils data and where efficient management practices are enforced

[b] Yield given in long tons per acre

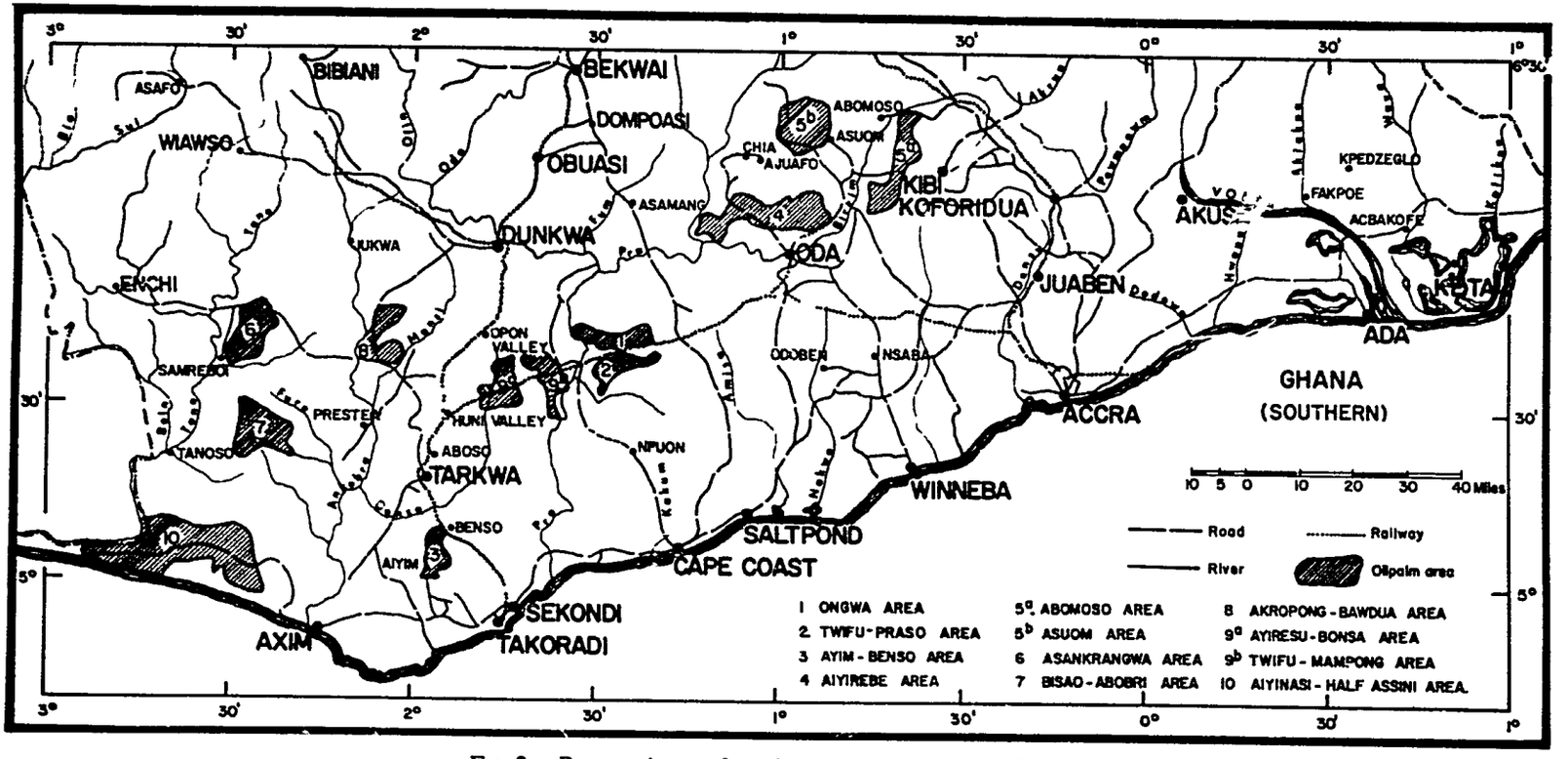

Fig 2 Proposed areas for oil-palm development in Ghana

Use of Soils Data in the Production of Import Substitution Crops

Of the import substitution crops in Ghana, the ones that soils data have greatly helped in acreage expansion and tremendous yield increases are oil palm, cotton, and groundnuts

Oil Palm

Data from the completed Regional and Special Project Soil Surveys, in addition to topographic and climatological data, have been utilized in delineating areas in Ghana considered best suited to extensive oil-palm development (Figure 2)

With the aid of the map (Figure 2) and after further detailed soil surveys (Asamoa and Ienadu, 1972, and Asiedu and Adu, 1975), large-scale farms have been established within areas 3 and 4 for the extensive cultivation of oil palm Several other oil-palm farms have been sited within areas 9A, 9B, and 1 and 2 since the launching of the OFYI programs in 1972 The data provided in Table 1 show significant increases in the acreage and the production of oil palm from 1971 to 1973

Cotton

Several cotton farms have also been established mainly by the Cotton Production Company, a subsidiary of the National Investment Bank (Ansah and Adu, 1975), and by textile companies in Ghana, with assistance from the Soil Research Institute Some of the companies are Akosombo Textiles, Ltd , Juapong Textiles, Ltd , and Tema Textiles, Ltd These farms have adopted improved systems of cultivating cotton through detailed soil surveys to select suitable soils for the crop and suitable management practices aimed at improving the fertility status of the soils, controlling erosion, and eradicating weeds and pests As shown clearly in Table 2, these improved systems have more than doubled the yields of cotton over and above those of the peasant farms, where traditional agricultural systems are still enforced.

Groundnuts

The production of groundnuts has also increased as a result of an increase in hectares of land devoted to the crop and the institution of better farming systems helped by the Soil Research Institute and the Grains and Legumes Development Board Detailed and semidetailed soil surveys have been undertaken not only on farms belonging to the Vegetable Oil Mills Division of the Ghana Industrial Holding Corporation but also on small-scale indigenous farms A typical example is the semidetailed soil survey of the Vegetable Oil Mills' groundnut project farm at Patuda in the Brong-Ahafo region of Ghana (Adu and Ansah, 1974) This survey has enabled the planting of the crop on soils considered suitable, as a result, significant increases in crop yield have been achieved Vegetable oil mills across the country are now in a position, therefore, to obtain raw materials locally without resorting to importation from neighboring countries

Use of Soils Data in the Production of Export Crops

Cocoa

The economy of Ghana is almost wholly dependent on agriculture from which it derives much of its foreign exchange earnings, mainly through exports The crop contributing the most foreign exchange earnings for the country is cocoa

In the period from 1939 through 1959, Ghana's cocoa production ranged between 200,000 and 250,000 tons annually (IDA, IBRD, 1970) In the 1960's, as shown in Table 3, production began to climb rapidly, culminating in a 1964/65 season crop of 557,000 long tons Since 1964/65, however, the crop has declined and in recent years yields have averaged about 400,000 long tons annually (Table 3) Since 1966, steps have been taken to resuscitate the industry, but progress has

Table 3 Cocoa production, 1947/48–1974/75 (in thousand metric tons)

	Region							
Year	Eastern	Ashanti	Brong-Ahafo	Western	Volta	Central	Ghana	World
1947/48	65	10	36	11	20	25	208	580
1948/49	67	82	44	15	26	44	278	591
1949/50	54	72	43	14	24	39	248	753
1950/51	56	78	45	17	25	42	262	799
1951/52	48	61	37	12	24	30	211	635
1952/53	50	78	41	12	28	38	247	784
1953/54	40	60	43	10	22	36	211	759
1954/55	41	69	43	11	22	34	220	788
1955/56	38	68	51	12	28	32	229	823
1956/57	40	78	55	15	32	44	264	881
1957/58	35	70	35	10	22	35	207	764
1958/59	39	85	70	8	21	33	256	891
1959/60	47	105	74	14	23	53	317	1,024
1960/61	64	148	96	23	31	71	432	1,156
1961/62	54	134	85	21	29	87	409	1,124
1962/63	82	149	81	23	21	66	421	1,155
1963/64	82	154	89	24	28	60	436	1,216
1964/65	106	187	121	34	27	74	557	1,482
1965/66	71	153	100	24	20	41	410	1,205
1966/67	68	128	86	25	19	49	376	1,333
1967/68	75	139	107	28	24	51	415	1,333
1968/69	56	107	92	21	14	40	334	1,221
1969/70	68	124	114	31	21	54	409	1,418
1970/71	73	128	110	86	15	59	386	1,480
1971/72	85	143	117	50	10	57	457	1,557
1972/73	74	124	111	43	22	43	411	1,377
1973/74	65	105	77	41	—	47	344	1,418
Estimate 1974/75	—	—	—	—	—	—	370	1,495

SOURCES *Cocoa Statistics Bulletin* FAO, various issues, *Cocoa Annex to Economic Report of March 9 1972* and Cocoa Marketing Board, Ghana, Gill and Duffus, 1975, *Cocoa Market Report*, No 265

been slow, inhibited both by Ghana's weak financial situation and by the major task involved in rebuilding the industry's institutions

Although there have been improvements, Ghana's cocoa industry is in a serious situation Capsid pests, and to a lesser extent a virus disease (swollen shoot), are reducing yields seriously, and the output of older farms is declining and tending to outweigh that of new or replanted farms. Because of the deterioration of the cocoa industry, though Ghana still remains the world's largest single producer of cocoa, its share of world cocoa production has declined from about 37% in the early 1960's to about 30% today Since Ghana's ability to raise resources for development is critically dependent upon cocoa exports, the decline in production must be reversed to allow the country to maintain its share of the world supply of cocoa, the demand for which, in the past

decade, has been increasing at an average annual rate of 4 5% (IDA, IBRD, 1970)

Ghana has recognized the need for strengthening its cocoa industry and has rightly decided to rehabilitate and replant the crop within the Eastern and the Ashanti Regions of the country In order to select the most suitable soils for the projects, preliminary and semidetailed soil surveys were organized by the Soil Research Institute within the Eastern and Ashanti regions of Ghana

The Eastern Regional Cocoa Rehabilitation project soil survey was undertaken during the 1968/69 fiscal year Of the total area of 63,375 62 hectares, 38,786 48 were found to be suitable for extensive cultivation of cocoa, the rest consisted of soils too shallow, too gravelly, too poorly drained, or occurring over too steep a slope to be considered suitable for the crop Of the approximately 38,787 hectares selected, 14,580 are to be replanted and 20,655 hectares of cocoa are to be rehabilitated through provision of credit to farmers for the procurement of the necessary farming inputs The project that should have been completed in the 1975/76 financial year is being extended to the 1976/77 financial year because of the drought of 1973, which slowed down progress (Whyte, 1974)

With such good prospects of success for replanting and rehabilitation of cocoa in the Eastern region, a more massive scheme has just been started in the Ashanti region, traditionally the best region for extensive cocoa cultivation in Ghana A preliminary soil and land-use survey of the region organized by the Soil Research Institute has revealed that out of a total area of 810,000 hectares inspected, 607,500 were found suitable for the extensive cultivation of cocoa (Adu et al, 1974)

Ginger and Black Pepper

To avoid overdependence on one cash crop for export purposes, Ghana has embarked on the diversification of her agriculture Several cash crops are being considered, the major ones being ginger and black pepper Soil survey investigations are being undertaken to select the most suitable areas across the country for the extensive cultivation of these crops Efforts are also being made to extend through soil surveys the area under the cultivation of coffee

Use of Soils Data for Irrigation Development

Various semidetailed and detailed soil surveys have been conducted across the country especially in the Coastal and Interior Savannah Zones to evaluate soils in terms of their suitability for extensive irrigated agricultural development Areas where such valuable soils data have been provided include the Accra Plains (Ministry of Agriculture, 1972), with detailed information available for Ashaiman, Dawhenya (Obeng and Appiah, 1963), the Asuatuare irrigation project areas, and the Vea and Nasia Valley flats in the Interior Savannah Zone These data have enabled several hectares of land to be extensively cultivated for rice, sugarcane, and vegetables to such an extent that Ghana is presently self-sufficient in the production of rice and vegetables

Application of Soils Data in Regional Agricultural Development

Aside from drawing on the immense soils data available for national development of agriculture in Ghana, several Regional Development Corporations have been established whose main purpose is to see to the regional development of agriculture Here again, the Soil Genesis, Survey, and Classification Division of the Soil Research Institute has played and is playing a vital role in the initial selection of suitable areas, within the nine political regions of Ghana, for extensive cultivation of climatically suited crops Few of the projects that have benefited from soils data provided are being successfully implemented for citrus or pineapple in either the Central Region (Asamoa, 1973), the Ashanti Regional Corporation's citrus project (Menisah-Ansah and Adu, 1975), the

Volta Regional Development Corporation's North Tongu cattle ranch project (Adu et al., 1973), or the Vegetable Oil Mills groundnut project in the Brong-Ahafo region (Adu and Ansah, 1974)

Socioeconomic Accomplishments

The overall success of the O F.Y.I programs of the Government of Ghana has caused tremendous increases in both food and cash crops to an extent unprecedented in the agricultural history of the country As a result, Ghana is self-sufficient in rice and maize production, and it is likely that within the next few years cotton and sugarcane production will rise to an extent where complete curtailment of imports will be possible

During the 10 years from 1964 to 1973, Ghana's GNP increased by only 1 3% annually while its population increased by 2 6% Thus the GNP per capital declined but at $242 in 1973, it still remained quite high by standards of West Africa Ghana's population was about 9 5 million in 1974, the second largest in West Africa Of the total GDP in 1973, agriculture (including forestry and fishing) accounted for 49%, and cocoa, 7%, while manufacturing and mining made up 11% The share of cocoa rose sharply in the 1974 financial year, with the higher price accounting for 29% of the total public revenues and 21% of the GDP

Ghana's population is projected to increase continually at 2 6% a year reaching about 11 million by 1980 The country's principal economic objectives are (1) to raise the overall GDP growth rate to reverse the decline in real per capita income, (2) to increase domestic production of food and raw materials, (3) to rehabilitate and expand vital sectors of the economy, such as cocoa, (4) to achieve a more equitable distribution of income, (5) to increase government budget savings; and (6) to increase export earnings from nontraditional and traditional activities

Because of the current significant increase in agricultural production the overall GDP is expected to grow at an average rate of 5% a year from 1976 to 1979, reaching 7% by 1979. The main impetus to growth will come from agriculture for which Ghana's basic resources are good, affording the potential for greatly increased output of nontraditional crops (such as livestock, cotton, coconuts, and palm oil) as well as traditional crops including cocoa (Whyte, 1974)

Significant Factors for Success or Failure

As aforementioned, the O F Y.I. programs of the Government of Ghana have accelerated agricultural growth to such an extent that the country is on the verge of becoming self-sufficient in the production of several climatically suited crops

In the field of livestock development for meat and dairy production, however, the picture is not so promising The foot-slope colluvial and low-level ironpan soils (for ground water laterites, see Brammer, 1962, for petrosols, see Obeng, 1975*c*) developed extensively in the Interior Savannah Zone are considered to be well suited to pasture development for large-scale livestock production It is necessary, therefore, for Ghana and other developing countries that have extensive development of such soils, normally considered unsuitable for arable cropping, not only to find ways and means of utilizing current technological innovations to improve indigenous forage crops and breeds of livestock and to introduce promising new ones, but also to find effective and ready remedies to the menacing effects of the tsetse fly In this respect, it is very encouraging that the Northeast Savannah Research Project, a joint venture between Ghana and the United States, which includes interdisciplinary, socioeconomic, and other studies involving cultivation practices, water availability, burning, overgrazing, and deafforestation has been started under the aegis of the Council for Scientific and Industrial Research The purposes of these studies are (1) to find solutions to the multiple problems hindering the efficient economic development of the vast Interior Savannah Zone of the country; (2) to bring about significant increases in crop and

livestock production, and (3) to improve upon the health and the economic well-being of the indigenous people (Obeng, 1975*b*)

Another hindrance to rapid achievement of the goal of self-sufficiency in Ghana's agricultural production is the apparent lack of effective agricultural extension services capable of transmitting soils data efficiently in simple terms that can be easily understood and applied by indigenous farmers This lack is caused mainly by the absence of soil-science specialists to complete the ideal effective three-way system of a well-trained, experienced, and disciplined cadre of research scientists, subject-matter specialists, and agricultural extension officers Ironically, the main reasons for this major setback are the inadequacy of trained personnel and the unattractive conditions of service

In the absence of the ideal three-way system that would see to it that soil research data are transmitted effectively to user agencies, the Soil Research Institute, in addition to supplying such data to government agencies, especially the Ministries of Agriculture, Economic Planning, Industry, and Cocoa Affairs, is engaged in direct project execution and advisory services to private organizations and small-scale indigenous farmers (Obeng, 1975*a*) The Institute's efforts have resulted in general improvement of the application of soils data in the development of agriculture in Ghana, especially on the part of the small-scale indigenous farmers, who are responsible for almost 90% of the total agricultural production of the country Given the firm establishment of a soil science extension service attached to the Soil Management Section of the Soil Research Institute, it is hoped that soils data will be fully utilized to increase substantially crop and livestock production in Ghana

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A Case Study of Tropical Alfisols in Sri Lanka

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Soil-survey data have been a useful instrument in formulating a national plan of priorities for the agricultural development of the Alfisol region in Sri Lanka The different categories of soil-survey data have enabled the drawing up of long-term proposals for a balanced development of the soil and water resources of the Alfisol region within the framework of three broad systems of land use irrigated farming, semi-irrigated farming and rain-fed farming

Soil-survey data are now being used at every stage in the planning and execution of irrigation projects However, soil-survey and soil-classification data per se do not provide all the information that is necessary for efficient microplanning at the farm level

There is yet a dearth of meaningful management experiences for tropical Alfisols even at the suborder and great group level Moreover, some basic soil management problems that relate to the high bulk-density of the Rhodustalfs their poor aeration porosity, and their very hard consistency in the dry state have yet to be satisfactorily solved

Transfer of experience within the Alfisols could be rendered more effective by improved definition and specification of parameters such as landscape norphology, hydrology and rainfall variability

The socioeconomic framework within which a soil region is to be developed has important implications for the kind of soil information that might prove useful or not Effective farm planning at the microlevel requires a close interaction among a number of related disciplines, both agrotecnical and socioeconomic

Before World War II, Sri Lanka's economy was based primarily on an export-oriented plantation agriculture, notably tea, rubber, and coconut These plantation crops had been successfully grown in the Ultisol regions in the wet zone of the country over a period of 75 years However, demand for food increased, and this was met by cheap imports from neighboring Asian countries This resulted in the stagnation of domestic food production

The consequence of World War II, combined with an increase in population growth, resulted in a sudden demand for accelerated local food production To meet this demand, Sri Lanka attempted in the late forties to develop rapidly the hitherto underutilized land resources in the Alfisol region in the drier zone of the country

At first sight, the solution to agricultural development in the Alfisol region was envisaged in terms of intensification of rice production on the irrigable lands, chiefly the Tropaqualfs, while in the unirrigable Rhodustalfs and Haplustalfs, it was thought that a replacement of shifting cultivation by modern methods of rain-fed arable farming would solve the problem Although rice yields in

the Tropaqualfs under an assured irrigation supply have increased to an average level of 4 tons per hectare, the alternatives originally envisaged for rain-fed arable farming on the nonirrigated lands have yet to bear out the initial hopes

The lack of adequate management information about tropical Alfisols in the early 1950's compelled Sri Lanka to embark on its own program of research investigations, especially in the hope of developing economic systems of settled arable rain-fed farming on land that was hitherto subject to shifting cultivation

Present Status of Soil Survey and Classification in Sri Lanka

Systematic soil surveys of the country were started in 1959 under the auspices of the National Soil Survey Project The classification of the soils of Sri Lanka into the great soil groups and subgroups was presented by Moormann and Panabokke (1961)

Soil maps on a scale of 1 60,000 are available for the whole country, covering an area of approximately 25,000 square miles These maps correspond to the low-intensity soil surveys, which show association of the great soil groups or subgroups, phases of the great soil groups where significant, and land units of various kinds including identified great soil groups

Medium-intensity soil surveys have been completed for approximately 4,300 square miles, and high-intensity soil surveys have been completed for approximately 410 square miles

A 1968 soil map of Ceylon contained cartographic units that could be correlated with internationally accepted systems, the 1972 soil map of Sri Lanka (scale 1 500,000) contains 31 map units, which show the areal distribution of the more important great soil groups and subgroups of the country and also the types of terrain on which they occur De Alwis and Panabokke (1972) prepared a supporting text for this map, which also gives the classification of Sri Lanka's soils according to the comprehensive American *(7th Approximation)* system

General Characteristics of the Alfisol Region and Its Resource Base

The Alfisol region of Sri Lanka is confined to the drier zone of the island and is located within the lowest peneplain that is floored by crystalline metamorphic basement rocks of the pre-Cambrian era In the gently undulating mantled plain of this peneplain, a typical catenary sequence of soils can be observed The Rhodustalfs and Haplustalfs occupy the well-drained parts of the gently convex landscape, and the Tropaqualfs occupy the imperfectly and poorly drained parts of the slightly concave and flat landscape

Dry weather flow in the second-order streams in this region usually ceases after about 45 cumulative dry days Very limited quantities of ground water are available only where the basement is highly fractured and weathered Surface water storage in low-head reservoirs is the traditional method of water conservation for domestic requirements and for supplementary irrigation

The meteorological data given in Table 1 are for the Maha Illuppallama Agricultural Research Institute, which is the central research station for the Alfisol region in Sri Lanka The modal soil member at the research station is a Typic Rhodustalf, loamy, kaolinitic, isohyperthermic

There are no serious limitations in the chemical fertility of the soils except for their low phosphorus status The more serious limitations of their physical properties are the high bulk-density values, low macro-aggregate stability, and the very hard consistency of the soils in the dry state A special feature of the soils is the soil-water energy relationship, where nearly 85% of the available moisture is lost at a tension of 1 atmosphere or pF 3 As a result, the soils dry out very early and also tend to get saturated very quickly after rainfall

The total area of the Alfisol region is close to 10,000 square miles Present land use in this region is as follows

Irrigated rice	650,000 acres
Rain-fed rice	150,000 "
Homestead gardens and other uses	400,000 "
Total	1,200,000 acres

Soil-survey data indicate that approximately 1,250,000 acres are marginal or unsuited for agriculture Of the remaining 4,000,000 acres that are suitable for agriculture, approximately 350,000 are subject to varying degrees of shifting cultivation Future development of transbasin and local water resources could render irrigable approximately 900,000 acres This leaves about 3,100,000 acres that will have to be developed in systems of rain-fed arable agriculture

Settlement Objectives, Past and Present

The chief objective of the settlement policies of successive governments since the 1930's has been to encourage and develop settled, arable small-holder farmsteads in the less populated Alfisol region Inducements in the form of various subsidies, offered by the Government, had attracted settlers in sufficient numbers from the highly populated Ultisol region of Sri Lanka

Up to the mid-sixties, the size of an irrigated farmstead was 4 acres, and the size of a rain-fed farm was 10 to 15 acres The increasing demand for irrigated land and the rapidly increasing capital costs of irrigation works have reduced the size of an irrigated farmstead now to 2 acres

In 1970, the Government declared that the size of an agriculture holding should be one that would generate an income not less than that earned by a white-collar urban worker This has resulted in an unprecedented demand for land by youth and also in a marked reversal in the rural-urban immigration patterns of the past Youth cooperatives and group farming are now rapidly gaining ground both in irrigated and rain-fed agriculture

Soil Management Problems in Alfisols

Organized interdisciplinary research on soil and water management problems in rain-fed agriculture in the Alfisols started in 1950 Abeyratne (1956) reported the results of the first phase of these investigations Based on results of subsequent research, Abeyratne (1962) and Panabokke (1967) have discussed general conclusions about the prospects for agricultural development in the Alfisols

The more important conclusions that stem from the foregoing studies and that

Table 1 Meteorological data for agricultural research institute, Maha Illuppallama

Month	Mean rainfall (cm) (65 years)	Mean evaporation open pan (cm) (20 years)	Mean temperature Maximum (°C) (25 years)	Mean temperature Minimum (°C) (25 years)	Mean relative humidity (25 years)	Mean percentage sunshine (25 years)
Jan	13 5	13 2	28 2	20 4	81	65
Feb	4 8	14 2	30 2	20 6	74	75
Mar	9 9	18 0	32 5	21 8	73	85
Apr	18 8	17 3	32 8	23 3	76	82
May	9.9	17 8	32 3	24 4	76	77
June	2 8	18.3	31 9	24 4	71	75
July	3 8	19.0	32 3	24 2	70	73
Aug	4.3	20.3	32.7	23 9	68	78
Sept	7 6	20.8	32 9	23 6	68	74
Oct	25 1	15.0	31.3	22 8	77	64
Nov	26.7	11 7	29 6	21.7	81	56
Dec	20 3	11 4	28.1	20.9	83	58
Total	147.5	197.0				

have a very significant value in transfer of experience are as follows:

1. Each minor drainage basin or microcatchment unit in the catenary landscape has to be treated as the natural unit of management for purposes of efficient water control
2. Rice culture in the lowermost hydromorphic soil associates will have to be closely linked with the rain-fed upland in the total farming system within each microcatchment
3. Since different cropping patterns are needed for the individual drainage associates of the catena, diversification of cropping at the farm level will be inevitable
4. An intensification of agricultural production involves both a proper choice of sowing time and a proper selection of sowing-to-harvest duration of crops, so that there is a maximum likelihood of the rainfall satisfying the crop's water demand (Panabokke, 1974)
5. As much as possible, tillage operations should be reduced to a minimum If tillage implements have to be used, they should be of a non-inverting type that leaves a maximum protection of stubble on the surface

Because of the inherent high bulk-density value of the soils, root development of crops tends to be restricted No practical solution to this problem has yet been worked out The very hard consistency of the soils in the dry state—and their highly abrasive qualities on tillage implements—is yet another serious impediment to efficient arable cropping under conditions of rain-fed farming

Research investigations about the Alfisols in relation to irrigated farming started in the late sixties There are no serious limitations to irrigated rice culture in the hydromorphic associates However, management of the Rhodustalfs and Haplustalfs under irrigation poses a few basic problems that have yet to be solved These relate to the low aeration porosity of the soils and the water-table behavior consequent on gravity irrigation.

Use of Soils Data

Little or no supporting soil information was used during the development period from 1950 to 1962 This was not unusual because the main focus of development was the restoration of the ancient irrigation works that dated from the first century These abandoned irrigation works consisted of both major and minor schemes that were in varying stages of disuse and disrepair from a period spanning 10 to 15 centuries (A major irrigation scheme is a scheme greater than 1,000 acres of irrigable command, a minor irrigation scheme is a scheme less than 1,000 acres of irrigable command) However, the irrigation command of these ancient schemes was confined to the bottomlands where the soils were low humic gley soils (or Tropaqualfs), and these were invariably quite suited for irrigated rice culture in their entirety

But maximum use of soil-survey data has been made during the development period from 1962 to 1974 The total capital investment on major and minor irrigation projects during this period was the equivalent of approximately 150 million U S dollars

The soil-survey data that became available by 1962 for the whole of the Alfisol region made possible the formulation of a scheme of priorities for the individual river basin development projects in this region Important decisions on transbasin diversion projects were also made with the aid of the soil-survey information that was now available This marked a definite change from the earlier period where, more often than not, an ideal dam site was the sole criterion considered when deciding on an irrigation development project

A national plan for the Alfisol region, allocating lands for requirements of agriculture, plantation forestry, forest reserves, wildlife and nature conservation reserves, and urban development, was formulated in 1967 The main recommendations, based on

soil-survey data, were presented in the Report of the Land Utilization Committee (Government of Sri Lanka, 1968*b*) and are now being carried out by the various state agencies responsible for the respective areas of development

By 1965, soil-survey data were being used in almost every stage in the planning and execution of irrigation projects The siting of the project, the initial feasibility investigation, detailed economic appraisal, selection of lands for irrigation, selection of suitable cropping patterns, and calculation of irrigation needs were all based on soil-survey and supporting soils data The first example of comprehensive planning and design of a large multipurpose irrigation project based on soil survey was the Uda-Walawe project, in southern Sri Lanka, whose construction work started in 1964 The soil-survey report on this development area of 60,000 acres was prepared by de Alwis (1963) and formed the basis for most aspects of the design and layout of this project

The Mahaweli transbasin diversion project was by far the most ambitious of the multipurpose irrigation development projects that were launched in early 1970 In the multidisciplinary feasibility studies conducted from 1965 through 1968 in collaboration with a UNDP team, medium-intensity soil surveys covering 947,000 acres were carried out, and the results have been reported in the Mahaweli Ganga Irrigation and Hydro Power Survey Report, vol 3 (Government of Sri Lanka, 1968*a*) The repartition of the total project into its individual phases and stages was also determined primarily by the soil-survey data In the second development stage of this project, high-intensity soil surveys covering 250,000 acres were carried out, and the results have been reported in the feasibility study for this stage (Government of Sri Lanka, 1973)

Soil surveys have their maximum application now in the irrigation development projects where each year between 10,000 and 15,000 acres of new land are brought under irrigation in the Alfisol region This includes both gravity and lift irrigation

Medium-intensity and occasionally high-intensity soil maps are used in the planning and layout of state farms for rain-fed agriculture, and more recently in cooperative youth settlement projects These maps show phases of soil series because they are important to rain-fed agriculture

It should be borne in mind, however, that the soil-survey maps by themselves do not adequately provide all the information required for efficient microplanning at the farm level Despite the availability of a considerable body of data on soil physical characteristics, irrigation engineers and irrigation agronomists have yet to work out more efficient design criteria for the on-farm irrigation layouts that are best adapted to the conditions of soil and terrain that obtain in the Alfisol region

Results of soil-management experiences from the Maha Illuppallama Research Station are directly applicable to the Alfisol regions as a whole A package of soil-management practices, in both irrigated farming and rain-fed farming, have been evolved at the research station, and these have been effectively translated by the extension staff to farmers' fields For extension requirements, the field identification of the drainage associates of the soil catena in terms of the well-drained member, the imperfectly drained member, and the poorly drained member has gained rapid and easy acceptance by the farming community This is to be expected in this soil-climate environment where the drainage class of the soil is observed to be the most important single soil parameter that influences crop adaptability and cropping potential in irrigated and rain-fed agriculture Furthermore, in this Alfisol landscape, where the distance from the crest of the ridge to the floor of the adjacent valley in the catenary sequence is never greater than three-fourths of a mile, a readily understood demarcation of the individual drainage associates is especially important

In the fertilizer recommendations for rice in the different Tropaqualfs in the Alfisol region, soil texture and the soil-drainage class have an important bearing on the optimum levels and frequency of application of nitrogen fertilizer On the basis of the work

reported about the fertility characteristics of the rice-growing soils by Panabokke and Nagarajah (1964) and subsequent studies about the capability classification of the rice-growing soils by Panabokke (1968), yield-potential benchmarks have been specified as the very high potential, high-potential, and medium-potential rice-growing areas The allocation of fertilizer and other resources inputs for each year's national agricultural production programs are now based on the foregoing information

Physical Accomplishments

The total acreage of agriculturally good soil in the Alfisol region far exceeds that of the total area that could be served by irrigation, even after the complete exploitation of all water resources, including transbasin diversion from the wet zone of the country This would naturally imply that a balanced agricultural development within the Alfisol region would have to be conceived within three broad categories of land use (1) irrigated farming, (2) semi-irrigated farming, and (3) pure rain-fed farming The information made available by the soil surveys has made possible the formulation of a scheme of priorities whereby a rational allocation could be made of available water resources in the future Accordingly, by 1970, a master plan was formulated for the soil and water resources development of this region

Recent developments in crop diversification on irrigated land have been made possible by identifying and demarcating the individual soil-drainage associates, and working out management practices for growing crops (other than rice) on the well-drained and imperfectly drained soils Extension of sugarcane into the imperfectly drained and a part of the poorly drained soils has been made possible by improved drainage and on-farm irrigation layout

In rain-fed agriculture, the sowing-to-harvest duration of crops for the different agroecological regions has been specified by matching the physical properties of water in the soils with the rainfall-confidence limits and the crop-water requirements.

Socioeconomic Accomplishments

In the last 15 years, somewhat more than 85,000 families have settled on approximately 300,000 acres of irrigated land in the Alfisol region Because of recent fiscal policies by the state, there has been a definite swing toward growing high-value import substitute crops in place of rice on the well-drained irrigated land Farmer incomes and employment opportunities have thereby been enhanced

Expansion in the rain-fed agricultural acreage has been mainly confined to the nonirrigated highland near village settlements and, to a small extent, in state farms Here again, the pricing policies of the state have made the cultivation of some rain-fed crops an economically attractive enterprise

It is now clearly evident that smallholder farmsteads cannot be completely independent of each other They have to band into some kind of unit for services and organization Farm planning is now carried out by an interdisciplinary team consisting of agronomists, soil scientists, sociologists, economists, and farm management specialists Its main aim is to create economically viable, market-oriented farmsteads and effect changes in cropping patterns, through planning at the individual farm level on the basis of soils and terrain.

Significant Factors for Success or Failure

Within the limits of the scientific information that has been available about Rhodustalfs and Haplustalfs, it has been possible to make a significant measure of progress in the development and management of the hitherto unutilized soil resources of the Alfisol region It should be noted, however, that the soil-survey and soil-classification information per se has not been the sole contributory factor in achieving these development goals The supporting research and

management experiences, which, at a certain period, had to be gathered independently of the soil-survey and classification data, have certainly played an equally important role

As indicated earlier, the dearth of meaningful scientific information on the management parameters of tropical Alfisols had compelled *de novo* research investigations to be initiated around 1950 at the Maha Illuppallama Research Station Up to the early sixties, soils that were broadly similar to Sri Lanka's Alfisols had been grouped under the general category of nonlaterized red earths of the tropics Little or no specific transfer of management experience was possible under these circumstances

The new classification concepts that evolved in the early sixties, especially that of the *7th Approximation*, made it possible to locate and define accurately the position of Sri Lanka's Alfisols in relation to the rest of the tropical world But this still did not enable any direct practical transfer of management experiences, largely because of the lack of controlled experimental data from soils belonging to similar great soil groups At best, it made it possible to infer selective strategies by an intelligent interpretation of a broad range of data then available for various kinds of Latosols

Only by the early seventies did the international soil literature begin reporting data specific to various lower categories in the tropical Alfisols More recently, experiences from the Oxic Paleustalfs from IITA (Nigeria) have shown that, for tropical Alfisols, a significant measure of interchange and transfer of results is possible, even at the suborder level

That a clearer specification of the total environment is essential for selective identification of transferable experience is evident. Apart from the modern nomenclatures of soil survey and classification, there is an urgently felt need for more precise definition and description of the landscape morphology, hydrology, and rainfall variability to ensure a satisfactory transfer of information For example, the nature of microvariability in small areas will have a profound bearing on the total agricultural system that will be best suited for a particular soil-landscape-environment complex Farm planning and layout, optimum size of economic holding, and proper settlement planning are all governed by the nature of the aforementioned parameters

Furthermore, the socioeconomic framework within which a soil region is to be developed has important implications for the kind of soil information that may or may not prove useful The scope of information that is generally used for capital-intensive, large-scale, and mechanized agriculture does not adequately fulfill the requirements for labor-intensive, small-scale development planning in most of the Asian regions

In conclusion soil-survey and soil-classification data do provide a reliable guide for selecting the more efficient paths that lead to certain goals of development, especially in developing countries whose capital resources are scarce and whose planners and decision makers often have to choose from among many possible alternatives To what extent contemporary soil-survey and soil-classification knowledge could really activate the whole complex of agricultural development would be determined largely by how imaginatively their selective functions could be harmonized at the respective level of the planner, the research worker, the extension worker, and the farmer

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Soils and Institutional Requirements for Regional Planning and Development

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The use of soils data in regional and national development has been gaining more and more importance as a means of making the most efficient use of natural resources, especially land resources The importance of such data stems from the need to feed rapidly expanding populations in the face of diminishing or deteriorating land resources in the tropics Therefore, clear recognition of the need for planning optimum land use as an aid in regional and national development is imperative

Four case studies are presented in this paper as examples of Iran (region of Khuzestan) Pakistan, India (region of Rajasthan), and Bangladesh Attention is focused on the fact that considerable efforts have been and are being made in the utilization of soils data and the results of soil surveys and soil and land classification for agricultural development in these countries However, there is much scope for further improvement

A review is presented of the dynamics of development and the interaction of factors involved in agricultural development planning the causes for variability in agriculture, and the major policies concerning the place of soils data in planning of development Reference is made to some sociopolitical factors, and examples of the People's Republic of China are cited A proposal for legislation for natural resources conservation and utilization is mentioned also

Finally a review is given of the FAO programs and policies in using soils data of the FAO's role in land evaluation, in the preparation of the Country Perspective studies, and in the agricultural development programming Assistance is being given to countries in the execution of their programs through technical assistance measures as well as through some programs of action for development

Regional and national development is a phrase much used now, justified usually by the closely associated factors of rapidly expanding populations and diminishing rural land resources in the tropics Recognition of the need for planning optimum land use inevitably leads to the demand for an inventory of soils and land resources and to the interpretation of these data into appropriate formats for, among other things, tax assessment, individual farm planning, and rural and urban development, this in turn leads to regional and national agricultural planning and development

The range of possible interpretations of soils data is vast, hence, it is impossible even to describe all applications in this paper let alone give examples of the main interpretations Therefore, I will describe in this paper four general examples in Asian countries where soils data have been used in formulating policies for regional and national agri-

cultural development (1) the Khuzestan development in Iran, (2) the soil survey of Pakistan and its effects on agricultural development in Pakistan, (3) the Rajasthan Canal survey and the Chambal soil survey and regional development of Rajasthan, India, and (4) the soil survey and agricultural development of Bangladesh, with special regard to drainage, irrigation, and land development

Four Case Studies

The Khuzestan Development in Iran

The Khuzestan plain in Iran, which covers about 3 million hectares in the southwest of the country, is a continuation of the Mesopotamia plain in Iraq Its northern boundary is formed by the Zagros Mountains, which are characterized by successive mountain ranges, its southern boundary, by the Persian Gulf The plain is level to gently sloping, its rivers flowing in a braidlike manner, forming a wide flat plain interwoven intermittently by channels

The soil survey conducted in the Khuzestan plain and a more detailed one in the Dezful area revealed a variety of soils developed partly under different climatic conditions in the past Through the interpretation of indications given by the traces of old irrigation systems in the area, information has become available about agriculture in different periods The soil mapping done has divided the soils into the following groups, which are all essentially alluvial (1) soils of the older landscapes, without irrigation cover, (2) soils of the older landscapes, with thick irrigation cover, (3) soils of the young landscapes, with thick irrigation cover, (4) soils of the young landscapes, with thin or no irrigation cover, and (5) miscellaneous soils including gravelly and hilly soils

The studies done and the soils and land-classification and land-use maps prepared have had a great influence on the planning of agricultural development in this region First of all, it became clear that in this plain the glory of the past could be revived, provided soil and associated water-development problems were taken care of (this region was the center of Susa and the great empire of Persia about 3,000 years ago) This important conclusion enabled the Government of Iran to invite a group of consulting engineers, headed by Messrs David Lilienthal and Gordon Clapp, who formed the Khuzestan Development Service and assisted the Government in preparing plans and programs for a speedy development of the region Detailed survey, soil fertility, and other related studies were carried out with the FAO's technical assistance All these activities resulted in planning, which established various agencies, starting with a newly established agency called the Khuzestan Water and Power Authority Finally, the Agriculture Department and other departments in Khuzestan joined the effort and worked out a blueprint (1) that permitted a large-scale investment in the Khuzestan area for agricultural and water-resource development, (2) that promoted in the region the development of agro-industries, including the sugarcane and paper industries, (3) that permitted the consolidation of agriculture into large-scale agro-industrial enterprises concentrating on such industrial commodities as sugarcane, animal products, vegetables and fruits, cotton, sunflower, and the like, and (4) that introduced, from 1957 to 1958, the use of fertilizers and promoted their efficient use (Table 1)

The program in Khuzestan served as a training ground for many Iranians in effective agricultural development programs, including efficient use of fertilizers, soils and water management, drainage and reclamation, and multiple cropping enterprises

Although in the beginning the development of the Khuzestan region was the responsibility of the Khuzestan Development Service, an agency working under the Planning Organization of the Government of Iran, the task has been delegated recently, by subject, to the technical ministries concerned.

The impact of agricultural development in Khuzestan is shown in Table 2 in rather approximate data that areas that have a high development potential have received—and will be receiving—a much higher invest-

Table 1 Fertilizer consumption in Iran, 1955–1973

Year	Supply of crude fertilizer (tons)	Nutrients (percentage)	Constituents (in tons)			
			NPK	K_2O	P_2O_5	N
1955	538	32	175	10	77	88
1956	2,096	41	859	143	346	370
1957	4,893	41	1,994	167	684	1,143
1958	15,010	40	5,972	409	2,850	2,713
1959	20,451	43	8,739	925	3,213	4,601
1960	36,145	37	13,196	1,300	4,246	7,650
1961	38,981	39	15,080	2,572	4,793	7,725
1962	47,307	41	19,307	1,996	9,236	8,075
1963	58,821	44	25,793	2,610	9,914	13,269
1964	71,202	46	32,530	2,167	14,364	15,999
1965	85,468	43	36,402	1,469	15,036	19,897
1966	122,510	45	54,966	1,599	25,306	29,069
1967	169,185	44	74,396	1,650	27,190	45,556
1968	184,515	44	81,012	1,528	27,647	51,837
1969	215,744	47	101,861	2,461	40,444	58,956
1970	225,116	46	102,622	676	35,801	66,145
1971	336,944	48	161,154	605	69,326	91,223
1972	359,322	48	171,785	430	65,245	106,110
1973	482,126	51	247,879	850	97,550	149,479

SOURCE Data from the Fertilizer Distribution Corporation
NOTE The Fertilizer Distribution Corporation was established in 1968

ment than that received by areas that have a poor land development potential

Agricultural investment in the Khuzestan area in the last 15 years has followed the pattern of investment and development in the areas of better soils—the areas in the northern sector of the Khuzestan plain Although comprehensive figures about investment are unavailable, it is estimated that, in the agricultural sector, the northern one-third of the area of the Khuzestan plain has had about five times more investment than the southern two-thirds, thus equivalent to ten times per unit area of investment This is related to the soils information and data obtained from the detailed and semidetailed surveys and classification over the last 22 years

Triggered by an understanding of the potential of its soils as determined by the soil survey and classification, and enhanced by the further assessment of productivity through studies of fertilizer response and efficient soil and water use, the Khuzestan regional development has become a spearhead in Iranian agricultural and rural development It has also promoted urban development, as evidenced by the cities of Ahwaz and especially Dezful, thus acting as a stimulus for the development of other regions.

Soil Survey in Pakistan

The soil survey in Pakistan was initiated in the fiscal year 1961/62 as part of the joint operations between the Government of Pakistan and the FAO, it was helped by funds from the U N Special Fund, the predecessor of UNDP Prior to the initiation of this survey, relatively little was known about the soils and soil resources of Pakistan, except for information gained by experiencing several centuries of grazing, rain-fed, and irrigated agriculture, and some 70 years of large-scale canal irrigation development.

Table 2 Impact of the agricultural development potential on investment in the Khuzestan plain, Iran

Soil group	Area (hectares)	Land development potential	Investment, present and proposed (million dollars)
A	(10%) 300,000	High to medium	900
B	(23%) 700,000	Medium to poor	600
C	(67%) 200,000	Poor to very poor	300

Particularly scarce were soils data on the rain-fed areas of Punjab, which comprise higher lands and where cultivation and grazing have been practiced since time immemorial, resulting in a continuous deterioration of the natural resources of soils and vegetation, a most serious problem The magnitude of the degradation is apparent in the form of severely gullied lands In irrigated areas, large-scale salinity, alkalinity, and waterlogging have led to considerable deterioration in land productivity

The soil-survey activities carried out between 1962 and 1974 have provided a new insight into the problems involved Contrary to previous beliefs, soil erosion was not the main problem of the rain-fed areas, and the devastation was not recent Geological erosion, which started about 20,000 years ago, is still continuing The new insight gained is that man has accelerated this erosion process in recent years Recent soil investigations indicate that the low productivity of these soils is due to low soil fertility, inadequate tillage, unsuitable cropping patterns, and uncontrolled grazing, in addition to soil erosion, which was suspected to be the main cause of soil deterioration

Recent recommendations for development of these large areas call for a shift in emphasis toward improving (1) agriculture in areas already under cultivation and (2) grazing on range lands, that is, the uncultivated areas These recommendations stem from the result of the soil survey and soil-data collection in these regions The development of soil conservation programs is an important step toward the improvement of the area, and the prerequisites for the development and implementation of such programs include designing appropriate legislation in this field and establishing institutions to carry out the laws

The salinity, alkalinity, and waterlogging associated with canal irrigation have also caused large areas in Pakistan to deteriorate, these areas have been deteriorating ever since the introduction of canal irrigation 70 years ago A determined effort by the Government, involving huge ground water development and other drainage and reclamation work initiated some 10 years ago, has reduced the speed and extent of the damage, and advance precautions are being taken in increasingly larger areas

The fundamental allocation of resources and finances is determined by the Planning Commission of Pakistan and the Ministry of Food and Agriculture, especially the Soil Conservation, Irrigation, and Reclamation Departments and the Water and Power Development Authority (WAPDA)

Obviously, different uses can be made of the same land A single agency should have the responsibility therefore for determining and planning land use However, after the single agency has determined the best use, the responsibility of implementing the decision should go to various agencies concerned with agriculture, irrigation, range-land development for animal production, forestry, urban development, and the like The soil

Table 3 Legends from the maps of areas emphasized for development

Area	Return (rupees per acre)
Irrigated agriculture	
1 Intensification of irrigation through improved levels of management on good land and emphasis on cotton (North) and sugarcane (South)	450
2 Intensification of irrigation through improved management and water supplies on good land for general cropping	310
3 Intensification of irrigation through improved management and water supplies on good land for general cropping locally restricted	300
4 Implementation of drainage measures on regional basis for irrigated cultivation with emphasis on sugarcane and rice	250
5 Groundwater investigations and tapping by tubewells for irrigated cultivation, with emphasis on fruit and locally grown vegetables	variable
Nonirrigated agriculture	
6 Improved management of rain-fed cultivation giving increasing emphasis on groundnuts and sorghum, local tapping of groundwater for irrigated cultivation	347
7 Implementation of soil-conservation measures and improved levels of management for rain-fed cultivation of groundnuts and sorghum	297
8 Encouragement of winter cropping on residual summer flood moisture and some tubewell installation in higher areas	200
9 Improved forest management for production of timber and associated controlled grazing and grass-cutting	130
10 Animal production through resown pasture and range development and complementary rain-fed interdune arable crop production, including groundnuts	47
Nonagricultural area	
11 No foreseeable development other than soil-conservation measures where necessary to protect adjacent good land	—

conservation agency in Pakistan has held an important role in this respect, and the practical effects and results of its activities are visible in many parts of the upland area

Some of the major soils groups in Pakistan and their environmental zones and development-emphasis areas are depicted in the legends of the maps of areas emphasized for development (Table 3) This has helped and continues to help the work of planners, policy makers, and decision makers in the general development of programs, their execution, and investment (Maps are not reproduced)

The Rajasthan Case in India

India covers some 3,270,000 square kilometers of land, of which 43% is arable and about 9% is under some kind of irrigation India's population is estimated at 586 million, its recent growth rate has been 2 2% About 70% of India's population is engaged in agriculture, which accounts for about 45% of the GNP

Rajasthan, the second largest state in India, although one of the less populated, has an area of 34 million hectares and a population of about 27 million, of which 80% is ru-

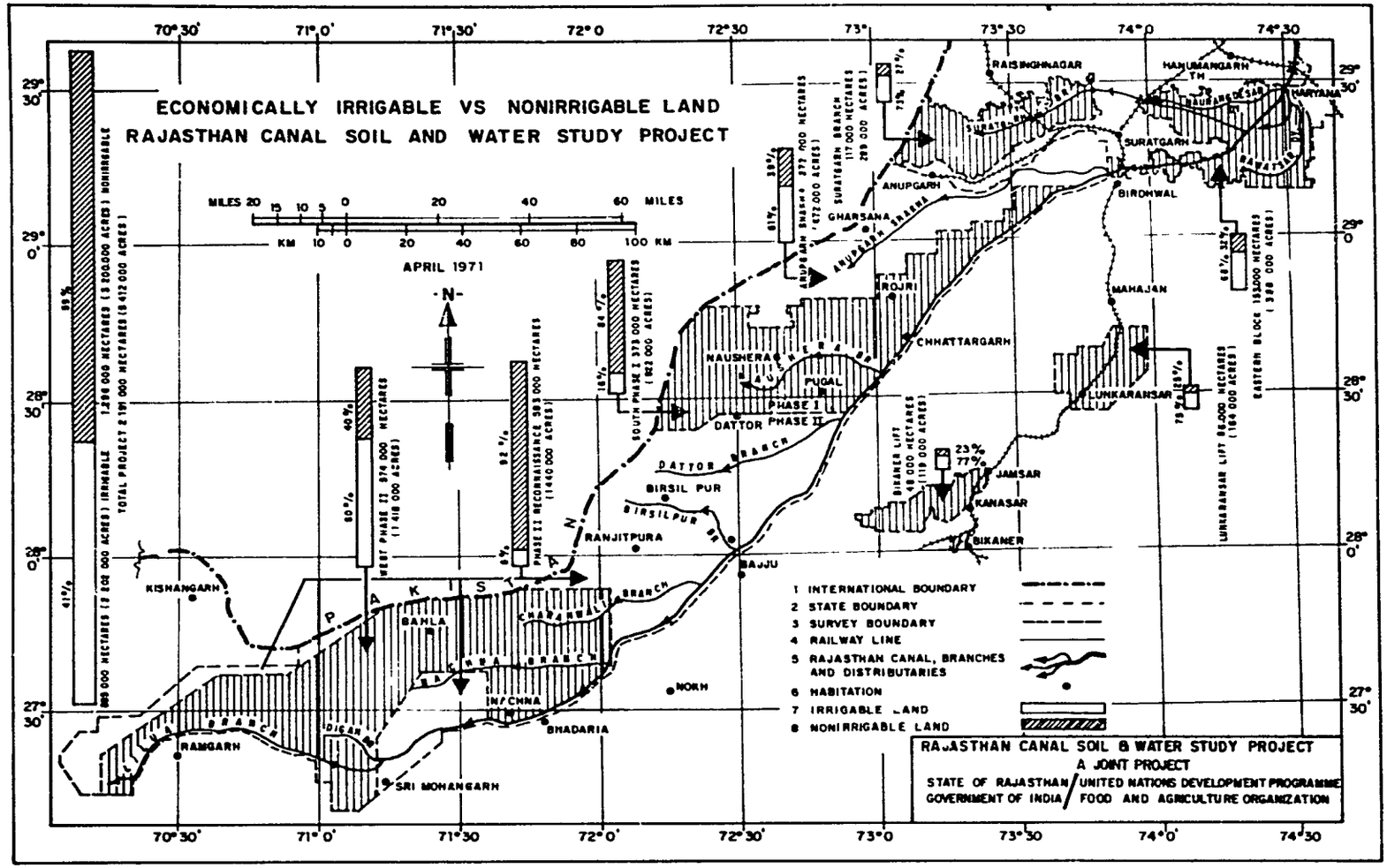

Fig 1 Economically irrigable vs nonirrigable land, Rajasthan Canal soil and water study project

ral The northwestern part of Rajasthan is arid, its rainfall is less than 300 mm and drains toward the Indus River The southwestern part can be called semiarid since it has rainfalls of 800 to 950 mm, which drain mostly to the Chambal River and thence to the Ganga system

About 13 million hectares in Rajasthan constitute a largely uncultivated desert, 1 million hectares are forests, and 14 3 million hectares grow rain-fed crops, mainly millet, sorghum, and chickpeas About 2 1 million hectares are irrigated 55% by dug wells, 35% by public canal systems, and 10% by tanks Irrigated crops include cotton, wheat, paddy, sugarcane, millet, pulses, oilseeds, fruits, and vegetables

Concern has been growing in India for the last several years over the inadequate utilization of irrigation systems In response, India's development program for the next 5 years emphasizes the command-area development, and thus the Rajasthan Canal project and the Chambal irrigation project, both in Rajasthan, will play a great role in the agricultural development plans of Rajasthan and India In general, the approach is to achieve integrated development of the land, water, and human resources in irrigated areas through unified project management

The first step, initiated in the mid-sixties for the Rajasthan Canal area and later for the Chambal project, was to carry out a soil survey and land classification of the project areas The map (Figure 1) of economically irrigable versus nonirrigable lands in the Rajasthan Canal area, based on detailed soil studies of this area of over 2 million hectares, is the basis of a large-scale development program for the region This development program, also applying to the Chambal project area where again detailed studies were carried out and soil maps were prepared, has had several important results for the development of Rajasthan

A Rajasthan Land Development Corporation (RLDC) is being established as a statutory body to be set up under an act Legislation would empower the RLDC to carry out on-farm development on a compulsory basis The RLDC will have a board of directors, chaired by a very senior officer of the Government of India, joined by the officers of the Agricultural Refinance Corporation, the Command Area Authority Commissioner, the Managing Director of the RLDC, and the like The purpose of the RLDC would be to act as a financial intermediary for the on-farm development that would be largely financed by credit to the farmers The RLDC would have an authorized shared capital of 100 million rupees The Government of India would subsidize certain categories of disadvantaged farmers, including *marginal* farmers (owning less than 1 hectare) at a subsidy rate of 33% of the costs of development, and *small* farmers (owning less than 2 hectares) at a subsidy rate of 25% For farmers who have excessive land-shaping costs and for farmers whose land has been seriously damaged by salinity, the subsidy would equal those costs determined to be beyond the farmers' capacity to pay Other categories of farmers would also be eligible for special loans from the RLDC

Thus, the Rajasthan Canal and Chambal projects in Rajasthan are two projects where the soil survey has paved the way for data evaluation for specific agricultural planning and has led to both institutional and financing changes

The projects are now under execution, assisted by a World Bank loan Their activities are summarized as follows (1) land development including reclamation, (2) lining of the irrigation system, (3) afforestation, (4) road construction, (5) domestic water supply, (6) use of fertilizers, and (7) other project components such as agricultural support services

Total project costs are estimated at 174 0 million U S dollars, and the foreign exchange component is 27% of the total project cost, based on the December 1973 price level, which includes a sharp increase in fuel cost

The result of the above project tasks has been to focus the attention of the governments of India and Rajasthan on measures to ensure prompt and full utilization of the created irrigation potential These measures, identified by a Committee of State Ministers

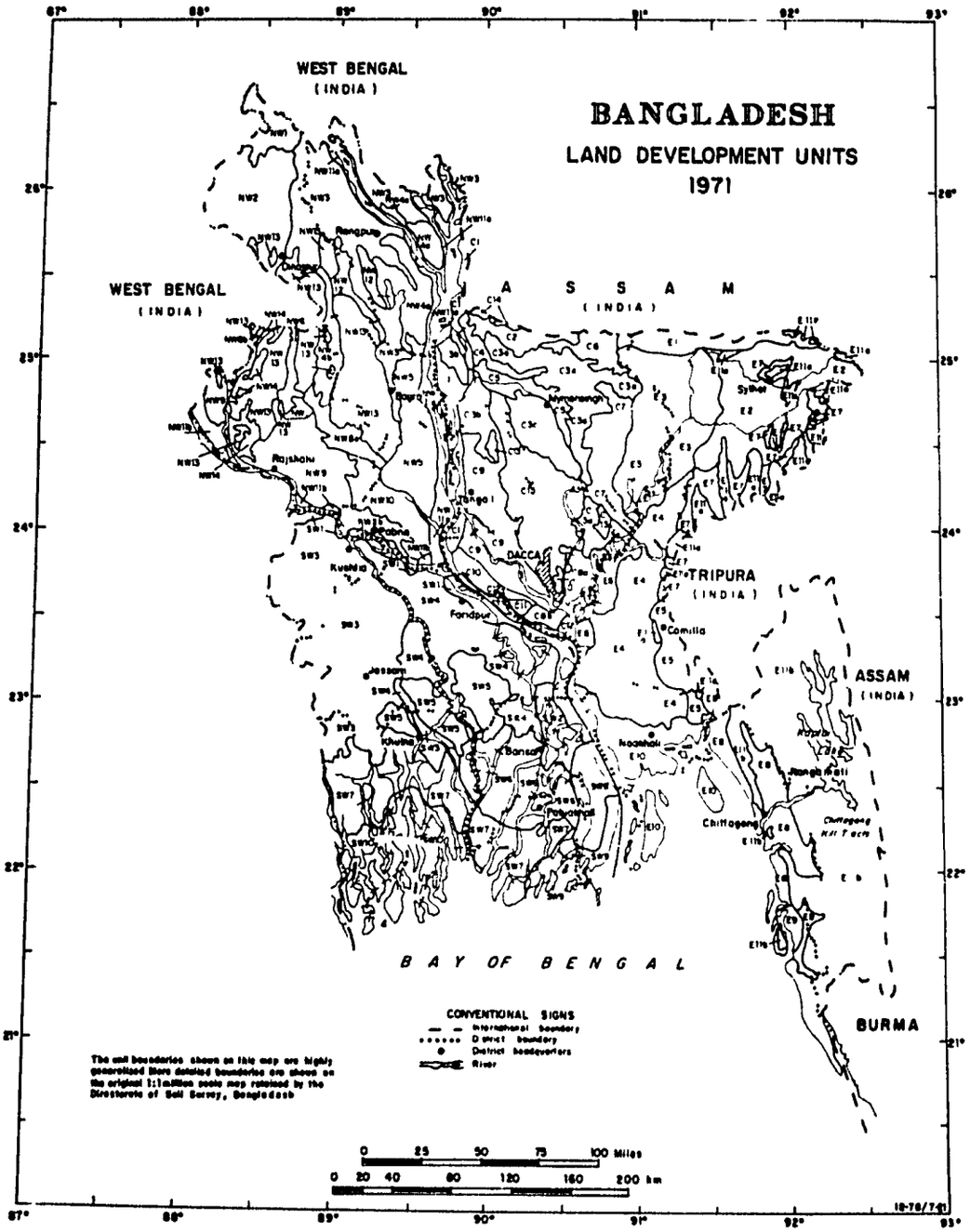

Fig 2 Land development units in Bangladesh, 1971

of Irrigation, are summarized below in the form of problems and suggestions:

1 Construction of field channels is not keeping pace with water availability
2 Inadequate drainage facilities hamper development of irrigation
3 Land preparation for irrigated agriculture, for example, land-leveling and land-shaping, is being neglected
4 Consolidation of landholdings in the command area is required
5 Anticipated crop patterns and water allowances under the project are not being realized
6 Adequate agricultural experimental and demonstration farms and training and extension facilities are lacking
7 Distribution of available supplies is poor and there are problems of cultivators at the tail end of the canal
8 Inputs and infrastructure facilities are lacking
9 Operation and maintenance of irrigation and drainage systems are often neglected
10 A development period of 3 to 5 years after the creation of irrigation facilities is recommended for full utilization of the irrigation potential
11 The Command Area Development Authority (which was established in 1974), as a high-power authority, must be vested with the power to initiate and carry out work, especially in a project that has a command area of 100,000 hectares

The above measures have been initiated but need more trained manpower, investment, support, efficiency, and drive to achieve multiple cropping through the command-area development, as an important part of agricultural development on a regional and national basis in India

The Case in Bangladesh

Bangladesh is situated in a deltaic plain of 13 million hectares, of which approximately two-thirds are cultivated, most of the soils being fertile The average annual rainfall is 2,200 mm, of which 80% falls in the monsoon months from June to October Floods occur commonly in the low-lying areas

Agriculture dominates the economy of Bangladesh it employs 80% of the population, generates 60% of the gross domestic product, and accounts for about 90% of the country's exports, the major export crop being jute The major industries of the country are also agriculture-based The production of food grains, mainly rice, which accounts for 82% of the production of all major crops in the country, is presently insufficient to feed the population of about 80 million

The soil survey and classification of the country have been completed also under the Soil Survey Project jointly assisted by the FAO and UNDP Data collected so far are summarized in five maps, entitled (1) Soils Map of Bangladesh, (2) Land-Use Map of Bangladesh, (3) Land-Capability Map of Bangladesh, (4) Land-Development Units of Bangladesh, and (5) Land in Bangladesh Suitable for Boro and Transplanted Aus Paddy

These maps, especially no 4 (Figure 2), indicate that about 50% of the cultivated area is generally unsuitable for intensive cultivation all year round This area includes about 800,000 hectares of low-lying land, which are flooded to a depth of 4 to 5 meters from June to October and can therefore be cultivated only when the floods subside in November, another 2 5 million hectares of cultivated land, which are flooded annually to a depth of 1 to 4 meters and which are used for floating rice, which occupies the land for 9 months from April to December, and another 1.2 million hectares in the coastal area, which are inundated with salty water and which can sustain only one rice crop in the main rainy season from June to October.

In the dry months, from November to March, there is not enough moisture in the soils in about 80% of the cultivated area;

hence irrigation is essential if multiple cropping is to be practiced Irrigation is being provided therefore through deep tubewells, shallow tubewells, and low-lift pumps; they are being given priority by the Government There are also abnormal floods and droughts and threats of cyclones from the Bay of Bengal, all of which impede agricultural development considerably

The use of the major soils of the area for crop production is very much governed by their nature and their location in respect to the flood level Crop diversification is also being practiced, and animal husbandry, forestry, and fisheries are included in the agricultural development programs

There are large bodies of water in Bangladesh—lakes, rivers, small and big ponds—which are often covered by water hyacinth and other aquatic weeds that do not permit the efficient use of these water bodies for fish culture

The soil-survey information and soils data collected in Bangladesh make it possible not only to identify the various types of land use that can be planned and programmed, but also to contribute vitally to the agricultural development planning and programming for the whole of Bangladesh This agricultural development planning will include not only multiple cropping in the cultivated areas but also pasture development in noncultivated areas and forestry and fisheries development

Many agencies are involved in the agricultural development process the Ministry of Agriculture, the Ministry of Food, the Ministry of Flood Control and Water Development, the Ministry of Rural Affairs, and the Planning Commission, which is the coordinating ministry, and the President's Secretariat, which plays a major role in program approval Because of the overlapping of responsibilities amongst these multiple governmental bodies, the practical effects and results achieved are slowed down The second impediment adversely influencing effective application is the lack of supporting capital required for (1) major flood-control structures, a good number of which are to be built outside the country, namely, in India, and (2) low-lift pumps for the second and third crops in the dry zones, and the hoped-for development of appropriate technology in the use of solar pumps The third hindrance to effective program application is lack of trained manpower

The Dynamics of Development and Interaction of Factors

Agricultural Development Planning: Basis for Decisions

Decisions are made normally on the following bases (1) allocation of resources to agriculture versus nonagriculture, (2) allocation to various inputs and institutions in the field of agriculture, (3) allocation among crops and regions both of which depend on soils, water, and people, and (4) optimal allocation demanding concentration of inputs in the more responsive situations (the optimal allocation formula is often changed for political or social reasons)

Variability in Agriculture

Variability in agriculture is caused by (1) physical conditions, including soils, water, and other natural resources, (2) cultural factors, (3) institutional variation, (4) economic variability, including price of inputs and outputs, and (5) geographic variability

Major Soils-Data Policies in Planning and Development

Soils-data policies should be such that their scope and functions include the following (1) an efficient organization for carrying out soil surveys and soil and land classification, including a land-evaluation system, (2) acceptance and utilization by the planning authorities of the soil and land data base for development, (3) the right to refuse sanctioning a project and providing investment and capital when there is no data base, (4) the consideration of enacting legislation if soil and land resources are endangered, such as a soil conservation act, or soil salinity or

alkalinity removal, or a land reclamation act, and consideration of establishing means and measures to enforce such acts, and (5) an integrated approach through development of physical and human resources

Significant Factors Influencing Effective Application

Sociopolitical factors

Although sociopolitical factors are not the primary subject of this paper, the process of agricultural development and its dynamics cannot be evaluated properly without reference to social and even to political factors For example, as more soils data and agricultural development data of the People's Republic of China become available, some important matters are coming to light, especially about communes and land productivity in the People's Republic of China Great emphasis is being given to development of areas of really good soils, but at the same time, it is being established that there are no really bad soils, because all soils can be improved by human and common efforts The People's Republic of China mentions eight agrotechnical regimes or measures as being essential for improving its agricultural yield and productivity (1) extensive irrigation construction and water conservation, (2) extensive utilization of fertilizers and organic manure, (3) reworking and improvement of soils including an increase in depth of plowing, (4) more dense sowing of crops, (5) use of improved varieties of seeds, (6) plant protection against damage and diseases, (7) improvement of agricultural equipment, and (8) care for all plants

Soils information is being used in the overall agricultural development programs, but great decentralization is achieved through the commune system Average yields of crops have risen considerably, and people's participation is the theme of the large action programs indicated in the eight points above

Participation of people

People's participation is illustrated by several programs in the People's Republic of China, such as the Red Flag Canal, 120 km long and built in 80 days by 1 2 million people, and the Yellow River Flood Control Project Some community development projects in India, Pakistan, and Bangladesh are also indicative of people's participation, but more education, training, and extension are required in these countries when compared with those of the People's Republic of China The monsoon lands of Asia have large populations that can be a great resource if properly utilized

Investment possibilities

Investment possibilities are provided by internal or external funding, including international or regional banks, bilateral agencies, and donor countries, which have sometimes formed a consortium for development aid

Legislation

The many problems raised by the requirements for optimum management of natural resources necessitate ever greater attention from governments and international organizations Concern stems from various causes, principally from the fact that some natural resources are limited quantitatively and qualitatively But, because of technological progress, there are increasing opportunities for these limited resources to be exploited There is a growing awareness of their interdependency and of the need to adopt an interdisciplinary approach in their regard This problem is further deepened by population growth, leading, on the one hand, to increased demand for resources and, on the other, to concern for the protection of environment

The time has come for the entire complex of natural resources to be treated as a common and integrated whole and as a constituent element, along with others, of the human environment Such a unified approach applies not only to the management of resources but also to the relevant legislation and to the organization of those institutions whose task it should be to administer them

In this connection, the FAO Legislative Study No. 9, *A Legal and Institutional Framework for Natural Resources Management* (Cano, 1975), is relevant Special reference is made to this work because soils are an important—together with water probably the most important—natural resource mankind has at its disposal

Review of FAO Policies in Using Soils Data

Land Evaluation

Since 1970, the FAO Soils Service (AGLS) has given increasing priority to the development of a Framework of Land Evaluation, which would be widely acceptable to survey and evaluation organizations and meet the needs of the widest range of possible users (*Land evaluation* as defined by the FAO is "the process of collating and interpreting basic inventories of soil vegetation, climate and other aspects of land in order to identify and make a comparison of promising land use alternatives, in terms applicable to the objectives of the evaluation") Preparatory work was undertaken in 1971 and 1972 by two multidisciplinary committees, one in the Netherlands and one within the FAO These activities resulted in the joint preparation of a background document (FAO/UNDP, 1972), which formed the basis for an international consultation on the subject, held at the International Agricultural Center, Wageningen, October 1972, and attended by 44 internationally recognized resource appraisal experts from 22 countries Papers describing various land classification systems used throughout the world formed part of the background document and were published by the FAO (1974*a*)

A summary of the discussions of the consultation and the recommendations agreed upon was published by the ILRI (1973). General agreement was reached on most of the questions discussed, and a major step forward was taken when a Framework for Land Evaluation was devised, into which national systems could fit. This Framework was later published by the FAO (1974*a*) and given wide distribution, with a request for comment Comments received were considered at a small ad hoc expert consultation in Rome, 10 major subject areas for improvement were identified, and an account of the proceedings was published by the FAO (FAO/UNDP 1975) A revised Framework is to be produced incorporating changes agreed upon at the consultation The concepts and development of the framework were the subject of the Tenth Session of the ECA Working Party on Soil Classification and Survey held in Czechoslovakia in September 1975

In essence, the Framework recommends qualitative or quantitative classification of land for well-defined utilization types, under unimproved and improved conditions, by suitability orders, classes, subclasses, and units A single-stage (physical and socioeconomic studies combined) approach or a two-stage (physical studies followed by socioeconomic studies) approach is allowed for, as appropriate to the requirements of a particular evaluation The latter point is the essence of the Framework, which, as its name implies, is intended to provide merely an outline of principles and terminology within which local systems of land evaluation may be formulated

At first sight, the concepts proposed do not seem unprecedented, but in practice they call for considerable change in traditional resource-interpretation thinking A multidisciplinary approach is required that uses a physical basis, in a social and economic context, for comparing land suitability Basic to this approach is the concept that land evaluation is meaningful only in relation to a clearly defined use

The Framework is rapidly gaining international acceptance and is already being used by several countries and in many projects

Future activities of AGLS involve further refinement of the Framework through expert consultations (Rome, 1976) and promotion of its international use through regional seminars and conferences on land evaluation

(Asia and the Far East, 1976, in cooperation with ESCAP and UNEP, Africa, 1976)

Country Perspective Studies

A perspective study of the agricultural development for Pakistan was prepared (FAO, 1974*b*) This study was launched primarily because of the increasingly felt need for the country's focus on agriculture The Country Perspective Studies (CPS) supply an analysis not only of major development objectives but also of mobilization of resources, income distribution, unemployment, foreign exchange earnings, and modernization of agriculture The core of the CPS relates to the exploration of alternative agricultural development strategies within the broad framework of the total economy and its overall development alternatives, in the context of a time horizon extending to the period from 1985 to 1990 The Country Perspective Studies are essentially economic studies, but they also take into consideration the physical base of the resources, including land and water Similar studies have been made for regions in Indonesia, Nepal, Malaysia, and Bangladesh

Agricultural Development Programming

Programming missions have been launched for Nepal and Pakistan and are being established for Indonesia and Bangladesh The purpose of these programming missions is to assist the national governments in the preparation of development programs, to identify areas for project development, and, where required, to assist in identifying technical assistance requirements in the food, agricultural, and rural sectors The missions focus their attention on the improvement of living standards and public services, equity of income distribution, generation of productive employment, regional development and integration, self-sufficiency, import substitution, and strengthening of the economic structure

Assistance in Execution

Assistance is being given to developing countries by the FAO under what is termed its Regular Program through field programs, which are financed mainly by the United Nations Development Program, through the Freedom from Hunger Campaign Action for Development, and through the so-called Government Cooperative Program, where the assistance is financed by donor governments and executed by the FAO (many Scandinavian countries are providing aid in this way, under programs such as the FAO/SIDA and the FAO/DANIDA) Some countries provide "Funds-in-Trust" to the FAO for the execution of projects, which are sometimes financed fully by these governments and sometimes on a cost-sharing basis between the government and the FAO/UNDP The FAO also plays a role in identifying projects and in analyzing or proposing them for investment by the World Bank and, probably in the future, by the International Fund for Agricultural Development

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Agricultural Land Utilization and Land Quality

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The quality of land determines both its present and its potential use under improved crop, soil, and water management This relationship can be expressed in a graphic model in which the relative proportion of land in use at a given time for a specific land-utilization type is shown on one axis and the quality of land in use is shown on the other Four land categories of decreasing suitability for the specific purpose are delineated in the model

A high proportion of category-I land is always in use As limitations to use increase and land quality decreases, the proportion of land in use decreases, although in areas of high population pressures, even unsuited land is used to some extent Only category-I and part of category-II lands give returns to the use of recurrent inputs, but the quality of land can be improved to increase productivity

Basic land ameliorations, such as irrigation development or land reclamation, increase land quality, but not always to a sufficient extent to ensure returns to recurrent inputs and to capital costs Such partial improvements can lead to disastrous consequences when other circumstances, such as a drought, expose other severe defects in land quality The recent failures in the Sahel zone are ascribed to partial amelioration, which appeared to, but did not, in fact, lead to sufficient improvement in land quality to support intensive grazing

Basic plant amelioration also increases land quality when crops are made less susceptible to existing land limitations The earliest work of the International Agricultural Research Centers benefited farmers on category-I and II lands, but attention is now being given to crop improvements that will cause improvements in quality for category-III and IV lands

Improper land use can lead to a decrease in land quality In severe cases, good land may become entirely unsuitable and "leave the model" Modern mechanized agriculture can aggravate this trend

The relationship between agricultural production and physical environment both in its natural condition and as influenced by mankind is well documented The relationship has been studied by a range of disciplines soil science, plant science, geography, economy, sociology, and others Recently, much emphasis has been given to the increase of crop production, more in particular to food crops in the so-called developing world From the point of view of plant-related disciplines, the most important progress has been made by the genetic manipulation of major food crops, leading to a *green revolution* in various areas of the tropical and subtropical zone Relating crop production to important attributes of the environment in which those crops are grown has been and is the subject of international discussions, stimulated to a large extent by the FAO and the University of Wageningen (Brinkman and Smyth, 1973) The main pur-

pose of the discussions by Brinkman and Smyth is to find a sound basis for the evaluation of land to introduce improved crop-production methods.

This paper is intended to indicate how the quality of land determines its present use and its potential use under improved management of crop, soil, and water The term *land* is used here to mean a specific area of the earth's surface, the characteristics of which embrace all reasonably stable or predictable cyclic attributes related to the atmosphere, soil, topography and hydrology, plant and animal population, and results of human activity (adapted from Christian and Steward, 1968)

The Model

The relationship between land in use for a specific agricultural purpose and the quality of that land is represented in a qualitative model (Figure 1) The quantitative expression of the model will vary much with the crop or crop combination considered and according to the area in which the model is applied The present model is inspired mainly by my experience with land on which rice is the main land-utilization type, either as a single crop or in combination with other crops The model can, however, serve as a general model for most agricultural land-utilization types, and it will apply in virtually all parts of the globe where crops are grown

On the *Y* axis is indicated the relative surface of land in use at a given time for a specific crop, or for a specified crop combination, or for a cropping system It is important to note that only land in actual use is considered Thus, land of excellent quality for rice-growing but not used for that purpose now will not enter the model until this land is actually developed and cultivated for rice or for

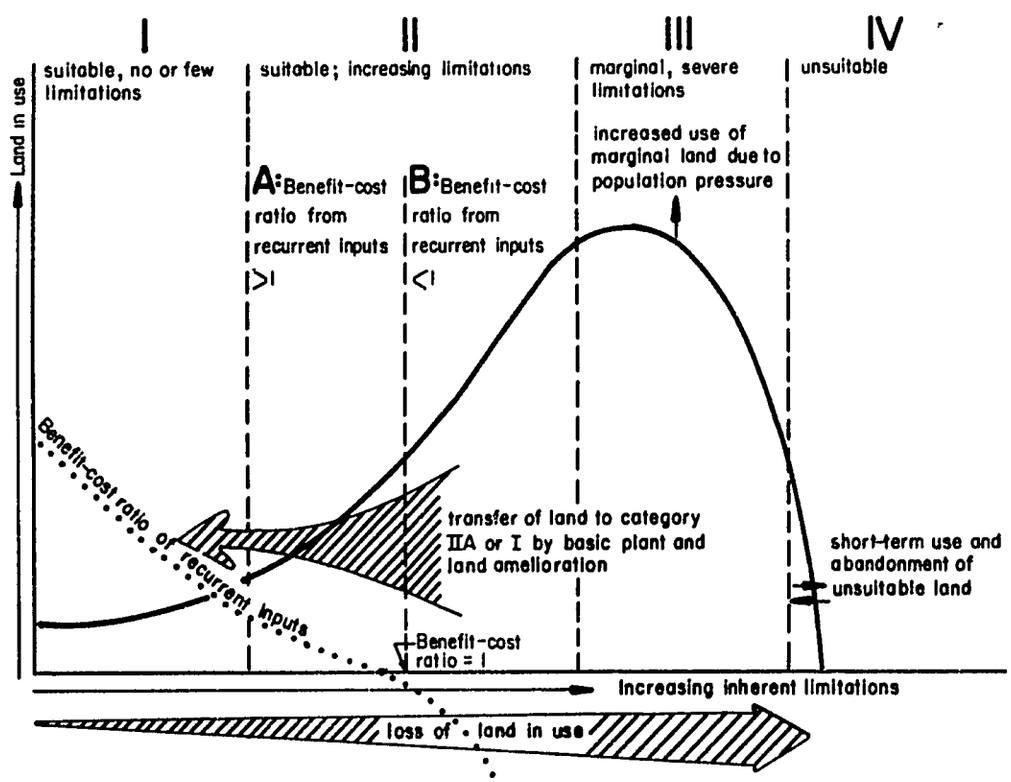

Fig 1 Qualitative model showing relationship between land in use for a specific agricultural purpose and land quality.

a crop combination that includes rice

On the X axis is indicated the quality of land for the specified use, as determined by environmental factors that limit productivity (soil, topography, hydrology, climate, etc) In the model, land quality decreases from left to right, but inherent limitations increase Although only limitations imposed by the physical environment are considered in some detail in this paper, it is clear that socioeconomic parameters that limit productivity could and should also be integrated in this type of study Four major suitability categories are introduced in the model, which are at present arbitrarily chosen but which can be based on existing systems of land-suitability classification

Category I stands for land of excellent inherent quality without productivity limitations or with only such limitations that can be corrected easily and economically

Category II is for land suitable for the specific land utilization under consideration, but whose limitations are increasingly severe and thus are more costly to correct

Category III is for marginal land of which the returns under any form of management are barely sufficient to cover input costs, in many cases, the returns are insufficient On marginal land, for instance, a severe drought in the growing season will lead to failure of the crop or crops under consideration

Category IV is for land unsuitable for the specified land-utilization type Such land, because of population pressure or poor technical planning, may be developed for a specific land-utilization type As indicated in the model, it will be abandoned again very rapidly if the crop fails through inherent limitations or through rapid land deterioration that reduces productivity after a short period of use

For most land-utilization types that include food-crop production as a major use, the form of the function would be comparable with the one given in the graph (Figure 1) if larger land surfaces are considered The function in Figure 1 is believed to be representative of rice-growing lands in the tropics and the subtropics

Categories I and IV are restricted in extent for reasons already mentioned The majority of the land in the tropical and subtropical regions falls in the intermediate categories Evaluation of these regions by using the available data on land and agricultural use ma' es it clear that most actual and potential category-I land for any agricultural purpose is already in use, certainly in Asia where it forms the backbone of agricultural production

So far, restricted areas of the potential category-I land remain unused or underused in other continents Examples of such potential category-I land are lands whose soils derive from basalt in Papua New Guinea and in Eastern Zaire 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 much unused because of a lack of adequate rice-growing technology For certain crops, especially tree crops, there is still a vast potential in the tropics, though such lands would fall in a lower category if they were to be used for producing annual food crops

The larger portion of the potential category-II land in the tropical and subtropical regions is also in actual use Where there is a high and increasing population density, much marginal land is being utilized and this use is increasing, as indicated in the model Such a situation has developed in large parts of South and Southeast Asia, but it occurs also in pockets in the other continents Overutilization for grazing, for instance, has developed in parts of the Sahel zone in Africa The restraints imposed by climate on this category-III land have inevitably led to a catastrophe when during a series of dry years, the carrying capacity of the marginal range land has dropped dramatically

The trend now in tropical and subtropical agriculture to increase agricultural production by improved technology has been considered in the model Such improved technology requires recurrent purchased inputs not only for improved seeds, fertilizers, and pest and disease controls but also for labor and mechanization, as well as amortization of nonrecurrent capital inputs The benefit-cost ratio of such inputs will be well over 1 in

the category-I land, but may be expected to drop below 1 in the lower-category lands if the whole package of inputs is considered. Therefore, the category-II land has been arbitrarily subdivided into two a subcategory IIA, where the benefit-cost ratio for recurrent inputs, required for improved agriculture, is greater than 1, and a subcategory IIB, where this ratio drops below 1 This benefit-cost line is, of course, variable depending on the kind and cost of the recurrent inputs, hence, it is subject to change with time For instance, the present higher prices for fertilizers and petrochemical products will tend to displace the benefit-cost ratio line to the left As a consequence, much land where fertilizers could be used profitably for a specific crop or a crop combination now falls in category IIB Subsidies on recurrent inputs will tend to move the benefit-cost ratio line to the right, as will higher returns from the agricultural produce

Judicious application of recurrent inputs will increase the productivity of land where such inputs are economically viable, with or without little capital investment Another approach to increasing productivity is the transfer of land from a lower to a higher category where recurrent inputs would be economic

Modifying Land Quality

Basic Land Amelioration

Improving the land is the first and most obvious step to increasing productivity, it is applied globally, for example, in irrigation- and land-reclamation projects The great danger in this approach is that the basic land amelioration will not transfer the land to either category I or even to subcategory IIA

It should be borne in mind that the recurrent costs in such projects will increase sharply if the capital inputs required for basic land amelioration have to be amortized In projects where amelioration costs are considered *a fonds perdu,* the farmer will not be burdened by this particular increase in recurrent costs and his land will be more easily transferred to an economically remunerative category.

There are examples of such developments, wherein the capital inputs need not or need only partly be amortized A most striking example in modern times is the irrigation development in the Negev desert in Israel, drawing water from the Jordan River, where the initial investment was made without regard to amortization of the capital costs for development Unfortunately, such examples are few More numerous are the extremely expensive development projects that failed because inherent limitations remained so severe that the sharply increased recurrent costs were not compensated by the improved productivity of the land

There is a general tendency to explain such total or partial failures in terms of socioeconomic constraints lack of the farmer's technological know-how, lack of a sound infrastructure in the project area, lack of a credit structure, lack of marketing facilities, etc It is my contention, however, that in most cases where basic land amelioration created category-I land for the chosen land-utilization type or types, the project was successful irrespective of the socioeconomic and technological difficulties encountered in the beginning One of the most successful projects in the tropical and subtropical areas was and is the Gezirah project in the Sudan, where a large surface of category-I land was created for land-utilization types including, among others, irrigated cotton It should be pointed out that this project became a success against tremendous socioeconomic odds, including the fact that the majority of the farming population of the area consisted of nomadic or seminomadic livestock producers

A recent issue of *Science* has a reference to a recent example of a project failure where an investment in category-III land did not result in the transfer of this land to a more remunerative category The provision of water supply to nomadic herds in the West African Sahel zone did not diminish in any way the inherent limitations of the land for grazing On the contrary, as was pointed out, the solution to only one of several problems

of this land resulted in increased pressure for land by the animal population, which proved fatal when the rains failed for several consecutive years.

Basic Plant Amelioration

Crops, and certainly the annual food crops, produce well only in a well-defined range of land conditions Beyond this range, constraints on productivity are such that common recurrent inputs such as fertilizers are no longer remunerative, hence, production remains on a low subsistence-type level Much of the rice land in Asia can be cited as an example Because of inherent land limitations, such as salinity, acidity, or their combinations, the "package deals" of the *green revolution,* which include improved seed, better plant nutrition, and improved production and cultural practices, do not work on this land One inherent limitation can cause the increased inputs to be uneconomic since the land remains in the same category IIB or III of the model When, however, crop varieties less susceptible to the existing limitations are selected or bred, the land for which such varieties are developed will move towards a better category in the model This idea of breeding varieties to suit specific problem soils, at least for the tropics, was formulated by the International Rice Research Institute (IRRI)

Up to now, breeding work, both in other international institutes and in national breeding programs in the developing world, has benefited mainly the farmers on category-I and category-IIA lands Even so, varieties of a number of crops better adapted to lower land categories have been developed almost unwittingly, this is because breeders are not as conversant with productivity-limiting factors as they should be The IRRI approach is a promising possibility for improved production of a number of food crops, especially if such an approach is combined with judicious basic land amelioration

Improper Land Use

The last element of the model to be discussed is the effect of improper land use Deterioration of land by man-induced erosion, salinization, acidification, and other causes is all too well known and has assumed truly catastrophic proportions in many project areas The progressive salinization of millions of hectares of the category-I irrigated land in the lower Indus basin is an example Such land rapidly loses its category-I status and is abandoned when salinization becomes severe, thus "leaving the model" altogether

Land deterioration by erosion in tropical areas is very severe globally and is frequently aggravated by the introduction of modern mechanized agriculture Much category-II land, and even more category-III land in the tropics, is rapidly losing most of its inherent qualities as a result and is becoming unsuitable for any of the major current land-utilization types

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PART V:
USE OF SOIL-RESOURCE DATA IN TRANSFERRING AGRICULTURAL TECHNOLOGY

Need for an International Research and Technology Transfer Network in Tropical Soils

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The *green revolution* has stimulated a growing number of international transfer networks of agricultural research and technology Among the best known are those for wheat, maize, and rice that find their anchor in the international agricultural research centers of CIMMYT and IRRI The nine centers now under the aegis of the CGIAR, while largely crop- or livestock-centered, have interdisciplinary teams, and several have substantive research programs in soils of the tropics

There is no single center of the CGIAR-supported type exclusively focused on soils of the tropics Nonetheless, there is a widely recognized need for increased research on tropical soils to develop the technology required for increased production of food in the countries of the tropics Some mechanism is needed to promote linkages (1) between soil scientists in the countries of the tropics, (2) between these soil scientists and concerned institutions in the temperate zones, and (3) between these scientists and institutions and the international centers already established Because of the great range in soils of the tropics, reservation is expressed as to whether an IRRI- or CIMMYT-type center is called for to form the nerve center of an international network

An analysis of successful international networks in agricultural research and technology transfer indicates that there are at least three requirements for success assumption of regional or international responsibility for networking by one or more participating institutions, commitment of financial support to these institutions for the networking activity, and willingness of concerned scientists in the network to participate effectively

Before visiting the tropics in the early 1950s, I had a very simplistic impression of the soil and vegetation in that part of the world The word *tropics* itself conjured up visions of lush tropical rainforests growing on highly leached, red, infertile soils This seemingly incongruous combination of vegetation and soil undoubtedly contributed to the feeling that soils of the tropics were mysterious and poorly understood

In 1952, after completing my academic studies and being ready to start a career as a soil scientist, I left the temperate climate of my country (United States) for work in Colombia, South America Certainly Colombia is in the tropics, but somehow I was not prepared for the great range in climate, vegetation, and soils there To be sure, there were the red, highly leached, infertile soils of the Llanos Orientales, but there were also the dark, neutral, and highly fertile soils of the Cauca Valley There was a host of other kinds also Through the experience of 7 years in Colombia, I learned that the variation in soils of the tropics is as great as that in those of the temperate zones

My experience in Colombia was followed by 12 years of corresponding work in India, where I served as a member of a team in a cooperative agricultural research program I was a soil scientist, or perhaps more correctly, an agronomist in a cooperative program whose focus was on the important food crops in the countries of concern to the program Also while in India, I had the good fortune of being involved in the now widely known All-India Coordinated Crop Improvement Projects, which involve national research networks built around individual major crops One, among many, is the All-India Coordinated Wheat Improvement Project This links wheat workers in each concerned state into an effective network of collaborative research, which, in turn and importantly, is linked to an international network on wheat, with the International Center for the Improvement of Maize and Wheat (CIMMYT) in Mexico as its focal point

Thus as soil scientists concerned with soils of the tropics and subtropics, my Colombian and Indian colleagues and I were working in support of these crop-oriented research networks, but we did not have the feeling of there being a comparable national or international research network on soils of the tropics

The purpose of my paper is to look at the growth of international research networks, particularly in relation to the roles of soil scientists and agronomists, and to examine the need for and feasibility of one or more international research and technology transfer networks focusing on tropical soils

Growth of International Agricultural Research Networks

Since I was in India during the *wheat revolution,* it seems appropriate to start by referring again to the international wheat research network that has developed within the last decade High-yielding varieties of semidwarf wheats developed in Mexico were introduced to India in the mid-1960s. Through the link with Mexico and CIMMYT, India rapidly embarked on a technology transfer and research program that facilitated a veritable wheat revolution. National production was doubled within 5 to 7 years (from around 12 million to about 25 million tons), an unprecedented increase in such a short time

The linkages in wheat research between CIMMYT and India are part of what is now a worldwide network of research and technology transfer The overall goal is to develop the technology needed to permit participating countries to meet their production targets of wheat In a real sense, wheat scientists, especially those working on the spring bread wheats, are linked in a worldwide cooperative effort

The CIMMYT-centered international wheat research network has its counterparts in maize and rice The maize network has its hub at CIMMYT, while that for rice is at the International Research Rice Institute (IRRI) Results from these two centers, primarily in the form of widely adapted, high-yielding varieties of wheat and rice, led to the *green revolution* and gave great impetus to the feasibility and utility of worldwide research networks focused on important food crops of the tropics and subtropics

Before going further, it is important to make clear that plant breeders are not the only people involved in the maize, rice, and wheat networks The *green revolution* technology was the product of scientists from several disciplines working cooperatively—among them, soil scientists, pathologists, entomologists, and agricultural economists, whose work was as important as that of the plant breeders (although the terminology of the resulting crop-oriented research networks tends to gloss over this important point)

The simple diagram in Figure 1 shows the structure of the international research networks centered around CIMMYT and IRRI. To keep before us the real customer of any new production-oriented technology, the farmer has been given pride of place at the top of the figure Unless our research has some meaning for him, we need to take another look at what we are doing. And, to avoid too great a simplification, the block

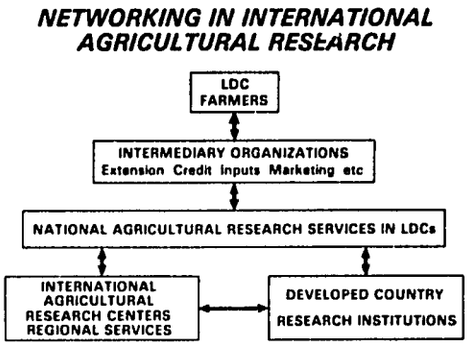

Fig 1 Networking in international agricultural research at CIMMYT and IRRI

immediately under the farmer recognizes the in-country organizations and services that determine if and how the farmer utilizes new technology Here we are dealing with such important matters as extension, production inputs, credit, and marketing

The three major institutional components of an international agricultural research network are shown at the bottom of Figure 1 First and foremost is the concerned agricultural research organization or system in a country that needs the technology to increase production Correspondingly, there are institutions in the more developed countries that are working on problems highly relevant to the technology needs of countries seeking them Then, to complete the trio, there are the international centers and related international or regional institutions or services

Several important points should be noted here

1 The farmer must be kept in mind—the nature of the research we do must be one that responds to his needs
2 The research system in the country desiring the technology is a critical consideration That is, inputs from research institutes outside the country or from international centers must flow to and through the national systems (As a corollary, strong national research systems are needed to fully take advantage of participation in international research networks India and Pakistan could not have so effectively capitalized on the *green revolution* technology for wheat and rice without their relatively strong national research systems)
3 International centers and related organizations do not stand alone To be effective, they must develop effective ties with client countries, on the one hand, and with research institutions in the more technologically advanced countries, on the other (In the latter, it is in part a matter of technical backstopping for research that the center is not able to handle)
4 Institutions (scientists) from the more technologically advanced countries do play an important role in international research networks
5 The flow of information and materials can and should be in both directions An ideal network is one that has a high level of mutuality of interest and benefit

Having CIMMYT as the nucleus, the international wheat network has ties with virtually all of the countries where spring bread wheats are important It also has important links to wheat research institutions in the temperate zone that are doing relevant work For example, CIMMYT collaborates closely with the following Oregon State University in a program of crossing wheats of the winter and spring types, the University of Nebraska, which concentrates on improving the quality of the grain, Kansas State University, in making wide genetic crosses involving wheat, and the University of Winnepeg in Canada, for backstopping in its triticale research program

In addition to CIMMYT and IRRI, there are seven international centers under the aegis of the Consultative Group on International Agricultural Research (CGIAR) Table 1 lists them and information about their major research areas All of these centers are oriented basically toward crops or major food sources However, increasingly, more of them are placing emphasis on farm-

Table 1 International centers and related activities sponsored by the Consultative Group on International Agricultural Research (CGIAR)

Center	Location	Research	Date of initiation
IRRI (International Rice Research Institute)	Los Banos, Philippines	Rice under irrigation, multiple cropping systems; upland rice	1959
CIMMYT (International Center for the Improvement of Maize and Wheat)	El Batan, Mexico	Wheat (also triticale, barley), maize and cold tolerant sorghum	1964
IITA (International Institute for Tropical Agriculture)	Ibadan, Nigeria	Farming systems, cereals (rice and maize as regional relay stations for IRRI and CIMMYT), grain legume (cowpeas, soybeans, lima beans, pigeon peas), root and tuber crops (cassava, sweet potatoes, yams)	1965
CIAT (International Center for Tropical Agriculture)	Palmira, Colombia	Beef, cassava, field beans, farming systems, swine (minor), maize and rice (regional relay stations to CIMMYT and IRRI)	1968
WARDA (West African Rice Development Association)	Monrovia, Liberia	Regional cooperative effort in adaptive rice research among 13 nations with IITA and IRRI support	1971
CIP (International Potato Center)	Lima, Peru	Potatoes (for both tropics and temperate regions)	1972
ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)	Hyderabad, India	Sorghum, pearl millet, pigeon peas, chickpeas, farming systems, groundnuts	1972

IBPGR (International Board for Plant Genetic Resources)	FAO, Rome, Italy	Conservation and utilization of plant genetic material with special reference to cereals	1973
ILRAD (International Laboratory for Research on Animal Diseases)	Nairobi, Kenya	Trypanosomiasis, theileriasis (mainly East Coast Fever)	1974
ILCA (International Livestock Center for Africa)	Addis Ababa, Ethiopia	Livestock production systems	1974
ICARDA (International Center for Agricultural Research in Dry Areas)	Lebanon with major stations in Iran and Syria	Farming systems including livestock with a focus on barley, wheat, broadbeans, lentils, and sheep	1976

ing systems research, with particular reference to the small, poor farmer. The Consultative Group on International Agricultural Research also provides support for three related activities. (1) the West African Rice Development Association (WARDA) (support for part of the research program); (2) the International Board for Plant Genetic Resources (IBPGR), and (3) the Current Agricultural Research Information Service (CARIS) at FAO

All of the centers are notable for the interdisciplinary approach to the major research thrusts Thus those dealing with major food crops have one or more soil scientists on the staff Notably, the International Center for Tropical Agriculture (CIAT), the International Institute for Tropical Agriculture (IITA), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and IRRI have substantial programs in soils of the tropics But, in the sense of these centers, there is no international center for research on soils of the tropics Is there an international transfer network of research and technology covering this important area?

An International Research Network for Soils of the Tropics

The ability of countries in the tropics to produce the food needed will depend largely on more effective use of the soil resource base Although the amount of research about tropical soils has greatly increased within the last 20 years, the current effort must be concluded as being inadequate Technology suitable for the small farmers on the wide range of soils in the tropics is unavailable The suitability of technology must take into account such constraints as scarcity and high cost of chemical fertilizers and other soil amendments, availability of mechanical power for managing the soil, and lack of capital. It means little to a farmer under such constraints to be told that soil tests show that 10 tons of lime are required per hectare or that an application of 500 kilograms of P_2O_5 per hectare is required For him, this is not a

relevant or suitable technology

Suffice it to say that there is an increasing need for research on tropical soils oriented toward increased crop production And, for the same reasons that international networking makes sense for rice, wheat, and maize, there is need for international networking in research and technology transfer for soils of the tropics

The examples of worldwide networks cited above involved an IRRI or CIMMYT type center as the hub and an integral component Does this mean that to have an international network on soils of the tropics, an international center must be established first?

The Technical Advisory Committee (TAC) of the CGIAR has devoted much time to the so-called factor research that includes work on soils and water Thus far TAC has concluded that, within the context of the international center, factor research should be integrated into the commodity-oriented center, and that if research on soils of the tropics needs to be strengthened under the CGIAR, it should be done by strengthening such work at, say, CIAT, IITA, or ICRISAT This is fine as far as it goes, but it leaves unanswered the mechanism to develop a strong international network of scientists working on tropical soils

I do not believe an international center is the answer Because of the tremendous range of the soils in the tropics, to argue for an international center would be tantamount to arguing for one international center for tropical crops TAC once debated at length a proposal for an international center for food legumes, but because of the diversity of this rather circumscribed group of food crops and because of their geographic distribution in the tropics, it concluded that one center was not feasible I find it relevant to mention that international research networks will likely develop around major food legumes (e g , soybeans or field beans) or clusters of them that have similar characteristics and distribution in the tropics Does this suggest a corresponding approach for soils?

TAC and the CGIAR recognize that new international centers cannot be set up for each new crop or problem area that needs an international research focus for which therefore a need for an international research network is indicated Thus other mechanisms have been and are being explored

For the food legumes, it was agreed that, within the framework of the international center, certain centers would have an international responsibility for specific food legumes Thus ICRISAT has such a responsibility for chickpeas, pigeon peas, and groundnuts, CIAT for field beans, and IITA for cowpeas Could or should this approach be applied to soils of the tropics?

The International Board for Plant Genetic Resources (IBPGR) under the CGIAR is an interesting example of giving an international focus to an important problem in agriculture without setting up a research center of the conventional type Instead, the plant genetic resources network has an international board as its hub The IBPGR is not set up to do research, rather it is designed to assist in focusing attention on priority needs, to foster links between international and national plant germplasm centers, and to seek support for meeting identified needs Correspondingly, the budget of IBPGR is quite modest in comparison with that of, say, IRRI or ICRISAT Nonetheless, IBPGR is a mechanism that is beginning to play an effective role in the worldwide linking of scientists concerned with collection, preservation, and utilization of plant germplasm Does IBPGR suggest a mechanism for an improved international network on soils of the tropics?

The International Soybean Resource Base (INTSOY), headquartered at the University of Illinois, is another mechanism that is proving effective in developing international networking in soybean research Although Illinois is in the temperate zone, an integral part of INTSOY is an arm based in the subtropics at the University of Puerto Rico Of course, in many ways, INTSOY operates as if it were one of the international centers under the CGIAR Is there some strong focal point of research on soils of the tropics that could serve as a headquarters for an international network?

Finally, it may be useful to look at the approach that TAC has taken in considering a possible recommendation for international cooperation in aquaculture research There has been an agreement, apparently, that a conventional international center is not the appropriate mechanism to foster an international aquacultural research network What is needed perhaps is something like an international board that would look at the overall situation, identify gaps in on-going research, promote linkages among workers, and seek support to meet needs In essence, the mechanism might be somewhat like the one for plant genetic resources, namely, the IBPGR

Where from Here?

In view of the foregoing, what is reasonable in moving toward a more effective mechanism, or mechanisms, for an international research and technology transfer network in tropical soils? First, let us consider briefly what appear to be some of the important requirements

A review of the most successful international research networks in agriculture seems to point to at least three common requisites responsibility, financial support, and cooperation

If a transfer network of research and technology is to be effective, some person or persons must assume a regional or international responsibility to serve as a coordinating or nerve center of the network This center, which may be quite modest in size, has the role of fostering links between cooperating scientists It consciously and deliberately encourages interchange of ideas, information, materials, and even scientists themselves The center of the network per se does not require an integrated research program about soils of the tropics, although this would be a distinct advantage For example, in theory the center of such a network could be at FAO or the World Bank However, I believe we would agree that it would be more effective and more credible if it were in some institution that has a strong commitment to research on tropical soils

Next, a coordinating or nerve center requires financial support The job envisaged cannot be done on a continuing basis as an *extra* responsibility to a central responsibility or on a purely voluntary basis The crop-oriented international centers budget specifically for these networking activities such as exchange of information, materials, and scientists Thus if a network or several interrelated subnetworks on tropical soils are to be established and kept viable, there must be a financial commitment Clearly, the level of funding would depend on the nature and scope of the network under consideration

Third, for a successful international research and technology network on soils of the tropics, there must be a desire for it on the part of those who would be involved There must be a willingness to really participate I am assuming that this requirement would not be difficult to meet

Now, what would be the options in moving ahead on this tropical soils network? Is it reasonable to identify one institution—an existing one since it seems unreasonable to contemplate establishing a center exclusively dedicated to an international network of research and technology transfer in tropical soils—that could be the coordinating or nerve center of the network? Or do we envisage a network with a number of institutions serving as focal points? If the latter seems more attractive, what would be the rationale for determining the particular role of each focal-point institution?

Let me make clear that I do not have a preconceived detailed idea or plan for this network But assume that we conclude that a network with several focal-point institutions is most reasonable I can see several approaches to determining who does what to insure that these key coordinating institutes play complementary roles

One approach could be to have an institution play a coordinating role for a region For example, IITA or some institution in the high rainfall tropics of Africa could be the nerve center of the network for that specific geographic area

Or an institution might be selected that would have primary responsibility in the net-

work for developing linkages among cooperators working on similar soils For example, would it be appropriate to have a specific coordinating center concerned with the Oxisols? This approach through soil groupings —such as families—may offer an attractive option Certainly the current work along this approach by the University of Hawaii and the University of Puerto Rico suggests careful examination

Another possibility would be to apportion responsibilities to the coordinating institutions on the basis of the major subdisciplines within soil science Thus one institution in the network may have primary responsibility for fostering cooperation in soil fertility, another in soil microbiology, etc

My intent in attempting to identify the basic requirements for a network of tropical soils, and to discuss some of the options in realizing it, is to encourage serious discussion about the actual development of a network I am convinced it is highly desirable to have a more effective international research and technology network on tropical soils

Soil Survey, Soil Classification, and Agricultural Information Transfer

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There has been little formal transfer of agricultural information based on soil classification either within Australia or between Australia and other countries In both cases there are politically based impediments to information flow because of the diversity of organizations involved in soil survey and because of incompatibilities in data and classification However, a considerable amount of information transfer undoubtedly has occurred informally through the movements of soil scientists and agriculturalists

Analogous transfer, i e, transfer of information between two entities having a high degree of similarity, is dependent on classification This is true whether the entities be soils in the landscape or taxonomic abstractions More, not less, research will need to be done in soil taxonomy in the future to ensure that this transfer is not based on false premises

Classification also has a major role to play in site-specific methods of assessment of biological productivity because it enables the delineation of reasonably homogeneous areas or groups of soils within which current statistical models, mostly linear and additive, can be expected to be predictive

Computer assistance can now result in increased accuracy, easier manipulation of data, and lower costs in individual surveys But integration by computer of information from different surveys will remain virtually impossible until problems of data incompatibility and data-base incompatibility are overcome by interorganizational and international agreement

Multivariate techniques feasible only since the advent of computers are now available to assist the soil taxonomist The use of informal classifications on an ad hoc basis are probably worth exploring in the future, but this would also be dependent on data from different sources being compatible

I propose that greater use of soil classification and soil survey could improve the transfer of agricultural information. Perhaps *exchange* would be a better term because *transfer* tends to imply a one-way process Information flow should be thought of as a reversible reaction, to use a chemical analogy Information flow in agriculture is not always from developed to developing areas, for example, Australia is now taking an increasing interest in grain legumes and looks to countries such as India for information about them and their culture

The principles underlying such information transfer are probably the same whether we are considering a farm-to-farm or a country-to-country relationship The difference lies in implementation—as we move up

the scale, the complexity and number of possible impediments to flow increase.

Australian Background

In many ways Australia is a microcosm of the world as far as soil survey and its potential usefulness are concerned Australia is a large land mass, whose climates vary from temperate to tropical and whose soils are diverse Superimposed upon this is a federal political system, in which the states are largely responsible for those areas of economic activity most likely to benefit from soil surveys Although soil (and land) surveys have been conducted by many units within both the federal and state spheres, there has never been anything remotely resembling a unified national soil survey, such as that of the United States

History of Soil Survey in Australia

Prior to 1927, there was little in Australia that could be called soil survey (Taylor, 1970) As is so often the case in other parts of the world also, the first 100 to 150 years of agricultural and pastoral development in Australia were built on trial and error The "soil surveyors," or more precisely "land surveyors," were the farmers and graziers who settled the land, and in later years the surveyors of the Lands Departments of the states

The establishment of the CSIRO Division of Soils in 1926 saw the beginning of detailed soil surveys (based on the series concept) in southern Australia, initially in potential irrigation areas of the valley of the River Murray and extending later to rain-fed areas Surveys in this prewar period were largely the province of the Division of Soils, and as a result reasonably standardized classification and survey procedures were used across the continent

The second period (1940–1955) was the golden age of soil survey in Australia, partly as a result of the demand for surveys arising from postwar land-development schemes This era saw not only many surveys being conducted but also many different approaches to soil survey, caused largely by the involvement of an increasing number of uncoordinated state and federal organizations Soil-association mapping tended to replace detailed soil mapping, and land-system mapping developed rapidly

In the mid-fifties, soil surveys began to decline for a number of reasons—a decrease in demand for surveys by government agencies, an increase in criticism of the soil classification in use, a deflection of surveyors to other tasks, and a swing to *land* surveys It is interesting to note about land survey that the land-system survey by CSIRO has now virtually ceased in Australia (and Papua New Guinea) I mention this because, coincidentally, this type of survey has become popular in a number of other countries around the world

In Australia today, there are over a dozen different governmental groups, both federal and state, carrying out soil and land surveys of various kinds In December, 1975, a working group met in Canberra to discuss the possibility of setting up a national soil survey I hope that more will result from its deliberations than did from deliberations of a similar committee that met in 1922

Information Transfer

All the activity in Australia over the last 50 years or so would lead one to conclude that a very large amount of information must have accumulated Because of the relatively small number of surveyors involved and their peripatetic nature, there can be little doubt that there has also been a lot of transfer of information between one part of the country and another The key to this transfer has been *people,* moving physically from place to place and carrying information with them, often in their heads But there has been little attempt either to formalize this process or to publish information transferred informally.

Conversely, there have been many instances of technology transfer without the benefit of soil and other environmental information to provide guidelines As a consequence, many such instances have not

been unqualified successes, to put it mildly A classic example in the early days of settlement was the introduction of bare fallowing, without consideration of the differences in climatic pattern and soils that exist between Europe and Australia A more recent example was the attempt to grow rice at Humpty Doo (near Darwin) in the Northern Territory, which also failed

An example of information transfer via detailed soil survey in Australia is Northcote's (1949) discussion of the horticultural potential of certain soils along the River Murray He recognized two broad categories of soils, namely, those of the highland areas and those of the river terraces and flats, and concerned himself with the former since only they were capable of horticultural development

Experience gained over 20 years of soil surveying by Northcote and others, plus the experience of horticulturists in areas already settled, was used to set up criteria so that evaluation could be made of the mapped soil types in relation to various crops and irrigation practices (The soil criteria that could be used to assess suitability for horticultural crops grown commonly in the Murray Valley are shown in Table 1) Criteria related to irrigation practice were also established in terms of soil color, soil texture, and soil drainage

1 Brown-colored soils are more productive and less liable to salinity problems than are soils that are dull brown to grey brown For example, at Coomealla, New South Wales, vines on Matong sandy loam (brown) yield up to twice as much as vines on Coomealla sandy loam (grey brown) do
2 Light-textured soils should be spray-irrigated, especially when they occur on the crests and upper slopes of sand-rises
3 Deep drainage is a corollary to furrow irrigation on all except the heaviest-textured soils

Although the preceding is a very sketchy account of the information available, it indicates that a formalized procedure based on soil types could be set up for transferring information to undeveloped areas within the highland zone In fact, this did occur subsequently, using soil-survey maps that were published in most cases at approximately 1 25,000 (The question could be raised whether it was necessary to map soil types in such a situation, this is considered later in this paper)

Next is an example of transfer of information from one side of Australia to the other in a very coarse way Nix (1973) delineated six agroclimatic zones in the nonarid areas of southern, eastern, and northern Australia and sought to estimate the amount of land potentially suitable for dryland agriculture in the northern zones As far as soils are concerned, this was accomplished by assuming that the same constraints known to operate in the southern zones also operate in the north By applying climatic, terrain, and soil constraints, he was able to estimate that only 1 to 2 percent of northern nonarid Australia is suitable for dryland agriculture The soils knowledge transferred to the north

Table 1 Criteria for evaluating soil suitability for horticultural crops

Crop	Soil depth above calcareous horizon (cm)	Soil texture
Citrus, apricots	> 60 to 75	Sand and sandy loam
Stone fruits (excluding apricot)	> 50	Sand, sandy clay, and loam
Pears	> 45	Intermediate and heavy textures
Vines	45	Wide range
Figs	< 45	Wide range

was that appropriate technology had not been developed to enable the full use of sodic duplex (texture-contrast) soils for cropping in the south and east; and that structured and massive earths and some cracking clays and alluvial soils can be used satisfactorily for arable cropping (but subject to the previously recognized climatic and terrain constraints) Nix did not delineate these soil areas specifically, but this could be done by interpreting the *Atlas of Australian Soils* (Northcote et al., 1960-1968)

I am not aware of a example of formal transfer of agricultural information, based on soil survey, from Australia to a developing country However, there has undoubtedly been some informal information transfer, just as has happened within Australia An example is perhaps the survey of Brunei carried out by two Australian surveyors (Blackburn and Baker, 1958) The soil classification used in their survey was a local system developed by the Kedayan people, which had possibly been in use for hundreds of years They did not try to relate this system to any other classification, from either Australia or elsewhere, so obviously formal information transfer on this basis was not possible Nevertheless, they must have drawn on their experience with analogous soils in Australia in making their recommendations about potential land use in Brunei As a sidelight, it is of interest to note that a Malay translation of the summary, conclusions, and recommendations was published, along with the English text, in the survey bulletin, in other words, some attempt was made to communicate with the local agricultural officers and farmers by *vertical* transfer of information.

Factors that have contributed to the dearth of formal transfer of agricultural information from Australia to developing countries include (1) the generally low level of overseas aid provided by Australia (with the exception of that to Papua New Guinea), (2) the emphasis on animal-based systems in primary industry, and (3) the divergence, over the last decade particularly, of soil classification in Australia from classifications in other parts of the world The last is discussed further below.

What Is Involved in Information Transfer?

In this section I shall try to analyze, in a general way, what is involved in information transfer This is necessary to provide a basis for considering whether and how computers can help in this process We can instruct the computers only if we can define explicitly what we want done, and it is evident that our thinking is still rather fuzzy about how we go about transferring information from one place to another.

Assessment of Biological Productivity

The ultimate goal of soil classification and soil survey in the agricultural domain is the assessment of biological productivity Nix (1968) suggests that there are three different, but not mutually exclusive, approaches to the problem of assessing biological productivity on any given parcel of land (1) analogue methods, (2) site-factor methods, and (3) simulation methods He further suggests that these represent some sort of evolutionary sequence in our "understanding of functional relationships between site parameters and biological production systems " The third approach is now in such an elementary state of development (except perhaps in the case of water-balance models) that we may ignore it for our present purpose.

The other two approaches, transfer by analogy and site-factor methods, are to my mind not related in an evolutionary fashion as suggested by Nix (1968) but are quite different, strongly complementary components of prediction of biological productivity The first is concerned primarily with information transfer, the second with information generation

In analogous transfer, information is transferred from farms or experimental sites to analogous areas as defined by soil (or land) classification Theoretically, no a priori knowledge of functional relationships between site parameters and crops is required for this transfer to be possible. The technique is based on the simple hypothesis that

if two occurrences of soil (or land) are similar, they will respond in a similar way to prescribed uses (crop type, management, etc) The problem lies in the concept of similarity *Similar* does not mean *identical,* it does mean *approaching identity to some degree* Unfortunately, the degree varies from case to case, and usually it is just not known at all Obviously, classification, whose role is to put similar things together, lies at the heart of the matter

"Site-factor methods seek to relate key parameters to biological productivity within a given environment" (Nix, 1968), and the most widely known and used of such methods is multiple linear regression Although I shall not discuss this particular technique further in this paper, I should point out that implicit in the idea of a "given environment" is the drawing of a boundary around a reasonably homogeneous piece of soil or land (in a geographical sense) or the grouping together of similar environmental entities (in a conceptual sense) Again, classification is of crucial importance

Analogous Transfer

There are three steps in any analogous transfer process (1) definition of a universe within which to operate, (2) classification of the entities within that universe, and (3) transfer of information from one entity to another within a class These are often not recognized explicitly, but it becomes increasingly necessary to do so as electronic data processing begins to play a role I shall not discuss the third step further here, except to mention that it may be mediated via electronic communication systems, by the printed page, or by microfilm, magnetic tape, or information in people's heads as they move from place to place

A universe within which to operate is perhaps most commonly defined, on the one hand, in a geographical sense, as the soils within an area of the earth's surface delineated by geographic coordinates or by physiographic or similar boundaries For example, in the detailed survey mentioned earlier, the universe within which information transfer was attempted was the Murray Valley highlands, which could have been (but was not) delineated on a map

On the other hand, a conceptual universe may be defined by taxonomic criteria, as was the case in the FAO publication about dark clay soils Overlap of geographical and conceptual universes can occur to varying degrees, but complete coincidence can occur only when all soils on the whole of the earth's surface are considered The only instance of this being approached is the World Soil Map (FAO/UNESCO, 1974).

A universe within which to operate having been defined, the next step is to group or classify the entities embraced in it These entities may be geographical units (such as mapping units or map faces) or taxonomic units (such as soil series, soil family, and great soil group) The importance of soil taxonomy has been discounted increasingly in recent years, a trend to be deplored since classification provides the essential basis on which analogous transfer can be made

Although I may be stating the obvious, let me point out that in any particular instance the classification used needs to be (1) related to the objective or objectives set by the user and (2) applied consistently across the whole universe under consideration About the latter, I have already mentioned certain problems becoming increasingly evident in Australia, where a variety of organizations doing survey work exist within and across political boundaries

The analogous situation on a worldwide scale is familiar to everyone As mentioned earlier, the only classification that has achieved worldwide coverage is that of the World Soil Map Unfortunately, however, this is too coarse a classification for most agricultural purposes The *Soil Taxonomy* (USDA, 1975) includes categories much lower in the taxonomic hierarchy and consequently is much more useful potentially Moreover, although it has not been applied universally, it seems to be gaining increasing acceptance, particularly in developing countries

Australia is now in a difficult situation vis-à-vis other countries, because over the past

decade classification in Australia has diverged widely from classifications used in the rest of the world Most commonly used are an Australian version of the great soil group genetic classification (Stace et al, 1968), the monothetic bifurcating classification of Northcote (1971), or a combination of the two An attempt has been made recently (Northcote et al, 1975) to correlate the great soil groups and the classes known as principal profile forms in Northcote's "Factual Key" classification (Northcote, 1971) with classes of the World Soil Map, but overall there is not particularly good concordance between them *Soil Taxonomy* (USDA, 1975) has not been used seriously in Australia Haantjens et al (1972) have used it in land system surveys in Papua New Guinea, but because little or no use has been made of these surveys, the usefulness of the Soil Taxonomy in this instance has not been tested The import of this situation for possible transfer of information from Australia to areas outside it or vice versa should be fairly evident Any transfer that has occurred or is likely to occur in the near future must of necessity be informal

Problems of Scale and Distance

The major obstacles to information transfer on a global basis relate to scale and distance There is a crude correlation between scale of survey and level of classification; in other words, the number of units dealt with per job tends to remain about the same, no matter what scale is used This is primarily a psychological matter—the human brain can comprehend only up to a certain number of entities at any one time, and this number is disconcertingly low Consequently, there is a need to break up the earth's surface into areas of appropriate size for mapping purposes and, likewise, a need for classification hierarchies

To go back to earlier examples mentioned in this paper, the surveys of potential horticultural areas in the Murray Valley were carried out at a scale (1 25,000) that enabled soil types to be mapped, and it was at this level that agricultural information, such as type of horticultural crop and irrigation practices, could be transferred In the second example using information from the *Atlas of Australian Soils* (1 2,000,000), it was not possible to transfer information much finer than that which said whether an area was potentially arable At the far end of the spectrum—the World Soil Map (1 5,000,000)—it is virtually impossible to transfer any agricultural information Obviously, in the transfer of information from one continent to another, we commonly have to contend with problems of scale and fineness of classification

A related but different problem is that arising from spatial separation of occurrences of soils placed together in the same class Intuitively, a soil surveyor takes contiguity into account when he draws boundaries around parcels of soil distributed over the landscape Further, many soil scientists have had experience with the dangers of trying to extrapolate map legends (i e, classifications) beyond the boundaries of a mapped area (i e, the universe originally defined) The surveyor's intuition is probably right that the greater the distance between two points, the less likelihood there is of discovering soils having a high degree of similarity at those two points

An example from southern Australia illustrates this point Some time ago, Oertel (1961) carried out discriminant function analyses on terra rossas and rendzinas in South Australia on the basis of chemical data alone Nineteen soils representing these two soil groups were sampled from two areas that are about 300 km apart Using five attributes singly or in various combinations, he showed that it was possible to discriminate between the two groups satisfactorily

Nevertheless, a second question poses itself with what confidence is it possible to transfer agricultural information from one area to the other within a particular soil group? The five attributes used by Oertel (1961) were deliberately chosen because they were related to field morphological attributes used as criteria in classification If we take a wider set of 18 chemical attributes (including the original five), which have some rele-

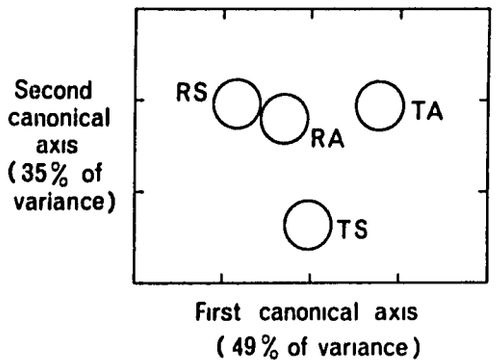

Fig 1 Canonical variate analysis of terra rossa and rendzina data from South Australia Scales of the two axes are the same Points are means for groups, circles indicate 95% confidence limits *RS* = rendzina, South-East, *RA* = rendzina, Adelaide, *TS* = terra rossa, South-East, *TA* = terra rossa, Adelaide

vance to plant growth, and subject the data to canonical variate analysis with the soils grouped into four sets (two great soil groups × two locations), it is somewhat disconcerting to find that not only are the soil groups easily discriminated but also the locations If we consider the first two canonical axes (Figure 1), which account for 84% of the total variance, we see that while the two groups of rendzinas are fairly close together (although they can still be discriminated), the two terra rossa groups are widely separated I would have some reservations about transferring agricultural information from one area to the other, within soil groups, at anything but a very general level, even though they are within the same broad climatic zone, on similar parent materials, and only 300 km apart

Even greater differences might be expected in comparisons made on an intercontinental scale Unfortunately, few such comparisons have been made, but recently a similar study about soils of Australia and Brazil was carried out by Isbell and Field (1977) Surface samples (0 to 10 cm) of soils identified by field morphological features (by the same person in both countries) as either red earths or yellow earths were collected from areas of approximately the same size in northern Queensland and northern Brazil, approximately 16,000 km apart Laboratory measurements with relevance to plant growth (nitrogen, organic matter, pH, exchangeable cations, etc) were made and the data subjected to canonical variate analysis Only poor discrimination between the Australian red earths and yellow earths was achieved, but the Brazilian groups were well separated Again, however, the most striking feature was the even wider separation between the groups from the two countries Perhaps caution should be exercised in placing much weight on this type of analysis, since it is designed to maximize differences between groups Nevertheless, I would be somewhat hesitant about transferring information by analogy via this particular formal classification without further exploration of its relevance for this purpose

Classification in Relation to Site-Specific Methods

As mentioned previously, transfers by analogy and by site-specific methods are seen as being complementary The roles of soil survey and soil classification in the former have been considered at some length; there is a role for them in the latter also This is, in simplest terms, the delineation of areas (in a geographical sense) or groups (in a taxonomic sense) that are *reasonably* homogeneous No one has been able to define what *reasonable* is in this context, but we probably all tend to try, in some intuitive way, to minimize variance within groups Note that the classificatory models commonly used in pattern analysis are minimum-variance models (Williams, 1976, p 133)

The point is that soil survey and soil classification help to provide reasonably homogeneous groups of soils within which site-group methods can be expected to provide useful predictions I think this is a vital function because I do not believe that there is a *universal model* that will cover all aspects of soil-crop interaction in all places The linear models commonly used by statisticians tend to fit satisfactorily over only small portions of the real and conceptual worlds that we

have to deal with, and for the foreseeable future there will be a continuing need to divide our worlds into these portions by means of soil survey and soil classification

Is Mapping Necessary?

My according the conceptual world an equal place alongside the real world is deliberate Assuming that transfer of detailed agricultural information can be carried out only at the series (or perhaps family) level, and with increasing use of soil association, land system, and similar surveys, it is obvious that soil classification must assume increasing importance in the future Soil classes must be erected and be capable of use for information transfer independent of indications of specific occurrences of those classes on a map Under these circumstances, it is desirable that a taxonomy allow accurate identification of a soil observed in the field, either in isolation or in the context of, say, a soil association This nas not been a notable feature of most soil taxonomies in the past

Thus mapping is not necessary for transfer of information, although classification is This does not mean that soil mapping should be discontinued, it definitely has evolved in soil survey as a very convenient way of summarizing and presenting data and can help in the transfer of information It does seem, however, that in the future more attention should be paid to soil systematics Formal classification may not always be necessary, and in some circumstances, it may be possible to get by with informal, ad hoc classifications, which are probably more feasible now that computer assistance is available

Can Computers Help?

The answer is yes, but a yes hedged by conditions. It has become fashionable of late to disparage the use of computers as glorified calculators or quick, accurate clerks The direct transliteration of manual data-handling to electronic data-processing has been, nevertheless, the only really successful area of computing to date, in the sense that, sooner or later, electronic data-processing almost invariably proves cheaper. It is true that often insufficient thought is given to what is being attempted in a particular job, but introducing a computer does not make that job any more meaningful

There are two phases involved in what we might call, broadly, information systems The first defines the way in which a system is structured and the procedures that should be carried out (modeling and programming), the second is the execution of these procedures Computers nowadays may be involved to varying degrees in the execution phase Although the two phases are independent theoretically, there is some interaction between them, for there is no point in setting up a system that obviously will not work The computer certainly brings into relief this relationship knowing what the computer can do may have a profound effect on how a system is structured

A point to keep in mind when considering the role of computers in the survey-interpretation-transfer process is that although computing facilities are now widely available around the world, people who have the skills to use them tend to be scarce outside North America and northern Europe

The Computer as Clerk

There is no doubt that much of the routine work associated with soil survey, in particular the storage, retrieval, and display of data collected in the course of a survey, can be done by a computer In my experience, computer assistance results in increased accuracy, easier manipulation of data (sorting, tabulation, correlation, etc), and lower costs, and I believe that many other people have had similar experiences But I am referring here only to computer assistance in individual jobs of survey For integrating information from a number of different surveys, the computer offers less promise because of two main problems (1) data incompatibility and (2) data-base incompatibility

Data incompatibility is a problem of the soil scientist Do two surveyors mean the same thing when they say, for instance,

drainage is poor? This point has been elaborated upon elsewhere (Moore, 1971) There is no possibility of direct interchange of data between countries or transfer of information via soil classification (which is ultimately based on data) if the data from the two countries are not compatible Possibly the biggest single factor in making information transfer possible on a worldwide scale was the introduction of the USDA *Soil Survey Manual* (USDA, 1951), followed by its FAO equivalent (Anon , 1968) and their ultimate widespread adoption as de facto standards

The problems of data compatibility are the province of the soil scientist, those of data-base compatibility are the province of the computer scientist Major areas of concern are the machine dependence of software, the variety of programming languages used, trade-offs between specific and generalized data base management systems, costs associated with these systems, and the lack of communication between people developing such systems For generalized systems, the Association for Computing Machinery has played a prominent role in setting up specifications (e g , CODASYL, 1969), but these are only guidelines that have to be implemented by interested people around the world A Working Group of Commission V of the International Soil Science Society has taken the initiative in bringing together people working on soil information systems, who tend to be scattered and largely ignorant of each other's work Its first workshop was held in the Netherlands in September, 1975 (Bie, 1975) and a second in Australia in March, 1976 (Moore and Bie, 1977) Further consultations regarding these problem areas among potential data gatherers, exhangers, and users could be a fruitful area for sponsorship by international organizations such as the FAO, UNESCO, International Soil Science Society, and the Consultative Group on International Agricultural Research

The Computer as Taxonomist's Assistant

I have emphasized that soil classification is a prerequisite for analogous transfer of information and that in spite of the current unfashionableness of soil taxonomy, it will be needing more emphasis in the future Furthermore, the taxonomist will need all the assistance he can get If he avails himself of the computer's help, he will tend to be interested in a different type of computing from the data-base manipulator He will want, in general, large amounts of calculations done on relatively small amounts of data

Orthodox multivariate statistical techniques (such as the canonical variate analyses discussed earlier in this paper) and newer pattern-analysis techniques (Williams, 1976) have become increasingly available, not as replacements for conventional soil taxonomy but as tools to assist in this area They have only become possible with the advent of computers

Although the above remarks refer essentially to development and refinement of formal soil classifications, perhaps now there is some reason to hope that informal "throw-away" classifications may be feasible, using the facilities provided by computer storage and retrieval, plus comparisons of a pattern-analysis type based on degrees of similarity between pairs of entities But because of the incompleteness and incompatibility of soil data, it is unlikely that this could be done currently for soils on an intercontinental scale Obviously, before we can take advantage of this approach, it is necessary that agreement be reached on what data should be collected and how they should be classified and measured Until this is done, the links between countries must continue to be human beings who, before making mental comparisons, are able to intuitively adjust and correct data, provided they know how the data were generated (If they do not know this, they are going to draw unreliable conclusions)

The use of informal classification can be illustrated in the area concerning climatic data, which are reasonably compatible worldwide (e g , Anon , 1958) For example, Russell and Moore (1976) have compared the climates of Australasia and southern Africa, using 16 attributes considered to have some relevance to plant growth. Of

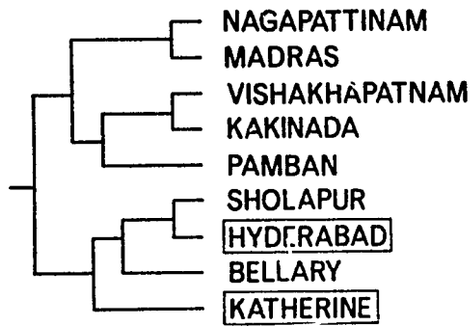

Fig. 2. Portion of a dendrogram relating 46 Indian and 55 Australian meteorological stations, using Euclidean distance as a measure of similarity and 16 climatic attributes on a monthly basis over the 4 monsoonal months (Courtesy J.S. Russell, CSIRO Division of Tropical Crops and Pastures)

more interest here is a comparison of the climates of Australia and India. A major northern Australian experiment station is located at Katherine, which is representative of the fairly restricted area of potentially arable land in the north If we wish to look for grain and pulse crops in India that are suitable for growing at Katherine, our first query is whether there are homoclimates in the two countries By comparing data from meteorological stations, using Euclidean distance as a similarity coefficient, we can have the computer search for such homoclimates.

On the basis of the same 16 attributes mentioned above, on a 12-month basis none of the Indian climates appears similar to any of the Australian climates. However, if we look at the 4 monsoon (kharif) months—i e, the major dryland cropping season—we do find a number of homoclimates for Katherine, as illustrated in Figure 2, which is a small portion of an overall dendrogram relating 46 Indian and 55 Australian meteorological stations (J S Russell, personal communication) Thus we would go, in the first instance, to the Hyderabad-Sholapur-Bellary area of India to look for suitable crop varieties for Katherine If we wanted to make comparisons for the postmonsoon season, the computer could do this for us also We have flexibility in that we can vary at will the suite of month-attributes used Having achieved our objective, we can then throw away the various analyses I can see this kind of procedure as a potential tool in transferring soil information, but not until we have rationalized our soil and land surveys and soil-data-generation procedures on a much wider international scale than we have had up to now

ACKNOWLEDGMENT I thank Dr. J.S. Russell, CSIRO Division of Tropical Crops and Pastures, for permission to publish Figure 2

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Agrotechnology Transfer and the Soil Family

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Agricultural research and experience which are transferred to widely separated parts of the world have a better chance of succeeding if the transfer is made to similar soils Soils which belong to the same phase of a soil family according to criteria set forth in the U S *Soil Taxonomy* are considered to be sufficiently similar to enable planners to transfer agrotechnology from one region to another To achieve this goal, a national soil survey based on a comprehensive soil classification system is necessary The soil survey can (1) be used to assess land use potential and (2) serve as a basis for accelerated, low cost national development through transferred technology

A problem that emerging nations face in agricultural development is the need to obtain quick estimates of soil-use potential Two things are needed for a proper evaluation of a country's soil resources They are (1) a soil classification system that serves as a guide for making and interpreting soil surveys and (2) a soil survey of the area itself To be effective, the classification system must be based on the best available knowledge and should be designed to accommodate all soils occurring in the world Classification systems for a specific country or region often do not meet this important requirement International transfer of agrotechnology requires the use of a comprehensive classification system that can accommodate soils on an international scale, it also requires a classification system that has sufficient depth to enable the user to predict soil responses to management and manipulation

The *Soil Taxonomy* (USDA, 1975) provides a comprehensive classification system that groups soils with similar physical and chemical properties that affect their behavior and use In this classification system, those properties that are useful in interpreting soil surveys for agricultural and nonagricultural use are provided in the family category To meet most of man's needs for practical interpretations, soils are grouped so that the responses of comparable phases of all soils in a family are nearly alike Hence, this system can serve as the basis for transferring soil technology among widely separated parts of the world

The purpose of this paper is to consider how the technical information contained in the family category of Soil Taxonomy can be used in planning and implementing agricultural development in the tropics

The Soil Family

The soil family is a condensed statement of what we know about a soil. The name as a word (or set of words) serves as a double mark to recall to ourselves the likeness of a former thought or object and a sign to make

it known to others (Mill, 1965)

It is immensely practical to call objects that look and behave alike by a single name, for through that name we may recall all we know about the objects that belong to that group It is unnecessary, for example, to study every individual in a group having the same name By definition, all objects that have the same name behave alike, therefore, if the pattern of behavior of one individual is known, the behavior pattern of all individuals with the same name is also known

The soil family name may also be thought of as describing an ecological niche The name of a soil family should bring to mind not only an image of a soil in a particular environment but also a picture of a well-defined management system This management system is unique to this family and applies to all members of this family wherever they occur Thus, soils that occur in widely separated parts of the world but are all members of the same phases of a family should have similar management requirements for any particular use

As an example, the Black soils of the Red-and-Black complex that are found in ICRISAT's experimental fields are, in terms of management, more closely related to the Black soils of the same family that occur in other subtropical regions of the world than to the Red soils that occur adjacent to them One of the deep Black soils at the ICRISAT field station has the formidable family name "fine, clayey, montmorillonitic, isohyperthermic, Typic Pellustert" Its red counterpart has been tentatively classified as "clayey, mixed, isohyperthermic, Udic Rhodustalfs"

These soils have some features that are alike and others that are unlike Two important common features indicated in their names are the soil moisture regime designated by the letters *us* in *Us*tert and *Us*talf and the soil temperature regime marked by the term *isohyperthermic* It is no accident that one of ICRISAT's main efforts is directed towards optimizing water management for crop production The pronounced dry spell which stands as a major food-production constraint, is indicated at a very high category in the classification scheme by the prefix *ust*, which is taken from the word *combust* (to burn)

There are soils at the ICRISAT field station, however, that remain wet for long periods during the year These are the soils occurring in the low depressions They are members of the fine loamy, mixed, isohyperthermic family of Fluventic Haplaquepts Their wetness is indicated by the letters *aqu* in *Aque*pts

The results of ICRISAT's soil-water management program, therefore, have wide application not only in the Indian subcontinent but also in all semiarid regions of the tropics and subtropics that have comparable soils ICRISAT's niche is clearly defined in the Soil Taxonomy by the ustic moisture regime Extensive areas in the tropics and the subtropics do have ustic moisture regimes and therefore can benefit from the practical management systems developed in ICRISAT

The ustic ecological niche, however, is still too broad to permit practical transfer of technology There are, for example, soils in Brazil that are classified as Acr*us*tox Unlike the high-base soils of the ICRISAT field stations, the Acrustox soils are weathered to the extreme (*Acr* means *extreme*) In Acrustox, fertility problems are as limiting as are the water constraints The fertilizer practices used in ICRISAT unless modified would fail if transferred to Acrustox Even the soil-water management systems would need to be modified to suit the conditions of Acrustox A high clay Acrustox and a high clay Chromustert would have very different water-holding and water-transmitting properties These differences among soils become increasingly clear as one moves down the taxonomic ladder

The soil-water relations, or for that matter many agronomically important soil properties of Acrustox and Chromusterts, are implicitly specified in the family category by texture and mineralogy In general, water-transmitting capacity decreases as clay content increases, but for equal clay contents, the water permeability of Acrustox is markedly higher than that of Chromusterts

Soil permeability is not explicitly given in

the family category As it is for the most important soil parameters, soil permeability must be interpreted from texture, mineralogy, and other diagnostic criteria used to classify a soil at the higher categories Particle-size distribution and mineralogy are the principal causes of the physical and chemical characteristics of a soil The effects such as soil erosion, water-holding capacity, phosphorus fixation soil compactibility, nutrient-retention capacity, and a host of other accessory characteristics must be inferred from the causative and diagnostic features The ability to extract as many useful accessory characteristics as possible from a classification system grows with experience One purpose of soil classification is to systematize what is known about soils so that others may use this experience in the proper place, in a proper way, in any part of the world and as often as is necessary

Although Soil Taxonomy is a natural or scientific system of classification, as opposed to a technical classification system designed to group soils for specific uses it includes important technical descriptions to distinguish families of soils within a subgroup For mineral soils the family differentiae are

1 Particle-size classes
2 Mineralogy classes
3 Calcareous reaction classes
4 Soil temperature classes
5 Soil depth classes
6 Soil slope classes
7 Soil consistency classes
8 Classes of coatings on sand
9 Classes of cracks

For organic soils they are

1 Particle-size classes
2 Mineralogy classes, including nature of limnic deposits
3 Reaction classes
4 Soil temperature classes
5 Soil depth classes

In mineral soils, the most frequently used family differentiae are particle-size, mineralogy, and soil temperature classes In organic soils, reaction and soil temperature classes are most commonly used The number of combinations of particle-size, mineralogy, and soil temperature classes is not large, but when the combinations are further subdivided according to subgroups, the number of soil families becomes large

Soils within identical particle-size, mineralogy, and soil temperature designations can and generally do have very different management requirements if they belong to different taxa in higher categories Thus the technical information used to differentiate families within subgroups is useful only if it is used in conjunction with the higher categories The higher categories are separated on the basis of properties that serve as marks of the causes of soil behavior These marks used in combination with the added technical description of the soil family enable the user to make estimates of soil responses to management and manipulation

Figure 1 shows an example of climatic gradients one might encounter in the tropics Warm temperature even temperatures at sea level, turns to freezing conditions at high elevations over a distance of several miles Although cloud cover rainfall, and temperature vary over short distances temperature at any point on the landscape remains relatively constant and rainfall and cloudiness vary predictably for a given time of year

If a soil classification system is to serve as a basis for agrotechnology transfer, the system must stratify climate as well as other crop production parameters, along the gradient illustrated in Figure 1 In Soil Taxonomy, cloud cover and rainfall are related to the soil moisture regime that appears at the suborder category, soil temperature, which is related to air temperature, appears at the family category

Figure 2 illustrates the relation between lettuce yield and phosphorus in the soil solution for several temperatures Increasing levels of soil solution phosphorus were obtained by increasing the application of phosphorus fertilizer The results tell us that more phosphorus is needed to obtain 95% of maximum yields as temperature decreases The soil temperatures are stratified into warm (hyperthermic), moderately warm (thermic), cool (mesic), and cold (frigid) for temperate cli-

Fig 1 Climatic gradient on the slopes of Mauna Kea in Hawaii A good soil classification system will stratify soils and associated climates into groups that respond similarly to management and manipulation

mates, and isohyperthermic, isothermic, isomesic, and isofrigid for the tropics This stratification enables the crop-production technology dependent on temperature to be transferred to widely separated parts of the world that have soils belonging to a common soil family Thus it is more reasonable to transfer the crop-production technology from the slopes of Mt Kilimanjaro to the slopes of Mauna Kea, halfway around the world on the same soil family, than to assume similar crop-production requirements on widely different soil families in either region

Utilizing Soil Surveys and Soil Classification Systems

Conducting soil surveys based on a comprehensive classification system is a necessary first step, but their mere existence does not and will not insure their utilization The taxonomists are simply the formulators of surveys and classification systems The users are the agronomists, the engineers, and the planners, but the large majority of users cannot be expected to acquire the skills to interpret soil surveys Thus a major second role of taxonomists is to inform users and potential users of the utility of soil surveys The user in turn must seek the assistance of the taxonomist to insure that soil surveys are used in the best possible way to achieve the desired goals The use of soil surveys, in short, should be a joint effort between taxonomist and user

Agrotechnology Transfer in the Tropics

There are scores of experiment stations in the tropics involved in research to increase efficiency in food production The research output from a single station may not be large,

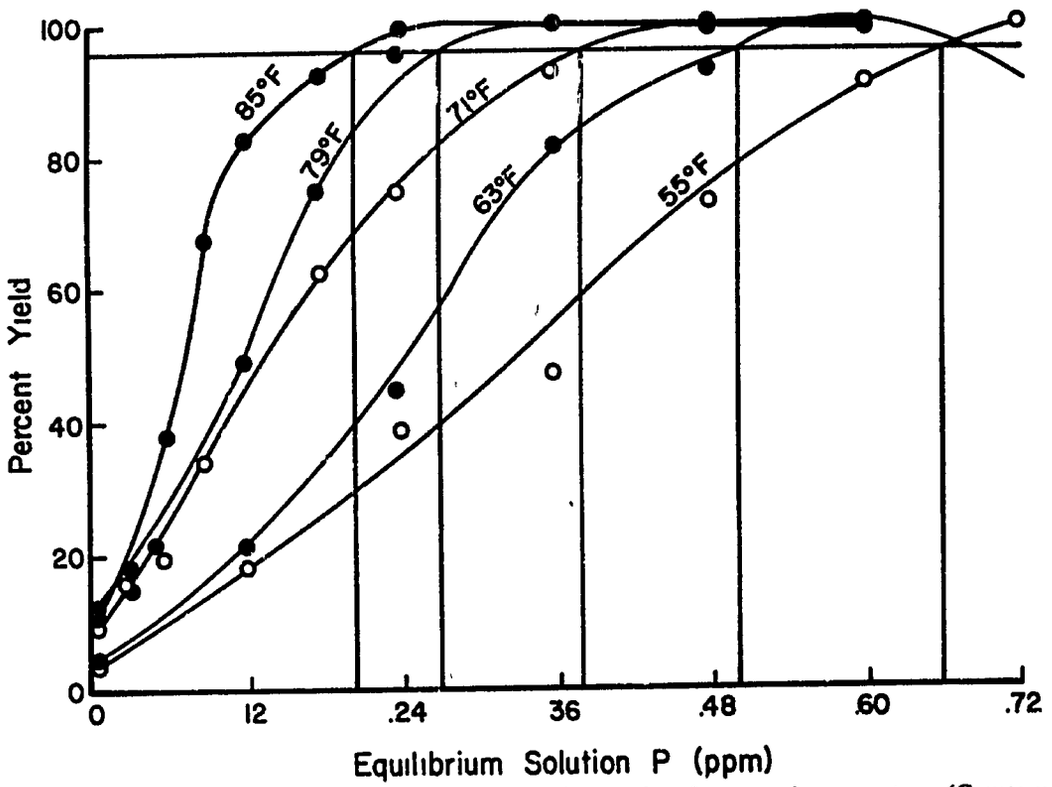

Fig 2 Relative lettuce yield as a function of soil-solution phosphorus and temperature. (Courtesy J P. Jones, University of Idaho, Moscow, Idaho)

but the combined output from all of the stations must be considerable It is also very probable that the research results of stations are relevant not only to neighboring areas but also to widely dispersed regions in the tropics. Research discoveries are most likely to fit in those places, however widely separated, where the physical environment is similar. The identification of similar environments is made possible through soil surveys and soil classification

It is also quite likely that many on-going research projects have already been completed on a similar soil, for the same crop, at another station A soil correlation of experiment stations in the tropics should serve as a key to opening channels of communication for information exchange Soil correlations do not eliminate the need to repeat experiments, but they do enable one researcher to profit from the successes and failures of others

Soil classification is knowledge organized to enable man to forecast soil behavior and to estimate soil potential for many uses Soil Taxonomy is a system of soil classification that offers the developing countries a technical package based on the best current knowledge to plan and implement agricultural development This system enables planners to import technology that is tailored to their country's needs

A Plan for Information Exchange

The need to benefit from exchange of agricultural innovation is nowhere greater than in the tropics Although exchange and transfer of technology can occur longitudinally as well as latitudinally, the exchange is more profitable and better suited in the east-west direction. It is no accident that similar

soil families cannot occur over long distances in a north-south direction Technology transfer from the high-latitude countries of the north and south to the tropical belt will predictably fail in some aspects unless appropriate modifications are made in the technology package These modifications must be tailored for a particular environment the soil family serving as the mark of this environment

The need to modify technology packages is greatly reduced when the transfer occurs in an east-west direction within the tropics The probability of locating similar or closely related families in an east-west direction within the tropical belt is high, and this enables the transfer process within the tropics to become one of exchange among sister tropical nations

A survey and classification of experiment station soils in the tropics based on Soil Taxonomy could serve as the logical basis for information exchange A document containing, in addition to the soils inventory, a brief description, for each station, of its research emphasis and of its crop studies would be desirable, such a document would streamline the total research effort in the tropics by helping stations and scientists locate others that have common interests and goals While the transfer of technology from outside the tropics must continue, it is the exchange of technology packages within the tropics that offers the greatest promise for achieving ends that suit the lifestyle of peoples firmly fixed to the tropical environment

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A Soil Research Network through Tropical Soil Families

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A proposal is made to establish a soil research network throughout the tropics based upon the soil family classification of the U S *Soil Taxonomy* The network would be voluntary, dependent upon the free association and contributions of cooperating institutions The University of Hawaii would support the establishment and operation of the network through its Benchmark Soils Project and its Bibliographic Information Retrieval Service for Tropical Agriculture The University of Puerto Rico through its Benchmark Soils Project would also provide support

The network will improve communication and stimulate cooperative research and training Its usefulness to any country will depend in large part on the contributions that country makes and the extent to which it tries to use the network to service its own needs Mutual aid is the orientation and underlying philosophy

The purpose of this paper is to describe the Benchmark Soils Project being conducted by the University of Hawaii in cooperation with the U S Agency for International Development and to indicate how, by an extension of some of the work of this project, it should be possible to establish a network of soil research stations throughout the tropical world The basis of the project and of the proposed network of stations is the soil family as defined in the U S. *Soil Taxonomy* (USDA, 1975)

The Benchmark Soils Project

The Benchmark Soils Project of the University of Hawaii was initiated in 1974 under a contract with the U.S Agency for International Development The purpose of the project is to correlate food yields with soil properties and soil management practices on deep upland soils It is hoped that the project will assist the cooperating tropical countries in Asia and Africa in improving the use of soils data in formulating agricultural development plans and will assist them in tapping the potential of upland areas for intensive food production Immediate objectives are to establish a network of benchmark soils and to determine scientifically the transferability of agroproduction technology among tropical countries

A similar project is being undertaken by the University of Puerto Rico for countries in Latin America Much of what is described here applies also to the Puerto Rico project.

Benchmark Soils in Common Soil Families

The benchmark soils in the network belong to common soil families as defined by the U.S. *Soil Taxonomy.* The soil family is

the fifth level of subdivision in the Taxonomy To quote from the U S *Soil Taxonomy*, " the intent has been to group the soils within a subgroup having similar physical and chemical properties that affect their responses to management and manipulation for use The responses of comparable phases of all soils in a family are nearly enough the same to meet most of our needs for practical interpretations of such responses "

Families are defined primarily to provide groupings of soils having restricted ranges in

1 Particle-size distribution in horizons of major biologic activity below plow depth
2 Mineralogy of the same horizons that are considered in naming particle-size classes
3 Temperature regime
4 Thickness of the soil penetrable by roots
5 A few other properties that are used in defining some families to produce the needed homogeneity

To quote from the *Soil Taxonomy*, "These properties are important to the movement and retention of water and to aeration, both of which affect soil use for production of plants or for engineering purposes "

The Soil Families in the Project

At this early stage in the project, one soil family has been selected for inclusion from the subgroups of Hydric Dystrandepts and Tropeptic Eutrustox Other families including a family from the great group of Tropohumults may be added

Hydric Dystrandepts

One family of soils derived from volcanic ash, the *thixotropic, isothermic family of Hydric Dystrandepts*, will probably be used in all countries participating in the Benchmark Soils Project with the University of Hawaii These are well-drained, upland soils used for plantation crops and diversified agriculture by small farmers Many are still forested, particularly those on steeper slopes.

Although these soils are recognized generally as desirable for agriculture in all countries, they are not being fully utilized They can be problem soils in engineering use, and maintenance of roads in these areas is difficult They are easily located by experienced soil surveyors who have adequate local knowledge

The soils have dark brown to dark reddish brown surface layers that are moderately to extremely acid, overlying dark brown to reddish brown subsoils that are silty clay to clay in texture, smeary, low in bulk density, and slightly to moderately acid The mineralogy is dominated by amorphous materials Mean soil temperatures at a depth of 50 cm are higher than 15° C but lower than 22° C, and the mean summer and winter temperatures differ by less than 5° C

Cation exchange capacities are high, base saturations low The soils fix phosphorus in forms that are available to plants only slowly

The soils have good physical conditions for plant growth, though requiring large amounts of phosphate fertilizers to make them productive Because of their permeable nature as well as their occurrence in locations that have wet climates, they require frequent applications of nitrogen and potassium fertilizers to ensure high production The soils also need calcium but seldom as much as the low pH would suggest

Tropeptic Eutrustox

The soils that will be used in Hawaii to link with Puerto Rico are members of the *clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox* These are well-drained, red, upland soils of subhumid regions Natural vegetation is savanna, deciduous forest or semideciduous forest In Hawaii they are highly productive soils when properly managed and are used almost exclusively for the production of sugarcane under irrigation and pineapple

These soils have not yet been found by the project in Asia, but they are expected to be common in Africa

The soils are developed in residuum or

old alluvium from basic rocks. They are nearly level to moderately steep The rainfall tends to be concentrated in a rainy season

These soils have surface layers dark reddish brown to dark red in color, sandy clay loam to clay in texture, and moderate to strong in structure The subsoils are similar to the surface soil in color and texture but are generally weaker in structure Mean soil temperatures are 22° C or higher at 50 cm, and the mean summer and winter temperatures differ by less than 5° C The soils are moderately acid to neutral throughout

Cation exchange capacities are low, base saturations are higher than 50% Organic matter is moderate to low The soils are high in kaolin minerals and iron oxides

The soils have physical conditions that are excellent to good for plant growth, although heavy equipment can cause compaction in the subsoil The heavy textures make plowing difficult The soils are well supplied with many nutrients, but they require fairly high phosphorus and nitrogen fertilization for maximum yields Much of the phosphorus is fixed when first applied but continues to be available to plants slowly over many cropping seasons The soils need at least supplemental irrigation for maximum use

Tropohumults and Tropudults

The extensive red upland soils in the humid regions of tropical Asia are Ultisols, which are acid soils that have red, clayey, and dense subsoils In the warmest parts of these regions, the soils belong to the great group of Tropudults Where the temperature regimes are cooler and where there is more humus in the profile, they belong to the great group of Tropohumults

The soils are underutilized because problems in their management have not been solved Several countries have asked the project to concentrate to some extent on these soils

Surveys of these soils generally have not been detailed enough to provide data for soil family classification Much soil survey and characterization work will be required before suitable benchmark sites can be located on these soils

The Experimental Work of the Project

The types of experiments to be conducted in the project were established at a workshop entitled Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs, held in Honolulu in May 1974 (Silva and Beinroth, 1975) The three experiments that will be used are transfer, variety, and management

Transfer experiments

Using only two variables, the transfer experiments for testing the hypothesis of transferability will be kept very simple The variables will be related to characteristics of the soil family P × pH and N × P were two treatment combinations suggested The same treatment combination will be used in all sites of the same family, but treatment combinations may differ among families The variables may also be those that are expensive to control, so that results from the experiments may have greater immediate economic value

To keep the experiments manageable and yet obtain sufficient information to develop production functions, five levels of the factors will be used A wide range of the factors is more important than many levels The anticipated optimum level should be near the middle of the range of levels selected The experiments have been designed so that all other controllable factors—that is, irrigation, other nutrients, plant protection, and plant density—are maintained near optimum levels so that treatment effects will be clear

Three replicates of each transfer experiment will be set out at each site The cost of replicates is small in comparison with the cost of selecting and establishing the site, and many things can affect the survival of experimental plots

The experimental design to be used in all transfer experiments is a 5^2 partial factorial developed by Escobar and described in the paper by Laird and Turrent of CIMMYT, as presented at the 1974 workshop by Silva and Beinroth. The design was chosen because of (1) its appropriateness for use in a graphic

estimation of economic optima, (2) its relatively small bias error, (3) its number of treatment combinations, (4) its flexibility in number of factors and number of levels of each factor, and (5) its relatively small variance error The design with its 13 treatments also has good coverage of the factor space

Variety experiments

The "best adapted local variety" has been decided upon to serve as the test crop in the transfer experiments For comparative purposes, yield experiments on all the varieties will be necessary in several places on primary sites Randomized block designs will be used in these experiments Where there is doubt about the best adapted variety for a location, some preliminary variety experimentation may also be necessary

Management experiments

Management experiments on maize will be installed at each primary site in each country The objectives of these experiments will be to provide (1) information to local governments about ways to increase production by improved availability and utilization of resources and (2) basic information to local farmers who have limited resources about ways to increase their yields Management variables to be investigated, each at two levels (one with variables and one without variables), will probably be irrigation, lime, weed control, insect and disease control, nitrogen, phosphorus, and potassium Details of the management experiments and other research to be conducted will be worked out with each participating country

Benchmark sites

Primary Sites

A primary site is being established on each soil family in each country All transfer, variety, and management experiments will be conducted at the primary sites The primary site, which will be in use throughout the duration of the project, will need to be 5 hectares or larger to provide sufficient land for the many experiments envisaged, and it should be located at a university or a government research station Complete weather stations and adequate storage (including water storage) and office facilities will be established at each primary site where these do not already exist

Secondary Sites

The transfer experiments will be conducted at three secondary sites on one of the soil families in a country The workshop (Silva and Beinroth, 1975) determined that this was necessary to test fully the transfer hypothesis and to account for significant, uncontrollable variables Weather instruments at each secondary site will record daily rainfall, daily sunshine, and maximum, minimum, and average temperatures The secondary sites will need to be as large as 1 hectare and be available for 2 years They will be fenced, but not otherwise equipped, except for water-storage facilities where needed

Climate Records

Climate is an uncontrolled variable in the design of agronomic experiments Hence, it is essential that significant climatic variables be measured at each experimental site to have meaningful transfer of agrotechnology from one site to another Temperature, rainfall, relative humidity, solar radiation, wind direction, and wind speed will be monitored at each primary site, and temperature, rainfall, relative humidity, and solar radiation at each secondary site Soil temperature and pan evaporation may be measured

Meteorological instruments have been selected for reliability, accuracy, and low maintenance A self-contained, battery-operated mechanical weather station (Model 755W) from the Weather Measure Corporation of Sacramento, California, is under test for probable installation at each primary site This weather station is capable of recording changes in temperature, relative humidity, rainfall, wind direction, and wind speed simultaneously and continuously on a strip-chart recorder Solar radiation will be monitored by a wig-wag radiometer manufactured by Beckman Instruments exclusively

for the Hawaiian Sugar Planters' Association. The wig-wag radiometer operates on solar energy and has been in use for many years in Hawaii A hygrothermograph, a standard, recording rain gauge, and a wig-wag radiometer will be installed at each secondary site.

Land Capabilities

The soils data, soil characteristics, yield data, and climatological data will be processed by methods of multivariate analysis to determine the desired land potential, land capabilities, and transferability information Local yield data and land-capability information where they exist will probably be included in the data base to improve the quality of yield predictions at various levels of the soil classification to cover a larger group of soils than will be represented by the benchmark soils network

Where similar soil indexes of production capabilities are determined by analysis, the information will be translated directly through the soil linkage, as a first approximation to production targets for these soils occurring in other tropical and subtropical lands

Expected Results

It is expected that the project will demonstrate that management systems implemented on one soil in one region can be transferred to the same soil in any other region

The land-capability schemes developed for the countries of the network should indicate suitabilities of different regions for development under high, medium, or low levels of input, and the probabilities for success of the information transfer from the network This information will be available for incorporation into the development plans of cooperating nations The project expects to work closely with national planning staffs to insure that they are able to communicate to the project their needs for soils information.

The project will also be able to provide some training for cooperating professional staffs and students. Annual meetings of the project staff and counterpart staff will be held to ensure uniformity of technique, to discuss experimental results, and to plan future experiments Project workshops will also be held to acquaint appropriate officials of cooperating countries with the purposes and benefits of the project and the specific and generalized results

Fellowships will be offered to students from cooperating countries They will receive academic training at the University of Hawaii and field experience on the experimental sites in their home country

Probable Limitations

Soil surveys that have sufficient characterization information to allow classification at the family level are not common in the tropics The Hydric Dystrandepts are comparatively easy to find in the field, and the criteria for family classification are easy to obtain But the Tropeptic Eutrustox and the Tropohumults are more difficult to locate accurately and characterize Only if cooperating countries are willing to provide the necessary soil-survey inputs will it be possible to include these important and often difficult-to-manage soils in the project

The classification of tropical soils in the Soil Taxonomy is not as certain as the classification of temperate soils Early results of the project may provide more information about criteria for classification than about technology transfer

Although the experimental designs for the transfer experiments are not complex, strict supervision of field plot work will be needed to obtain sound scientific data. The total number of experiments must be large enough to reduce the errors to a manageable size

Experimental crop yields are likely to be several times more than local yields and related to impressive amounts of agricultural inputs including irrigation Only more advanced farmers will be prepared to make the efforts needed to achieve comparable results. Only the wisest of national planners will appreciate that experiments on a high-manage-

ment level are *necessary to prove the hypothesis* and that such experiments do not imply that only high-management-level technology is transferable

It should be recognized that transferred technology can only relate to production targets Many social and economic questions will need to be answered before production targets become production realities

The Soil Research Network

The soil research network that AID supports can be established through formal administrative structures and arrangements or through cooperative, technical linkages between interested institutions using the soil family as the basis Whatever merits the former has, the latter is undoubtedly simpler, does not require intergovernmental agreements, and can be established almost immediately It can be implemented by expanding the network of benchmark soil locations or by classification, at the family level, of the soils of existing agricultural research stations

Expanding the Benchmark Soils Network

Project families in other countries

The three or more soil families that are or will be part of the project undoubtedly exist in more countries than the three that will be cooperating fully with the project Countries where these soils are located and countries that have suitable sites established can be added to the network The Benchmark Soils Project, to the extent allowed financially, will entertain requests for extending the network and will assist in equipping the sites, in carrying out transfer, variety, and management experiments, and in training cooperating staff

Additional benchmark families

We feel that, as the value of the soil family concept becomes evident, the cooperating countries would wish to extend the approach to other soils. The project will assist in designing and installing experiments on additional closely related benchmark families, particularly in relation to soils that are important in the country's development plans but are not in the soil families receiving initial attention

It should be easy to add families that vary only slightly from the project families and in which the cause of the variation has a predictable effect upon crop production This would include, for example, the isohyperthermic or isomesic families of Hydric Dystrandepts, for which the effect of the variation—in mean, annual soil temperature—on crop production can be computed It would also include, in relation to the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox, the parallel family of Eutrorthox, in which the variation from a seasonally dry to a usually moist climate is likely only to increase the reliability of good crop yields without irrigation

It would probably not include a change from Tropeptic to the parallel family of Typic Eutrustox Typic soils in this great group have deep oxic horizons that have a very weak structure and generally occur on very old surfaces Tropeptic soils have shallower oxic horizons that have a noticeable structure and occur on younger surfaces, usually over basic or intermediate rocks We do not know enough about these variations to be able to predict satisfactorily what they mean to crop production It is possible, at least in principle, to determine the effect experimentally, but this work would need to be undertaken separately from the project

Classifying Soils of Existing Agricultural Research Stations

The soil scientists who participated in the 1976 seminar in Hyderabad were requested to bring with them information about the soils of the main agricultural research stations of their countries We hope to use the information to classify the soils of the stations at the family level The family classifications of the soils at the main research stations in Hawaii and the soils at ICRISAT are

Table 1. Soil family classification of soils at ICRISAT

Fine clayey, montmorillonitic, isohyperthermic Udorthentic Chromustert
Clayey, mixed, isohyperthermic Rhodic Paleustalf
Fine loamy, isohyperthermic Fluventic Eutrochrept
Fine loamy, mixed, isohyperthermic Fluventic Haplaquept
Clayey, mixed, isohyperthermic Ultic Paleustalf

Table 2 Soil family classification of soils at the main agricultural research stations in Hawaii

Research station	Soil family and subgroup	Mean air temperature (°C)	Annual rainfall (mm)	Elevation (meters)
Wailua, Kauai	Clayey, ferritic, isothermic Typic Gibbsihumox	23	2489	162
Poamoho, Oahu	Clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox	24	1118	200
Waialee, Oahu	Very fine, montmorillonitic isohyperthermic Typic Pelluderts		1016	12
Waimanalo, Oahu	Very fine, kaolinitic, isohyperthermic Vertic Haplustolls			
	Fine, mixed, isohyperthermic Cumulic Haplustolls	24	1524	24
Haleakala, Maui	Clayey, oxidic, isothermic Humoxic Tropohumults	18	2007	610
Kula, Maui	Medial, isothermic Typic Eutrandepts	18	762	914
Lalamilo, Hawaii	Medial, isothermic Typic Eutrandepts	19	762	762
Mealani, Hawaii	Thixotropic, isomesic Hydric Dystrandepts		1422	853
Hamakua, Hawaii	Thixotropic, isomesic Hydric Dystrandepts Thixotropic, isothermic Typic Hydrandepts		2540	853-671
Volcano, Hawaii	Medial over thixotropic, isomesic Typic Hydrandepts		4648	1219
Waiakea, Hawaii	Duic, isohyperthermic Typic Tropofolists Dysic, isohyperthermic Lithic Tropofolists	22	4000	160

shown in Tables 1 and 2. If similar soil classifications are made at many other agricultural research stations, we will have the technical base for a soil research network throughout the tropical world.

The Uses of the Soil Research Network

The soil research network based on soil families will:

1. Improve communication between researchers and planners in different countries working under similar soil and environmental conditions
2. Increase the value of published data, reports, and regional development plans.
3. Provide the bases for cooperative research on soil and water management and on crop responses to manufactured inputs.
4. Be useful in designing experiments

to ascertain crop responses to the variables that constitute soil family criteria.

5 Provide in-country type locations for soil classification
6 Aid in refining soil family criteria for the tropics and in testing the general usefulness of the soil family concept for land-use planning and development

Assistance from the Benchmark Soils Project in Establishing the Soil Research Network

The Benchmark Soils Project will be able to

1 Assist in classifying the soils at the family level, including analytical work to fill in missing data where needed
2 Publish and distribute a compilation of the soil family data obtained
3 Store the data in the University of Hawaii Soil Data Bank and provide free access to the Bank to all contributors
4 Assist, if required, in establishing contacts between countries that have similar soils
5 Make arrangements to incorporate published reports of research performed at the stations of the network in the University of Hawaii's Bibliographic Information Retrieval Service for Tropical Agriculture and provide access to that service for contributors
6 Advise on the various research projects outlined under The Soil Research Network in this paper, and on the Fertilizer INPUTS Project of the East-West Center's Food Institute

This assistance can be provided from existing funds of the Benchmark Soils Project If additional funding were obtained, it would be possible to develop stronger linkages and communication through exchange of visits, seminars, and workshops, to provide training in soil classification in Hawaii and elsewhere, and to assist in implementing cooperative research projects and organizing meetings for the discussion of research results The University of Hawaii has made no attempt to ascertain whether such funds are available but would be willing to do so if the response to this proposal for a soil research network is favorable

The Critical Assumption

The critical assumption behind this proposal is that the soil family level of the U S *Soil Taxonomy* is usable in technology transfer In a sense, the proposal assumes the correctness of the hypothesis that the Benchmark Soils Project is testing

This is not necessarily unsound We accept as axiomatic that technology cannot be transferred from temperate to tropical regions We recognize, that is, a need to stratify the environment in a statistical sense to improve the accuracy of communications about agricultural technology The FAO used a form of environmental stratification in recent years, when it conducted two meetings to examine agricultural research needs and progress in the Sudanian and the Guinean zones of Africa These two broad ecological terms include considerable ranges of soils and climatic conditions Much food aid has been provided to countries in yet another of these broad African ecological zones, the Sahelian zone, where severe droughts in 1973 and 1974 caused much misery and loss of life

The soil family is a form of ecological stratification at a much finer level of subdivision than the Sahelian, Sudanian, and Guinean zones It may in some respects be too fine, but this should not cause any problem Examination of research results from several stations in related zones over a period of time will soon reveal whether less subdivision, equivalent to higher orders of the Soil Taxonomy, will suffice Certainly it is much better to define the ecological circumstances in which research is undertaken than to assume, as is often done, that all agricultural research in the tropics has wide applicability Our proposal, if carried out, will put us far ahead of others less ecologically minded.

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PART VI: SPECIAL PROBLEMS OF THE SEMIARID TROPICS

Use of Soils Information in Planning Agricultural Development in the Semiarid Tropics

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The semiarid tropics (SAT) located in the seasonally dry tropical climates, are spread over four continents occupying all or part of 48 countries On an average, about 34% of the total land area in 48 countries is in the SAT, the total area of which is estimated at about 19 6 million km²

Alfisols Vertisols Entisols Inceptisols and Oxisols are most widespread in the SAT These soils are briefly described in the paper Water is the most dominant natural constraint to increased and stabilized agricultural production in these areas The severity of this constraint is amplified by the great diversity in physicochemical and biological properties of the soils of the SAT Two examples are given to illustrate the effect of soil-water storage capacities on soil moisture profiles and estimated runoff amounts based on the long-term climatological data of Hyderabad (India) To stabilize production particularly in low and medium moisture-storage-capacity soils, it may be necessary to collect and store runoff and to recycle the water at an appropriate time The major goal of the ICRISAT research is to evolve land- and water-management techniques, which along with improved crop technology will increase and stabilize agricultural production

Agricultural development planning signifies the scientific improvement of the agricultural infrastructure of a locale in its various facets Of the many interacting factors, the environment soils and socioeconomic situation play major roles in the agricultural development The role of soils in agricultural development has been appreciated since time immemorial This is evident even today in the population concentrations in relatively agriculturally productive areas of agrarian societies

In appraising the productivity of the soils of an area, one needs to have a fair knowledge of the kinds and distribution of the soils, their input requirements, and their relative responsiveness to the input applications The prediction of the input needs and expected output requires information on soil properties and their relationship to the application of technology The specificity of the predictions depends upon the homogeneity of the soil unit that serves as a basis for such projections

We now recognize that the more we base our reasoning on accepted principles of the soil's behavior in response to management manipulations, the more dependable are the results likely to be If the soil properties physical, chemical, and biological are ignored during either general or detailed plan formulations, not only will obstacles arise in plan implementation but also irreparable damage may be done to the land and water resources A fairly detailed operational soil survey, therefore, is one of the soundest investments of public funds

Soils of the Semiarid Tropics

The semiarid tropics (SAT) are the areas located in seasonally dry tropical climates, spread over four continents occupying all or part of the land mass of 48 countries The total area of the SAT is estimated at about 19 6 million km² On an average about 34% of the total land area in these 48 countries is semiarid tropics (Ryan et al , 1974) The soils of the SAT show great diversity in physicochemical and biological properties These variations have a significant effect on their soil-air-water relationships, water-holding movement, and release characteristics, drainage properties, and responsiveness to soil management and manipulation It is not feasible to describe all kinds of soils occurring in the SAT However, some soil types are more widely spread throughout and are briefly summarized below

The Red and Grey Soils

The red and grey soils (Alfisols) are moderately well drained and have a reasonable hydraulic conductivity The texture of the surface soil ranges from stony to sandy and loamy in the pale yellow and light red groups and from loamy to clayey in the deep red and grey groups (Rayachaudhuri et al , 1963) The clay in the red soils is predominantly of the kaolinitic, nonswelling type

The depth of the surface soil may vary from 0 to 30 cm, often underlain by a more clayey subsoil This layer is in turn underlain by a gravelly disintegrated rock subsoil called *murrum* The total depth of the profile may vary notably, and this has a great impact on moisture retention and other important crop production factors In the dry season, these soils are difficult to cultivate because of surface hardness These soils are susceptible to sheet erosion, particularly on the steeper slopes The moisture-storage capacity of a red soil profile is generally less than 150 mm and may be sufficient to support a standing crop for only 2 to 4 weeks, and normally only a monsoon crop is grown (Swaminathan, 1973)

The red soils are usually developed from ancient granites or gneisses The soils are weathered and leached and thus low in all bases Because of the type of parent material and soil-formation processes under SAT conditions, the soils are usually low in nitrogen, phosphorus, and sometimes zinc The potassium level is usually medium to high The pH ranges from 5 5 to 7 0 These soils cover the largest area of the semiarid tropics and are found extensively in India (72 million hectares) and also in many other semiarid tropical regions e g , in Angola, northeast Brazil, north Cameroon Chad Dahomey Ghana, Mali, northern Nigeria Sudan Togo, Upper Volta, and Zambia (Cocheme and Franquin, 1967, FAO, 1974)

The Black Soils

The black soils (Vertisols) are usually poorly drained and possess a low hydraulic conductivity The texture of the topsoil is always clayey (40 to 60%), the clay being of the montmorillonitic type characterized by pronounced shrinkage during drying, resulting in extreme cracking and swelling during wetting The black soils are hard in the dry season, muddy and sticky in the wet season, and difficult to cultivate without perfect water control Erosion is a serious problem on these soils, particularly under cultivated fallow

The profile of these soils is of varying depth (30 to 180 cm) The subsoils are mostly clayey but sometimes sandy (Cocheme and Franquin, 1967) Lime is usually present either in a diffused form or as small concretions The quantity of lime and lime concretions normally increases with depth in the profile Iron and magnesium concretions are often also present On shallow black soils only a monsoon crop is grown, whereas on a deep black soil a postmonsoon crop is usually grown

The black soils are often referred to as self-mulching because repeated wetting and drying cause clods to crumble into small aggregates forming a surface mulch They are also referred to as being self-swallowing because the surface mulch falls into the deep cracks and becomes incorporated into the

subsoil After the soil is rewetted, the resulting pressures cause the formation of slickensides and a heaving of the soil blocks between the large cracks Black soils (also called black cotton soils) are formed from a variety of rocks that includes traps, granite, and gneiss, particularly those rich in lime feldspars Thus they are usually rich in bases including potassium, calcium and magnesium The pH ranges from 7 0 to 8 5, and the lime content from 1 to 10% Because of their formation under SAT conditions, the soils are low in organic matter (0 4 to 0 8%) and are usually deficient in nitrogen, phosphorus, and sometimes zinc About 64 million hectares of black soils are found in India, these soils also occur for example in the central delta of the Niger, and in Chad Dahomey, Senegal, Upper Volta and Sudan

The Alluvial Soils

The alluvial soils (Entisols) are extremely variable in moisture-retention release and drainage characteristics They are found in existent or former river valleys (the latter particularly in the SAT of West Africa) The texture of the surface soils may range from drift sands to loams and from silts to heavy clays These soils usually possess good physical qualities are easily tilled and are moderately permeable The water-holding capacity is relatively low compared with that of the black soils These soils are usually low in organic matter and are deficient in nitrogen and sometimes low in phosphorus and zinc Potash may also become deficient after prolonged intensive cropping Large-scale gravity irrigation and tubewells are often found in the river valleys and this has in some places resulted in problems of salinity and alkalinity The areas with large irrigation projects are not within ICRISAT's area of concern

The Sandy Soils

These soils (Inceptisols) are very sandy (often drifting sands) and thus lack the water-holding capacity needed to support plant life through prolonged dry periods The sandy soils are easily workable but subject to wind erosion These soils are found extensively south of the Sahara in Mali, Mauritania Niger, Sudan and Chad, they also occur in South-West Africa and Botswana

The Lateritic Soils

The lateritic soils (Oxisols) are well drained with a satisfactory hydraulic conductivity The texture of the topsoil is loamy or clayey with many concretions, and the clay is of the kaolinitic or illitic type The topsoil is of varying depth underlain by laterite (ferruginous deposits, hardening on exposure) In some areas the topsoils have been eroded leaving behind a slaglike mass Trees and shrubs are often found on these soils, at low elevations, however, monsoon food crops are also grown Lateritic soils are generally associated with undulating topography in regions that have a relatively high average annual rainfall They cover 13 million hectares in India and fairly extensive areas in Chad South Mali, Niger, Nigeria, Upper Volta, and other countries

Water, the Major Physical Constraint

The basic characteristic of crop production in the SAT is that crop production is carried out under a wide spectrum of soil moisture regimes, ranging from seasons that have below average conditions to those that have an adequate moisture supply Water is the most dominant natural constraint to increased and stabilized agricultural production in these areas The severity of this constraint is amplified by the great variability of soils, which (as described earlier) range from coarse sandy soils, having limited water-holding capacity, to heavy clayey soils, having an appreciable water-holding capacity The soils vary in depth from a few centimeters to several meters

In recognition of the fact that water is the major natural constraint to increased and stabilized agricultural production in the SAT, the major goal of ICRISAT research is the development of land and water management

Table 1 Medians, quartiles, and deciles (probability levels) of available soil moisture (mm) in three soils having variable water-holding capacities, Hyderabad, 1901–1970

Period and time of year	Soil[a]		
	Shallow	Medium	Deep
Commencement of the kharif crop season			
Week 27 (July 2 to July 9)			
First decile	4	33	34
First quartile	8	47	49
Median	16	66	72
Third quartile	28	91	100
Ninth decile	43	118	130
Middle of the kharif crop season			
Week 33 (Aug 13 to Aug 19)			
First decile	7	67	128
First quartile	12	83	158
Median	22	104	196
Third quartile	36	128	230
Ninth decile	52	153	285
Commencement of the rabi crop season			
Week 44 (Oct 29 to Nov 4)			
First decile	0 4	47	149
First quartile	2	61	174
Median	7	80	204
Third quartile	19	102	238
Ninth decile	36	125	272
End of the rabi crop season			
Week 8 (Feb 19 to Feb 25)			
First decile	0	3	39
First quartile	0	5	49
Median	0 1	10	62
Third quartile	1	17	76
Ninth decile	4	25	91

[a]Approximate available water-storage capacity 50, 150, and 300 mm, respectively

Table 2. Relationships between variables and runoff for black-soil catchments (ICRISAT)

Variables included in regression models	R^2
1. $(\text{Rain})^2$[a]	0 85
2 $(\text{Rain})^2 \times$ (cumulative rainfall)	0 86
3 As in (2), ($\text{rain}^2 \times$ slope), ($\text{rain}^2 \times$ land condition), and ($\text{rain}^2 \times$ vegetative cover)	0 88
4 As in (3), ($\text{rain}^2 \times$ rainfall intensity)	0 88
5 $(\text{Rain})^2$, ($\text{rain}^2 \times$ soil moisture), ($\text{rain}^2 \times$ slope); ($\text{rain}^2 \times$ land condition); and ($\text{rain}^2 \times$ vegetative cover)	0 88
6 As in (5), ($\text{rain}^2 \times$ rainfall intensity)	0 90

SOURCE Subrahmanyam and Ryan, personal communication, 1976

[a] Rain = rainfall per day

techniques to sustain productive cropping systems. Special emphasis is being placed on the collection, storage, recycling, and efficient utilization of runoff water on a catchment basis (Krantz and Kampen 1976).

In the following pages, two examples are given to illustrate the effect of soil-water-storage capacities on soil-moisture profiles and estimated runoff amounts, based on long-term climatological data for Hyderabad (India).

A water-balance model to give estimates of week-to-week changes in available soil moisture was designed with the aid of computer processing using estimated mean weekly evapotranspirational withdrawals and actual rainfall inputs. The assumptions made in applying the model are that actual evapotranspiration is proportional to the amount of available soil moisture and that maximum loss occurs when the soil has water at field capacity. Soil-moisture-holding capacities (available water) have been assumed as 50, 150, and 300 mm in the root profiles of shallow, medium-deep, and deep soils, respectively.

Table 1 shows that at the commencement of the kharif[1] season, the shallow soils are likely to contain much less available water compared with medium or deep soils. This has implications in relation to seedling survival in cases of occurrence of drought early in the season. Similarly, in the middle of the kharif crop season, the drought probabilities are high. The data show that the chances of drought injury to crops are likely to be in the order shallow > medium > deep soils. The crops selected for each of the soils will, therefore, be different, as will the production stabilities.

During the rabi[2] cropping season, there is little rainfall at Hyderabad, and crops are grown primarily on conserved moisture. The evapotranspirational requirements for most rabi crops are estimated to range between 200 and 300 mm. Obviously, rabi cropping is not feasible in shallow and medium deep soils (without supplemental water), although it is distinctly possible in deep soils in most of the year. Table 1 also shows that for achieving optimum water-use efficiency, the crop or genotype may have to be changed to suit the variable soil-moisture status.

For stabilizing production, particularly in the low and medium (< 150 mm) soil-moisture-storage capacity soils, it may be necessary to collect runoff and recycle the water at appropriate times. A number of factors affect the amount of runoff. Subrahmanyam and Ryan (1976, personal communication) have carried out a preliminary study, based on data of 1973 and 1974 for various catchments at the ICRISAT research center, for evaluating the influences of rainfall, antecedent soil moisture, land condition, slope, and vegetative cover on runoff. The results show that of the three multiple regression models used [linear, quadratic (with intercept term), and quadratic interaction (with no intercept term)], the last one gave by far the highest R^2 values. R^2 values with this model were not substantially improved when variables in addition to rainfall were added to the models (Table 2). These authors did not compare different soil types, but it is evident that soil type and rainfall play dominant roles in determining runoff.[3]

Based on the above information, we estimated runoff values for two soil types (low and medium to high water-holding capacity), using long-term (1901–1970) rainfall records for Hyderabad (Table 3).

Table 3 shows that the amount of runoff is substantially higher in soil that has low water-holding capacity compared with a soil that has medium to high water-holding capacity. Obviously, the size of the tank (maybe its design) would be different for these two

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[1] *Kharif*: Crop-growing season during hot and humid monsoon months.

[2] *Rabi*: Crop-growing season during cool and dry winter months.

[3] This is just an illustration. The data pertain to a cultivated situation where some of the crops were grown on ridges under optimum agronomic conditions having a moderate slope < 1%. The seasonal rainfall was 750 and 800 mm for the years 1973 and 1974 respectively. Data for some other locations to be evaluated if the same general results are obtained are being analyzed by Subrahmanyam and Ryan.

Table 3. Estimated runoff in two soils having variable soil-moisture-holding capacities (Hyderabad, 1901–1970)

	Water-holding capacity[a] (mm)					
	Soil A: low		Soil B medium-high		Rainfall (mm)	
ANNUAL						
First decile	24		2		549	
First quartile	59		5		648	
Median	134		39		772	
Third quartile	257		154		911	
MONSOON PERIOD	Median	Mean	Median	Mean	Median	Mean
May 21 to June 17	0.1	1	0	0	42	57
June 18 to July 15	1.1	15	0 1	4	122	132
July 16 to Aug 12	6 8	45	1 5	26	141	154
Aug 13 to Sept 9	6 9	44	3 2	33	125	141
Sept 10 to Oct 7	9 9	63	6 0	54	123	145
Oct 8 to Nov 4	0 7	14	0 3	7	27	64

[a]Low = ca 50 mm available water-holding capacity in the root profile, Medium-high = at least 150 mm available water-holding capacity in the root profile

soils An estimate of the lower values of the amount of water (medium and mean) for different months shows the relative amount of runoff water expected at different periods during the rainy season This information, coupled with the crop phenology and water requirements at different stages of growth, can be immensely useful in crop planning and in devising midseason corrections in case of drought.

Considerations in Selecting the Location of ICRISAT

Soil and climate were two of the major criteria in choosing the location for the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) The two major soil groups of the SAT are the red and grey soils (Alfisols) and the black soils (Vertisols) Fortunately, the ICRISAT location has extensive areas of both of these important soil groups, ranging from shallow to deep profiles These soils also represent a wide range of water-holding capacities, from 300 mm in the root profile (about 180 cm) in the deep black soils to 100 mm or less in the shallow red sandy soils The slopes range from 1 to 4%, the span normally encountered in cropland areas Having extensive areas with each of these conditions at ICRISAT, research workers are able to simulate many conditions that exist in the semiarid tropics Water utilization research conducted on an operational scale in the natural catchments at ICRISAT provides an opportunity to develop principles and determine parameters of the soil and climate resources, which are most necessary in developing sound soil and water management systems in any given region The information, along with crop information and socioeconomic parameters, will help provide the guidance necessary to implement the most effective resource development for increasing and stabilizing agricultural production.

Need for Benchmark Locations

In the future, ICRISAT plans to establish research programs, in cooperation with national institutions in various countries, to represent SAT soils and rainfall patterns that are distinctly different from those of the ICRISAT center These benchmark locations are also essential to represent the wide diversity of people and socioeconomic conditions These locations will be chosen only after thorough investigation of the various factors involved to represent the SAT with a minimum of locations As in the case of the ICRISAT center, the basic principles of soil and water management will be emphasized

Information on soils and their characteristics is essential to develop improved soil, water and crop management systems These, when integrated with improved varieties, fertilization, and plant protection, can aid in developing economically viable farming systems, which can increase and stabilize agricultural production in the SAT

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Soil and Water Management in the Semiarid Tropics

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Undependable rainfall is the major cause of low crop yields and unstable agricultural production in the semiarid tropics (SAT)

Population increases in recent years have caused expanded cropping into steep and unsuitable land, overgrazing, and forest denudation This has resulted in greatly increased runoff, soil erosion, downstream flooding of cities and agricultural lands, sedimentation of reservoirs, low and unstable crop yields, domestic water shortages, scarcities, famines, and other forms of human tragedy

In the SAT, although enormous sums of money are being spent in various types of disaster relief programs to reduce starvation and human tragedy during the recurring drought periods research money spent per unit of production in the SAT is much less than that in any other agroclimatic region of the world

Past approaches to improved soil and water management and conservation such as fallowing, mulching, traditional bunding, and projects for full irrigation of small land areas have not provided the basis for increased food production in the vast areas of the SAT

Preliminary results from national programs in the SAT and from ICRISAT indicate that improved resource utilization, along with improved technology applied to all phases of crop production, is a great potential for generating economically viable farming systems capable of increased and stabilized agricultural production

Rain-fed agriculture has failed to provide even the minimum food requirements for the rapidly increasing populations of many developing countries in the semiarid tropics (SAT). Although the reasons for this are many, a primary constraint to agricultural development in the seasonally dry tropics is the lack of suitable technology for soil and water management and crop production under the undependable rainfall conditions The severity of the constraints is amplified by the generally high evaporative demands and, in many areas, soils of shallow depth that have limited water-holding capacity

In many areas the total precipitation is sufficient for one, and in some cases two, good crops per year However, the rainfall patterns are erratic and brief, or extended droughts are frequent Much of the rain occurs in high-intensity storms resulting in runoff During the rainy season, the storage capacity of the root profile is sometimes exceeded resulting in percolation of water to deeper layers or ground water

This situation has resulted in unstable food production and continually low yield levels in much of the SAT Because of the uncertainties and the ever-present risk of droughts, the farmers in the SAT have been reluctant to adopt the use of available high-

yielding varieties, fertilizers, and other inputs Thus there is an urgent need for new techniques of resource management that will effectively conserve and utilize the soil and water, along with the development of production systems that will increase yields and stabilize production

Because the population of many areas in the SAT doubled in the past 35 years, farmers have attempted to double agricultural production But because there has been no appreciable increase in per-hectare yields during this period, near doubling of the cropped areas and livestock numbers has resulted Thus steeper and more erodable lands are being overcropped and overgrazed and forest lands are being denuded Studies in India show that a higher proportion of land is cropped in the SAT than in the rest of the country (Anon 1970) This situation, along with high rainfall intensities has resulted in increased runoff and soil erosion, reduced groundwater recharge in the upper reaches of watersheds, downstream flooding of cities and agricultural land, greatly accelerated sedimentation of tanks and large reservoirs, and the loss of precious water to the seas

Approaches to Soil and Water Management in the SAT

Until recently, the research and extension approach in much of the SAT was patterned after the "dryland agriculture" of the temperate climatic zones At first glance this would seem logical, however, a careful investigation reveals many differences and few similarities between the two zones Although it is recognized that the SAT is not a homogeneous area as there are climatic, soil and socioeconomic differences, there are also many characteristics that prevail throughout the area These characteristics include the following

- Intensive rainfall interspersed with unpredictable droughts
- Relatively short rainy seasons
- High evapotranspiration rates, particularly during dry periods
- Highly variable rainfall during the wet season
- Low soil organic matter content
- Low infiltration capacity of soils
- Great water-erosion potential
- Small farms having many small fields
- Limited capital resources
- Mainly animal or human labor-power sources

Scientists at ICRISAT and in some of the national programs are studying these and other characteristics of the SAT as a basis for developing improved resource management, conservation, and utilization for increased and more stable agricultural production

Water is the major natural constraint to increased and stabilized agricultural production in the SAT Alleviation of the effects of this barrier is the ultimate aim of the Farming Systems Research Program at ICRISAT and has been the central focus for the initial activities This goal can be accomplished (1) by providing optimum conditions for monsoon and postmonsoon cropping through proper management of the soil and of all the precipitation that falls on the land and (2) by better utilizing the improved environment through more productive cropping systems In many areas this may require the collection and storage of surface runoff and efficient utilization of runoff water and ground water by means of a watershed

The purpose of this paper is to describe the setting and present situation in the SAT and to discuss approaches to developing systems for improved management of the natural human and capital resources of the SAT Although we recognize the importance of the development of new high-yielding varieties and a whole system of crop-production technology for the SAT, we will not discuss it in this paper Likewise, there are many socioeconomic problems that must be investigated and understood if technology is to be adapted to the farmers' situations Improved soil and water technology can be of significance only through economically viable systems of production The problems faced by farmers in the SAT are such that an interdis-

ciplinary approach is absolutely essential for securing tangible results

Preliminary observations indicate that the productive potential of land and water resources can be raised substantially in many regions of the SAT This can provide the basis for increased and more stable production and for a better life for the 400 to 500 million people of the SAT Since food shortages are already being experienced in these areas, the time required for research and implementation must be minimized

The Setting

The SAT is an extensive area and represents considerable diversity Below is our preliminary attempt at characterizing the environment of the SAT, so essential to conducting effective research Much additional work will be necessary to arrive at more precise and specific delineations and descriptions of the major areas of concern

Climate and Precipitation

Definition of the SAT

Semiaridity has been defined in various terms It is essential to realize that most of the earlier definitions by Meigs (1953), Thornthwaite, etc were derived with specific attention to the more temperate arid and semiarid regions The conventional, quantitative description of semiaridity is not valid for many tropical regions for the following reasons

1 The length of time that precipitation occurs is not considered
2 The lower limit of the rainfall in tropical semiarid areas becomes unacceptably high
3. An extreme discrepancy exists between quantitative and qualitative descriptions of semiaridity for tropical regions

Troll (1966) more recently described semiarid areas by a number of classes as follows

V3 Wet and dry tropical climates that have 4 5 to 7 "humid months"[1] ($P \geq PE$) and 5 to 7 5 "arid months"[2] ($P < PE$)
V4 Tropical dry climates that have 2 to 4 5 humid months in the warm season and 7 5 to 10 arid months
V4a· Tropical dry climates that have the humid months in the cooler season

Thus, Troll's classification, when summarized, defines the tropical semiarid regions as those that have from 5 to 10 arid months and conversely from 2 to 7 humid months Troll's classification has been accepted as the general climatic description of the world region of concern in ICRISAT's Farming Systems Research Program In certain areas of this region, sorghum and millets occupy a favorable competitive position in present food production systems, primarily because of the distribution and amounts of precipitation and the evapotranspiration patterns These areas will receive primary attention Other areas in which sorghum and millets have not yet found an important place but are needed and can be expected to compete well should also be examined The SAT regions of the world according to the classification by Troll (1966) are shown in Figure 1

Precipitation

When a world map of isohyets is studied, yearly precipitation in the regions classified as semiarid according to Troll (1966) appears to vary from approximately 500 to 1,500 mm. Areas in the cooler tropical regions that have somewhat less than 500 mm of precipitation would probably still be considered semiarid.

Cocheme and Franquin (1967) published

[1] "Humid months" are those in which precipitation equals or exceeds the potential evapotranspiration ($P \geq PE$)
[2] "Arid months" are those months in which potential evapotranspiration exceeds precipitation ($P < PE$)

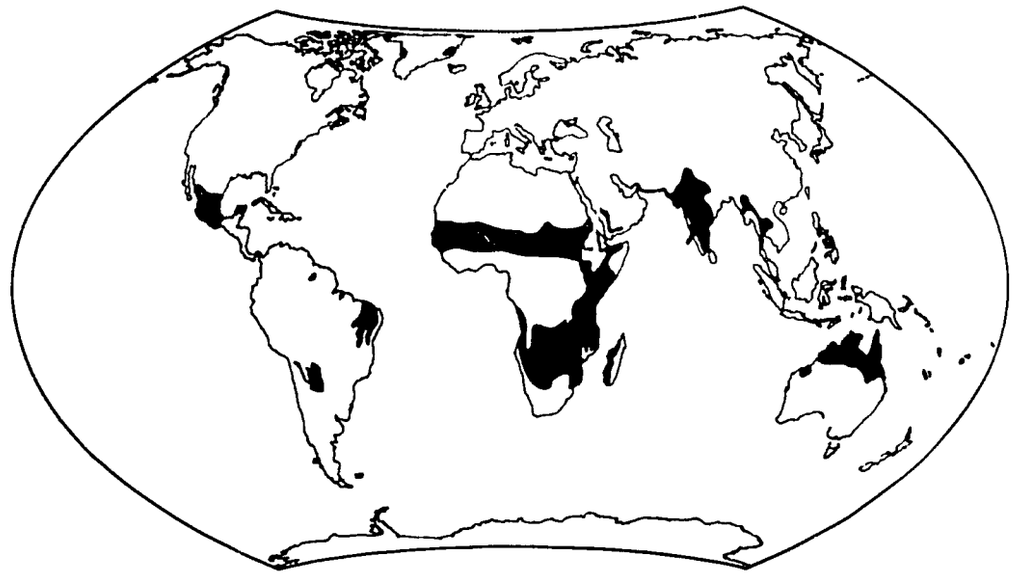

Fig. 1 Map of the semiarid tropics of the world (Source Troll, 1966)

a study of the agroclimatology of the semiarid areas south of the Sahara in West Africa From these investigations and more fragmentary data for other semiarid regions, the following characteristics of rainfall in the seasonally dry tropics can be derived (Webster and Wilson, 1966, Arnon, 1972)

1 The beginning of the humid season is uncertain, the monsoon may begin 4 weeks before or after the mean date of arrival
2 More than 95% of the annual precipitation occurs during the rainy season[3] that generally lasts from 4 to 7 months
3 At least one-third and often more than two-thirds of the annual rainfall occurs in the humid season, which in most of the seasonally dry tropics lasts from 2 to 5 months
4 Precipitation during the wet season is often extremely variable not only from year to year but also within one single season
5 The mean daily rainfall intensities[4] are two to four times greater than in many temperate regions, the short-duration intensities frequently exceed the intake capacity of the soil
6 The maximum short-duration rainfall intensities increase only marginally with greater annual rainfall In some areas in West Africa, high rainfall intensity increases with decreasing yearly precipitation

Variation of rainfall in the semiarid tropics consists primarily of the amount and intensity of the precipitation during the wet season, with relatively minor differences in the length of the season (Reid, 1941) In most of the regions studied, the duration of the humid season is 3 to 5 months The rainfall patterns are generally erratic, and short-duration droughts may occur often during the mon-

[3] The rainy season here is defined as that period of the year in which monthly rainfall exceeds one-tenth of the monthly potential evapotranspiration

[4] The mean daily rainfall intensity is computed by dividing the mean annual rainfall by the average number of rainy days per year

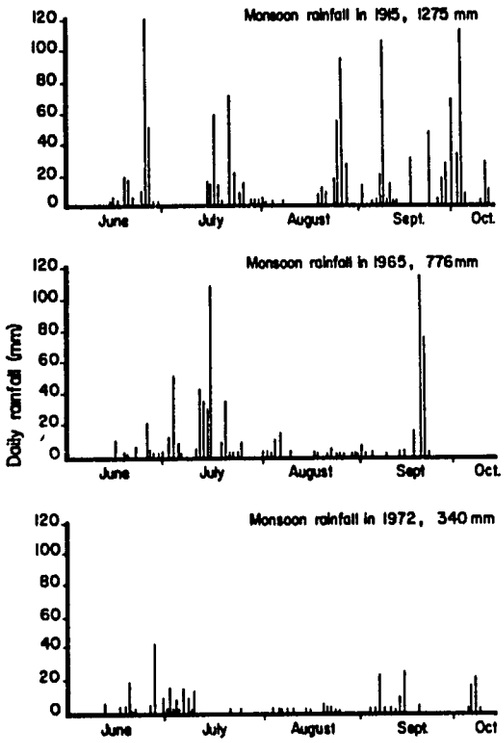

Fig 2 Example of short-duration droughts during the monsoon season

soon Figure 2 shows an example of this phenomenon The total monsoon rainfall was above normal at Hyderabad in 1965, but it was a year of drought, floods, and low crop production Even in 1915, the wettest year on record, there were obviously drought periods that occurred during the growing season Conversely, in 1972, the driest year on record, at least one high-intensity storm with substantial runoff was recorded In tropical semiarid regions, the variation in yearly rainfall is much greater than that which is normal in temperate regions

In many areas, a rather low proportion of the annual precipitation is effective rainfall for crop production because of the undependability of rainfall, other climatic factors, soil profile characteristics, technological limitations, and economic and social constraints Surface runoff, deep percolation, transpiration by weeds, and evaporation from soil frequently account for a major portion of the total quantity of rain received by a given land area

Low effective rainfall causes low yields and has severe repercussions on "rainfall use efficiencies"[5] Statistics on regional production indicate for example that cereals like sorghum and millet, even in the relatively high rainfall areas of the semiarid tropics, generally produce less than 750 kg per hectare (Government of India, 1971, FAO, 1973) On the basis of an assumed mean annual rainfall of 100 cm, this amounts to less than 7 5 kg per cm In lower rainfall areas (mean annual precipitation 500 to 750 mm), average yields of less than 500 kg per hectare are not uncommon With considerably higher than average levels of land and crop management, demonstrations on farmers' fields have attained rainfall use efficiencies of well over 30 kg per cm (Rastogi, 1974) Initial experience at ICRISAT would seem to indicate the possibility of rainfall use efficiencies exceeding 60 kg per cm in some regions (ICRISAT, 1974)

Soils and Soil Erosion

The soils of the SAT show great diversity in texture, structure, type of clay, organic matter content, and depth These variations result in significant differences in infiltration, erodability, moisture-holding capacity, drainage characteristics, aeration, susceptibility to and recovery from compaction, and general response to management and manipulation However, particular soil groups are widely spread throughout the seasonally dry SAT The major soil groups found in the SAT are as follows

1 red and grey soils (Alfisols)

[5] "Rainfall use efficiency" is defined as the agricultural production (in kg or the monetary equivalent) in relation to the annual precipitation (in cm)

2 black soils (Vertisols)
3 alluvial soils (Entisols)
4 sandy soils (Inceptisols)
5 lateritic soils (Oxisols)

The Alfisols and Vertisols, which are by far the most extensive in the SAT, are the two major soils of ICRISAT Krantz et al (1976) described these five soil groups, along with their locations in the SAT

Nutrient level in soils of the SAT

Under the continuous high temperatures of the SAT areas, the crop residues and organic wastes decompose rapidly and the native organic-matter content of the soils is low (usually about 0 5% seldom exceeding 1%) The levels of several important nutrients are also low This is especially true of total and available nitrogen and available phosphorus In areas where the surface soils have been removed by erosion bund building, or land shaping zinc deficiency is often observed in zinc-sensitive plants The potassium level now is fairly adequate in most SAT soils In the black soils the level is usually quite high Experience in other areas of the world indicates that potassium deficiency will become more evident as crop production increases The rate at which this will occur will depend upon the handling of crop residues and organic waste Most of the potassium uptake by the plant is contained in the crop residues If exploitive agriculture is continued whereby the crop residues are all removed and most of the farmyard manure is burned for fuel the time of occurrence of several deficiencies will be hastened

The nutrient level in any one field will of course depend upon several factors including the native fertility level the length of time under cultivation and the management, particularly the application of manures and fertilizers in the system The use of fertilizers in the SAT has been very limited because of the risk involved due to the uncertainty of monsoon rainfall Residues and organic wastes such as farmyard manure are usually returned to fields close to the village, those fields are often somewhat higher in fertility level

Erosion and runoff

Anyone familiar with the landscape of the semiarid tropics, particularly during the rainy season, recognizes the vast damage and the rapid decline in the productive potential of the land caused by soil erosion Some authors indicate that deforestation and subsequent poor management of the land may reduce long-term precipitation averages and cause changes in climate (Krishnan, 1973) Heseltine (1961) points out a decrease in land and water resources in tropical Africa due to a lack of proper management Kanwar (1972) reports that in India alone 6 000 million tons of soil are lost annually, a significant portion of this loss occurring in the SAT of India As a result, in large areas soils have become shallow and stony and the land in such areas is cut by deep, meandering gullies Vanderspen et al (1972) estimated that under conditions of about 800 mm annual rainfall in India, between 100 and 300 mm are lost annually as runoff

A recent report (FAO 1974) states that, in many developing countries, increased pressure on the land in low rainfall areas has resulted in expansion of cultivated agriculture into marginal areas and intensification of agricultural activities on unsuitable lands The result is increased exposure of land resources to the hazards of wind and water erosion Overstocking and overgrazing, deforestation and the cultivation of steep slopes are causing permanent damage to vast areas The land resource endowment base is shrinking and the productive capacity, diminishing This in turn again increases the quest for more land To break this vicious circle, more stable forms of land use that preserve and maintain the productive capacity are urgently needed

Soil and Water Management and Conservation in the SAT

Four conventional approaches to ameliorating the problems faced by farmers in the rain-fed SAT have been

1 To fallow the land during the rainy

season in an attempt to accumulate a moisture reserve in the profile
2. To implement soil and water conservation practices
3. To meet droughts and food crises by emergency programs.
4. To develop irrigation facilities

Fallowing

In many of the temperate semiarid regions, the total moisture-storage capacity of the soil exceeds the normal annual rainfall. Under these conditions, clean cultivated fallowing during 1 or more years will often increase yields substantially because of the greater quantity of moisture available to the crop (Pengra, 1952). However, in the SAT the high-intensity rainfall often exceeds the infiltration rate, and total seasonal rainfall is frequently much greater than the capacity of the root zone to store moisture.

In many deep black soils, especially in India, cultivated fallow is practiced during the monsoon season, but not cropping, which is done only during the postmonsoon season. The reasons for not cropping during the monsoon season are many, including such factors as poor drainage, difficulty in cultivation and weed control, undependability of monsoon rains, and inadequate soil and crop technology (Kampen et al., 1974). However, the consequences of this traditional fallowing system in these deep black soils are serious with regard to runoff and erosion. Jacks et al. (1955) noted that a few minutes of high-intensity rainfall on some bare soils are sufficient to cause surface sealing, which drastically reduces infiltration. Arnon (1972) stated that frequent cultivations to produce a soil mulch often result in an impaired soil structure, thus increasing runoff and soil erosion. Ellison (1944), Hudson (1973), and others have pointed out the serious consequences of a clean-cultivated fallow system on soil erosion and the critical importance of vegetative cover during high-intensity rains.

Mulching

Much research has been done on the use of mulches to reduce evaporation, to increase infiltration, to prevent the soil from blowing and washing away, to control weeds, to improve soil structure, and to increase crop yields. The effects of mulching seem to depend upon climate, season, and soil type and are not universally advantageous. The yield-increasing effects of mulches from crop residues have not been clearly established in the SAT (Kampen, 1974). Also the feasibility of attempting to provide large quantities of organic materials as mulches is a questionable practice, since the fodder or straw is needed as cattle feed in much of the SAT.

Traditional Bunding

Contour bunds or graded bunds are used to decrease soil erosion and to conserve water above the bunds by increasing infiltration into the soil. In the SAT environment well-designed and well-maintained systems of bunds have been found to decrease soil erosion on a watershed basis. However, substantial erosion and sedimentation may occur within the areas between the bunds. This phenomenon is demonstrated by the large elevation differences frequently observed upslope and downslope from the bunds. Although large quantities of water are held back by the bunds, the increased infiltration often affects only a small portion of the land in the watershed.

A study of the effect of bunding on the yields of monsoon crops was conducted at the Bellary Soil Conservation Centre on deep black soils during the seasons between 1960 and 1967 (ICAR, 1970). The average annual rainfall in this area is about 550 mm. It was found that contour bunding decreased the average yield of sorghum and cotton by 25 and 30% respectively. The decrease in yields in these cases was explained by the delay in cultural operations and the crop damage caused by stagnant water above the bunds.

The effect of bunding on wheat yields following monsoon fallowing on deep black soil in central India was studied in 1972 (Kam-

pen, 1974) These data indicated no increase in wheat yields because of the water trapped near the bund There was a decrease in wheat yields in the pit just above the bund caused by removal of surface soil during the construction of the bund This effect, plus the area removed from cropping by the bund, shows that bunding under these conditions has a negative effect on total production

Emergency Measures

During droughts and the associated food crises, large sums of money are often spent on hastily conceived programs for various types of famine relief Food aid is often provided and crash resource conservation and development schemes are designed and carried out However, after the calamity is over and life returns to normal, the acute problem may be forgotten till the next crisis occurs Severe droughts in the Indian subcontinent from 1965 to 1967 and from 1972 to 1973 and the recent drought in the Sahel region of Africa provide examples of this type of effort It is self-evident that these types of activities seldom result in improving the stability and long-term productive potential of the environment Only sustained programs of research and development, along with vigorous programs of extension and training for implementation of improved technology, will produce lasting results

Irrigation

To eliminate the basic cause of uncertainty in agriculture in the SAT, three types of irrigation facilities have been developed in some areas These include large irrigation projects, small runoff-storage reservoirs (called tanks in India), and wells Large irrigation projects were initially envisioned as supplemental water facilities for upland crops Experience over the last two decades has shown that these projects do not supplement variable rainfall because of lack of flexibility in the system, which is inherent in large irrigation schemes Thus, irrigation in the SAT from these projects most often consists of providing continuous water on a seasonal basis In many cases the added irrigation water, plus the rainfall, has resulted in waterlogging and salinity problems, particularly where drainage facilities were inadequate

Wells are owned mostly by individuals Although water may be drawn from an area beyond the individual property boundaries, the benefits of irrigation accrue exclusively to the well owner Intensive irrigation of a small area rather than supplemental irrigation of rain-fed crops over an extended area is frequently the result

The small runoff-storage reservoirs are characterized by inefficient use of water and considerable loss of land The shallowness of these storage facilities results in large evaporation and seepage losses, while substantial areas of otherwise productive land are occupied Siltation caused by lack of erosion-control measures in the watershed has significantly reduced the storage capacity of many reservoirs

Thus, it appears that present water-resource development in the SAT often results in the creation of "islands of relative wealth" in "a sea of poverty" This situation may contribute to social tension at a later stage The fact that the total water resources are insufficient to cover any substantial portion of the cultivated land through conventional irrigation has been neglected Few serious efforts have been made to explore the question of how the limited water resources can be used to stabilize and support large proportions of agriculture in the SAT for the benefit of a greater number of farmers In other words, no clear answers are available to the question of how all available ground and surface water can best be used to back up farming systems in the SAT rather than replace a small part of rain-fed agriculture

Approaches to and Potentials for Improved Soil and Water Management

Until recently the major thrust of agricultural research and development in the less developed countries was aimed at increasing

food production in the irrigated areas[6] The situation of limited resources and serious food shortages made this approach appear logical In recent years, however, there has been an increasing concern about agriculture in the rain-fed (unirrigated) areas of the SAT Fortunately, many countries are launching national research programs for rain-fed agriculture In India, the All India Coordinated Research Project for Dryland Agriculture, initiated in 1970, provides an excellent example of an integrated approach towards research and action on the problems of SAT agriculture On a global basis, the concern about the SAT and the new confidence in the productive potential of these areas resulted in the creation of ICRISAT in 1972

Strategy for Research and Development

The basic strategy for recent soil and water management research and development in national programs and at ICRISAT has been to investigate the natural, human, animal, and capital resources and to develop programs to optimize the utilization of these resources on a sustained basis This is in accordance with the preamble to the international development strategy for the second United Nations Development decade, which states. "The ultimate objective of development must be to bring about sustained improvement in the well-being of the individual and bestow benefits to all" (FAO, 1974)

At ICRISAT the following immediate soil and water management research needs are envisaged

1 To decrease runoff and soil erosion
2 To develop effective surface drainage systems where needed
3 To increase the proportion of rainfall used in crop production
4. To achieve higher rainfall-use efficiencies
5 To utilize available ground and surface water more effectively
6. To generate appropriate technology for land and water development and management

Goals of the Farming Systems Research Program at ICRISAT

The goals of the Farming Systems Research Program are

1 To generate economically viable, labor-intensive technology for improving and utilizing while conserving the productive potential of natural resources
2 To develop technology for improved land and water management systems that can be implemented and maintained during the extended dry seasons, thus providing additional employment to people and better utilization of available animal power
3 To contribute to raising the economic status and the quality of life for the people in the semiarid tropics by developing farming systems that increase and stabilize agricultural output

The Farming Systems Research Program consists of the following four complementary components

1 Research on individual production factors
2 Resource utilization research on an operational scale
3 Cooperative research with national and regional organizations
4 Extension and implementation through national programs

All four components are interrelated, and success is dependent upon continuous dissemination and feedback between each of

[6] The limited research in rain-fed areas of the SAT was largely aimed at the adaptation of dryland agricultural practices from the temperate regions of the world As pointed out on page 228 the characteristics of the SAT are distinctly different from those of the temperate dryland regions and thus require a problem-oriented approach related to the resources of the SAT

the components Likewise, the realization of the agricultural potential of the SAT is critically dependent upon the generation of suitable high-yielding varieties These varieties should represent a wide range of maturity dates and morphological characteristics to fit into various cropping systems necessary to utilize the varied environments of the SAT

Research on Individual Production Factors

Research on individual production factors involves experiments special investigations, and development activities in the following major program areas or disciplines agroclimatology hydrology, soil physics land and water management, agronomy, soil fertility and chemistry farm machinery and power, plant protection, and economics and sociology

The research on these program areas can be carried out in experimental plots, screen houses, growth chambers laboratories machine shops markets and villages Investigational studies are being initiated to evaluate and understand the present circumstances in the various regions and to help direct research toward priority problems in each program area

Resource Utilization Research on an Operational Scale

In the resource utilization research program, the central objective is to make the best use of the rain that falls on a given area To study water as an input natural watersheds (also called catchments) were chosen as the unit for research Also, since water is the major natural constraint to agricultural development in the SAT, it is expected that watersheds will become the focus for resource development and utilization in any given region

At ICRISAT this component of research is aimed at the development of "watershed-based resource utilization," which has been described as follows

> Watershed-based resource utilization involves the optimum utilization of the watershed precipitation through improved water, soil and crop management for the improvement and stabilization of agriculture in the watershed Rainfall utilization can be attained in one or more of the following ways
>
> 1 Directly through infiltration of monsoon rainfall,
> 2 After runoff collection, storage and utilization, or
> 3 After deep percolation and recovery from wells

Briefly stated, the watershed-based studies encompass investigations of resource development management, and conservation, water-balance studies, and research involving the integration of improved components of soil, water, and crop technology By the integration of all of these components, it is possible to develop alternative farming systems that can be carefully monitored on a field scale to evaluate such factors as water-utilization patterns, production effects, resource conservation, and economics In other words the watersheds serve not only as units for conservation and water-balance studies but also as "pilot plant studies" for the integration of a wide range of management technologies on an operational scale

Cooperative Research with National and Regional Organizations

The agroclimatological environment at ICRISAT is being used for the generation of principles, approaches, and methodologies to arrive at improved farming systems However, before application to the diverse regions of the SAT, these principles have to be converted into applicable site-specific technology Where areas characterized by various conditions are to be served, the first step is to collect detailed quantitative information about the physical and biological settings in the different regions Climate, soils, crops, and cropping systems are the building blocks for improved farming systems

Matching the need for sound physical and biological technology is the requirement for socioeconomic investigations involving hu-

man and capital resources, basic needs, constraints, market potentials for improved technology, and mechanisms for group action in soil and water management. Several approaches will be used to develop the necessary information and methodologies. These will include the following

1 Simulation techniques based on mathematical modeling.

2 Establishment of a limited number of benchmark locations in cooperation with national programs to represent distinctly different climatic, soil, and topographic conditions

The objective would be to cover the spectrum of conditions having a minimum of locations These benchmark locations will be placed at strategic national research stations, and the programs will be developed in cooperation with the national and state institutions, with the aim of adapting and developing information for the areas involved

Extension and Agricultural Development through National Programs

The implementation of new systems of farming will require an effective extension-education program, along with developmental action programs supported by the necessary technical assistance Although no operational responsibility is envisaged for ICRISAT, ICRISAT scientists would expect to provide training and technical back-up where desired, particularly in the initial stages It is visualized that benchmark locations or other strong national research centers having a farming-systems emphasis would provide a focal point for initiating training and improved agricultural development programs The interaction with and the feedback process from the national programs would be extremely helpful in guiding the focus of ICRISAT's research and training programs

Preliminary Observations on the Management and Conservation of Soil and Water

Preliminary observations and results of studies on the management and conservation of soil and water done at ICRISAT have been discussed in several publications (ICRISAT, 1973-1974, 1974-1975, 1975 1976, Kamper et al, 1974, Krantz et al, 1974) Some of the highlights relating to soil and water management are given below

Studies on Ridge and Furrow Systems

An effective soil and water management system should reduce runoff and soil erosion while increasing infiltration of rainfall, without causing surface-drainage problems Systems involving graded, narrow, or broad ridges or beds separated by furrows draining into waterways appear to possess many of the essentials for fulfilling these requirements The surface-drainage function of ridges and furrows has been shown by Choudhury and Bhatia (1971) and Krantz and Kampen (1973) Preliminary research at ICRISAT indicates that by altering the slopes of the ridges and furrows, the system can also be used, within limits, to manipulate the amount of runoff and to reduce erosion (ICRISAT, 1974-1975)

During the 1975 season, a broad (150-cm) ridge and furrow system was compared with the 75-cm ridge and furrow system on red soil In the 75-cm ridge and furrow system, cross flow and erosion had been encountered especially in slightly depressional areas caused by the instability of the narrow ridges This problem was overcome by the use of a broad ridge and furrow system, which resulted in less runoff than either flat- or narrow-ridged cultivation Also, the 75-cm ridge and furrow system was found to have limited flexibility for intercropping as well as postmonsoon cropping at close spacing Using broad ridges, it is possible to plant 2, 3, or 4 rows per ridge at spacings of 75, 45, and 30 cm respectively This also allows for

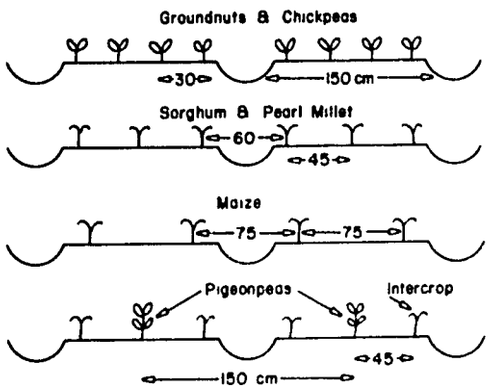

Fig 3 Possible cropping patterns using the broad (150-cm) ridge and furrow system

planting pigeonpeas at a desired spacing of 150 cm, along with a wide range of plant geometries of the intercrop Figure 3 shows an example The 150-cm ridge and furrow system can be easily prepared with a bullock-drawn ridger The implement used has ridger units placed 150 cm apart with a board-leveling unit in between the two ridgers

The ridges or beds function as minibunds at a grade which is normally less than the maximum slope of the land Thus, when runoff occurs, its velocity is reduced and its infiltration-opportunity time is increased Instead of allowing runoff to concentrate in large streams, the excess water is carried off the land in a large number of small flows This tends to minimize soil erosion and provides more uniform infiltration over the whole watershed area Some advantages of this system observed in operational scale research on watersheds are as follows

1 Only minor earth movement (smoothing) is required
2 Implementation can be executed by animal power
3 Pre-formed ridges and furrows provide a guide for bullocks to follow, which speeds up planting and facilitates uniform row spacing
4 During plantings between early monsoon showers, the tops of the ridges or raised beds dry more quickly than the soil in flat-cultivated areas, thus facilitating planting in ridged areas
5 The germination of grassy weeds in the early part of the crop season is less in the ridge and furrow system than in the flat-planted system
6 No land is taken out of production by the ridge and furrow system
7 No further land development is necessary to facilitate application of supplemental water, if available
8 Soil on the ridges remains friable, facilitating initial land preparation immediately after harvest of the last crop of the season

Effect of Soil Management upon Runoff and Soil Loss

Preliminary results show that runoff and soil loss are greatly affected by soil management treatment in the black soil watersheds (Table 1) In each of the three storms in September, the runoff from a monsoon-fallowed watershed (BW4B) was about five times that of the adjacent cropped watershed under a ridge and furrow system (BW3B) Soil loss from the former system was more than twelve times that of the latter

The soil erosion loss on the monsoon-fallowed watersheds amounted to about 7 tons per hectare, this was approximately five times the quantity measured from cropped watersheds in a ridge and furrow system In addition to the soil loss observed at the outlet of watershed significant sheet erosion was observed between field or contour bunds on flat-planted watersheds, compared to areas cultivated in a ridge and furrow system Cultivated fallow during the monsoon has shown no advantage in terms of moisture conservation or postmonsoon crop yields, compared to the situation observed in cropped watersheds during the monsoon under the climatic conditions experienced at ICRISAT during the first few years

Proportion of Rainfall Used in Crop Production

The moisture content of soils has been

Table 1 Runoff and soil loss during five storms in 1974, from a cropped watershed with ridge and furrow system (BW3B) and from a monsoon-fallowed, rabi-cropped watershed (BW4B)

Date	Rainfall (mm)	Runoff (mm/ha)		Soil loss (kg/ha)		Ratio of soil loss
		BW3B	BW4B	BW3B	BW4B	BW3B to BW4B
Aug 9	51 9	1 74	3 00	182	455	1 to 2 5
Sept 12	35 2	0 64	2 87	16	265	1 to 12 0
Sept 24	29 2	0 68	3 81	37	445	1 to 12 0
Sept 25	12 8	0 45	5 33	12	281	1 to 23 3
Oct 23[a]	56 3	4 57	10 00	420	941	1 to 2 2

[a] Monsoon crops had been removed and the postmonsoon crops were recently planted in BW3B

monitored in each watershed unit on a year-round basis to help determine the effective use of rainfall and to quantify the soil-moisture utilization by different postmonsoon crops The moisture losses during the 3 to 5 months of the hot, dry, noncrop period just before the onset of the monsoon were also determined Preliminary data in 1974 at ICRISAT indicate that improved systems of farming used a much higher proportion of the rainfall in crop production than traditional practices The percentages of monsoon rainfall used in crop production for watersheds were as follows 30% for those having postmonsoon cropping only (BW6B), 70% for those double-cropped on ridges (BW1), and 80% for those double-cropped on ridges using recycled runoff water (BW5) (ICRISAT, 1974-1975)

It would appear that for the black soils, principles of technology are now available to attain considerably higher efficiencies of use of rainfall and greater production than are attained in traditional systems of farming

Runoff Collection and Use of Supplemental Water

In the 1974 season, most of the constructed water-storage facilities (tanks) were partially (50 to 70%) filled during the early part of the monsoon, thus providing water where necessary for life-saving irrigation during a drought When the tanks were completely refilled during the latter part of the monsoon, a substantial amount of water was lost through the spillways Evaporation and seepage loss data were collected and analyzed for all storage units The evaporation losses measured from partially submerged pans were of similar nature in all tanks The amount of evaporation loss during the early part of the dry season ranged from 3 to 5 mm per day which was about 20% less than that observed in the open-pan evaporimeter in the meteorological observatory Since the water in these tanks must be used during the early part of the postmonsoon period before temperatures start rising, the proportion of water loss by evaporation from deep tanks is relatively small Seepage losses ranged from 2 6 to 18 mm per day depending upon the nature of the subsoil material where the tanks were located Thus seepage losses were in most cases the major cause of decreasing water supply Studies on low cost means of reducing seepage are underway

The results of supplemental irrigation to crops on red soils during a 30-day drought in late August and early September were quite spectacular Yields of sorghum and maize were approximately doubled by the application of a 5-cm irrigation At product prices prevailing at the time of harvest, gross rupee values of the average increase in two fields (RW-1C and RW-1D) because of the application of a 5-cm irrigation at a critical

time of growth were 3,120, 2,780, 1,085, and 650 rupees per hectare for maize, sorghum, pearl millet and sunflower respectively At these values, the rupee value of a hectare meter (8 1 acre feet) of water (neglecting application losses) would be 62,400, 55,600 21,700 and 13 000 rupees for maize sorghum pearl millet, and sunflower respectively

Effect of Soil Management on Infiltration in Black Soils

Infiltrometer studies on black soils indicated substantial differences in the rates of water intake between soil management treatments In initial observations monsoon-fallowed land was found to have a low infiltration rate of approximately 1 mm per hour after 2 or more days of observation Final infiltration rates on land that was cropped and cultivated in the ridge and furrow system were in the range of 6 mm per hour In the cropped, flat-planted areas the average infiltration rate was about 2 8 mm per hour Monsoon rainfall is often characterized by extremely high intensities and therefore higher infiltration rates may increase moisture availability for plant growth Although these results need further confirmation, they seem to emphasize the importance of vegetative cover and adequate drainage in land management and cropping systems for black clay soils during the monsoon

Power- and Labor-Use Efficiency

Animals are used in all cultural operations in the watersheds, and preliminary efforts are underway to adapt and develop more effective farm equipment to improve soil and water management The improved versus traditional watershed units provide an opportunity to study the power- and labor-use efficiency as well as production, rainfall-use efficiency and resource conservation Preliminary observations indicate that improved farming systems including land development and double cropping make fuller and more timely use of animal power than traditional agriculture Future research will be aimed at increased power-use efficiency and rainfall-use efficiency involving studies of timing of land preparation, minimum tillage, and zero tillage using herbicides

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Management of Rain-fed Agriculture in Semiarid India

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Inadequate information on the soil characteristics of *murrum* or plow layer and the difficulty in managing black soils are major obstacles to improved agricultural productivity in India Information on the relationship of the soil's physical properties to water permeability and retention and root penetration of the murrum layer need to be obtained The importance of the very deep black soils at the lowest topographic level is stressed because of the potentially high crop yields of these soils

Management of soil and water is an integral part of the total resource management and takes into consideration the environment and the end use The objectives of soil and water management in rain-fed agriculture will thus be minimizing soil and water losses, optimizing crop production and meeting the aberrant weather conditions

Management practices applicable to the red and black soil types in India, with typical examples, are discussed

Semiarid Red Soil Zone

This zone comprises many of the red soil areas in the Deccan having a rainfall of 500 to 750 mm per year Typical examples are Hyderabad and Anantapur

Because the soils are derived from coarse crystalline acidic granites, the soils are light textured (loamy sands to sandy loams) and shallow They exhibit mechanical translocation of clay resulting in textural profiles The subsoils consist of a mixture of nonexpanding illitic clay and small-sized gravel and are compact They are moderately high to excessively drained as evidenced by the high terminal infiltration rate of 5 to 15 cm per hectare However, root penetration of most of the crops is impeded by the compact subsoils Shallow spreading of the root system, forking of the tap root "button formation," and paucity of fine roots in the compact subsoils are common in such soils

The pH of the soil ranges from 6 5 to 7 5 Soils are low in nitrogen (0 02 to 0 04%), and poor in available phosphorus (0 to 2 ppm Olsen's P) The clay being illitic the soils are rich in nonexchangeable K (500 to 700 ppm extractable in boiling 1*N* HNO_3) Even though the exchangeable K is low (~ 150 ppm), little response to fertilizer K is obtained at Hyderabad The nonexchangeable K being low (300 ppm) at Anantapur, there are indications of response to applied K

A deficiency of secondary or micronutrients has not been reported under the existing low levels of production Once the yield levels are raised by the application of N and P fertilizers, deficiency of zinc is anticipated At Anantapur response to zinc application has been reported

Toposequence consists of gravelly skele-

tal soils at the highest level of topography, followed by loamy sands and sandy loams at intermediate levels and by sandy clays at the lowest elements Of these, loamy sands and sandy loams occupy the largest area

These soils are cropped only during the rainy season Sorghum and millet (pearl, finger, and foxtail) are the important cereals, pigeon pea, cowpea, and *Dolichos biflorus* (horse gram), the important grain legumes, and castor and groundnut, the important oilseed crops The planting of the crops is done early with the first soaking showers in the month of June By the time intense showers occur in the month of September, full crop canopy is attained Because of the high infiltration rate and the crop-canopy development, the erosion hazards are less than 5 to 6 tons per hectare However, considering the lightness of the soil, even this loss cannot be ignored

The approved soil conservation practice consists of putting up contour bund of about 0 8 m^2 per section at vertical intervals of 1 to 1 5 m on lands that have slopes exceeding 2 to 3% Because of the limited moisture-storage capacity (about 5 cm) in the profile and because of crusting, both surface runoff and subsurface seepage are important The runoff is collected in large reservoirs and tanks, which are used to irrigate lowland rice Well irrigation is also common An irrigated area is usually not more than 10% of the total cultivated area

Soil Management

The soil management practices are designed to prepare a firm weed-free seedbed, avoid or overcome crust problems, improve root penetration, and improve soil fertility

Seedbed preparation

Year-round tillage practices have been developed They consist of (1) plowing or blading the soil immediately after the harvest of the standing crop or whenever the soil is in condition by making use of rains in the noncrop season, and (2) blading to make the seedbed firm and to remove recent weed growth After planting, blading is done to control the weeds and keep the soil open and moisture-retentive

Table 1 Short-term carry-over of moisture

Treatment	Soil moisture in 30-cm of soil depth after a 60-mm rainfall (cm)	
	1 day after	10 days after
No mulching	2 22	0 84
Soil mulching	2 58	1 38
Organic mulching	3 06	1 68

Crust problems

Crust problems are quite serious in the red soils of Hyderabad and Anantapur When the crust is formed after seeding, it interferes with stand establishment of crops The recommended practice to overcome this problem consists of working a spike tooth harrow if the crust is formed within 1 to 2 days after seeding, of seeding on the side of a ridge, which is less prone to crust formation, and of mulching the seedlines with organic residues to minimize the beating action of rain If the crust formation occurs 3 to 4 days after seeding, there is no practical way of saving the stands, and the crops have to be resown There are differences amongst crops in their reaction towards crust formation Crops like castor and pigeon pea are not affected severely by crust formation Crops whose seed rate is normally high are also less affected The worst problems are in the case of small-seeded crops such as finger millet, pearl millet, and sometimes sorghum

Table 2 Profile modification in red soils

Treatment	Sunflower yield (q/ha)
Shallow plowing	9 92
Chiselling	10 36
Deep plowing	12 37

C D (0 05) = 1 63

Table 5 Effect of sowing dates on the yield of kharif crops, Hyderabad, 1973 1974

Date of sowing	Yield (q/ha)		
	Sorghum (CSH-1)	Pearl millet (HB-3)	Finger millet (Sharada)
June 8	54 1	32 0	22 6
June 22	46 1	41 9	19 8
July 7	17 2	34 1	29 5
July 20	0 9	23 9	30 7
August 3	0 9	17 4	37 3
August 17	0 7	18 0	Failed

move weeds and is shaped to serve the purpose of interrow water harvesting

Water Management

Water management practices fall into two groups those designed to minimize losses of moisture stored in the soil and those designed to collect inevitable runoff for its best use

The most efficient use of moisture stored in the soil is achieved by choosing crops that penetrate the subsoil and therefore are able to tap moisture from deeper layers An example is given in Table 3, which shows a comparative performance of sorghum with pigeon pea at Hyderabad in 1972 on a shallow soil

The need for keeping the soil surface open by interculture has been emphasized earlier Timely and thorough weed control is essential, particularly in years of subnormal rainfall Early weeding, usually within 3 weeks of emergence is critical (Table 4)

The other practices designed to improve efficiency of moisture use are intercropping systems, dust mulching, and finally harvest at the physiological maturity stage

Since aberrant weather is of common occurrence in the semiarid red soils, water management practices should indirectly relate to the choice of crops according to the season The basic principle here is to choose shorter-duration varieties of crops since the onset of monsoon is delayed by a week to a fortnight and to change over to short-season crops when the onset is further de ayed The choice of crops for the Hyderabad region is given in Tables 5 and 6

Management of runoff stored in tanks and wells requires considerable improvement First, except where it is impossible to grow other crops rice cultivation should be discouraged Because of the riparian rights, it is very difficult to alter the existing practice of growing rice under established tanks However, it should be the policy that new tanks and reservoirs will be designed for providing supplemental irrigation to the rainfed crops This will involve a change in de-

Table 6 Alternate crops in Hyderabad

Seeding time	Crop
June to mid-July (normal)	Sorghum and pearl millet having redgram as intercrop
July	Castor and finger millet
Late August and early September (late)	Horse gram, cowpea, and safflower in deeper soils

Crust formation seriously affects water intake For example, moisture penetrates up to 30 cm deep in soils kept open by blading, as compared with 10 cm in a crusted soil At ICRISAT it was observed that runoff from crusted red soils exceeded that from black soils in the early part of the monsoon

Crust formation also indirectly affects moisture in the seed zone That is, there is less moisture in the seed zone of crusted soils (Table 1) This, together with the hardening of the crust, restricts the sowing time available in terms of rain Studies at Hyderabad indicate that even soil mulch makes it possible to extend the sowing time by preserving the moisture in the seed zone

Improving root penetration

In the textural profiles of the red soils, root penetration is impeded by the subsoil characterized by rigid pores Two approaches have been developed for overcoming this limitation The first one consists of deep tillage, with or without inversion In an experiment using the red soils of Hyderabad, profile modification was attempted with deep plowing Sunflower was the test crop Table 2 gives the results

This approach requires heavy machinery, which is not generally available A practical modification of the principle consists of deep tillage in the seedlines, as against the entire field This work, initiated by the Indo-French team at Anantapur, is continuing An indirect advantage of deep tillage whether in the entire field or in the seed furrow is that it mixes the heavy subsoil with the light surface soil thus minimizing the crust problem

An entirely different approach is being developed at Hyderabad Here advantage is taken of such crops as castor and pigeon pea, which are capable of penetrating and opening up the subsoil Studies are underway to examine the effect of such crops on succeeding crops that are incapable of penetrating the subsoil

Improving soil fertility

Nitrogen and phosphorus are the most commonly deficient nutrients, and the recommendation is to apply 30 to 40 kg of nitrogen and 30 kg of P_2O_5 per hectare It is recommended that the entire phosphorus and one-third to one-fourth of the nitrogen be applied along with the seed to promote early seedling vigor to overcome nonspecific stresses, particularly weed competition The remaining nitrogen should be applied in installments depending upon the crop and the season

Improving efficiency of fertilizer use is achieved by the use of set furrows, in which farmyard manure and other fertilizers are incorporated This practice is extensively used in the Saurashtra region of Gujarat The furrows in which crops are sown are fixed and not changed from year to year The furrows are opened with a country plow well in advance of the monsoon, the fertilizer applied in the furrows simulates placement Farmyard manure keeps the soil open, improves water intake, and minimizes crusting The land between furrows is bladed to re-

Table 3 Moisture-use efficiency

Crop	Variety	Moisture-use efficiency (kg/ha mm)
Sorghum	CSH-1	2 6
	CSH-6	4 0
Pigeon pea	Ageti	5 4
	ST-1	8 3

Table 4 Crop-weed competition and yield of HB-3 pearl millet

Treatment		Yield (q/ha)
Weed-infested for	10 days	14 17
	20 days	13 79
	30 days	5 38
	40 days	5 68
	50 days	2 29
Unweeded check		1 31

C D (0 05) = 3 63

Table 7 Effect of supplemental irrigation on crop yield

Crop	Grain yield (q/ha)	
	Rain-fed	5 cm of supplemental irrigation
Sorghum	18 0	38 8
Pearl millet	20 4	32 4
Maize	29 6	57 5
Sunflower	9 0	12 0

sign of the canals to supply supplemental water to all the farmers in the command area in a short time The Andhra Pradesh Government has already taken up development of such minor irrigation works

Even under the existing wells an attempt is being made to wean the farmers from rice-rice systems to rice-wheat and short-season grain legume systems to achieve increased water-use efficiency Practices designed to improve water use for individual crops are available for rice wheat and a few others

A recent development in water management is the attempt to provide supplemental and minimal irrigation to the donor catchment from which runoff has been collected Several ideas have been generated on water management in such systems but no firm recommendations are yet available A single irrigation having a small quantity of runoff water at the critical stage resulted in a 50 to 100% increase in yields of crops at ICRISAT (Table 7) and at Hyderabad Dryland Center (Table 8)

Table 8 Effect of critical irrigation on grain yield

Irrigation	Grain yield (q ha)	
	1973	1974
Control	3 8	25 1
Irrigated	8 3	36 8
(Water applied)	(1 5 cm)	(0 6 cm)

In the experiment conducted at the Hyderabad Dryland Center, "confined" furrow system of irrigation was practiced To minimize surface wetting and lateral spread, water was applied in furrows 10 cm wide near the base of the crop Since the sorghum is spaced in rows 60 cm apart, 0 5 cm of water applied over the entire soil surface is equivalent to 3 0 cm of water applied in the "confined" furrow Because the moisture profile is pendulous deeper penetration of moisture occurs and loss by evaporation is minimized For example, a uniform surface application of 1 cm of water penetrates only 10 cm of soil, whereas the same quantity of water applied in confined furrows 10 cm wide and spaced 60 cm apart penetrates 20 cm or more of soil

Semiarid Black Soil Region

The region comprises several districts in Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, Gujarat, and Madhya Pradesh, of which the typical ones are Bellary, Bijapur, Sholapur, Akola, Rajkot and Indore

The black soils are clayey (40 to 70% clay) and retentive of moisture Depth variation ranges from shallow (less than 22 cm) to medium (22 to 45 cm) to deep (45 to 90 cm) and very deep (greater than 90 cm) As a rule the water intake is low in black soils particularly in soils of granitic origin as in Bellary The clay is montmorillonitic, and the soils have high swelling and shrinkage They crack heavily They are also easily dispersed and therefore highly erodable The underlying murrum is variable, at Bellary it is calcareous and impermeable, at Sholapur, Indore and Akola it is highly permeable being of trap origin The soils are generally deficient in nitrogen, and those of granitic origin also in phosphorus

The soils of Bellary are calcareous throughout the profile, free $CaCO_3$ varying from 10 to 15% in the surface to well over 40% in the lowest horizon Because of low infiltration (~ 0 1 cm/ha), salt accumulates

Table 9 Hydraulic conductivity of black soils as influenced by ESP

ESP		Hydraulic conductivity (cm/hour)
5 08		1 28
7 32		1 15
9 85		0 66
10 59		0 38
14 37		0 20
18 00	(normal soil)	0 12
26 65		0 06
32 84		0 05
40 75		0 00

in the profile of Bellary soils The soils of Akola, Rajkot, and Indore are nonsaline Salt occurrence at Sholapur and Bijapur is influenced by topography

Depending on the rainfall patterns, the black soils are cropped either in kharif, as in Rajkot and Akola, or in rabi as in Bellary, Bijapur, Sholapur, and Indore Because of topo-sequence, minor variations are also encountered in cropping patterns

Unlike in the red soils, the erosion problems are quite serious in the black soils because of the erodable nature of the soil itself, high-intensity rains, and, in the rabi areas, absence of vegetative cover during the monsoon There are also drainage problems in the lower levels of topography It is for this reason that soil- and water-conservation measures become extremely important in the management of black soils

The Bellary Region

The mean annual rainfall is 518 mm The rainfall during the months of June, July, and August is inadequate to raise a kharif crop Thus these soils grow essentially rabi crops Soil-conservation measures consist of putting up contour bunds Although these bunds may be effective in minimizing erosion losses, their value in improving moisture storage is questionable Often a considerable area near the bund remains inundated, and because of the low water intake, contour bunds do not contribute to retaining soil moisture

To improve water intake and thus conserve moisture, ICRISAT developed a "ridge-furrow" system laid on a gradient of about 0 5% This system is ideal but difficult to practice because it requires implements the farmers do not have The alternative is a "graded trenching and bedding" system, which is under test at Bellary This system, though perhaps less efficient than ICRISAT's system, has the advantage that the farmer can still use his native implements It is abundantly clear that under Bellary conditions all the practices aimed at improving the "opportunity time" remain useless unless the water intake itself is improved Studies conducted at Bellary reveal that application of gypsum to reduce the soil ESP (exchangeable sodium percentage) to 5 0% increases the water intake rate from 0 12 cm per hour to approximately 1 3 cm per hour (Table 9)

Organic mulching also maintains whatever little structure the soil has and prevents

Table 10 Yield of sorghum having vertical mulch (q/ha)

Spacing of the vertical mulch (meters)	Subnormal year	Adequate moisture years		
	1972	1973	1974	1975
Control	0 17	11 20	12 01	9 82
2	2.86	16 41	14 95	10 27
4	4 08	16.92	17.75	12 46
8	2 76	16 14	17 70	11 22

its deterioration by protecting it from the beating action of rain Vertical mulching has been shown to be effective, particularly in years of subnormal rainfall (Table 10)

Vertical mulching consists of digging trenches 15 to 20 cm wide and 30 to 45 cm deep and loosely packing them with sorghum stalks so that they protrude 10 to 15 cm above the ground level Vertical mulching at 4-meter intervals is most effective

Improving soil fertility in the rabi black soils of Bellary region poses several problems, since the crops are grown practically after the cessation of the monsoon Hence, to improve fertilizer efficiency it is necessary to advance the sowing of the rabi crops from the traditional October to as early as possible in September This practice results in two advantages First the crops benefit from one or two showers before they become entirely dependent upon the stored moisture Second the one to two showers received during the early stages improve the uptake of nutrients Data on sorghum are given in Table 11

Recent studies indicate that phosphate carriers such as ammonium phosphate are much more effective sources of phosphorus than is superphosphate The problem of building up soil phosphorus remains unsolved Any phosphorus applied is washed down the cracks, along with the soil by the rains in the next season

There are some indications, still to be proven, that nitrates are preferable to either ammonia or urea

Aberrant weather is extremely common Practices available to overcome aberrant weather consist of changing from grain sorghum to fodder sorghum, and from sorghum to hardy crops such as safflower and chickpea, and adjustment of the plant population depending upon the October rains and the moisture storage Examples of crops found suitable for adequate (20 cm or more) and limited (15 to 20 cm) stored moisture at Bellary are given in Table 12

Starting with a plant population density of 10^5/ha sown in the month of September, the full population density of sorghum is retained when there are at least 2 rains in October and when the rainfall amounts to 10 cm If the rainfall in October is 5 cm, every third row is bladed and the population density is reduced to two-thirds, if the October rains are 3 cm or less, only half the population density is retained

Table 11 Effect of sowing dates on the yield of sorghum (M 35-1)

Year	Yield (q/ha) September	Yield (q/ha) October
1973	34 44	17 32
1974	10 74	2 40
1975	16 50	7 40

Collection and storage of runoff pose no problem since the seepage losses are very small Utilization of the runoff needs to be worked out in detail (Table 13) It is clear that minimal irrigation should be given only after October rains and before the soils begin to crack It is also clear that a single application over a large area is preferable to repeated applications of water in a small area

The Sholapur Region

The region receives a mean annual rain fall of 742 mm Rainfall is bimodal having a

Table 12 Crop and varietal choice for different moisture conditions

Moisture condition	Crop	Variety
Adequate	Sorghum	CSV 7R
		M 35-1
		36A X 148
Limited	Sorghum	CSH-2
		CSH-3
	Safflower	7-13-3
		A-300
	Chickpea	A-1
		N-52, N-59
	Dolichos lablab	CO-7

Table 13. Effect of supplemental irrigation on sorghum, Bellary, 1972–1973

Time of irrigation	Grain yield (q/ha)	Response to unit water (q/ha)
None	4 3	—
Knee high	13 7	9 4
Boot leaf	10 0	5 7
Seed setting	12 4	8 1
Boot leaf + seed setting	16 5	6 1
Knee high + boot leaf + seed setting	22 6	6 1

small peak in the month of July and a high peak in the month of September

A toposequence consisting of shallow, medium, deep, and very deep soils occurs in the region The shallow soils are cropped in kharif The problems of soil and water management are similar to those in the semiarid red soil zone

The medium and deep soils are extensive in the region These soils are traditionally cropped in the rabi, after cessation of the monsoon in October Erosion is heavy, and crop yields are low The best recommendation to date for medium and deep soils is to grow either kharif or rabi crops depending upon the seasonal rainfall as indicated in Table 14

The management problems of the very deep soils remain unsolved These soils occur in the lowest elements of the topography on relatively flat lands and are subject to intermittent flooding by runoff from the adjoining catchment Unless surface drainage is provided, these soils cannot be cropped until late in the season usually November, which restricts the choice of crops to either safflower, chickpea, or wheat Of these, wheat is not an efficient crop of the region (Table 15) Because of their location, the deep soils tend to be saline, which further restricts the choice of crops

The very deep soils of the Sholapur have the potential for raising two crops, one in kharif and the other in rabi An analysis of the problem indicates the need to provide crop drainage in the kharif A modified ridge-furrow system or bedding system that has trenches laid on a grade is needed The system is then linked to a farm pond in which excess runoff may be collected for recycling The whole system is supported by graded bunds to take care of heavy and intense rainfall The above method, however, is yet to be initiated

Unlike in the Bellary region, well waters

Table 14 Cropping patterns for medium and deep soils of the Sholapur region

Season	Months when rainfall adequate to sow	Suitable crops and varieties
Early kharif	June to July 15	Pigeon pea HY-2 and HY-4 Sorghum CSH-5, CSH-6, and CS-3541 Groundnut TMV-2 Blackgram T-9
Late kharif	July 15 to August 15	Blackgram T-9 Sunflower
Early rabi	August 15 to September 15	Safflower M-300, and 7-13-3 *Dolichos lablab* CO-7 Sorghum M 35-1 and CSH-7R
Late rabi	September 15 to October 15	Sorghum M 35-1 Safflower Chickpea N-59

Table 15 Yield of late rabi crops (q/ha), Sholapur region

Crop	1971	1973	1974	Mean
Chickpea	10 99	15 01	16 16	16 00
Safflower	9 97	16 21	15 11	13 76
Wheat	8 16	6 20	12 18	9 01

C D (0 05) = 2 05, 2 10, 2 03, and 1 76 respectively

ll ne red, medium soils of Sholapur are suitable for irrigation The problems of runoff recycling are the seepage losses in the medium soils (because of permeable murrum) and the system of runoff utilization in the deep and very deep soils

The Indore Region

In this region shallow, medium, deep, and very deep soils are encountered in a toposequence The region receives a mean annual rainfall of about 1,050 mm, most of which is received in the months of June, July, August, and September October rains are occasional Winter rains are rare

Traditionally, the region grows kharif crops in 30% of the area, mostly in the shallow and medium soils No special problems are noticed The deep and very deep soils that are cropped in rabi occupy 70% of the area It is these soils that pose problems Erosion is serious Even in the subnormal rainfall years, runoff is about 30% of the rainfall and remains unutilized The first step is to crop as much area as possible in the kharif to protect the soil and obtain high yields Data from the Indore Dryland Center are given in Table 16

Table 16 Kharif and rabi crop yields at Indore

Season	Crop	Yield (q/ha)
Kharif	Soybean	29 0
	Maize	50 6
	Sorghum	31 8
Rabi	Wheat	8 5
	Chickpea	13 0
	Safflower	21 0

For raising a successful kharif crop in the deep and very deep soils, crop drainage is needed Ridge-furrow systems or bedding systems are found suitable

Contour bunds are not suitable for the region because they lead to water stagnation The value of graded bunds has still to be established Interterrace land treatment is essential to minimize erosion and improve moisture storage When this is done, it is possible to raise two crops in deep and very deep black soils of the region The best sequences are soybean-safflower, maize-chickpea, and sorghum-chickpea Although there is considerable area under dryland wheat in this region, its productivity is low Chickpea and safflower yields are better (Table 17)

Table 17 Performance of rabi crops in the Indore region (kg/ha)

Crop	1971	1972	1973	Average
Wheat	1,003	270	1,766	1,013
Chickpea	1,170	810	1,728	1,236
Safflower	2,165	2,780	2,277	2,407

Wells are the major source of irrigation water The quality of water is good, and the most common irrigated crop is sugarcane Because of permeable soil and murrum, seepage losses are high from tanks and ponds in all soils, except probably the very deep soils Data on supplemental irrigation are not available

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APPENDIXES: PROCEEDINGS OF THE SEMINAR

Appendix 1. Welcoming Address

RALPH W CUMMINGS
Director, International Crops Research Institute for the Semi-Arid Tropics
Hyderabad, India

Mr Minister, Chairman Ladies,
and Gentlemen

I am pleased to welcome you to Hyderabad on behalf of the International Crops Research Institute for the Semi-Arid Tropics We had considerable reservations initially about hosting this seminar at ICRISAT which was to be planned with the University of Hawaii, the Consortium of U S universities who are concerned with USAID-supported programs in tropical soil science and the USAID We welcomed very much the idea of the seminar but we recognized that at this stage of the Institute's development our facilities were quite limited for hosting the seminar

You can see that the room we have here is full We had to limit the number of participants There are many others who would have liked to participate in this meeting and whom we would have liked to have participate, but the limitation of space and facilities just did not permit a larger group But the practice of moving ahead with our program development and with consultation with our professional colleagues around the world is something of a hallmark of our institution The Institute was formerly constituted in 1972, on July 5 at the first meeting of the Board of Trustees We got access to our land site on April 22, and when the Trustees first met we had our first crops in the ground We had our scientist, Bert Krantz, on location at that time But we began to assemble our staff and develop our program of research at headquarters Immediately we also began our series of consultations with our colleagues with whom we expected to work out programs of cooperation around the world Recognizing that if we were going to serve the segment of the agriculture in the rain-fed semiarid tropics, a segment of agriculture that had been left behind, we needed from the outset to consult with our colleagues who are working with those problems in the semiarid tropics seek their counsel and take into account their experience, as we were developing the program

We have had several seminars and workshops in the interim, and we are now in the process of trying to develop, consolidate, and work out appropriate working relationships with the organizations in all of the nations with whom we hope to develop cooperation and whom we hope to serve in the future And it was in this spirit, and with the expectation that you would appreciate the limitations in our facilities and be tolerant of us, that we accepted with gladness the responsibility of attempting to work with you in hosting this seminar We welcome you most heartily We realize that if we are going to serve the people of these regions, it is go-

ing to be essential that we understand more completely the resource base with which we are going to have to work and for which we are going to have to find ways of developing improvements over the years And obviously the soil base and the climatic conditions under which the soils are developed and in which the crops are grown on the soil must be understood in their various complexities if we are going to really serve these regions adequately

With the steering committee representing the different agencies who are sponsoring this seminar, a very careful program has been planned, and I am delighted to see that practically everyone, with very few exceptions, who has accepted to participate in this conference, has found it possible to come here and to be present at the opening of this session I am sure that all of you will be participating most actively throughout We hope that as you see, in the course of the week, the present state of our facilities and the program we have under way you will share with us your thoughts and your suggestions about how we might improve our program and our approach We will watch with very great interest and concern and attention the observations that will emerge from this conference Looking at the soil resources of the areas with which we are concerned, how might we go about managing these resources or developing programs for managing these resources more effectively in the years ahead?

We welcome you most heartily We hope that you will be reasonably comfortable while you are here and that the conference will be most productive

Appendix 2. Inaugural Address

THE HONORABLE SHRI SHAH NAWAZ KHAN
Union Minister of State for Agriculture and Irrigation and WAQFS
Government of India

Dr Cummings, Distinguished Scientists
Ladies, and Gentlemen

At the outset, I wish to convey to you the good wishes of my senior colleague, Shri Jagjivan Ram, Union Minister for Agriculture and Irrigation who unfortunately is unable to be here today because he has to be in Delhi for important Parliamentary work He has asked me to convey to you his apologies and also good wishes

I am happy to have the privilege of being with you today to inaugurate this international seminar on problems relating to soil survey and land-use planning I am particularly happy that so many distinguished soil scientists from different parts of the world have gathered together here On behalf of the Government of India I would like to extend a very warm welcome to all of you who have come here from other countries

We are always happy to receive suggestions from all parts of the world and to exchange our experience with others We are also happy that ICRISAT within a span of 4 years, has made a good start in improving the yield potential of sorghum, pearl millet, chickpea, and pigeon pea More recently, groundnut has also been added to the scientific mandate of this Institute What is even more important is the integration of crop improvement work with research on soil and water management In most of the unirrigated areas, a crop variety alone cannot work wonders What is important is to look at the problems of soil and water conservation in their totality and fit in a suitable crop and crop variety according to the moisture-holding capacity of the soil and the interspell duration of rainfall Some very good work has been done in India on soil-crop-weather relationships, I hope you will have an opportunity to study it

We in India have serious problems of soil-fertility management At the suggestion of Shri Jagjivan Ram, Union Minister for Agriculture and Irrigation, the Indian Council of Agricultural Research therefore is planning to initiate a program of training Primary Soil Health Workers We feel that this is particularly important in view of the large irrigation projects we are taking up Prime Minister Shrimati Indira Gandhi has recently announced, as part of a 20-Point Economic Program, the extension of the irrigated area by another 5 million hectares during our Fifth Plan period She has also proposed a national program for scientific ground-water utilization This brings me to the problems of waterlogging, salinity, and alkalinity, which have appeared in some of the old irrigated areas

During the last 20 years, several reservoirs were constructed to store water At

that time of construction, it was feared (and those fears later were proven true) that unless soil conservation measures were taken, these reservoirs may get silted resulting in lower storage capacity But before any soil conservation measure could be taken, we needed to know about the characteristics of the catchment Hence, the Soil Conservation Wing of the Department of Agriculture of the Government of India was given the responsibility of surveying the soil in the river catchment areas, during the Second Five-year Plan period The organization of the soil survey was strengthened by the headquarters at the Indian Agricultural Research Institute and by the four regional stations in Delhi (Northern Region), Calcutta (Eastern Region), Nagpur (Central Region), and Bangalore (Southern Region) By the end of 1971, 90 million hectares covering about 27% of the country's area were covered by reconnaissance and detailed survey, and 16 million hectares were covered by detailed survey A total of Rs 8 crores has been allocated for the Fifth Plan period in addition to the allocation for soil survey in the irrigation project areas It is hoped that a soil map of India at 1 1 m (million) scale will be available within the next 10 years We are also strengthening the State organization for general survey and for development programs

We are aware that to save time in soil survey, we need to have aerial photographs These photographs are now available for a major part of the country, and the Surveyor General of India can now provide aerial photographs of any particular area on request To train the people in the use of aerial photographs, an Aerial Photo Interpretation Institute has been established at Dehra Dun, which not only imparts training in basic photo-grammetry, but also trains the personnel working in the Departments of Soil Survey, Hydrology, and Forestry

Collaborative projects in the field of remote sensing of agricultural resources by carrying out multispectral photographic aerial surveys and interpretations have been initiated in the District of Anantapur in this State of Andhra Pradesh In this project, the Indian Space Research Organization and the ICAR are cooperating The objective is to prepare a comprehensive agricultural resources inventory, crop identification, and correlation with the data compiled by the Directorate of Economics and Statistics, to identify and locate areas affected by different diseases, and to carry out soil classification and mapping Preliminary reports for some parts of this district have already been released A similar experiment has been started in the Patiala District of Punjab In another pilot project for determining the feasibility of using multiband imageries for preparing resource inventory, in cooperation with the Space Application Center Ahmedabad have been undertaken The studies indicate the possibility of preparing resource inventory maps from remotely sensed photo imageries We have also completed rural engineering surveys in about 8 500 villages spread over 24 drought-prone districts The main purpose of these reports was to have detailed information about the different engineering and agricultural problems in the area

I am happy to know that you will be discussing in detail the usefulness of these surveys to the poor farmers It has been my experience that many times excellent reports are prepared by spending huge amounts but seldom used by the planners or the executors of the program This may be either because the persons responsible for implementation of the programs are not conscious of the importance of the soil survey or because they may find these reports too academic to be of any practical use I am sure that, as a result of your discussions, ways and means will be found that will have these reports written in such a manner that even persons who do not know much about soil science could use them in the planning and implementation of the programs

I also notice from your program that problems about classification will be discussed In India, four broad soil groups have been recognized for centuries These are black, red, laterite, and alluvial soils Every one of these soils has its peculiar management problem But even within each of these soil groups, there are considerable variations

For example, we have three different types of black soil, that is, shallow, medium, and deep, and again management of the deep black soils is much more difficult than management of shallow soils I understand that the classifications used in the United States have not given adequate thought to these black soils developed under conditions of the semiarid tropics where periods of excess rains are followed by very dry periods Very little information about the effect of irrigation on these different types of soils is available I am informed that the present international classification does not give much importance to the salts in the black soil areas of the semiarid tropics One of the major problems in our deep black soils however, is the development of salinity, [illegible] c ally under flat land topography Even such simple practices as contour bunding have resulted in more problems in these soils About 25 broad soils groups are now recognized in India But it is not always possible to use this information while planning on a microlevel Detailed soil survey may take considerable time, and in the context of present-day agriculture, it is not possible for us to wait that long I would, therefore, urge this group to discuss in detail how the information already available could be applied at the microlevel

I am happy to see from your program that on the last day you will have a plenary session to formulate recommendations of soil and land data needed for national planning I look forward to receiving these recommendations, and I assure you on behalf of my Ministry that we will take immediate steps to implement any important recommenda .on that will emerge from this seminar

I wish the seminar all success

Appendix 3. Keynote Address

WILLIAM P PANTON
International Bank for Reconstruction and Development
Washington, D C, U S A

Honorable Minister, Ladies,
and Gentlemen:

From the moment I first learned of the intention to hold this seminar I have been an enthusiastic supporter of the proposal, and I am therefore most pleased to see that proposal now become a reality

I am sure I am speaking for all when I commend the Governing Board of ICRISAT, the USAID, the University of Hawaii, and the Consortium on Tropical Soils for their initiative in sponsoring such an innovative meeting

Innovative because it brings together representatives from two disciplines - soil science and planning - who are so vital to effective programming of agricultural development in the tropics, but who generally work so far apart and seldom come together, even in their working lives, much less at international seminars such as this

I feel sure that this seminar will reveal that these two groups, one of which usually works in the higher reaches of the administrative and planning firmament and the other at the grass roots or back-room level, have much in common and that each has something of value to learn from the other And I say this with some conviction, because I have worked for many years in each of these fields

The physical remoteness of the two groups is undoubtedly one of the impediments to communication between them, in spite of their common interests, upon which I will say more in a few minutes

But incomprehension resulting from a language barrier, can be an even greater hinderance to the development of the dialogue and the closer understanding that are necessary for effective planning and implementation of agricultural development programs And I am not referring to the problems of communication between persons of different mother-tongues or of dialects, but of jargon—of technical jargon

Now what exactly is jargon? My dictionary describes it rather slightingly as gibberish, or the twittering f birds! But more to the point, it defines jargon as a "mode of speech full of unfamiliar terms"

And I think that summarizes rather well the situation that often exists when a soil scientist and a planner try to communicate either orally or, worse still, in writing, where it is impossible to ask a person what he means by a certain word

Let us face it— our disciplines are among the worst in their addiction to long and peculiar words and phrases How many planners can honestly say they know what a podzol is, much less a dystric podzoluvisol, and whether these soils—which is what they are—are

good or bad, fertile or infertile? Likewise, how many soil scientists can claim an understanding of marginal investment propensity or even know with any exactitude what a growth pole is in physical-planning parlance?

The soil science terms mean little or nothing to the uninitiated, the planners' phrases, even those that are commonplace on television, often convey to the unacquainted a different meaning from what is intended

The lesson we should draw from these examples and apply to our meeting is to curb our tendencies towards blinding one another with the terminologies of our respective sciences and instead to strive toward simplicity of expression

I understand that the basic objectives of this seminar besides increasing communication between scientists and planners are to bring out the practical usefulness of soil classification in interrelating work done in different tropical areas and in physical and economic planning especially in respect to agricultural sector programs These objectives are highly commendable at the same time they are not very original because the application of soil science towards the attainment of these objectives is already well understood and practiced in many parts of the earth

Unfortunately however this understanding is far from universal and it is interesting to consider why this is so In my view there are two basic reasons both historic

First the study of soil is a new science a young science and a polyglot science at that So far as the tropics are concerned, I would term it a post-World War II science Its practitioners are few and are concentrated in a small number of countries mostly those with temperate climes Its professional cadre is young as well as small and in consequence it has not yet established a secure or final niche in scientific circles or in the institutional structure of government and society It is still seeking its way, establishing its foundations, and gaining acceptability in fits and starts, and the pattern, in terms of application, is in consequence very uneven

Second, soil science is coming of age at a time of rapid sociopolitical change on the world scene, and a feature of this changing scene is the increasing extent to which governments are taking an initiative in directly fostering and controlling developments This initiative, which is also largely a post-World War II phenomenon, is in marked contrast to the preceding period when laissez-faire attitudes towards development predominated

In the absence of centralized government initiative or control, profitable operation or improvement of existing agricultural lands or new agricultural land development is the responsibility of individuals or private groups if they succeed the satisfaction and reward belong to them if they fail, disappointment and loss are also theirs

But when a government takes over this development responsibility, which is increasingly the case in tropical, developing countries success is attributed by each individual beneficiary to himself, while failure tends to be blamed on the government

And the record shows that inadequate knowledge of the soil or insufficient understanding of its capability or both, are frequent causes of failure, whether through poor choice of site, inappropriate selection of crop or cropping pattern, or inadequate management

Why do these things happen? If simple farmers can cultivate their own land profitably, one may ask, why cannot a government agency which has superior financial and technical resources, do likewise?

Some of the reasons are obvious so obvious that I do not intend to dwell on them But a few, which may not be so obvious, are of direct relevance to this seminar

For one thing, as every soil scientist knows well, no two soils are ever alike The slightest change in only one of a wide range of factors, such as parent material, slope, or drainage or characteristics such as pH, organic matter content, or soil consistency, can profoundly affect the suitability and hence the yield potentiality of the soil for a particular crop

But these important differences, which can be easily overlooked, occasionally even by skilled and experienced soil surveyors in the course of detailed surveys, are well ap-

preciated, although not necessarily understood, by the farmer who has long familiarity with his land In the case of those whose ancestors have farmed the same land before them, I suspect that much of this awareness is subconscious or conditioned by family custom, habit, or superstition They know how to give back to the soil what they have taken from it

Is it any wonder therefore that farmers, knowing the variability and unpredictability of their land, and with their sound ecological knowledge based on experience, are basically conservative and suspicious of innovation? They have too much to lose by being otherwise

But what about government agencies that come in with the best intentions to help, or occasionally to take over? Why, so often, do they go astray? It is in large part because the people in charge do not understand the natural variability of the land in question and consequently have great difficulty in accommodating the factor of variability to the inevitably large scale of their operations

Put another way, because of the larger scale, the TLC—Tender Loving Care—element, whether it be of the soil or the plant, is often lost

So here is a very fundamental area where the soil scientist can help, through his exact knowledge of the soil and of the response of the plant to changes in the soil, be they natural or artificially induced Admittedly, his idea of tender loving care may be different from that of the farmer, for after all his field of operation is larger, and because he is a scientist, he applies scientific methods

Essentially, however, he does the same things as the farmer but in a different way He first gets to know the peculiarities of his land, by carrying out a survey, at a degree of detail and according to criteria of which he is, or should be, the best judge He then relates his findings about the soil to the crop or crops that will be grown, or, equally important, should not be grown if his findings are contraindicative

Or if he has reasonable doubts either way, he will be cautious and recommend experimentation or a pilot scheme.

But very frequently this judgment is never called for Simply because of the lack of specific land classification data and in the absence of a competent soil scientist, someone else with a confidence granted only to those who lack the requisite knowledge makes the decision Very often it is a politician, or an administrator, or—dare I say it?—even a planner, who should know better

Conducive to this attitude is the fact that there are always plenty of excuses when things go wrong "no soil survey data were available and a decision had to be made" or "no professional advice could be found so we had to make up our own minds" However, valid as these excuses may be, in reality, they are often just another way of saying, "We like to gamble, especially with someone else's money, and professional opinion would have been too cautious, which could have prevented us from going ahead with our pet scheme"

Why do government projects (and big business projects too) so often go wrong in this way? A few examples may prove instructive, but it usually boils down to inadequate project identification or preparation, where the importance of site suitability for crop (or crop suitability for site) was insufficiently appreciated

Often, the very rationale for siting a project or selecting a crop may be at fault In recent years I have seen enough examples of overemphasis on border security, accessibility (present or potential), legalistic availability, national or local crop self-sufficiency excess processing, transporting or storage capacity, diversification policy, political or personal preference, and occasionally and regrettably examples of just plain bribery and corruption or ineptitude governing the choice of site or crop to the exclusion of scientific evidence concerning ecologic suitability to convince me of the dangers awaiting those who do not take the trouble to check the natural resource conditions of their site before they proceed with development

This can result in such absurdities as growing moisture-loving crops in drought-prone areas without adequate irrigation, cultivating erosion-inducing crops on exces-

sively steep slopes, planting deep-rooting crops intolerant of high water-table conditions in flood-prone swamplands or next to paddy fields or even opening up land for agriculture like mountain sides or impossibly salt-toxic lands which no local farmer in his right mind would consider for the crop in question or for any crop

Of course a feasibility study is no guarantee that mistakes will be avoided, but experience shows that a feasibility study if properly done is well worth the time and money spent and is of fundamental importance because the scientific basis it offers provides adequate soil survey and land classification data and advice from which sound criteria for choice of site or crop can be determined

The World Bank in common with other international and bilateral assistance agencies is becoming increasingly interested in seeing that these proven techniques for assessing the suitability of land for specific development projects are applied in the planning process

This is evidenced in recent years by the Bank's cosponsorship with the FAO and UNDP of the Consultative Group on International Agricultural Research which this year is contributing about 65 million dollars in support of international agricultural research at 12 institutes including our host institute here in Hyderabad

The transfer of knowledge through linkages with national and regional research institutions throughout the world is an important objective of the work at these institutes, and fundamental to the success of this work is the strengthening of the soils research network which will be discussed at our Session 5

The Bank is complementing this international effort with support for national agricultural research that has similar objectives of assisting the transfer of knowledge (Malaysia, Indonesia), it is also supporting national mapping projects that have the objective of accelerating the progress of integrated land-resource surveys (Indonesia)

In the processing of all Bank loans and credits, evidence of the compatibility of a project with the soil and other environmental circumstances of the area where it will be sited is mandatory

Remarkable strides have been made in surveying and classifying world soil resources, particularly those of the tropics in the last two decades More extensive and larger-scale base map coverage improvements in remote sensing aides including false-color and infra-red aerial photography and most recently the application of satellite technology to earth-resources inventory work have proved particularly useful

The adoption of a standardized nomenclature and the gradual acceptance of one natural or taxonomic system of soil classification have enormously facilitated the task of correlating soils on a global scale and of comparing their suitability for specified crops their productivities and their land-utilization potentials or capabilities

In other words the theoretical basis for soil classification and the techniques and methodology of soil survey are now well understood The stage is set for applying this knowledge to the solution of practical problems of site selection and crop choice of transferring the knowledge from site to site

Undoubtedly, the constraint at this time centers around the dearth of accurate soil and other relevant land-resource inventory and the relatively small number of scientists able to extend the survey coverage, carry out trials, and make the necessary comparative judgments whereby each country can learn from the successes and failures of another rather than duplicate the work learn the hard way, or repeat the same mistakes

From what I have said so far, some of you may feel that I am overemphasizing the importance of the soil scientist in the decision-making or planning process If so, let me make amends by addressing myself to the wider problems of national and regional development-policy formulation and planning and by viewing the soil scientist's contribution in that context

It seems that the more we learn about planning, the more we discover that no one profession has all the answers Taken to extremes, we might say that anyone can be a

planner, so long as he or she has common sense, for planning is simply forward-looking common sense

But let us not go to extremes I think it is sufficient for us to recognize that there are many types of planners—economic, fiscal, physical, urban, agricultural, manpower, infrastructural, environmental, and so on

I hope that we have at least one representative from each of these disciplines here at this seminar to ensure a balanced discussion of the relevance of soil survey and classification to the several aspects of planning

We now know that effective national or regional policy-making and planning calls for contributions from these several specialists, which can best be provided through multidisciplinary teams responsible to a central agency of government, and it is at this level that the soil scientist has a major role to play and a contribution to make which is not confined to planning in the agricultural sector alone

After all, the planners' grist is information—data—facts, about the three basic tangibles for development, namely, human, financial, and natural resources

The soil scientist deals with the last of these resources, and his study of the soil embraces the factors that condition the character of the soil, namely, climate, parent material, topography, vegetation, and time

He is therefore particularly well equipped for evaluating the potentials of land and its resources through training and experience and through his ability to visualize in three dimensions what he interprets from two dimensional maps, which are the main vehicles for presenting land-resources data

Which brings me to another point Land-resource information, whether it concerns soil, mineral, vegetation, or water resources, or natural topography or climate, must be supplemented for planning purposes by information about the present use of land, and it seems to me that the dearth of up-to-date information on actual land use and ownership status is one of the greatest impediments to comprehensive land-use planning in the tropics at this time

The current trend towards more centralized planning and continuing improvements in planning technique is likely to confirm this deficiency, and I will be interested in discussing this problem with other planners during our seminar

There is a real danger, of course, that all this information—all these facts, figures, and maps that gradually accumulate as surveys, census, experiments, and feasibility studies are completed—can confuse rather than enlighten the conscientious planner

Irrelevant data will only clog up the system, and this can be worse than having no data at all, which leads me to make an appeal for relevance

This appeal is directed particularly at the suppliers of the facts, in our case the soil scientists, who, if they believe that their work is relevant outside their own specialized field, must take greater pains than has usually been the case in the past to present their results in a readily understandable form

But my appeal is also directed toward the planners, for they have a duty to express their needs to the soil scientists This can be quite a problem, which can best be overcome if the planners will take a little effort to find out something about soils My advice to them is to get themselves out into the field as often as they can, if possible with an articulate soil scientist or otherwise with a general agriculturist, a farmer, or an ecologist, and then ask questions without embarrassment and press them for answers And listen

They should also learn how to read maps visualize landscape in three dimensions from a contour pattern, and orient themselves in the field It is surprising in my experience how many people, even quite senior in planning circles, have difficulty in doing these simple things

They should also gain an understanding of the land-capability or soil-suitability classification system in local usage These are usually simple interpretations of the much more complex soil-classification systems, which fortunately, in view of their strangeness and complexity, can generally be ignored by the nonspecialist For purposes of national, sector, or regional planning, the

more general or broader-scale information is usually the most relevant

Disproportionate allocation of scarce staff to highly detailed surveys and classification exercises of relatively small areas is unlikely to be very cost-effective in a national-development context, except when related to specific research problems whose solutions are likely to have immediate practical impact

A broad-scale national inventory of soils or of any other natural resource deserves high priority in any country that has made a strong committment to central or regional planning, for the sensible identification of priority areas within a national boundary is only possible when the facts are available In the case of soils and the assessment of their capabilities, this requires a survey coverage of a uniform scale and accuracy for all present or potential agricultural lands This type of inventory will also greatly facilitate the transfer of information and technology and will aid the development of cooperative international research programs between countries, which are among the basic objectives of this seminar

Judging from the titles of the papers to be presented at this seminar and knowing many of the contributors as I do, I am confident that we shall all benefit substantially from our discussions in the next 4 days And I am also most optimistic that many of the lessons we shall learn can be immediately applied with profit to the development planning process

Since national representation at this seminar includes one soil scientist and one planner from each country, I would like to close by expressing the hope that the dialogues that will be established between us during the next few days will continue long after the seminar has ended If they do, this seminar will have succeeded

Appendix 4. Program

Sunday, January 18

1030-1330	Registration at the Ritz Hotel
1800-1900	Get-acquainted cocktail hour at the Ritz Hotel

Monday, January 19

Opening Plenary Session

Chairman L D SWINDALE

0730-0800	Registration of participants
0800-0810	Introductory remarks—*L D Swindale*
0810-0820	Welcoming address—*R W Cummings*
0820-0845	Inaugural address—*Shri Shah Nawaz Khan*
0845-0915	Keynote address—*W P Panton*
0915-0930	Vote of thanks—*J S Kanwar*
0930-1000	Tea and coffee recess

Session I. Modern Soil Classification Fundamentals

Chairman R.S MURTHY
Reporter· W.M. LAW

1000-1030	Soil Classification and the Design of Soil Surveys—*W. M Johnson*
1030-1130	Some Fundamentals of Soil Classification—*F H Beinroth*
1130-1200	The Occurrence and Significance of Climatic Parameters in the Soil Taxonomy—*H Ikawa,*
1200-1330	Lunch

Session II. Soil-Survey Interpretation for Technology Transfer

Chairman: G.B. BAIRD
Reporter: G.A. NIELSEN

1330-1400	Agrotechnology Transfer and the Soil Family—*G. Uehara*
1400-1430	The Contribution of Soil-Survey Interpretation in Land Appraisal—*A.J. Smyth*

1430-1500	Soil Survey, Classification, and the Transfer of Agricultural Information *A W Moore*
1500-1530	Soil-Survey Developments for Improved Rubber Production in the Malay Peninsula *H Y Chan*
1530-1600	Tea and coffee recess
1600-1700	General discussions of Sessions I and II

Tuesday, January 20

Discussion Groups on Soils Information Available for Planning

Chairman M L DEWAN
Reporter J B COLLINS

0800-1030	Discussion Groups	Discussion Leaders
	A	*F R Moormann*
	B	*R W Arnold*
	C	*H Brammer*
1030-1100	Tea and coffee recess	
1100-1200	Reports from discussion groups	
1200-1330	Lunch	

Session III Use of Soils Data in Land-Use Planning

Chairman N N NYANDAT
Reporter F H BEINROTH

1330-1400	Land Evaluation for Agricultural Land-Use Planning *J Bennema*
1400-1500	Techniques for Displaying Soils Data to Planners and Decision Makers *G A Nielsen*
1500-1530	Tea and coffee recess
1530-1600	Soils and Land-Resource Mapping in Iran *M Lakthan*
1600-1630	Soils Data for Land-Use Planning in India *R S Murthy*
1630-1700	General discussion of Session III
1830-1930	No-host cocktail
1930-2200	Dinner ICRISAT and University of Hawaii

Wednesday, January 21

Session IV. Use of Soils Data in Regional and National Development

Chairman I I ASHAYE
Reporter Y P BALI

0800-0830	Soils and Institutional Requirements for Regional Planning and Development—*M L Dewan*
0830-0900	Soils Data for Agricultural Development in Ghana *H B Obeng*
0900-0930	A Case Study of Tropical Alfisols from Sri Lanka—*C R Panabokke*
0930-1000	Coffee and tea recess
1000-1030	Use of Soil-Survey Data in Korea Land Selection for 'Iongil' a New Rice Variety *Yong Hwa Shin* (presented by *Ki Tae Um*)

1030-1100	Interpretation of Small- and Large-Scale Maps for Land-Use Planning in the North Indian Plains—*H S Shankaranarayana*
1100-1200	General discussion of Session IV
1200-1330	Lunch

Discussion Groups on Soils Information Needed for Planning

Chairman E.B PANTASTICO
Reporter K.A DE ALWIS

1330-1530	Discussion Groups	Discussion Leaders
	A	*A R M Mekki*
	B	*B Balankura*
	C	*R B Miller*
1530-1600	Tea and coffee recess	
1600-1700	Reports from discussion groups	
1730-1930	Dinner	

Session V. Expanding the Soils Research Network

Chairman F R MOORMANN
Reporter H IKAWA

1930-2000	Need for an International Research and Technology Network in Tropical Soils—*G B Baird*
2000-2030	A Soil Research Network through Tropical Soil Families—*L D Swindale*
2030-2200	General discussion of Session V

Thursday, January 22

ICRISAT Field Tour

0730-1030	Hotel pick-up and travel to ICRISAT farm

Session VI. Soil and Water Management in Rain-fed Agriculture

Chairman D. MULJADI
Reporter: P. SINGH

1030-1100	Soil and Water Management in the Semiarid Tropics—*B A Krantz* and *J Kampen*
1100-1130	Management of Rain-fed Agriculture in Semiarid India—*Ch Krishnamoorthy*
1130-1200	Use of Soils Information for Planning Agricultural Development in the Semiarid Tropics—*B A Krantz, S M Virmani*, and *S Singh*
1200-1330	Lunch

Final Plenary Session

Chairman J S KANWAR
Reporter G UEHARA

1330-1530	Planners Panel Recommendations of Soil and Land Data Needed for National Planning Panel Members *W P Panton, M Rahman, T F Shaxson, R D Wahab.*
1530-1545	Closing remarks—*T S Gill*
1545-1600	Vote of thanks—*B A Krantz*

Appendix 5. Summary of Discussions and Recommendations

Summary of the Discussions of Sessions

Session I. Fundamentals of Modern Soil Classification

J L SEGHAL Soils with Natric horizons may have considerable differences in soil structures, one soil may have a columnar structure, and another, a blocky structure The management of these two soils could be very different, but the classification might be the same

W M JOHNSON The definition of the Natric horizon was written after intensive study of the importance of prismatic and columnar structure as related to exchangeable sodium percentage and other characteristics of sodium-affected soils Strict application of the differentiating criteria is absolutely essential to consistency of classification Of course, the definitions of horizons and of soil classes can be changed if there is sufficient positive evidence to warrant change

J L SEGHAL There appears to be some confusion caused by using the same criterion at different categoric levels For example, soil moisture regime is used at the suborder and great group levels, and base saturation is used at the order and great group levels Examples are Ustalfs and Ustochrepts, Ultisols and Eutrochrepts

W M JOHNSON Differentiating criteria are used at categorical levels appropriate to their importance at that level To use a given criterion uniformly (at the same categorical level throughout the taxonomy) results in many " mpty classes," that is, classes with no known examples in the universe of soils

K A DE ALWIS The phase was described as cutting right through all the categories of the system How is this reconciled with the use of certain phase criteria, for example, soil slope at the family level?

W M JOHNSON No soil characteristic is used exclusively as a phase criterion Any soil characteristic may be used as a phase differentia if not already used at some categorical level in Soil Taxonomy Soil slope may be used if necessary as a differentiating criterion at the family level (see chapter 18 in *Soil Taxonomy)* If it is used as a differentiating criterion, obviously it is not a phase but a criterion in the Taxonomy itself

J C BHATTACHARJEE What are the summer and winter months to be taken into consideration for defining the soil temperature regime? Should the summer dry months be taken into consideration or the summer wet months? In the eastern part of India, hot and dry months extend from March to May, while in Western India they are April to June Air temperature drops immediately after rain

H IKAWA The 5° C difference or the "iso" temperature class refers to soil temperature not air temperature Soil temperature at a depth of 50 cm tends to be constant throughout the summer or winter months prescribed in Soil Taxonomy

H Y CHAN In our experience of measuring temperatures for rubber-growing soils in Malaysia, we find a regular pattern of correlation between air and soil temperatures in shaded conditions under mature rubber trees but no such pattern in unshaded open areas In view of such fluctuations it will be much more reliable to measure actual soil temperatures and not rely upon correlations with air-temperature measurements

Session II Soil-Survey Interpretation for Technology Transfer

W M LAW Some of the comments indicate a need for clarification of the use of the term *land capability* in Malaysia The term relates to classification of land for mining agriculture, forestry, grazing recreation and other uses Land-capability classifications are made by the Economic Planning Unit of the Prime Minister's Department *Soil suitability* is a term used in Malaysia to rate soils for agricultural crops only

K A DE ALWIS How much information on day length and other features that affect plant growth are included in Soil Taxonomy?

G UEHARA Many factors like the one you mention will not be predicted by the Taxonomy

E B PANTASTICO What is the cost of conducting soil surveys with modern methods?

H Y CHAN In rubber-growing areas of Malaysia, the cost is about 1 00 to 1 25 U S dollars per hectare Mapping is on a scale of 1 50 000

T JEAN Do termite activities have significant impact on soil genesis in soils under rubber in Malaysia? Does this feature cause problems in classification using the Soil Taxonomy?

H Y CHAN There is some influence, but it does not cause problems in classification These features, if present and significant, can be accommodated at the subgroup levels

Session III Use of Soils Data in Land-Use Planning

T F SHAYSON In addition to Dr Murthy's statement, "The purpose of soil survey is not fulfilled unless a suitable land-use plan is projected on the soil map," I would add "The purpose of planning is not fulfilled unless an acceptable, feasible, adequate, and appropriate land-use plan can be put on the ground and remain there "

E B PANTASTICO Much has been said about soil-survey interpretation for technology transfer that should be useful for planners and ultimately farmers All of this seems to indicate that we expect our soil surveyors to be extension workers or even businessmen selling a product Have you ever thought about what a soil surveyor really is? Is he merely a glorified laborer who can be pushed around at any time to any place as desired by the administrator? Or is he a well-respected man who is trusted by the government planners? What is his standard of living compared with that of his fellow government employee? Unless this is known, it is difficult to impose on him many other activities that he has not been trained to do Please give this some thought

K A DE ALWIS Dr Murthy, were soil moisture properties, such as water-holding capacity, determined before and after implementation of the improved management practices at the two sites?

R S MURTHY Further data including water-holding capacity are in the process of being obtained A follow-up of the initial experiments will be undertaken

T F SHAXSON When planning developments at farm and field scale, the use of the third dimension—to show topography over two-dimension soils data—is an indispensable requirement By use of contour and topographic maps and stereoscopic pairs of airphotos, the natural watershed and catchment of the land surface can be identified and then used as the basic framework for effective conservation layouts, which are planned to be integral parts of the proposed improved farming system on that particular and unique piece of land

Session IV. Use of Soils Data in Regional and National Development

T I ASHAYE These papers illustrate the use of soils data to increase development activity and investment The Sri Lanka experience with Alfisols is a good example of optimum utilization of known soils information Korea has shown us how satisfactorily a demand for soils information for a new variety can be met The presentation from India was a good example of the special needs of climatic regions having low moisture

S M VIRMANI Climatic data for narrow intervals of a week or less should be analyzed with available refined methodology in place of monthly means, for which the coefficient of variation for arid and semiarid climates is very high

T F SHAXSON To make soil-survey data usable to the field implementator as well as to the economic planner, I would like to encourage soil surveyors to consider themselves as collectors of land-resource data, not just soils, and to present their soil-survey results on topographic base maps (e g , contoured line maps or airphotos annotated to show crests and drain lines) In this way, physical plans of development can be sketched immediately as an overlay

H Y CHAN Information about soil slope can be derived directly from completed soil survey reports

R B MILLER The speakers have described scientific work and have shown how this has led to increased crop production and land development For these programs to succeed there must have been linkages between the scientists, the farmers, and the development authorities We need to know more about the details of these planning and implementing mechanisms

Session V. Expanding the Soils Research Network

M J KILIAN Can the Benchmark Soils Project assist with technology transfer to small farmers? Can you in your experiments include studies of the use of different practices for preparing the soils for crops?

L D SWINDALE In principle, any level of technology is transferable if it is adequately defined We could carry out experiments with hand tools in the Benchmark Soils Project if our cooperators thought that was important But I suggest that this would be better suited to the network of agricultural research stations that we have also discussed

T F SHAXSON In addition to the development of a research network, we might also consider an extension network through which a cadre of extension people could become familiar with the characteristics of various soil families and assist the extension workers in specific countries by bringing to their attention what has already been learned somewhere else

J S KANWAR These proposals are very important for the future of agricultural research They should help reduce greatly the amount of repetitive work that is done I am particularly interested in the proposal to classify the soils of agricultural research stations This will allow us to try out crop production under different management systems in different places and provide us all with valuable information It will save the developing countries and the international agricultural centers a great deal of money

I BENNEMA Although the soil characteristics of soil in a family may be the same, the soil qualities of these soils may be different that is, a soil family is not the same as an ecological niche It is necessary to conduct basic soils research to determine the exact relationships between soils and agriculture

I S GILL AID is interested in the Benchmark Soils Project because it is hoped that the Project will provide a shortcut to agricultural information for the developing countries If the concept works and you can as easily prove it on soils covering only a few hundred hectares as you can on soils covering vast areas, the Project will provide us with a new and powerful tool for bringing agricultural information to those who most need it

R B MILLER There are many small countries in the Pacific that do not have the resources themselves to carry out the experiments of the Benchmark Soils Project The Project could be of great value to them and they might be able to obtain some assistance from the South Pacific Commission and the New Zealand aid program How can such countries become involved with the Project?

L D SWINDALE I suggest that a proposal for a South Pacific Regional Benchmark Soils Project be developed for consideration by the South Pacific Commission or other aid agencies This would specify maybe six key sites of important regional extent for agricultural experimentation Results from these sites could be used to provide the basis for extension activities throughout the region

N N NYANDAT In Kenya we have problems in extending information gained at research stations to the farmers We find it necessary to carry out simpler and more numerous trials and demonstrations on farmers' fields Does the Benchmark Soils Project have any relevance to this important type of work?

F R MOORMANN The task of the Benchmark Soils Project is to prove a widely applicable concept It will be a national task to extend it further at the level of detail that you have referred to

D MULJADI We are pleased to be involved in this Project and hope that it will include families of Tropudults because of their importance to future food production in this region My own institute is already working on the problems of these soils We believe this Project can provide valuable complementary assistance to our work

K A DE ALWIS Does the soil family concept work for agricultural transfer within the United States?

L D SWINDALE Yes Some soil families contain several series extending over several states Experience does show similar agricultural practices and problems throughout the range

F R MOORMANN There has been evidenced in this discussion an enthusiastic acceptance of the benchmark soils concept, and I hope that something good will come from this session I believe we must accept the fact that the immediate results of the experiments of the Benchmark Soils Project cannot be directly applied to small farmers, but our future research can be developed in directions that will make technology transfer relevant to them

Session VI. Soil and Water Management in Rain-fed Agriculture

G H CANNELL In your approach using a watershed-based farming system for the semi-arid tropics, do you visualize the small farms for the implementation of your technology?

B A KRANTZ Definitely yes For the implementation of watershed-based farming systems, there is a need to do research on socioeconomic aspects Details are being worked out to carry out this system on small farms

H W CHAN In the semiarid tropics of India where the availability of manual labor may not be a problem, you may be able to emphasize manual rather than chemical means to control weeds However, there may be situations where both ways are required and, in some cases, even preemergent herbicides may be needed

B A KRANTZ We are definitely interested in the chemical control of weeds Purely mechanical means are not possible when the soils are wet Also, particularly in the early years of cultivation of land, when the weeds are a real problem, some chemical control is essential We will do benefit-cost analyses and decide how best to control weeds with a minimum of cost, particularly of inputs We are also studying the ecology of weeds under different management systems to understand the weed species involved and develop economically viable systems of weed management

Y P BAIT It is encouraging to note the utilization of soils data in water harvesting to assist in efficient design of small farm ponds and tanks In trying to provide benefit-cost ratios of soil surveys, it is often suggested that the cost of soil surveys be allocated to the one specific program for which the project was initiated, whereas the soils data generated through soil surveys are useful for other programs as well as for users outside the field of agriculture

S M VIRMANI My observations on benefit-cost ratios in dryland agriculture compared to irrigated areas are based on current economic analysis Dryland areas do need careful assessment of soil resources, and these should be mapped and surveyed

J S KANWAR I appeal to all the participants to classify the soils in their own countries that appear similar to those we have at ICRISAT This will help us provide valuable information by extending our research projects to similar soils in different climatic environments

Reports of the Discussion Groups on Soils Information Available for Planning

Summaries

F R MOORMANN summarized the discussions of Group A as follows

1 Planners need information in addition to that contained in *Soil Taxonomy* This additional information includes cropping combinations, crop performance or crop ecology data, alternative uses, specific recommendations, site-specific information, and climatic data
2 The mechanism for proposing changes in *Soil Taxonomy* should be discussed and made universally available, consideration should be given to standardizing permanent phases (such as slope and previous land history) Additional categories should be created for soils that at present cannot be placed in the system (such as the epiaquic subgroups).

3 A working committee on soil taxonomy should be created to make the Taxonomy more useful for the tropics
4 There is a need to bridge the communication gap between soil scientists and planners

R W ARNOLD summarized the discussion of Group B as follows

1 Pedological data should be separated from the interpretations needed by planners
2 Interpretations for use and management should be stated as simply and as accurately as possible
3 Small-scale country soil maps are excellent for broad-scale planning
4 Since the numbers of soil surveyors are small in many countries, soil surveyors should be involved in planning at an early stage to avoid time constraints on their survey work
5 There is a need to inventory the soils information that is currently available
6 Soil scientists need to bridge the communication gap with other disciplines
7 The Benchmark Soils Project should be encouraged to make an inventory of the soil information available in the tropics

H BRAMMER summarized the discussion in Group C as follows

1 There is a need to formalize the dialogue between pedologists and planners so that it will continue when the participants return home
2 More consideration should be given to those who will actually implement or use the land-use plan
3 Soil surveyors should be responsible for packaging the soils information in a useful and understandable form
4 Soil surveyors should work with other specialists, extensionists, and planners, and not in isolation
5 Some countries have, but most countries do not have, a successful model for the use of soil survey and classification in planning and implementing agricultural development
6 Consideration should be given not only to the horizontal transfer of technology to other subject matter specialists but also to the vertical transfer of technology to the small farmer in the tropics

M L DEWAN summarized the session as follows

1 Improvements in soils information and soil interpretations are needed, and the information currently available should be assembled in the form of a data bank, as is being done by FAO and in some countries
2 There is a need to transfer technology horizontally as well as vertically to the small farmers in the tropics
3 Soil scientists should interact with, and relate to, all other disciplines involved in agricultural development
4 Soil surveyors should be exposed to orientation and familiarization courses in planning Planners and development economists in turn should be exposed to soil survey and classification and their field application in actual development
5 Planning at various levels has been attempted in some countries Interchange of information in this respect would be very helpful, and this seminar should stimulate such exchange
6 Since development and not planning is the ultimate goal, consideration should be given to the means available to execute a plan and the economic, social, political, and cultural implications of a land-use plan

Discussion

A J SMYTH I am happy to hear that the participants are interested in the team approach Who should lead the team should probably be determined on an ad hoc basis, it is not necessary for us to learn the language of each other's discipline

N N NYANDAT The real problem is not soil taxonomy or land-use planning, but implementation How do we implement land-use planning? Countries with successful models should make them available to others

M VAKILIAN In the arid and semiarid regions, much data is available but it is not coordinated There is a need for an office to coordinate the data from different agencies and make it available in the form of a data bank, this would save time, money, and energy

R FEUER An inventory of the kinds of soils and soils information available to the tropics at each research or experimental station would be useful

Reports of the Discussion Groups on Soils Information Needed for Planning

Summaries

A R M MEKKI summarized the discussions of Group A as follows

1 Further soils information is needed in planning
2 Closer cooperation should be established between soil scientists and agricultural researchers in other disciplines to produce more integrated crop-soil information for planning In particular, communication between soil scientists and plant breeders is necessary to determine what kinds of genetic manipulation might be necessary for different kinds of soil
3 Subject matter specialists trained in soil-survey interpretation are needed to interpret soils reports for planners and extension agents

B BALANKURA summarized the discussions of Group B as follows

1 Soil-suitability (capability) maps showing *(a)* quantification of the areas, *(b)* economic productivity of a specific crop, *(c)* the required scale and, *(d)* alternative options are required
2 Interpretative maps should be accompanied by written material, which should be understandable and accurate and which should state the implications of the options as well as the assumptions
3 Early involvement and interaction of soil scientists with people in other disciplines such as agronomists and economists would improve the quality of the planning work
4 There should be a review of the terms such as *capability, suitability, planners,* and *policy makers* to make them more consistent in national development

R B MILLER summarized the discussions of Group C as follows

1 Planners are considered as planners in agricultural development, not those in high-level national economic planning
2 The planners feel they need *(a)* interpretive maps, not soil maps showing soil terminology, *(b)* accurate maps, *(c)* maps understandable by planners and showing clear delineation of classes, quantitative data, areas estimated even if units are not

homogeneous, and caveats regarding use of the data, *(d)* scales suitable for the particular objective, *(e)* flexibility so that alternative possibilities are shown, *(f)* data integrated for specific crops (or groups of crops having similar soil requirements) with benefit-cost calculations, and *(g)* maps showing relative land potentials taking account of the given level of inputs

3 The soil surveyor is well equipped to coordinate the assembly of this physical data, including information about water, energy, climate, agronomy, and vegetation

4 The soil surveyors need from the planners *(a)* the right question, *(b)* resources —soil surveys cannot be done without staff, equipment, and transportation, *(c)* time —even if time is short, some data can be provided, but planners and politicians must realize that good planning needs good basic data and that the planning program should allow time for it to be collected

5 It is generally felt that soil surveyors and planners must work together Interaction and consultation should take place at the project level right from the start At the national level there should be planning teams with other specialists and soil surveyors should constantly plan ahead to foresee future requirements A team approach is essential

6 It is necessary that relevant soil-survey information get to the land user or farmer This is best done through an extension worker, who is often the planner at the field level The soil surveyor must make his information available to the extension worker in terms the extension worker can understand and pass on to the farmer Demonstration and communication are key factors in extension The relationship between the soil surveyor and extension worker needs development

Discussion

J BENNEMA The soil scientist may not have all the expertise required to integrate data for land-use decisions It depends on the work to be done For example, in an irrigation project the economist or agronomist may be the best person to integrate the information for planning I would also like to comment about the flow of information to the planner A team should synthesize the material before it goes to the planner In other words, some of the planning should be done before the information flows to the planner

R B MILLER The conclusion was really that there should be continuous consultation in a team with planners

A J SMYTH In regard to the report from Group C, it appears that the aim is to produce interpretative maps for specific purposes showing quantitative data useful to planners To reach this goal, we need to consider location economics also The economics of each alternative will depend on distance to markets, roads, etc Are soil scientists willing to introduce location economics in this way?

T F SHAXSON The responsibility for location prospects should properly be that of the physical planning specialist who should discuss, and draw final conclusions about, the economics of the proposals with an economic planning counterpart

S J PANDEY Soil survey should be followed by research that should flow to extension and then to the farmer Without communication with the farmer, soil survey is meaningless Agronomic trials in India have often been done without regard to soil The soil-test inferences should be superposed on soil-survey information

R W ARNOLD We speak a lot about the small land owner Yet, soil surveys on a detailed scale are very costly I have very little idea of the risk factor that the small farmer has So

without soil-survey information at the small farm level, how are we to implement the recommendations without exposing the farmer to considerable risk?

R. FEUER: I am dealing with very small holders of rice. Our first consideration is to avoid risk When the farmer says he cannot afford the risk, we give him low cost credit facilities The small-scale farmer likes to see new technology demonstrated before accepting it

T F SHAXSON Even reconnaissance-scale soil surveys can be used in the small-scale farmer situation as a means of giving guidelines to field extension workers about crop types, animal enterprises, etc It is also feasible and possible to train extension workers in simple techniques of soil survey and physical and economic planning for the individual small farmer or cooperative groups of small farmers

J.S KANWAR When we are thinking of agricultural technology based on soil survey and selling it to planners, we have the feeling that the latter are reluctant to take it In many cases, however, the information from the soil survey has not been utilized to indicate what can be produced from an area at a particular level of technology For example, at IRRI and other institutes, there is no information regarding soil benchmarks Trials are carried out usually only in regard to the local situation These benchmark experiments can be made only in collaboration with national groups

Summary of the Discussions of the Final Plenary Session

Summary

A panel of professional planners described their responsibilities and the need for soils information. Planners can generally be subdivided into those who work at the macrolevel on national plans and national sector analysis and those who work at the microlevel in planning specific projects Macroplanning is carried out in the context of predetermined national goals It is usually performed under considerable time pressure, and choices between different uses of physical, human, and financial resources must always be made

Indicative macroplanning is normal in most developing countries Local governments and the farmers themselves make the ultimate decisions The planning agencies try to create conditions that will cause these decisions to contribute to the fulfillment of national goals Macroanalysis is usually performed by economic sectors (e g , the agricultural sector) and by subsectors (e g , agricultural credit) Sectors and subsectors need to be carefully defined, and the analyses to be performed in each case, carefully described

The planning agency usually has some authority for implementation, normally through budgetary review and recommendations on funding for specific projects

Soils and land-use data for macroplanning need to be in the form of interpretative small-scale maps, tables, and narratives General suitabilities or capabilities were satisfactory at this level, but alternatives and a range of options should be given Relative land potentials at different levels of defined inputs are valuable Single factor or single commodity interpretations are very useful Current land use and land-use trends over time should be related to soil-suitability classes to indicate opportunities and hazards Limitations to use should be specified They can be combined with suitabilities into categories of maximum permissible intensities of use

It is recommended that land-use surveys and soil surveys be conducted and interpreted by the same agency

Because many interpretations and recommendations change with time, they should be brought up-to-date regularly

Planners often find that data are provided to them in unsatisfactory form, and are concerned about their quality and reliability They do not believe they should be responsible for format and quality, and instead recognize a need for regular formal and informal contacts with soil surveyors

The panel recommends international standardization of the terms used in soils and land appraisal

Although much planning is at the macrolevel, there is recognition that this is too often unsuccessful There is a trend toward regional planning at county or district levels In time macroplanning might be usefully done by aggregating more detailed plans

Detailed planning requires detailed soil surveys and detailed interpretations Yield predictions are required at the levels of current practice and under high intensities of management

Project analysis particularly by external leaders is very thorough, and tends to use all available information It is most effective when incremental increases in rates of return can be calculated for incremental increases in yields or management levels

Discussion

M RAHMAN We have been asking for a great deal of information Is it really the responsibility of the soil surveyor to obtain so much information outside his immediate field?

W P PANTON It certainly should not be left to the central planning agency to obtain it But soil scientists, foresters, geologists, etc might all come together into a single physical planning group to provide such information More soil scientists should also become subject matter specialists in planning organizations

T F SHAXSON Because soil scientists are asked to do so much, they should be given reasonable lead time, and planning agencies should ensure they be given adequate support in terms of staff, operational funds, vehicles, and equipment Only with adequate support can they provide the new information and regularly up-dated information that have been requested

M L DEWAN There is a trend in the developing world for soil-survey organizations to become soil- and land-research institutes incorporating scientists from other disciplines Also the typical soil surveyor is broadening his perspectives and training throughout his career so that his responsibilities will change towards more interpretative work as he becomes more knowledgeable and more senior

R W ARNOLD Because planners wish to build such a large superstructure of interpretations and plans on the basis of our soil surveys, we need to be very sure that we have good quality control in any survey at any scale There is little research around the world into soil-survey quality or in developing methods for quality control in soil surveys

J BENNEMA FAO is preparing a framework for land evaluation We hope that this will provide an agreed approach to what goes into land evaluation and eventually to agreement on common terminology

T F SHAXSON How do we decide what information needs to be collected? There is a danger that these few soil surveyors we have will be asked to collect data, much of which is never used

W. M. JOHNSON: Most soil-survey organizations must serve the needs not only of planning agencies but also of other public agencies, engineering and development firms, and individual land owners, and to meet all of these needs without producing excessive detail at excessive cost In the United States, we hold an annual soil-survey work planning conference in every state The people who will do future surveys come together with those who will use them to discuss the priorities and the designs of the surveys Also when a survey is about to begin, another conference is held for similar purposes In this way we try to learn all about the needs before the job begins

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