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SOUTH PACIFIC REGIONAL FORUM ON SOIL TAXONOMY

SUVA, FIJI

2-13 November, 1981

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SOUTH PACIFIC REGIONAL FORUM ON SOIL TAXONOMY

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INSTITUTE OF NATURAL RESOURCES
THE UNIVERSITY OF THE SOUTH PACIFIC
SUVA, FIJI

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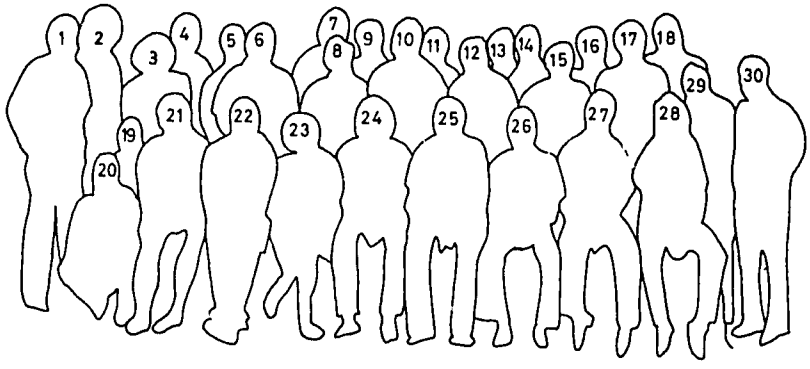

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F O R E W O R D

J.A. Maraj
Vice-Chancellor,
University of the South Pacific

The University of the South Pacific, through its various Institutes, has organised in the past few years a significant number of training courses and seminars aimed at making Pacific Islanders more aware of the resources and potential of the South Pacific Region and at increasing their involvement in the development and use of these resources. These seminars and workshops have usually been organized and run by USP staff with the occasional assistance of one or two external consultants. When a seminar on Soil Taxonomy was first contemplated the demand from the Region for such a programme and the response from overseas consultants was most encouraging, and it was immediately apparent that a significant number of people both within and outside the Region were interested in the problems of soil classification and use. It was therefore decided that a Forum was a more appropriate way in which to bring together people from outside the Region who could present material on the development and use of soil classification systems (particularly Soil Taxonomy) and Regional agricultural staff who could contribute information on the particular problems that occur in the Pacific Island countries.

I am not a soil scientist; in fact, I know very little about soils, but as an administrator I appreciate the need for the classification and organization of information. As someone who has worked in both Commonwealth and Regional Institutions I also appreciate the need for a common language between workers in any field. Thus the development of Soil Taxonomy, which provides a comprehensive classification (but yet utilitarian) system, and its gradual acceptance as a common language by soil scientists around the world mark, for me, major advances in soil science.

I have also been impressed by the concept of agrotechnology transfer as studied in the Benchmark Soils Project. Agrotechnology transfer has been practised for a considerable time now, but always with only limited success. The failures of the past, we are now aware, have frequently occurred because of an inadequate soil information base. It is not sufficient to rely on factors such as climate. With Soil Taxonomy to provide this soil information base in the future agrotechnology transfer will both facilitate and promote the sharing of land use knowledge. The resultant lowering of research duplication, an improved prediction of crop performance and an increased agricultural production will be of major importance to developing countries, particularly those of the South Pacific Region.

These are the countries which this University serves, and we are grateful to all those who contributed skills, experience, or resources to enable this Forum on Soil Taxonomy to take place, and to be so successful. I also extend my congratulations to colleagues who worked to painstakingly to make the Forum a reality. But the benefits of such a Forum must be made available as widely as possible, and I welcome this publication as a prime means of achieving this. I am sure that my colleagues and friends involved in agriculture, both in the South Pacific and further afield - and I use the term deliberately - will find its contents informative and of practical assistance.

OPENING ADDRESS

Hon Jonati Mavoa
Minister of Agriculture and Fisheries, Fiji

I am pleased to be here today at the beginning of this very important Forum.

It is, I am sure, heartening to the organisers to have such a good response as indicated by the number of participants from the Region. I understand representatives have come from Guam, Hawaii, U.S.A., Cook Islands, Niue, Western Samoa, Tonga, French Polynesia, New Caledonia, New Zealand, Solomon Islands, and Papua New Guinea. We in Fiji are delighted to have you with us and I hope that you will have an enjoyable time during your stay here.

This interest in soils and soil classification reflects the concern we all share about the land resources of our island countries, limited as they are in most cases, with perhaps a few exceptions.

Your respective governments, like mine, recognise the important place soil characterisation has in better understanding our land base, and the implications of wise soil use to our respective economies. We should all recognise that as island nations we have been endowed with limited land resources and our people form the base on which we rely for our economic development. This has been true in the past, it is true during our life, and it will still be true in the future. This makes your deliberations all the more important, aimed at giving you a better understanding of the different types of soil, the uses they can be put to, and providing you, furthermore, with a good basis on which to advise on land use. You will thus be contributing to the enhancement of the socio-economic well-being of people at all levels, particularly at the village level. You will appreciate, I am sure, that the technical information can be much more valuable if it can be translated in

a meaningful and practical way to the individual villager/farmer.

Let me digress for a moment to tell you of what has been attempted in the past. As a result of work carried out over the past 30 years it can be said that our Region has to date been well served with soil mapping and the general characterisation of our land resource. We in Fiji value the contributions made by Twyford and Wright whose extensive field work in the mid 1950's provided us with 2 miles to one inch (1:126,000) scale soil and land use maps, which are still being extensively used as the basis for all types of land use planning.

I understand that Western Samoa and Niue have also benefited from Charles Wright's soil mapping and have very comprehensive bulletins and maps. The work of ORSTOM in Vanuatu, Tahiti, New Caledonia and in some parts of Fiji have provided more modern and up to date work. Similarly Land Resources Division (UK) with their land system approach has provided much needed information in the Solomon Islands and since 1974 DSIR (NZ) have been upgrading their earlier work in the Cook Islands, Tonga and Niue. All these have given the Region valuable soil information as it relates to the broad area of land use planning - not just for agriculture, but also for forestry, town and country planning, urban uses and the conservation of natural resources.

In 1976, Fiji was the venue for the South Pacific Commission Regional Soils and Land Use Conference, during which workers in soils from within the Region deliberated over what is certainly a complex subject, assessing regional priorities for future work and, perhaps more importantly, establishing a consensus regarding the desirability for some regional standardization of correlation, interpretation and classification procedures for soils. The conclusions and recommendations were subsequently incorporated in a report of the SPC, but for a variety of reasons, including the lack of financial backing, their implementations have not received the attention they deserve. It is pleasing, however, to note that ORSTOM and NZ DSIR have both continued their work in the Region.

From that brief historical sketch, I go on to the subject of the Forum - Soil Taxonomy. This system of soil classification has been developed over more than 25 years by the USDA and is now being increasingly used in many countries, particularly in developing nations. As you all know, there are several different soil classification systems operating, but from what little I know of the subject, Soil Taxonomy is a quantitive scheme in which the criteria used to separate soils are based on practical land use experience with heavy emphasis on those factors that are important to plant growth - for example, soil temperature and soil moisture to name but two such factors.

I understand that soil survey with classification of soils according to Soil Taxonomy may provide a basis for transferring agro-technological information from a developed country to developing countries. This should help to bridge the gap which now exists between these groups of nations - the production gap. You will agree this is an exciting prospect and one that the Benchmark Soils Project is currently evaluating. It is hoped that the results that will emerge will point to the possibility of transfer of land use experience. You will be hearing more on this project during the Forum and all I need say is that it appears to have great potential. Bearing in mind that Soil Taxonomy is the basis for this transferring of information, it seems to me that this Forum is very timely. We must have people within our Region who know Soil Taxonomy, who are able to work with it to keep up with developments taking place in soil science as new information becomes available.

I have said earlier that with a few exceptions we are all island nations with limited land resources. It behoves us to use our land wisely and know on what soils we can obtain optimal yields from specific crops. To neglect to do so would mean that economic progress would be slow and soils problems compounded. Take for example the problem of soil erosion which is always with us, perhaps in varying degree from country to country. It is well recognised that soil erosion reduces the size of the productive land as well as productivity from that land. I may be so bold as to say that perhaps in the past the problem has not been given the attention it deserves, considering

the importance of agriculture to our national economies. Agriculture is the sector that is worst affected as the area and degree of erosion increases. The spin-off, of course, is the increased cost of production which in turn results in lower productivity per unit area and in lower financial returns. This drastically affects the income level of our rural people whose standard of living we are all anxiously trying to improve.

For all these reasons we would like the problem studied in depth so that some meaningful long term policies and programmes could be formulated to help guide us in our endeavours to find solutions. I see this as an area where your knowledge in soils and Soil Taxonomy could play a very important role.

In conclusion may I say that all of you who are gathered here are people your respective governments look to to provide the correct answers to our soil management and development needs.

I must also commend the good work put into organising this important Forum by the University of the South Pacific, in particular John Morrison and his staff - there is much that has to be done behind the scenes both before and during a Forum of this nature. I am sure that you would al. o wish me to express appreciation to the USAID for the valuable financial contribution it has so generously provided.

I wish you well with your discussions, and trust that you will benefit from the Forum, become more conversant with Soil Taxonomy and more importantly its implications and application to land use.

APPLICATION OF SOIL TAXONOMY FOR AGRICULTURAL DEVELOPMENT IN THE SOUTH PACIFIC

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Introduction

An expanding population and the threat of food shortages are two related problems that the world must solve in order to secure world order. We are reminded that the world's land area is finite and our quality of life will diminish if we do not take action now to increase food production and control of population growth. But if we look around us, we see extensive areas of under-utilised and potentially arable lands. What we see in the world, and particularly in the tropics, is an uneven population distribution. People tend to congregate in areas where water is plentiful and the soil is fertile. Such conditions are found on the deltas of the Mekong, Chao Phraya, Irrawady, and Ganges-Brahmaputra rivers, in countries such as Rwanda and Uganda on the rejuvenated landscapes of the African Rift, and along the Pacific circle of fire that sprinkles nutrient-rich volcanic ash on the South American Andes, Central America, the Philippines, Java and Bali.

On the other hand there are extensive, sparsely populated areas in Kalimantan, Sumatra, Central Brazil, the Eastern Plains of Colombia, and Equatorial Africa. There is a great temptation among government officials to move people from the densely populated regions to the sparsely populated areas. Indonesia's transmigration programme is the best known case of government efforts to redistribute people within a nation. Another example is Brazil's effort to entice people to move to the sparsely populated Cerrado region by moving its capital city to the interior.

Such efforts are in the main predictably slow, costly, and fraught with errors. The technology that the immigrant farmer takes to the new location generally fails in the new environment. A technology that was fully appropriate in a given environmental setting became inappropriate and useless in the new location. The people remained the same, but the agroenvironment did not. To succeed, agricultural development requires the transfer, not only of people, but the extrapolation of agrotechnology that matches the skills of the people, the quality of the land and the objectives of the development scheme.

Agrotechnology Transfer

Agrotechnology transfer is defined as the taking of agricultural innovations, knowledge and experience from their site of origin to a new location where they are likely to succeed. When an immigrant farmer takes his experience gained through years of trial and error to a new agroecological zone, the chance that his experience will apply equally well in the new location is small. What the farmer instinctively does is to transfer experience. To be successful, however, the farmer must transfer experience based on knowledge. To have knowledge is to know why a particular experience fails or succeeds, which is to say that to have knowledge is to know the causes of effects. The farmer is primarily interested in effects that affect his livelihood, whereas the scientist who is hired to help the farmer may be more interested in the causes of effects. In his aim to understand causes of effects, the scientist is attempting to develop the means to predict effects so that costly errors can be avoided.

When placed in a new environmental setting the farmer may discover that the seeds he brought with him perform differently, that the insects, weeds and diseases are different, or that his tillage implement which worked so well before does not now perform in the same manner. In short, there is a mismatch between the capability of his old technology and the characteristics of his new land. The farmer is forced to alter his practices and go through the long, trial and error process of discovering new ways to cope with a new environment. This trial and error process can be markedly reduced by agrotechnology transfer.

Horizontal and Vertical Agrotechnology Transfer

The problem of agrotechnology transfer is not restricted to the immigrant farmer. It is very common in our attempts to transfer results from research centres to farm fields. The problem is not so much the lack of technology, but finding the means to match a particular technology to a given set of environmental conditions. At this point it is important to make a distinction between two kinds of technology transfers, namely horizontal and vertical transfers. Horizontal transfers involve the taking of an agricultural innovation from one location to other locations with similar agroenvironments. The aim of horizontal transfer is to minimize the mismatch between the environmental requirements of agrotechnology and the characteristics of the land. Horizontal agrotechnology transfer is necessary but not a sufficient condition for farmer acceptance of the technology. Vertical agrotechnology transfer on the other hand is designed to ensure that a technology which is biologically and technically sound, is also economically feasible and socially desirable. This paper is largely concerned with horizontal agrotechnology transfer.

Analogue and Matching Agrotechnology Transfer

There are two ways in which the immigrant farmer or the scientist can successfully transfer agrotechnology horizontally. These are called analogue and matching transfers. A subsistence farmer who chooses to leave his old farm to accept a government offer of new land elsewhere will have little difficulty adjusting to the new site if the soil and climate of the old and new locations are similar. His seeds, implements and management practices will perform equally well in both locations. He will encounter about the same kinds of pests and they will come and go with seasonal changes familiar to him. The farmer succeeds because he unknowingly transferred his experience and technology to an analogous environment. It is highly unlikely that a farmer would be so fortunate as to find himself in such a situation. Similarly, a researcher who wishes to distribute seeds of a newly-developed, high performance cultivar, will find his cultivar distributed to a wide range of agroenvironments. He can

predict that the cultivar will perform at the expected level in similar (analogous) environment, but he can say very little about its performance in other environments. In different environments, the cultivar may do as well, better or more poorly than in the research plots.

The fact that a cultivar can perform equally well in two different environments indicates that the two environments although different, have a set of common characteristics that enable the cultivar to do well. This is to say that environments, no matter how different, will permit an environmentally sensitive crop to perform well, if the environment possesses the characteristics essential to the proper performance of the crop. Thus to predict the performance of a crop or technology, one must know the requirements of the crop and ascertain whether these requirements are met by the environmental characteristics of the land. Unlike analogue transfer, matching transfer depends on one's ability to know and match the requirements of a crop to the characteristics of the land. Matching transfer is more difficult to achieve than analogue transfer because matching requires knowledge of the cause and effect relationship between the performance of a crop and the characteristics of a land.

Soil Taxonomy for Agrotechnology Transfer

Before analogue and matching transfers can be used to predict outcomes of farming practices and agricultural development projects, one must have a means to characterize and name the various types of agroenvironments. In a way, Soil Taxonomy serves this important purpose. Soil Taxonomy is a multicategorical system of classification in which 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 response. This implies that research results or farmer experience obtained in one location may be transferred to any location with comparable phases of soils in the same family.

Implication for the South Pacific

The South Pacific comprises many island nations spread over a vast ocean expanse; some of them being small, both in size and economy. Most depend heavily on agriculture for income and would like to develop agriculture in a manner that is profitable, socially desirable and environmentally sound. To do so, the island nations must have access to information and technology for agricultural development. Very few have the resources or the numbers of trained scientists to produce the needed information. But if one travels through the Region, it becomes quickly evident that in aggregate, the Region has a reasonable number of research centres and trained scientists. What is also evident is that a great deal of the same kinds of research on similar crops on similar soils and climate is being conducted by the various nations. Individually most nations have inadequate research and development capabilities, but as an aggregate, the nations of the South Pacific and the Pacific as a whole have an immense potential for exploiting their human and physical resources. By using the principles of analogue and matching transfers the results of each national agricultural research centre may be extended to the Region as a whole. Such an effort can be achieved by sharing results of research on coconuts, cocoa, pasture, coffee, citrus, root crops, vegetables and their management. This in turn will enable the national research centres to re-examine their priorities and select new crops and practices for research and development. A Regional network of collaborating agricultural research centres using a common language for agrotechnology transfer offers hope for accelerated agricultural development in the island nations of the South Pacific.

Creating the Network

The will to create a Regional Network of Collaborating Agricultural Research Centres must come from within the nations of the South Pacific. The scientists of the Region must inform national leaders of the desirability of creating such a network. With the approval of the national leaders, the scientists can proceed to prepare a proposal for submission by a regional committee to an international development agency for funding.

The preparation of a proposal acceptable to the nations of the South Pacific and the funding agency will require the efforts of experienced scientists with leadership qualities. The role of the scientists is to identify goals and objectives of the Network, develop work plans for each collaborating agricultural research centre, indicate the expected outputs over the life of the programme and specify the inputs required to achieve each output. It is assumed that after a reasonable period (say 10 years), the Network will sustain itself through regional support and that it will have a measurable impact on agricultural development at the national and regional level. A proposal that contains these elements cannot be prepared on an ad hoc basis - it must have the full support of the national leaders and the granting agency. A modest planning grant funded by a potential granting agency will give the drafters of the Network proposal an opportunity to meet individually with national leaders and convene regional meetings of scientists and decision makers to ensure that the best possible proposal is prepared.

Network Activities

One of the first activities of the Network will be to retrieve and analyze past research conducted in the Region. The purpose of this effort is to ensure that needless work is not duplicated and what is already known is not rediscovered. This in itself will be a major contribution of the Network.

The second activity which can take place simultaneously with the first should be the characterization of the soils of each research centre and installation of weather monitoring instruments so that the variance in crop performance data can be explained on the basis of soil potential, weather factors, and management inputs. Climate and soil information is essential for the transfer of research results between different parts of the Region.

A Committee of National Directors of Agricultural Research will set the priorities for research to be undertaken by the collaborating research centres. The role of the Committee is to ensure that research

undertaken by the Regional Network of research centres significantly improves agriculture in the Region. The Committee will have at its disposal the combined capability of the entire Region to solve regional problems through shared resources and effective agrotechnology transfer.

What is Transferred?

The most common technology that is transferred is seed or germplasm. A scientist can condense years of research in the seed of a high performance crop. But the seed that emerges from the soil is very sensitive to the quality of the soil, the climate, and management by the farmer. For this reason, those who transfer technology must have available the capability to make reasonable predictions about the performance of the technology in the new location.

Requirements of Agrotechnology Transfer

Two factors are required for successful agrotechnology transfer. They are (1) a common language for technology transfer and (2) a network of collaborating research centres to provide and receive the technology. In this regard, Soil Taxonomy can serve as the common language, and the Regional Network of Agricultural Research Centres as the framework for generating and accepting new technologies. The Regional Network should also have a close link with the network of International Agriculture Research Centres such as the International Potato Centre, the International Centre for Maize, Wheat and Millet, the International Centre for Tropical Agriculture, the International Institute for Tropical Agriculture, the International Crop Research Institute for the Semi-Arid Tropics and the International Rice Research Institute.

Conditions for Agrotechnology Transfer

All technologies that are readied for transfer must meet the following conditions. The technology must be (1) technically possible, (2) economically feasible, (3) socially desirable, (4) environmentally

sound, (5) administratively manageable, and (6) politically acceptable. These are important considerations because research centres tend to emphasize the technical potential of an innovation and do not give adequate attention to the economic, social or environmental consequences. In addition, many countries have strict plant introduction regulations. This means that germplasm transfer must take into consideration the desire of countries to keep themselves free of unwanted pests.

Training New Scientists

A proposal to create a new Regional Network of Agricultural Research Centres for agrotechnology transfer should also contain a training component. A new type of scientist trained at agricultural development in a manner that is holistic, interdisciplinary, dynamic, farmer based, and socially responsible is needed.

Conclusion

Soil Taxonomy is a system of classifying agroenvironments so that the knowledge used to classify the agroenvironment may be used to predict the potential of lands, identify their best use, estimate their productivity, and transfer the organized knowledge to other regions. Soil Taxonomy can help to accelerate agricultural development by enhancing economy of thought and action. It serves as a common language for agrotechnology transfer. Agrotechnology transfer can increase research efficiency by minimizing duplication of efforts and by avoiding rediscovery of what is already known.

Agrotechnology transfer requires the adoption of a common language for technology transfer, and the establishment of a network of collaborating agricultural research centres to produce and receive new technologies. The island nations of the South Pacific have an opportunity to accelerate agricultural development by means of agrotechnology transfer through a network of Regional agricultural research centres.

Discussion

P. Drysdale: Could you outline the important considerations used to determine optimal site selection for agrotechnology transfer trials ?

G. Uehara: These would be determined by the local advisory panel. This panel would consider the goals of the project in any particular situation and then select the criteria to meet those goals.

L. Chase: Is it fair to say that the Benchmark Soils Project is really only an extension of what agriculture researchers do all over the world, with the major improvement of better site characterization?

G. Uehara: Agriculture research is now so complex in many cases by scientists for scientists - that little disseminates down to the farmer. The Benchmark Soils Project must be seen to benefit the individual profit motivated farmer.

M. Leamy: Are there any plans for the extension of the Benchmark Soil's Project?

G. Uehara: An International Benchmark Soils Network (IBSNET) is being considered but the situation is uncertain and it would be unwise to present further details at this time.

V. Seru: Why is the Benchmark Soils Programme not likely to continue or expand in its present form?

G. Uehara: The Benchmark Soils Programme will simply prove what we all suspect about agrotechnology transfer. Once it has done this, it has completed its goal.

M. Asghar: Why has the family level of Soil Taxonomy been used as the basis of agrotechnology transfer; could higher levels in Soil Taxonomy not be used?

G. Uehara: Higher levels like the sub-group or great group could be used. However, no transfer is 100% efficient; using the family level we are likely to get reasonably good transfer efficiency, but at higher levels the percentage of useful transfer will decrease.

M. Asghar: Were there any situations where enthusiasm about the project waned?

G. Uehara: I can answer that best by saying that as long as the agrotechnology transfer projects emphasize the utilization of results there is enthusiasm. If projects fail to emphasize this point then they will fail.

HISTORY OF THE DEVELOPMENT OF SOIL TAXONOMY AND THE NEED FOR AN INTERNATIONAL SOIL CLASSIFICATION SYSTEM

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People seem to have a natural urge to sort out and classify the elements of their environment, and soils are no exception. History reveals that soils have been sorted into different types by most civilisations. including the Roman and the Chinese. In New Zealand the indigenous population, the Maoris, were aware of soil differences and there are records in some of the early New Zealand Soil Bureau Bulletins of Maori Chiefs exchanging views about the different types of soil to be found in particular tracts of land. These early practical systems of soil classification were quite simple and were based on properties such as colour or texture or other properties which were readily discernible and clearly of importance to the population using them. However, with the increasing sophistication of agriculture and greater knowledge about soils as a collection of independent natural bodies, and also the greater complexity and diversity of soil uses, the classification of soils has become more scientific and organised.

Let us look at the purposes of classification before proceeding to a detailed discussion of the principles of soil classification and the way in which it evolved. John Stuart Mill (1925) discussed the logical basis and principles of the classification process for natural objects, and much of his philosophy underlies soil classification today. There are five main reasons for classifying soils. First, to organise knowledge, and thereby to contribute to economy of thought. Second, to understand relationships among individuals and classes of the population being classified. Third, to remember the properties of the objects classified. Fourth, to learn new relationships in the population we are classifying; and fifth, to

establish groups or sub-divisions of the objects under study in a manner useful for practical applied purposes in (a) predicting their behaviour, (b) identifying their best uses, (c) estimating their productivity, and (d) providing objects or units for research and for extending the extrapolating research results, or our observations about soil behaviour. During this Forum, we will be going on a number of field trips and the first of these will be to Koronivia Research Station where we will look at an alluvial sequence of soils. I suggest that, during this exercise, you bear in mind these five main reasons for classifying soils - to organise, to understand, to remember, to learn, and to use - these are the key words.

There are differences between technical and natural classifications. In a technical classification, which is a general and simple classification system, we arrange or structure the system so that it does some, if not all, of the five functions that we have discussed (Cline, 1949). However, in scientific activities and in other cases where we are organising our knowledge without reference to a specific applied objective, we wish a classification system set up in such a way that each group has as many unique natural properties as possible, and its name and its properties relate it to, yet separate it from, all others. Such a system may be called a scientific or natural classification. Stated another way, a natural classification is one in which the purpose is, in so far as possible, to bring out the relationships of the most important properties of the population being classified without reference to any single specified and applied objective. In our present soil classification we try to approach a natural classification system as an ideal, though we tend to give weight to properties of higher agricultural relevance. An example of the difference between these two types of classifications, the technical and the natural, is supplied by soil surveys done for different purposes in Fiji over the years. Around the period of the Second World War, soil surveys were performed to define areas which would be suitable for airports, and these used a classification system for that particular purpose - that was a technical classification. At present detailed soil surveys are

being undertaken for all the Agricultural Research Stations administered by Fiji MAF, and the purpose of this is to extend agricultural prediction to a wide range of soils. The classification system being used is a natural classification based on the properties of the soils themselves.

Now we should look at the structure and the definitions of a classification. Certain terms are used in Taxonomy with narrow and very specific meanings. Let us look at those which are important to our understanding in soil classification. The first is a Hierarchy - a Hierarchy is a pyramid of categories in which similarities accumulate as we go from the top to the bottom of the pyramid, so that at the top of the pyramid similarities are real but not many; at the bottom of the pyramid there are many similarities among the soils.

The second is a Taxon, which is a class at any taxonomic level of generalisation. The plural of taxon is taxa.

A Category is a series or array of taxa produced by differentiation within the population at a given level of abstraction or generalisation, and is composed of all the classes at one level of generalisation. We talk of classification systems being multi-categoric if there are a number of categories at different levels.

A Differentiating Characteristic is a property chosen as the basis for grouping individuals or classes; individuals similar with respect to that characteristic are placed in the same group. These definitions can be illustrated by looking at the order Oxisols, the suborders of Oxisols and the great groups of the Aquox suborder. The three levels, the order, the suborder and the great group constitute a hierarchy; each one of those is a category, each individual within the category (like the Aquox or the Ustox) are taxa and the differentiating characteristics are the properties which group together soils into any one taxon.

Now let us look at some of the main principles of soil classification. There are four that I think are important.

First, the genetic thread principle. Theories of soil genesis provide a framework for aiding and determining the significance and relevance of soil properties for use as differentiating characteristics. This principle is followed in the use of theories of evolution as a framework for taxonomy in the plant and animal kingdom - an example in soils would be that the differentiating characteristic chosen for Oxisols is an oxic horizon which is a strongly weathered horizon (it is strongly weathered because of great age and/or tropical climate). We could well have chosen the genetic characteristic itself, such as the position in the tropics on an old land surface, but this is not a soil property and it is better to derive a soil property from those genetic threads, so we use the oxic horizon.

The second principle is the principle of accumulating differentiating characteristics. In a multi-categoric classification system, differentiating characteristics accumulate or pyramid from the higher levels of generalisation to the lower levels. As a result, classes at the lower levels are defined and differentiated not only by the differentiating characteristics used at a given categorical level, but also by those which have been used as differentia at higher levels. In the lowest category, a large number of differentiating characteristics have been accumulated such that the classes are quite narrowly and completely defined.

The third principle is the principle of wholeness of taxonomic categories. All individuals of the population must be classified in each category according to the characteristics selected as differentiating at that level. Some of our earlier soil classification systems violated this principle by omission of certain kinds of soils from the classification at one or more of the categorical levels. Another way of stating this is that any differentiating characteristic should classify all the individuals of a given population.

The fourth principle we should discuss is the principle of limited applicability of differentiating characteristics. This principle was first developed and applied in Soil Taxonomy. It

means that properties which are used to identify differences between soils are not uniformally applied to all soils at a given categoric level. Thus, an argillic horizon can be used to separate soils at the order level as in the Ultisols and the Oxisols, or at suborder level as between the Argids and the Orthids, or at great soil group level as in the Argiustolls and the Vermudolls.

The Provision and Changing Nature of Soil Classification

We should always remember that soil classifications are based on the body of knowledge which we have at the present. This body of knowledge changes with continuing research and therefore our classifications must change with this new knowledge. We must accept the provisional, ephemeral, changing state of current knowledge and consequently of classifications based on it, particularly in a relatively new and rapidly developing field such as soil science. We must be prepared to accept additional changes in soil classification - indeed, we should help make them.

Another point should be considered:- it is easy for classifcation systems to prejudice the future, and for us to become prisoners of our own taxonomy (Cline, 1961). This has been a particular problem with soil classification systems in which conventional wisdom has at times and in places frozen soft tentative hypotheses into hard dogma, preventing the acceptance of new ideas and concepts, or, worse, restricting research patterns so as to preclude the acquiring of new facts in certain subject matter areas. Therefore, a classification system, particularly in a field such as soil science, must have a self-destruct mechanism, a procedure for continuing re-evaluation of the body of theories making up the genetic thread in our taxonomy. Also we must avoid selection of soil genesis theories and hypotheses as basic differentiating characteristics, although we may use them with caution as guides to relevant properties of the soils themselves, which may be used as differentia. As far as Soil Taxonomy is concerned, this process of modification and upgrading is proceeding apace through the International Committee

activity. There are currently a number of International Committees which are looking at the classification in certain sectors of Soil Taxonomy and undergoing discussions and workshops to improve that classification in the light of better and more detailed knowledge.

The History of Soil Classification

The evolution of soil classification can be subdivided into five general periods. First, an early technical era. Second, the period of the founding of pedology by the Russian group of soil geneticists. Third, the early American period. Fourth, the middle period of general development of soil classification and soil surveys in the world, and especially in the United States. And, fifth, the present modern period of quantitative pedology.

The early technical period in the classification of soils had its inception and flowering in Western Europe in the middle and later parts of the nineteenth century. These were, in the main, technical classifications for a specific purpose such as wheat growing, and they used factors which were not soil properties as differentiating criteria. For instance, one classification recognised four classes within a group of clay soils which were designated as black clay heavy wheat soils, strong wheat soil, weak wheat soil and thin wheat soil. These classifications were strictly pragmatic and practical and they are presented here for comparison with later, more comprehensive, systems as an historical record and as an indication of the first stirrings of new field/soil science with its subfield of pedology.

The second period was the period of founding of pedology. During the latter part of the early technical period, soil studies were underway on the Moscow Plains in Russia which were to have a tremendous impact on soil science, and which were to be the foundations of modern pedology. On the great central Russian upland of the present-day Soviet Union, rather uniform, loess-like, parent materials extend for hundreds of miles. An

increasing temperature gradient is imposed on this area from north to south, and an increasing annual rainfall and moisture gradient extends from east to west. Associated with these are important vegetational pattern differences, especially the major shift from forest to prairie. These factors have left their imprint on the relatively uniform parent material producing distinct soil differences. These differences were noted by the founder of modern pedology, Dokuchaiev,who first understood the full significance of the soil differences and thereby established the concept of soil as an independent, natural body. From Dokuchaiev's studies, the ideas of the soil forming factors began to emerge. These factors were parent material, time, topography, vegetation and climate. Glinka was the most influential and prolific writer of Dokuchaiev's pupils, and the best known in the western world because of widespread translations of his works. His first book introduced the new Russian concept of soils, soil classification and the major soil type names of Chornozem, Podzol and Solonetz to the western world. Glinka emphasised soil geography, soil formation and weathering processes (Glinka, 1931).

The early American period was approximately from 1899 to 1922. In this period the emphasis and bias were more on technical or single factor classifications and operational programmes of the United States Soil Survey. In these programmes there was bias towards geologic techniques and nomenclature, though there were some notable exceptions. Hilgard pioneered early soil classifications and mapping in the United States. He apparently was first in America to conceive of soil as a natural body and pointed out correlations between soil properties on the one hand and vegetation and climate as casual factors. Milton Whitney developed the first American Soil Classification System related to soil survey and it was used as a basis for soil mapping operations. This system was published in 1909 (Whitney, 1909), but actual soil surveys started in the United States about 1899. Whitney's classification is a broad one mainly according to physiographic regions or provinces and the texture of the soil. The Whitney classification was

geologically biased and separated soil largely on the basis of the rocks they were formed on. Coffey was apparently the first in the United States to propose soils as independent natural bodies that should be classified on the basis of their own properties, and that differences within these properties were due to climatic and associated vegetational differences from place to place. However, his concepts and proposals apparently were not generally accepted and were not made the basis for any operational soil survey programme. But his ideas did serve as a forerunner or signal of changes to come in soil classification in America.

In the middle American period C.F.Marbut was the central figure in the evolution of Soil Taxonomy. He it was who introduced Dokuchaiev's idea to the U.S., after translating into English a German edition of Glinka's work on Types of Soil Formation and Soil Groups of the World. This caused him to introduce the soil-forming factors of climate and vegetation, and to reduce the emphasis on geologic nature and origin of the soil materials as developed by Whitney. He evolved his ideas on classification in separate steps (Marbut, 1922, 1927) which culminated in his master work on soil classification published in the Atlas of American Agriculture (Marbut, 1935). Marbut must be considered the founder of American pedology based on his many contributions, in addition to his world-wide influence. Some of his many contributions were:

1. Establishment of the soil profile as the fundamental unit of study - he focussed attention on properties of soils themselves rather than their geologic ralationships or broad soil-forming factors.
2. Preparation of the first truly multi-categorical system of soil taxonomy.
3. Establishment of the criteria for soil series which are still in use today.

Additional information and further developments and improvements in soil genesis have brought out some difficulties and problems in Marbut's classification that are now being rectified in our

present efforts in soil classification. Some of these are:

1. His multiple category system was not truly comprehensive. He admitted the classification of immature and abnormal soils in one or more categories. This was because of his emphasis on normal soils on normal landscapes, meaning the well drained soils of the ' .l slopes. There was some violation of the principle of wholeness of taxonomic categories.

2. Certain of his criteria for differentiation, based on assumed genesis or genetic inferences have been shown by later study to be incomplete or incorrect. For example, his assumption that zonal or normal soils could be divided into two broad classes, one in which calcium carbonate accumulates (Pedocals), and another in which aluminium and iron accumulate (Pedalfers), has been shown to be inadequate and not satisfactory. As a differentiating characteristic, this assumed difference does not produce mutually exclusive classes.

3. His normal soil on a normal landscape concept as a basic frame of reference for soil cla ification, has not been found appropriate because of its tendency to ignore more poorly drained soils and because of the complexity of landform and consequent differences in soil age, as well as differences in climate over time which make it difficult, if not impossible, to establish which is the normal soil of reference in many landscapes.

4. It also appears that more emphasis is needed on the three-dimensional aspects of soils, rather than the extreme emphasis given the two-dimensional soil profile by Marbut.

A comprehensive effort to revise the Marbut system as new information was obtained and the evolution of concepts took place was made by Baldwin, Kellogg and Thorp (1938). This classification marked the start of a truly comprehensive and quantitative soil

classification. There was a return to the Russian zonality concept with the recognition of zonal, intrazonal and azonal orders at the highest level. These orders were defined in genetic terms and not on the basis of the properties of the soils themselves, and this was a difficulty which soon became evident. Another problem was that the order classes are not mutually exclusive since a soil can be zonal in one region and intrazonal in another. Great soil groups were not clearly defined, their definitions were comparative and qualitative and it was difficult to obtain agreement among different persons on the appropriate great soil group in which certain soils should be placed. And nomenclature problems were great, especially for soil groups with a hybridization of folk and coined names from different sources; names such as Chernozem, Podzol and Planosol.

The modern quantitative period was commenced with a revision of the 1938 classification in 1949 by Thorp and Smith. This signalled the start of the modern period of classification. In 1951, the decision was made in the United States of America to develop a new system of classification and Dr Guy D. Smith was given the brief.

Why was a new classification needed? There were several reasons.

1. The order category of the 1938 system was based on zonality and did not provide mutually exclusive taxa. It was not possible to define clearly the differences between zonal and intrazonal soils.
2. The classification at higher levels was based on external environmental factors and assumed genesis, and not on the properties of soils themselves. For instance, what we know as Mollisols were classified as dark coloured soils of semi-arid, sub-humid and humid grasslands.
3. Some definitions were based on virgin soil profiles under native vegetation without allowing for modification due to tillage or erosion.

4. There was too much emphasis on soil colour as a differentiating characteristic without consideration of its relevance or number of associated features.

5. The taxa at low levels were defined loosely and without precision. Measured or accurately described differentiating characteristics were required.

6. No suitable classes were provided for some known soils. A new classification needed to make provision for all soils and to make allowance for soils yet to be discovered.

7. Soil families had not been clearly defined.

8. The nomenclature was a collection from several sources and was awkward and confusing. A new system of nomenclature was needed.

The Development of Soil Taxonomy

This was commenced in 1951 under Guy D. Smith and was developed by a series of approximations each one fully discussed by scientists in the United States, and later in Europe. In 1960 the Seventh Approximation was published and supplements to this were published in 1964 and 1967. Finally, the document, "Soil Taxonomy - A Basic System for Making and Interpreting Soil Surveys", Agriculture Handbook 436, was published in 1975.

Key Features of Soil Taxonomy

1. There was a new nomenclature. It was derived from classic Greek and Latin sources. Each element of the nomenclature is connotative so that each symbol conveys information about the soils. The elements of the nomenclature are carried down the categories.

2. Differentiating characteristics are properties of the soils themselves, including soil moisture and soil temperature.

3. Genesis is not used directly, only as a guide to the selection of soil properties. For instance, Oxisols are not defined by their presence on old land surfaces in the tropics, but by

having an oxic horizon which has a low cation exchange capacity (a sign of strong weathering).

4. Definitions are precise and measurable, not comparative, and are written in operational terms. For instance, a mollic epipedon is defined as a surface horizon that when mixed to a depth of 18 cm contains 1% or more organic matter with colour values darker than 5.5 dry and 3.5 moist. Structure cannot be massive and hard, base saturation is over 50% and the horizon is not naturally dry more than three months per year.

5. The system has six categories - order, suborder, great soil group, subgroup, family and series.

6. The principle of limited applicability of differentiating characteristics applies. This means that differentiating characteristics are not uniformally applied to all soils at a given categoric level. For instance, there is no aquic suborder in Aridisols.

The Need for an International Soil Classification System

Soil classifications so far have developed almost entirely in the northern hemisphere, temperate zone countries. Much of the world, for instance the Pacific, has been relatively neglected, and little of the data used to formulate the system has been derived from these other parts of the world. But agricultural experience is transferred via soil classification systems and unless a system can accommodate soils of tropical and subtropical countries, this transfer of agricultural experience can be less than helpful. Soil Taxonomy is the only system that has been developed which is comprehensive enough and flexible enough to accommodate all soils, including tropical soils. Vigorous efforts are now being made through the International Committees to improve Soil Taxonomy for tropical soils.

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Discussion

M. Purea: Since Soil Taxonomy is a hierarchical scheme is it possible to develop keying-out tables to use with the main volume?

M. Leamy: Yes. In fact, some flow diagrams have been developed by staff of the New Zealand Soil Bureau*, and others are in preparation.

M. Purea: Since your department has gone ahead with the classification of soils using flow diagrams, is there a possibility of computerising it?

M. Leamy: Yes. Soil Bureau is currently negotiating with the Soil Conservation Service (USDA) for a contract to computerize Soil Taxonomy using the flow charts.

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*Thomas, R.F., Blakemore, L.C., Kinlock, D.I.

Flow Diagram Keys for Soil Taxonomy

New Zealand Soil Bureau Scientific Report 39.

A. Diagnostic horizons and properties: mineral soils (1979).

B. Soil moisture and temperature regimes, and horizons and properties for organic soils (1980).

C. The key to Soil Orders (1980).

D. Histosols and Spodosols (1981).

E. Oxisols and Vertisols (1981).

F. Aridisols (1981).

SOIL MANAGEMENT SUPPORT SERVICES[1] and INTERNATIONALIZATION OF SOIL TAXONOMY

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Developers of the research strategy for the Benchmark Soils Project (Benchmark Soils Project, 1979) noted that effective technology transfer depends on horizontal information exchange among nations and vertical delivery of appropriate technology to the farmer. For technology transfer-especially horizontal transfer-to be successful, both the donor and recipient must speak a common scientific language. Furthermore, technology transfer is not a mere grafting of technology from one area onto another area; technology has to be adapted to meet the needs of the receiving nation and the local users.

Every country should have a good knowledge of its resources, including soil resources. Soil surveys provide the geographical distribution of the resources and a classification arranges the soils in an orderly manner so that areas of similar kinds of soils can be grouped and, more important, recommendations for the use and management of groups of soils can be made. It is evident that a

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[1] Soil Management Support Services (SMSS) is a programme of international technical assistance of the Agency for International Development (AID). The assistance is provided by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture under PASA No. AG/DSB 1129-5-79.

good classification system is a national convenience and asset.

Soil Taxonomy describes the system of soil classification used by the United States Department of Agriculture. The premise of Soil Management Support Services (SMSS) is that Soil Taxonomy (Soil Survey Staff, 1975) can be an effective vehicle for agro-technology transfer.

Few nations can afford to experiment with all of their soils to determine the best use for each. Experimentation is costly in both money and time. Many less developed countries (LDC's) do not have enough money, time, or scientific personnel, and they cannot afford to wait to develop a technology. For quick solutions, they frequently tap the experience of neighbouring countries or of more distant countries with similar ecology.

Using the neighbour's experience, however, can lead to costly mistakes unless a common language is available. Most sciences, such as chemistry, botany, and zoology, already have a common terminology, but until recently, one was lacking for soil science. Soil Taxonomy can fill this gap. SMSS was established partly to assist nations, institutions, and scientists to use Soil Taxonomy. In discussing agro-technology transfer, Beinroth et al.,(1980) conclude that the classification of soils by an internationally used system is a pre-requisite for effective transfer of agronomic research.

General Strategy of SMSS

The overall goal of SMSS is increased food production leading to self-sufficiency in the LDC's. To help reach this goal, the general strategies of SMSS are (1) to provide technical assistance in soil survey and interpretation and (2) to assist in technology transfer by refining Soil Taxonomy for more effective use in tropical countries and by encouraging its greater use in these countries.

Technical assistance

Technical assistance through SMSS is provided at no cost to the recipient country and normally for a period not exceeding 6 weeks. It can include (USDA and AID, 1980):

1. Helping the countries establish policies and programmes for solving problems in land use and food and fibre production;

2. Helping plan, carry out, and evaluate soil surveys and soil conservation programmes;

3. Providing laboratory and field testing services;

4. Publishing soil management information that is needed in land use planning and for food and fibre production;

5. Conducting seminars and other training sessions on improving soil management and on classifying soils;

6. Interpreting soil properties to determine the potential of the soils for agriculture and to predict their response to management; and

7. Disseminating new ideas for increasing soil fertility, improving plant nutrition, and controlling soil erosion and sedimentation.

Requests by a country for technical assistance are transmitted to SMSS by the local AID mission via AID Headquarters in Washington, D.C. Depending on the kind of help requested, a specialist is sought from the staff of SCS, from universities in the U.S., or from abroad. SMSS maintains a file of interested individuals. On completion of the assignment, the specialist prepares a report, which is transmitted to the recipient country through AID. Follow-up activities are coordinated by AID or SMSS.

In its first 2 years of operation, SMSS responded to 25 requests from LDC's. Some of these, such as a fuelwood project in Senegal,

required detailed soil surveys of experimental areas. Others, such as a request from Sudan, called for an assessment of the requirements for a national soil survey laboratory. Assistance was also provided for developing soil survey programmes (Rwanda) and evaluating ongoing programmes (Ecuador).

Technology transfer

In 1978, Cornell University organized a workshop for AID-Soil Resource Inventories and Development Planning at that workshop. Cline (1979) stressed the need for improved inventories.

> "The problem is especially serious in the developing nations. Many of the soil survey programmes are relatively new, and experience with both making and using soil inventories is limited. Resources for the work, including qualified soil scientists, are commonly limited. Administrative authorities responsible for policy and allocation of funds rarely appreciate what is needed to conduct a soil survey and to achieve and maintain quality. Funds for correlation, even within countries, for example, are not readily available and quality control is severely restricted. This is not to imply that soil inventories in developing nations are necessarily poorly planned and executed. Many excellent surveys have been made, but the obstacles are very great and the usefulness of many inventories has suffered as a result."

The difficulty with data from several uncoordinated sources is illustrated by information that has been assembled by the International Soil Museum and SMSS. Nineteen laboratories were sent samples of the same soils for analysis. Table 1 illustrates unacceptable range of values obtained for five of the samples. The four properties listed are commonly measured by all laboratories supporting soil surveys.

The objective of SMSS is not only to encourage LDC laboratories to improve the quality of laboratory work but also to help them do so. Technology transfer is meaningless if the data base is unreliable, if the soils are misclassified, or if the classification does not permit adequate interpretations. Many project failures can be related to these problems rather than to inappropriate technology. Use of Soil Taxonomy can prevent many of these problems.

Table 1. - Range in values of selected soil properties as measured by 19 soil laboratories.

Property	1	3	5	7	9
Clay %					
Highest	21	18.5	36	90	58.7
Lowest	12.2	6.8	25	46.6	1.7
CEC meq/100g					
Highest	7.2	3.7	25.3	22.4	44.8
Lowest	2.8	1.1	15.5	8.1	9.5
Silt, % (2-20μ)					
Highest	19.8	6.5	12.5	25.6	27.0
Lowest	15.4	0.1	9	4.0	73.2
Silt, % (2-50μ)					
Highest	34.0	7.0	15.6	35.5	88.1
Lowest	24.0	0.8	4.0	6.0	33.8

Soil Taxonomy for Agro-technology Transfer[2]

Soil Taxonomy has several merits that make it uniquely suited to serve as a vehicle for agro-technology transfer. At the same time, it has several limitations that must and can be corrected with

[2] This section is adapted from Arnold (in press).

minimal distortion.

The six categories of the taxonomic system are designed in such a way that the amount of information in each category increases in successively lower categories; however, depending on the objective, each category can be used without the lower ones. The highest category - the order - has 10 classes, the suborder has 47 classes, and each succeeding category has an increasing number of classes. Soils in the United States have been classified into about 185 great groups, 1,000 subgroups, 5,000 families, and more than 13,000 series.

The orders are differentiated by the presence or absence of diagnostic soil properties that indicate the degree and kind of assumed dominant soil-forming processes. The orders can be used for a very generalized portrayal of the soils of the world.

The suborders can be used to indicate more specific geographic distribution of the soils. One differentiating criterion in most of the suborders, is the soil moisture regime as a major control of soil-forming processes. The dominant suborders can be indicated on very small-scale maps (1:10,000,000 or 1:20,000,000) and commonly depict broad agro-ecological zones.

The great groups contain much more information than the suborder and can be used in the legends of small-scale maps (1:1,000,000 or 1:5,000,000). Frequently, the map units of these maps are phases of great groups, such as Paleudults, gently sloping. The information contained in the great groups permits some general statements on the use and limitations of the soils (Eswaran, 1977). In some small scale maps, the subgroups can also be used to identify the dominant components of the map units.

The soil series gives the greatest amount of information and is the most useful for technology transfer. However, because of the large number of possible series and the lack of well-defined series in many regions, it is not the most practical category for country-to-country transfer. Because soil at a site can be classified at the family level, the Benchmark Soils Project is using the family

category for research on the transfer hypothesis. The basic assumption is that information obtained from a soil family in one country can be applied to soils of the same family in another country. This kind of research reduces the need for expensive, time-consuming experimentation.

An informed soil scientist can make several kinds of interpretations based solely on the family name. Some soil limitations that can be derived from names in Soil Taxonomy are given by Eswaran (1977).

Internalization of Soil Taxonomy

The Need

Internationalization implies the expansion of our knowledge base and the free interaction of soil scientists everywhere, so that Soil Taxonomy can be refined to permit its increased use and wider application.

What is the reason for the desire to internationalize? Basically, because of the increased use of Soil Taxonomy, particularly in the less developed countries. To date, more than 25,000 copies of Soil Taxonomy have been printed - a remarkably large number for a national soil classification system. The Soil Survey of India has published an Indian edition and more than 1,000 copies have been sold. The Italian government recently published an Italian translation. A survey of Cline (1980) indicates (Table 2) that at least 12 countries use Soil Taxonomy as a primary system and that many others frequently use it.

Giving soil names according to Soil Taxonomy is becoming an increasingly accepted practice by a large section of the scientific community for several reasons. Basically, the system is designed for practical purposes - making and interpreting soil surveys. A second reason is that the quantitative system permits different individuals to arrive at the same classification for a given soil.

In addition, the logic of the system appeals to the trained mind and the system is based on real soils. Soil Taxonomy was the result of the combined efforts of many people. At each stage of its 25-year period of development, the all-important question was asked: "Do these groupings permit us to make meaningful predictions of soil behaviour?"

Table 2. Use of Soil Taxonomy by country (Cline, 1980)

Used as the primary system	Used frequently as a secondary system	Used occasionally
Argentina	Belgium	Australia
Chile	Bolivia	China
Columbia	Brazil	France
Ecuador	Canada	Guatemala
Guyana	Costa Rica	Haiti
India	England	Hungary
Iraq	Ghana	Mali
New Zealand	Iran	Mauritania
Pakistan	Ireland	Mexico
Sudan	Japan	Netherlands
United States	Kenya	Niger
Venezuela	Nigeria	Norway
	Peru	Panama
	Romania	Scotland
	Sierra Leone	Senegal
	Sri Lanka	South Africa
	Thailand	Upper Volta
	Tanzania	Union of Soviet Socialist Republics
	Trinidad	West Germany
	Wales	Zimbabwe

The designers and users of Soil Taxonomy realize that the system is not perfect. There are some inherent weaknesses, particularly in the classification of soils of the Tropics, but all systems reflect the knowledge available at the time they were designed. An advantage of Soil Taxonomy is its basic structure, which can be improved without major modifications.

The need to internationalize also arises because few other systems that could be applied throughout the world provide information for quantitative predictions.

The Mechanism for Internationalization

SMSS is promoting the internationalization of Soil Taxonomy primarily through several international committees and workshops.

International committees are discussing many selected weaknesses in Soil Taxonomy. We believe that, through the participation of the international cooperators, the system can be made more accurate, more reliable, and better suited to conditions in the LDC's.

Seven international committees (ICOM's) are discussing different aspects of Soil Taxonomy. The International Committee on Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC) was organized by SCS in 1975 with Dr Frank Moormann as chairman. The proper management of LAC soils differs markedly from that of soil with high amounts of 2:1 lattice clays. It is considered unsatisfactory to leave the distinction of LAC from high-activity clay (HAC) soils at a low categoric level, i.e., the subgroup. A related problem is the identification of the argillic horizon in some LAC soils. The mandates of ICOMLAC are to recommend changes in the classification of the Alfisols and Ultisols and to define the necessary LAC taxa and their diagnostic properties.

The discussions of ICOMLAC clearly showed a need for reexamining the order Oxisols. Accordingly, ICOMOX was formed in 1977 with Dr Hari Eswaran as chairman (the present chairman is Dr Stanley Buol).

In the last two decades, much more information has become available on the genesis and properties of Oxisols. Apart from minor modifications, the definition of the oxic horizon seems to be generally accepted. The order should be more precisely defined to create a mutually exclusive class. Because soils are a continuum, this is not always an easy task.

When Soil Taxonomy was published, the concept of variable charge systems had already been established, but not enough data were available to build this concept into the classification. Many Oxisols have a high variable charge and these Oxisols could have been separated on the basis of this characteristic, but there was little information on the management implications and satisfactory limits for their recognition. The variable charge component in Oxisols is different in kind and magnitude from that in volcanic ash soils which Soil Taxonomy considers as Andepts, a suborder of the Inceptisols. The order Inceptisols is itself a mixed lot, and many workers have felt that the Andepts were misfits. Dr Guy D. Smith, realizing that he could not make statements with any level of confidence on the use and behaviourof these soils as currently classified, proposed in 1978 that the suborder of Andepts be upgraded to an order. He suggested the name Andisols and made some suggestions for developing the lower categorical levels. In the same year, a committee (ICOMAND) was formed with Dr Mike Leamy as chairman.

Soil moisture regimes (SMR) and soil temperature regimes (STR) are used as classification criteria at many of the categoric levels in Soil Taxonomy. Some believe that the classes of SMR and STR are insufficient and that some distinction must be made between Tropic - and Temperate - zone soils with the same SMR or STR. A committee on moisture regimes of the Tropics (ICOMMORT) was formed in 1978 with Dr A.Van Wambeke as chairman to investigate the possibility of increasing the number of SMR classes applicable in tropical areas.

Three other committees have been formed recently as a result of requests from individuals or proposals from international workshops.

The committee on Aridisols (ICOMID) with Dr A. Osman as chairman will examine several topics including (a) significance of the argillic horizon in Argids, (b) proposals to include hypergypsic and hypercalcic materials in the classification, and (c) the use of other management-related criteria in the classification.

The Vertisol committee (ICOMERT) with Dr J. Comerma as chairman will reexamine the Pell- and Chrom- prefixes in the great groups. Wet Vertisols and acid Vertisols are other areas of concern. Recently, another committee (ICOMAQ) was created to evaluate the Paddy soils and other selected soils with aquic soil moisture regimes. This committee, with Dr Frank Moormann as chairman, will also make proposals for appropriate classification of these soils.

The ICOM's work is facilitated through international soil classification workshops. The first three workshops - in Brazil in 1976, in Malaysia and Thailand in 1978, and in Syria and Lebanon in 1980 - were organized by the University of Puerto Rico. Apart from serving the purpose of the ICOM's, the workshops provide an opportunity for the international experts to meet and talk with LDC scientists. They also provide an opportunity for onsite testing of the recent proposals concerning Soil Taxonomy. These workshops are one of our most productive efforts in internationalization.

Other Means of Internationalization

The increased use of Soil Taxonomy has created a need for a publication on the rationale and concepts of the system. The late Dr Guy D. Smith, who was one of the chief contributors to the classification system described in Soil Taxonomy, was interviewed shortly before his death by scientists from the U.S., Europe, and several countries in Asia and South America. We hope to produce a monograph that will elaborate on the considerations that went into the development of Soil Taxonomy. Because of the increasing use of Soil Taxonomy in French- and Spanish-speaking countries, efforts are underway to translate the book into these languages.

Although SMSS gives considerable attention to increased use of Soil Taxonomy, we also try to keep track of developments in other national or international classification systems. The International Soil Science Society, with support from FAO, UNEP, ISM, and national and regional groups, is developing a reference base for international soil classification. The objective of this effort is the same, i.e., to build a common basis for agro-technology transfer. All of us stand to gain by supporting this effort.

Concluding Remarks

Internationalization is a two-way effort. There is heavy reliance on the inputs of the scientists from LDC's, because they are the people who know their soils, can inform us of the management-related properties, and can propose criteria and limits. However, in some instances, before LDC scientists can contribute effectively they must become familiar with Soil Taxonomy and its application. Some of our internationalization activities are directed to this need.

As stated earlier, the structure of Soil Taxonomy enables new information to be incorporated with minimal distortion of the system. Soil Taxonomy was published only 6 years ago and we still have not developed a mechanism to adequately handle foreign proposals. Soil Conservation Service hopes to computerize the text of Soil Taxonomy to assist in keeping track of changes; a change in one part of Soil Taxonomy has implications in many other parts. SMSS will study all well-documented proposals and suggestions and channel them to the Soil Conservation Service. We welcome your suggestions on ways to enhance the internationalization of Soil Taxonomy.

A major objective is to produce within this decade a new edition of Soil Taxonomy that incorporates the results of our combined efforts.

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BASIC CONCEPTS AND PHILOSOPHY OF SOIL TAXONOMY

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Introduction

Dr Guy D. Smith was one of the prime movers behind the soil classification system described in Soil Taxonomy (Soil Survey Staff, 1975). Perhaps better than anyone else he knew the details of the thinking, discussions, and arguments that shaped the development of the system.

This paper outlines the broad concepts and philosophy of Soil Taxonomy. In writing it I have drawn heavily from transcripts of several interviews of Dr Smith by several distinguished scientists, beginning in 1976 with Dr Michael Leamy of New Zealand. Some of the interviews have been published in the newsletter of the New Zealand Soil Science Society and in the periodical Soil Survey Horizons, which is printed in the United States.

A monograph based on the interviews is now being prepared. It will give a full account of the rationale and concepts of Soil Taxonomy. The monograph will be published through Soil Management Support Services, a programme of international technical assistance carried out by the United States Department of Agriculture, Soil Conservation Service, with funding from the United States Agency for International Development.

Historical Background

Soil Taxonomy did not happen overnight; it evolved over several decades. An excellent review is given by Cline (1979). Modern classification systems obtained their initial spark with the recognition by Dokuchaiev (Glinka, 1927) that soils are natural bodies; some of the concepts of Dokuchaiev are still to be found in Soil Taxonomy.

In the U.S., two early works on classification were written by Whitney (1909) and Marbut et al.,(1913). There were several inconsistencies between the genetic theories of Marbut and field observations, and by 1935, when Marbut died, the stage was set for a review of the system then in use.

Dr Charles E. Kellogg became the principal soil scientist of the U.S. Soil Survey after the death of Marbut. In 1936, Henry Wallace, then Secretary of Agriculture, requested a yearbook of agriculture on soils; in 1938, Soils and Men was published with a chapter on soil classification by Baldwin, Kellogg, and Thorp (1938). This classification, later revised, is popularly known as the 1938 classification. It introduced to the U.S. scene N.M. Sivertsev's concept of Zonal, Intrazonal, and Azonal soils (see Afanasiev, 1927). It also introduced the concept of great soil groups, but it did not provide a link with the lower categories. As a result, there were virtually two systems in the U.S.: one consisting of series, types, and phases and the other of higher categories.

After the Second World War, an attempt was made to rectify this situation. The initial effort, according to Cline (1979), was mainly to "patch up" the 1938 system. By then, about 5,000 soil series had been identified in the U.S. and correlation of the series became an important problem.

A special issue of the journal Soil Science was published in 1949 devoted solely to soil classification. Soon afterwards, the Soil Conservation Service took the momentous step of deciding to develop a new classification system and Dr Guy D. Smith, Director of Soil Survey Investigations, was charged with leadership of the project. The system was developed through a series of seven approximations and was finally published in 1975.

Designing the system was not an easy task. Several hundred man-years of work were required. Methods had to be developed, soils had to be analysed, concepts had to be tested, and personal bias had to be sieved out. When we look back and evaluate all the efforts that resulted in Soil Taxonomy, we can see that few organizations in the world could have matched them. In addition, Dr Smith's leadership was critical to coordinate, guide, and encourage the workers and even to terminate some extreme ideas.

Logic of the System

Cline (1949) provides a succinct summary of the system's logic:

> "The purpose of any classification is 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. As the things important for one objective are seldom important for another, a single system will rarely serve two objectives equally well."

This statement of Cline makes three important points. First, since a classification system reflects only the knowledge existing at the time, it should have the capacity to change as more information becomes available. A good example is the use of mineralogical

parameters. Before 1950, soil mineralogical techniques were not well developed and classification systems carried little or no information on soil mineralogy. Since then, we have come a long way; mineralogical family classes are present in Soil Taxonomy. There are still problems with these classes, mainly that of quantification. When this problem is solved, "the solution" or "quantification" will be incorporated in the system.

Second, Cline states that a classification has specific objectives. Most broadly, the objectives of a classification may be categorized as being either theoretical or practical. If a soil classification system has the sole objective of organizing genetic theories, it will be in a state of flux and will be continuously contested as knowledge grows and concepts change. The practical objective, therefore, must be clearly determined before the system is developed. If this objective is not determined, the developed system may never be used. The objective of Soil Taxonomy is the making and interpretation of soil surveys used to guide land planners and managers.

Third, soil classification requires the grouping of objects on the basis of common properties. For example, Sibirtsev's Zonal, Azonal, and Intrazonal concept attempted to subdivide soils according to genetic theory. The soils within each of these genetic classes were then assigned some properties. Soon, however, it was found that some Azonal soils had Zonal properties or vice versa. Using atmospheric climate to divide soils implies that they have few similarities - the implication is that soils are different because the climate is different. Smith (1965) believed that this misconception would prevent the average mind from comparing the actual properties of the soils of two different climatic regions. Genetic theories, far from being ignored in Soil Taxonomy, were used for the conceptual development of the categories. But the categories and the classes within them are defined according to measurable soil properties.

The Unit of Classification

It is easy to describe a house, car, cat, or fish and identify it by placing it in a category of a classification system. These are discrete objects with well defined limits. Classifying soils is much more difficult, because soils are a continuum - their properties may change very gradually with distance over the landscape. To classify a soil, one has to identify the individual soil unit that is to be classified. In defining the individual, we focus on a specific part of the continuum, and in doing so we recognize that specific properties of a soil individual can vary within certain limits. It is only by this recognition that we can proceed to the next step, grouping the soil individuals into classes.

In Soil Taxonomy, the soil individual is called the pedon. A pedon is like the unit cell in a crystal. The pedon is the unit of sampling, that is, it is the smallest area that is described and sampled. It is three-dimensional, and its lateral dimensions are large enough to represent the nature of any horizons and variability that may be present.

The unit cell or pedon can theoretically be as small or as pure as one would like it to be, but such an approach would serve few practical purposes, because it would ignore the reality of soils as a continuum having variations in properties. In any given segment of a landscape, we can identify many distinct pedons. We can also identify polypedons, which are sets of contiguous pedons that differ from other contiguous pedons in properties affecting use and management. The polypedon has shape, transitional margins, and natural boundaries. Polypedons are the real things that are classified.

Characteristics Used for Classification

Cline (1949) recognized three kinds of soil characteristics - differentiating, accessory, and accidental. A property that is used as the basis of grouping is a differentiating characteristic.

Accessory characteristics are co-varying properties about which precise statements can be made, and accidental characteristics are properties that are independent of the basis for grouping. Some properties, such as cation exchange capacity (CEC) or the presence of gibbsite, can be considered as differentiating, accessory, or accidental characteristics, depending on the level of classification being discussed. CEC of less than 16 meq per 100 g clay is a differentiating characteristic in Oxisols. Low CEC is an accessory characteristic in some Ultisols where the presence of an argillic horizon and low base saturation is used to define the order. Low CEC in the Ultisol identifies a subgroup and is a differentiating characteristic at this level.

The presence of a small amount of gibbsite is an accidental characteristic in some Oxisols and Ultisols. If a large amount of gibbsite is present, it is a differentiating characteristic in some of the Oxisols, e.g., to define the great group of Gibbsiorthox. Selection of the attributes becomes critical in developing the classification of a given soil. Several rules are followed in Soil Taxonomy.

o First, the definition of each taxon should carry as nearly as possible the same meaning to each user. The definitions have to be precise and, whenever possible, quantitative.

o Second, the taxonomy has to be multicategoric.

The highest category, the order, has only 10 classes. Succinctly, lower categories of the taxonomy contain increasing numbers of classes arranged in a logical development. One need know only a few rules to understand the relationship of the lower categories to the higher.

o Third, the taxa should be concepts of real bodies that are known to occupy geographic areas.

Hypothetical soils should not be considered in the classification. This differentiates Soil Taxonomy from some other hierarchical systems,

which have slots for soils that theoretically might exist somewhere but have never been described. The system should be constructed, however, so that a soil can be classified if it is found and described.

o Fourth, differentiae should be soil properties that can be observed in the field or properties that can be inferred from the observed properties or from the combined data of soil science and other disciplines.

If the property cannot be measured or evaluated, it has little value in the classification. Two properties that Soil Taxonomy has introduced are soil moisture and temperature. At present there are few available data on these properties because they are not routinely measured, but they can be inferred from atmospheric data.

o Fifth, the taxonomy should be capable of modification to fit new knowledge with a minimum of disturbance.

No individual or group can claim to have seen all the soils of the world. Soil scientists are continuously studying soils - soils they have seen before, as well as those they have not seen before. The classification system becomes obsolete if it cannot incorporate new information that the scientists provide.

o Sixth, the differentiae should allow for keeping an undisturbed soil and its cultivated or otherwise man-modified equivalents in the same taxon as far as possible. We do not want to change a classification just because some properties of a soil have changed through use and management.

o Seventh, the taxonomy must be capable of providing taxa of all soils in a landscape.

o Eighth. the taxonomy should provide for all soils that are known, wherever they may be.

These last two items indicate that the system has to be complete if it is to be functional.

Taxa and Categories

A group of individuals that form a class is called a taxon. A taxon has the maximum number of properties or attributes in common, and because of these similarities we can make the most numerous and most important statements about a taxon. A category is a group of taxa, defined at about the same level of abstraction and including the entire population of individuals. In Soil Taxonomy, there are six categories: order, suborder, great group, subgroups, family, and series. The categories serve specific purposes and the amount of detail that goes into the definition increases in the lower categories.

Orders

The orders are differentiated by the presence or absence of diagnostic horizons or features. These are marks indicating differences in the degree and kinds of the dominant sets of soil-forming processes that have gone on in the past. Ten orders are described in Soil Taxonomy - Alfisols, Aridisols, Entisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols. The order category provides a conceptual grouping of the soils based on common but important properties.

Suborders

The suborders generally are defined on the basis of properties that affect the current processes of soil development. In most suborders, soil moisture and temperature regimes are the properties used. Currently, 47 suborders are recognized and the differentiae for the suborders vary with the order. The following examples illustrate this:

Entisol	Alfisol	Aridisol	Vertisol
Aquent	Aqualf	Argid	Xerert
Arent	Boralf	Orthid	Torrert
Psamment	Ustalf		Udert
Fluvent	Xeralf		Ustert
Orthent	Udalf		

Suborders are generally used for making small scale-maps on scale 1:5,000,000 or 1:1,000,000. They are used for delineating broad geographic areas.

Great Groups

In the category of great groups, a number of soil properties are identified. The whole soil is characterized, including the assemblage of horizons and the most significant property of the whole soil as determined from the number and importance of accessory properties. Although the differentiating properties of the great group are few, there are many accessory properties.

About 200 great groups have been identified in the U.S. The great groups contain enough information to allow some general statements about use of the soil. They are frequently used in small-scale maps.

Subgroups

The categories above the subgroup focus on the marks or causes of sets of processes that appear to dominate the course or degree of soil development. In addition, many soils have properties that are subordinate but still are important marks of soil-forming processes.

Within a given great group, the soil may show marks of processes that are dominant in other orders, suborders, or great groups, but in the given great group these processes serve only to modify other dominant processes. Identifying these less significant

processes at the subgroup level helps to show the relationship to other kinds of soils. In addition, some properties can be used to define a subgroup that are used as criteria of any taxon at a higher level.

Consequently, there are three kinds of subgroups:

o The typic subgroup, which defines the central concept of the great group. The typic subgroup may not be the most extensive.

o The intergrades, which define the relationship to other orders, suborders, or great groups. For example, Ultic subgroups are intergrades to the order of Ultisols, Orthoxic subgroups are intergrades to the suborder of Orthox, and Dystropeptic subgroups are intergrades to the great group of Dystropepts.

o The extragrades, which have properties not used in higher categories. Examples are cumulic, lithic, and ruptic subgroups.

Families

In this category, the intent has been to group the soils within a subgroup that have similar physical and chemical properties affecting their responses to use and management. In some instances, phases of families are used because the information contained in the family may be insufficient to make the desired kind of interpretations.

Families are defined to provide groupings of soils with restricted ranges in:

o Particle size distribution in horizons of major biologic activity below plough depth,

o Mineralogy of the same horizons that are considered in naming particle-size classes,

o Soil temperature regime,

o Thickness of soil penetrable by roots, and

o A few other properties that are used to produce the homogeneity needed to define the family.

Series

The soil series is the lowest category, and in the U.S. there are about 13,000 series. Differentiating properties of a series cannot fall outside the limits established for the family. Differentiating properties of series in the same family must meet three tests:

o The properties must be observable or inferrable with reasonable assurance.

o They must fall within a unique range for each series, and this range must be significantly greater than the normal range of errors of measurement, observation, or estimation of qualified soil surveyors.

o The properties must have some relation to horizon differentiation if horizons are present.

Polypedons, as mentioned earlier, are real things, but a soil series is conceptual. The dominant kinds of polypedons that are delineated on a map are given the names of soil series. A polypedon may be a series or, more commonly, a phase of a series.

Structure of the Classification

Diagnostic Horizons

One of the unique innovations in Soil Taxonomy is the diagnostic horizon. In developing Soil Taxonomy, the conventional A, B, C nomenclature of soil horizons was dropped and in its place diagnostic

surface and subsurface horizons were introduced.

The diagnostic surface horizon is called an epipedon, and it is important to note that this is not a synonym for the A horizon. An epipedon can include all or part of the B horizon if the darkening by organic matter extends from the soil surface to the B. Soil Taxonomy identifies six diagnostic surface horizons and describes their properties.

Several diagnostic subsurface horizons are also identified. In general, these horizons are below the diagnostic surface horizon, but may include the uppermost soil horizon if the soil is truncated. Soil Taxonomy defines several other diagnostic soil characteristics including soil moisture and temperature regimes.

Taxonomic Placement of Soil

To classify a soil, it is imperative to use the keys provided for the descending hierarchy of categories in Soil Taxonomy. It is incorrect, for example, to have a preconceived notion of the order and suborder and go directly to the great groups for examples. Even the experienced classifier must use the taxonomy systematically and determine that the soil meets all the requirements of the keys for the order, suborder, and so on.

Each taxon in each category also carries a definition. The classifier must check this definition before proceeding to the key of the next lower category. Recently, a few inconsistences have been found between the definition of a taxon within a category and the key of that category. Such inconsistencies are now being rectified.

Conclusion

Soil Taxonomy makes it possible to classify all the soils that are known. Its structure serves equally well for organizing existing knowledge about soils for project planning and for

relating test results and research to specific soil properties. It is now possible to increase the knowledge about soils in an organized manner and this would permit application of new knowledge in planning future projects.

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Discussion

L. Chase: How does the series extend the family level information? Are there any series differentiating criteria?

H. Eswaran: The series criteria are defined in Soil Taxonomy. They are fairly pragmatic, but must meet the family criteria.

DIAGNOSTIC HORIZONS

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One of the most significant changes introduced in Soil Taxonomy is the concept of diagnostic horizons. It is a concept that amalgamates and, in some places, cuts across the traditional A, B, C, horizon nomenclature and accumulates the properties of particular genetic horizons so as to express a combination of properties of soils for classification purposes.

I well remember Guy Smith telling me many times that as he wrote Soil Taxonomy on his dining-room table in the weekends, because pressure of work at Soil Conservation Service did not allow him time to do it there, he struggled for a breakthrough which would begin to express the ideas he felt were important for soil classification. That breakthrough he regarded as the recognition of diagnostic horizons and properties. The concept begins to emerge in the fourth, fifth and sixth approximations of Soil Taxonomy and was finally defined in the seventh approximation.

In the final publication of Soil Taxonomy, a number of diagnostic features are defined and used to separate taxa. To date, there are six epipedons, seventeen subsoil diagnostic horizons, five types of diagnostic organic materials, ten types of other diagnostic soil characteristics - such as abrupt textural change or fragipan, three types of diagnostic contacts to non-soil material - such as lithic contact, and most importantly, ten temperature and seven moisture regimes.

The following are definitions and descriptions of diagnostic features common in tropical soils. It should be emphasised that these are not the full definitions as given in Soil Taxonomy, but

are greatly abbreviated versions - in many cases definitions are still being discussed and revised, but it is doubtful if the basic meaning attached to each term contained in this material will be changed.

The Mollic Epipedon. This is a surface horizon that, when mixed to a depth of 18 cm contains 1% or more organic matter with colour values darker than 5.5 dry, and 3.5 moist. Structure cannot be massive and hard, base saturation is over 50% and the epipedon is not naturally dry more than 3 months of the year.

The Umbric Epipedon has a surface horizon like the mollic epipedon, but is less than 50% base saturated and not naturally dry more than 3 months in the year.

The Ochric Epipedon has a surface horizon that is light in colour, colour values are greater than 5.5 dry, and greater than 3.5 moist, contains less than 1% organic matter, or is hard or very hard and massive when dry or dry more than 3 months in the year.

The Argillic Horizon. In general, this is a B horizon that has at least 1.2 times as much clay as some horizon above or 3% more clay content if the eluvial layer has less than 15% clay, or 8% more clay if the eluvial layer has greater than 40% clay. It is formed by illuviation of clay and illuviation argillans are usually observable unless there is evidence of stress cutans. It should be 1/10 as thick as all overlying horizons, or more than 15 cm, whichever is the thicker.

The Spodic Horizon has an illuvial accumulation of free sesquioxides and organic matter. There are many specific limitations dealing with Al, Fe and organic matter, and clay ratios depending whether the overlying horizon is virgin or cultivated.

The Cambic Horizon is a subsoil horizon of very fine sand, loamy fine sand or finer texture, with some weak indication of either an argillic or spodic horizon but not enough to qualify as either.

For example, less than 1.2 times as much clay as an overlying horizon.

An Albic Horizon is a light coloured A2 horizon with colour values equal to or greater than 4 dry, or equal to or greater than 5 moist.

The Oxic Horizon is at least 30 cm thick and contains equal to or more than 15% clay. It has a high content of low charge 1:1 clays and sesquioxides retaining less than 10 meq. of cations per 100 g clay from unbuffered ammonium chloride and less than 16 meq per 100 g clay by the ammonium acetate pH 7 method. It cannot be an argillic or natric horizon, contain more than traces of weatherable minerals or have rock structure.

A Placic Horizon is a single, thin 2-10 mm thick, dark reddish brown to black iron or manganese pan that lies within 50 cm of the soil surface, and is wavy, involuted and slowly permeable.

Duripan is a subsurface horizon at least half cemented by silica. Air dry peds do not slake in water or hydrochloric acid, but will be destroyed by hot potassium hydroxide after acid washing.

Plinthite is a humus poor sesquioxide rich horizon which hardens irreversibly to ironstone hardpans or aggregates on drying. The red indurating portions of the layer are usually mottled with yellow, greyish or white bodies.

An Abrupt Textural Change refers to a boundary between an ochric epipedon or albic horizon and an underlying argillic horizon. If the ochric epipedon or albic horizon has less than 20% clay, clay content doubles in 7.5 cm or less. If the ochric epipedon or albic horizon has more than 20% clay, an absolute clay content increase of 20% clay is required in 7.5 cm or less.

All these diagnostic horizons and features were illustrated by slides.

Discussion

L. Chase: Is a duripan only cemented by silicon?

M.L. Leamy: No, it could also be cemented by iron oxides.

SOIL MOISTURE AND SOIL TEMPERATURE REGIMES

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The majority of soil classification systems have recognised the influence of climatic parameters on physical and chemical properties of soils. As these properties are the ultimate determinant of land use potentialities, climatic definitions in soil classification are important to the understanding of different environments associated with soils.

Soil moisture and soil temperature regimes are therefore recognised and precisely defined at various category levels in Soil Taxonomy (Soil Survey Staff, 1975).

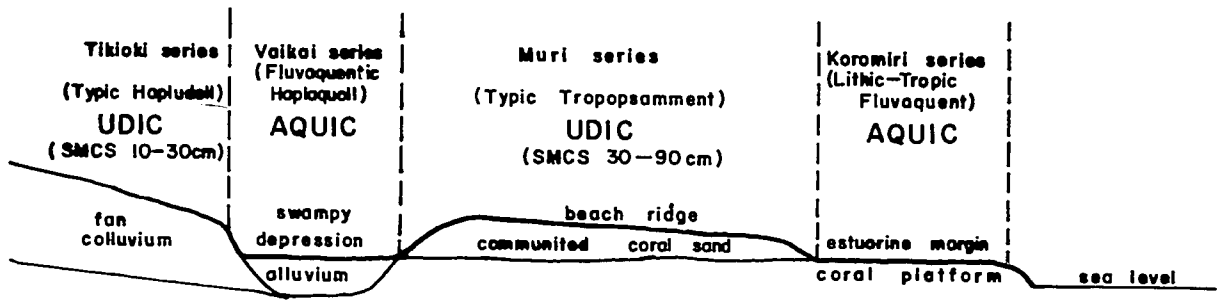
Material discussed in the paper is based on pp.51-63 (inclusive) of Soil Taxonomy and all quotations are from that source. Emphasis is given to the soil moisture and soil temperature regimes of the inter-tropical regions.

A. SOIL MOISTURE REGIMES

Some soils are saturated for most months in the year; others receive sufficient water to cause removal of soil material in solution to deeper horizons in the profile (leaching); while for some soils in dry climates (non-leaching environment) water in the soil deposits carbonates and more soluble salts higher in the profile due to upward movement, where evapotranspiration rates greatly exceed the amount of rainfall received by the soil.

In Soil Taxonomy, the soil moisture regime refers to the presence or absence either of ground-water or of water held at tensions of less than 15 bars (moist), or greater than 15 bars (dry) in the soil,

(Ia) Coastal soil sequence, Rarotonga, Cook Islands.



(Ib) Hill soil sequence, Nawaicoba, West Viti Levu, Fiji.

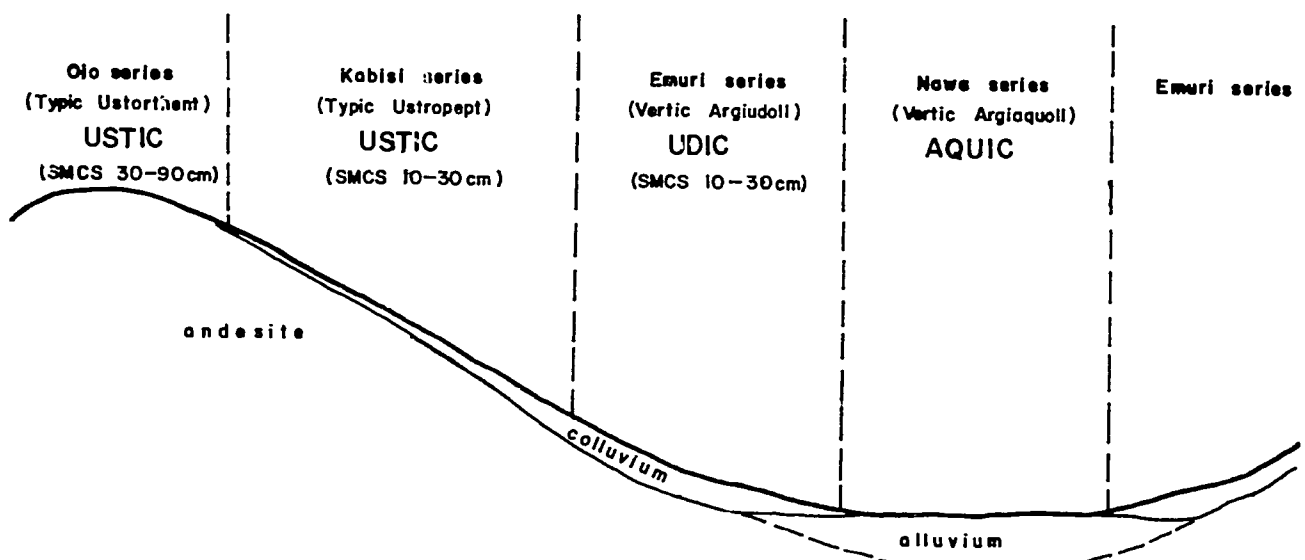


FIG. I. Soil moisture regimes in relation to landscape position.

or in specific horizons, at different times of the year. "A soil may be continuously moist in some or all horizons throughout the year. It may be moist in winter and dry in summer or the reverse. In the southern hemisphere, summer refers to the months of December, January, February, and winter the months of June, July and August. A soil or a horizon is considered to be saturated with water when water stands in an unlined bore-hole 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."

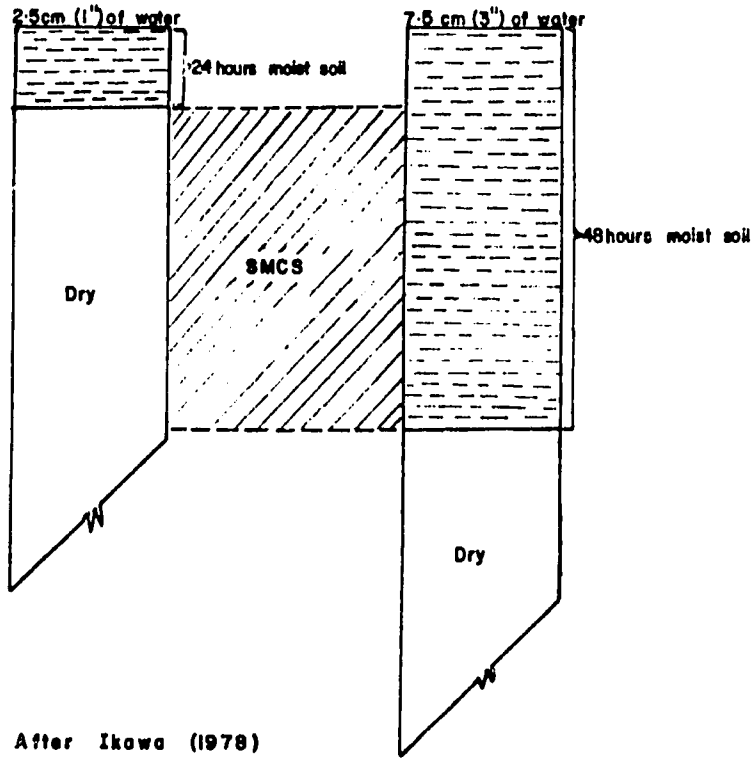
Most deep, free-draining soils, under high and well distributed rainfall have water that is available to plants most of the time. However, soil moisture regimes are not always a function of climate, position in the landscape often being of equal importance. Figure 1 presents two examples, one from the Cook Islands the other from Fiji, that demonstrate that in any given landscape with a uniform climate, associated and adjacent soils can have quite different soil moisture regimes. If the influences, as they relate to soil genesis and land use, imposed by different moisture regimes are to be used as diagnostic properties in soil classification, then the nature of the soil moisture regime must be quantitatively defined. Soil Taxonomy does this, and moisture regimes are used to define classes both at the very high categories (suborder) and as qualifiers at the lower level (subgroup).

"As most moisture regimes of soils are determined by the present climate, and a small scale soil map can be interpreted in terms of the many accessory characteristics that are common to most of the soils that have a common climate. These characteristics include the amount, nature, and distribution of organic matter, the base status of the soil, and the presence or absence of salts. The most important of the interpretations are the potentials for growing different plants and the cultural practices required to grow them."

1. The Soil Moisture Control Section (SMCS):

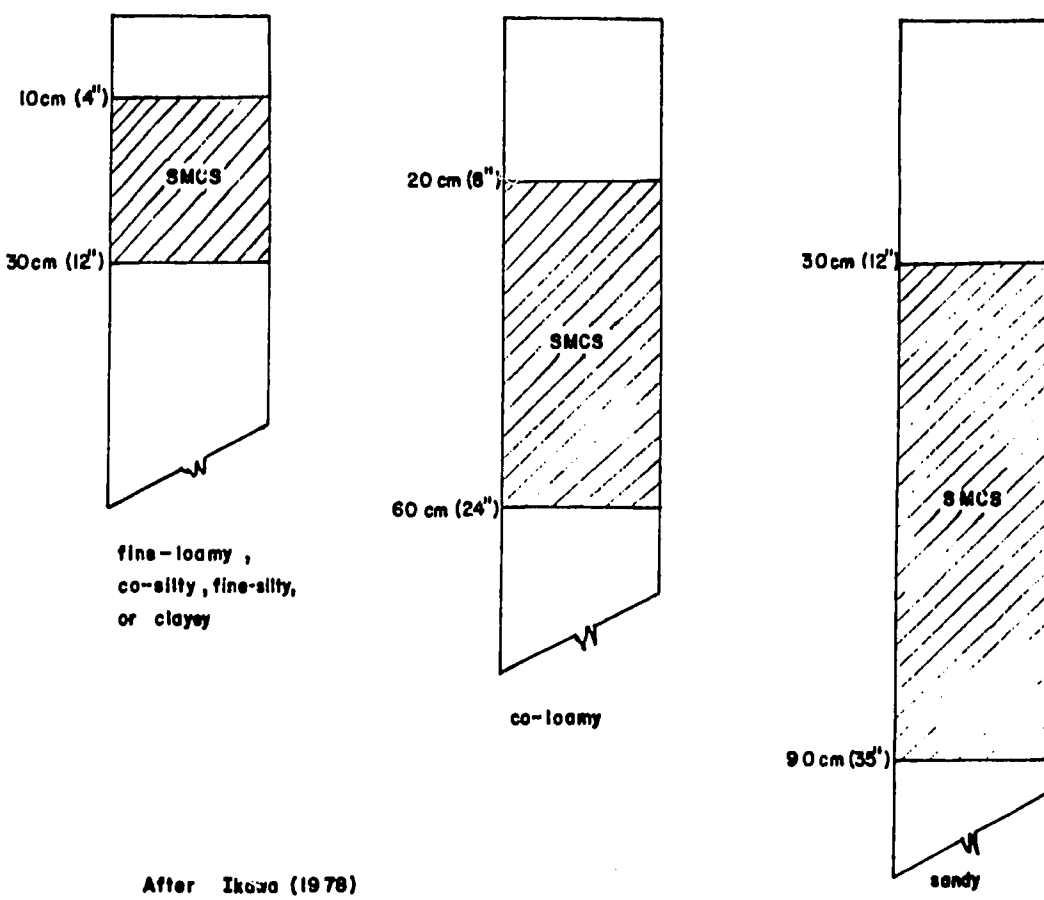
Water in soil can be monitored but, more commonly, the soil moisture regime is determined by measurement of soil properties

FIG. 2. The upper and lower boundaries of the soil moisture control section.



After Ikawa (1978)

FIG. 3. Approximation of the soil moisture control section based on particle-size class



After Ikawa (1978)

(features that indicate oxidation/reduction conditions, for example) in the field and by estimation based on meteorological data. Soil Taxonomy refers to soil conditions rather than climatic conditions, and though these closely correlate, correlation is not perfect. Thus, definition of a SMCS is required so as to determine the soil moisture regime from climatic data.

"The upper boundary of the control section is the depth to which a dry (tension > 15 bars, but not air dry) soil will be moistened by 2.5 cm of water within 24 hours. The lower boundary is the depth to which a dry soil will be moistened by 7.5 cm of water within 48 hours" (Fig. 2).

The profile texture determines the retention and release of soil water and if the particle size class is known the SMCS can be estimated. "As a rough guide to the limits, the SMCS lies between 10 and 30 cm 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 if the particle-size is coarse-loamy, and from 30 to 90 cm if the particle-size class is sandy" (Fig. 3). The presence of stones and rock fragments deepens these limits, and variations to the SMCS are also affected by factors that influence the movement and retention of water, such as, soil structure and pore size distribution.

The basis for estimating soil moisture in the SMCS 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 energy 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."

2. Classes of Soil Moisture Regimes:

Five classes of soil moisture regimes have been defined and are named aquic, aridic (or torric), udic, ustic, and xeric.

Aquic Moisture Regime: (Latin aqua, water)

"The aquic moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated by ground water or by water of the capillary fringe." For differentiating in the highest categories of soils, the whole soil must be saturated. So at suborder class Aqults, Aquolls, Aqualfs, Aquods, Aquepts, and Aquents are recognised as the class of the 6 orders that have an aquic moisture regime. In the subgroups only the lower horizons are saturated and a prefix modifier is used to indicate the intergrading subgroup,e.g.,Aquic Paleustalf.

Aridic and Torric Moisture Regimes: (Latin aridus, dry, and Latin torridus, hot and dry)

"These terms are used for the same moisture regime but in different categories of the taxonomy,i.e.,aridic at order class and torric, subgroup class. In the aridic (torric) moisture regime, the SMCS in most years is:

(i) 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

(ii) 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 moisture regimes normally occur in arid climates, and rarely occur in the Pacific Island countries of the inter-tropical region. Hawaii has examples.

Udic Moisture Regime: (Latin udus, humid)

Soils with a udic moisture regime are moist throughout the year. They are common in humid climates with well-distributed rainfalls or with enough rain in summer months "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 SMCS." Water moves freely through the soil in all months. Thus an extremely wet moisture regime is called 'perudic'.

Many of the highly permeable soils formed on porous volcanic rocks in Western Samoa would have a perudic moisture regime.

Ustic Moisture Regime: (Latin ustus, burnt)

Soils with an ustic moisture regime have limited moisture, but are moist in the season when the soil is suitable for plant growth. They are intermediate between aridic (torric) and udic moisture regimes.

In the inter-tropical regions, "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 SMCS in the ustic moisture regime is dry in some or all parts for 90 or more cumulative days in most years. But the SMCS 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."

Xeric Moisture Regime: (Greek, xeros, dry)

Soils with a xeric moisture regime have alternating moist and dry conditions in the soil, with the moist period in the season when the soil is cool, and potential evaporation is at a minimum.

TABLE 1: Keyout for soil moisture regimes in inter-tropical Regions after Thomas *et al.*, (1980)

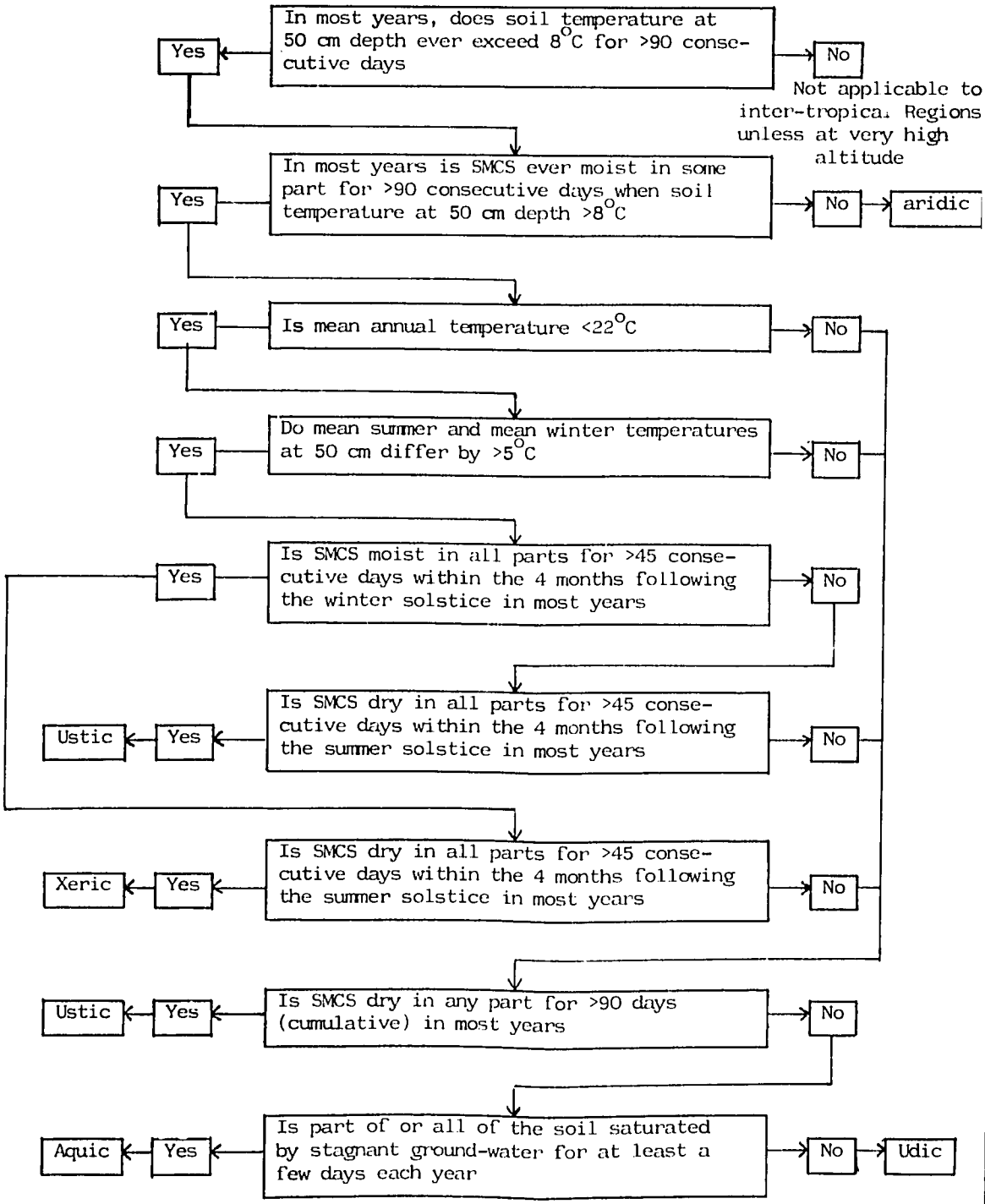


TABLE 2. SOIL MOISTURE REGIMES FOR INTER-TROPICAL REGIONS

Moisture Regime	Temperature Regime	DRY (> 15 bars) Days SMCS is dry (accumulated)	Days SMCS is dry (consecutive) within 4 month after summer solstice	Time SMCS is dry with soil temp. > 5°C at 50 cm	MOIST (< 15 bars) Days SMCS is moist (accumulated)	Days SMCS is moist (consecutive)	
USTIC	Isomesic Isohyperthermic	> 90 days (S)			*1 >180 Days (S)	*2 >90 Days (S)	Either *1 or *2
	Mesic Thermic	>90 Days (S)	*3 <45 Days (A)	<50% (A)		*4 >45 Days within 4 months after winter solstice (A)	*3 only if *4 is found
UDIC	Mesic Thermic	<90 Days (S)					
	Hyperthermic Isohyperthermic	<90 Days (S)	<45 Days (A)				
AQUIC	All Temperature Regimes	MUST BE SATURATED AND HAVE REDUCING CONDITIONS					
PERUDIC	RAINFALL EXCEEDS EVAPOTRANSPIRATION IN ALL MONTHS OF MOST YEARS - MOISTURE TENSION RARELY BECOMES > 1 BAR IN THE SMCS						

SMCS = Soil Moisture Control Section

(A) = All parts of the SMCS

(S) = Some parts of the SMCS

They are associated with the Mediterranean climate, i.e., moist and cool winters and warm and dry summers.

To assist estimation of soil moisture regimes in the inter-tropical region a flow-diagram key is included (Table 1) with a quick reference diagram (Table 2).

B. SOIL TEMPERATURE REGIMES

The temperature of a soil determines the direction soil formation will follow and, given available moisture, controls plant growth. In terms of land use, soil temperature is one of the more important soil properties for it influences the biological, physical and chemical processes in the soil.

The temperature regime comprises "the mean annual temperature, the average seasonal fluctuations from the mean, and the mean warm and cold seasonal soil temperature gradient within the main root zone, which is the zone from a depth of 5 to 100 cm." Summer and winter months are as those defined for moisture regimes.

Soil temperature is measured at a 50 cm depth, or at a lithic or paralithic contact, whichever is shallower, because soil temperatures near the soil surface are influenced by air temperature changes and so experience diurnal fluctuations that are not relevant to the rooting zones for most plants.

Actual soil temperature records are not always available but the temperature regime can be estimated with adequate precision from air temperature data (see Soil Taxonomy, pp. 61-62, for estimation procedures).

Classes of Soil Temperature Regimes:

The names of the classes of soil temperature regimes are pergelic, cryic, frigid, mesic, thermic and hyperthermic. The latter three classes related to the inter-regional region, and for the purposes of this paper those classes for colder climates are not discussed.

Mesic

For the Mesic regime "the mean annual soil temperature is 8°C or higher but lower than 15°C, and the difference between summer and winter mean temperature is more than 5°C."

Thermic

For the Thermic regime "the mean annual soil temperature is 15°C or higher but lower than 22°C, and the difference between summer and winter mean temperature is more than 5°C."

Hyperthermic

For the Hyperthermic regime "the mean annual soil temperature is 22°C or higher, and the difference between summer and winter mean temperature is more than 5°C."

Where the difference between the mean summer temperature and mean winter temperature is less than 5°C, the name of a soil temperature regime has the prefix iso - i.e., isomesic, isothermic and isohyperthermic.

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LABORATORY INFORMATION - PHYSICS
AN INTRODUCTION TO ITS USE IN SOIL TAXONOMY

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A limited range of physical properties is used in Soil Taxonomy to define diagnostic horizons, and classes at various levels. In this brief introduction these properties are discussed in broad terms, and their use is outlined. In a later session of the Forum, each property will be examined in more detail, techniques for their measurement will be described and the implications of the taxonomic limits used will be discussed.

The most widely used physical property is probably particle size distribution. Particle size analysis means the determination of the amounts of various size fractions (clay, < 0.002 mm; silt, 0.002-0.05 mm; sand, 0.05-2.00 mm) present in soil material. Particle size analyses have usually been carried out on material passing a 2 mm sieve; that is on the portion of the whole soil known as the fine earth fraction. The same fraction is used for chemical measurements, and material dried and crushed in preparation for chemical analysis is often used for measuring particle size distribution. In some recent methods, material which has not been previously dried is used.

In the United States Department of Agriculture (U.S.D.A.), the texture of soil is defined in terms of the amount of sand-, silt- and clay-sized material present in the fine earth. Assessments of soil texture are made during detailed descriptions of soils by rubbing a mixture of soil and water between the fingers and estimating the contribution of each size fraction to the "feel" of the slurry. Such assessments are influenced by the nature of the soil material and the amount of organic matter present. Hence it has been found desirable to use an objective measurement of texture. After

determining the amounts of sand-, silt-and clay-size material present, a textural name is assigned to a soil by using a triangular diagram. This defines the area occupied by each textural class as defined by the U.S.D.A. (Fig. 1). Other triangular diagrams with different shaped areas are used elsewhere.

Soil Taxonomy also uses particle size data determined on whole soil material. Horizons may be assigned a particle size classification, but more commonly a particle size class is used to describe the material in a defined particle size control section. When this is done, the name of the particle size class is used as part of the family name of the soil. Thus a soil may be classified, for instance, as a Typic Gibbsiorthox, clayey, oxidic, isohyperthermic. The words "clayey, oxidic, isohyperthermic" are the family modifiers. The defined particle size classes in "Soil Taxonomy" are listed in Table 1.

The particle size control section used in a particular order is defined in different ways, depending on whether an argillic horizon is present (Fig. 2).

Where there is no argillic horizon, or one occurs at below 1 m and the soil is not in a Grossarenic subgroup, the particle size control section is from the surface to a lithic or paralithic contact if this occurs above 36 cm (a in Fig. 2), or from 25 cm to 1 m (c), or from 25 cm to a shallower lithic or paralithic contact (b). When an argillic horizon occurs with its base above 25 cm, the control section extends from the top of the argillic or the base of the Ap horizon (whichever is shallower) either to a lithic or paralithic contact, or to 1 m (d). If the top of the argillic horizon is below 25 cm and it is less than 50 cm thick, then the control section coincides with the limits of the argillic horizon (e). If the argillic horizon is thicker than 50 cm, the control section is the upper 50 cm of the argillic horizon (f). This applies also to Grossarenic subgroups.

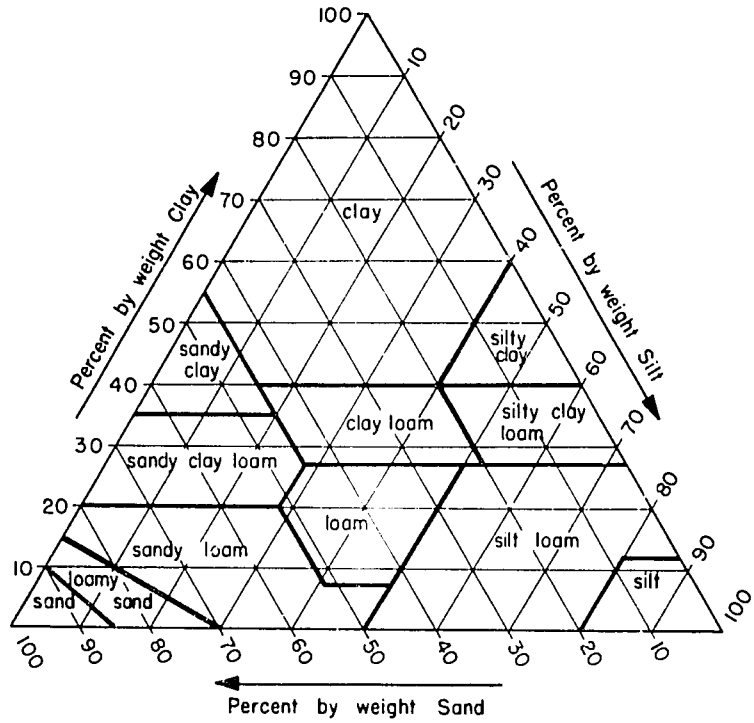

Fig. 1. Textural triangle, showing the percentages of clay (below 0.002 mm), silt (0.002-0.05 mm), and sand (0.05-2.0 mm) in the basic soil textural classes

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Fragmental
Sandy-skeletal
Loamy-skeletal
Clayey-skeletal
Sandy
Loamy

Coarse-loamy
Fine-loamy
Coarse-silty
Fine-silty

Clayey

Fine
Very fine

Table 1. Particle Size Classes used in "Soil Taxonomy."

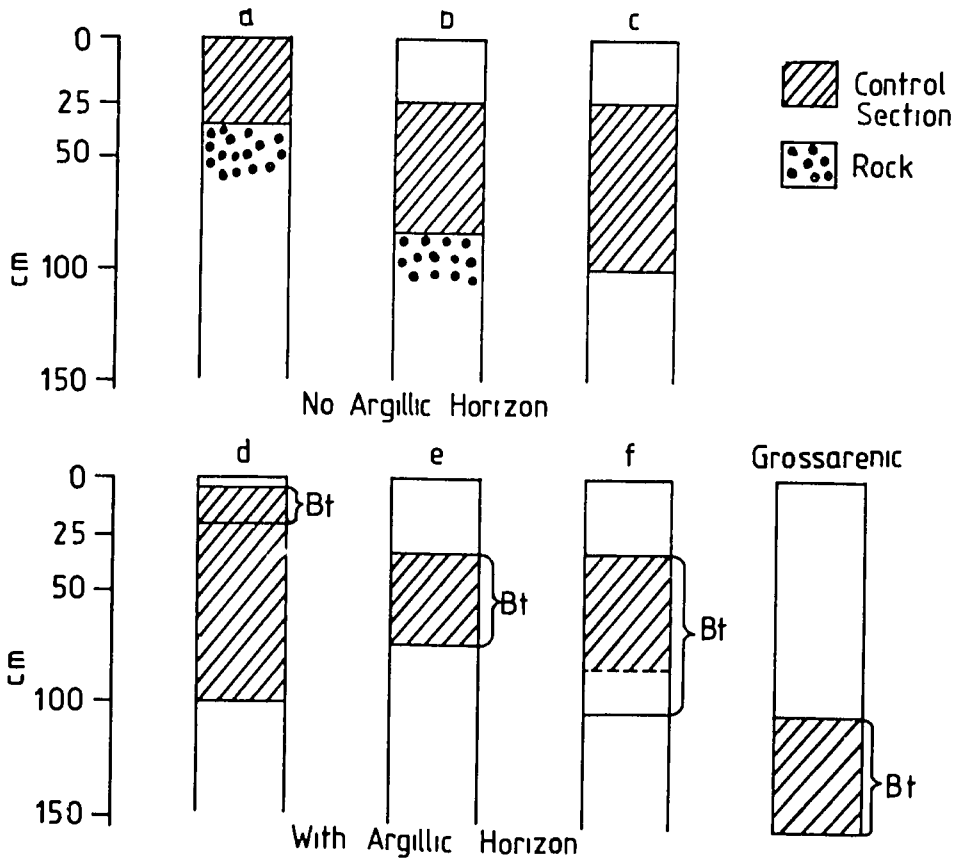

Fig. 2 Particle Size Control Section

The particle size modifier, applied to the particle size control section and used in the family name, conveys information, in a broad sense, about the transmission and storage of water in the soil. Some information of engineering significance may also be inferred. Provision is made for recognising the existence of strongly contrasting particle size classes where a change in particle size distribution may have important effects on the drainage characteristics of a soil profile. Thus, for a profile in which loamy fine

sand overlies clay within the particle size control section, the appropriate family modifier is "sandy over clayey". A number of strongly contrasting particle size classes are specified in Soil Taxonomy, but others may be recognised if required.

The amount of clay in a soil is used in several places as an element in the calculation of particular taxonomic limits, as for instance in defining the spodic horizon.

The second physical property used in Soil Taxonomy is bulk density. This is defined as the dry mass of solid material in unit volume of natural soil. Some soils shrink or swell as their water content changes seasonally. In order that bulk density may be measured for all soils under standard reproducible conditions, the U.S.D.A. has devised a method in which soils are brought to equilibrium at a standard water tension of 1/3 bar before their volume is measured.

There are two purposes for which bulk density is used. Some Andisols in the proposed Order (or Andepts) are defined if, among other properties, they have a bulk density of less than 0.85 T/m^3 (g/cm^3). When occurring in combination with certain other properties, low bulk density is often associated with the presence of allophane (or other minerals with only short-range order). Such soils have important agronomic and engineering properties which are discussed in more detail elsewhere. In addition, bulk density is used to define Andic (or Andeptic) subgroups in other orders, but with a higher density being allowed.

Bulk density is used also in defining suborders in the Oxisol and Ultisol orders, and the great group of Humitropepets. These taxa are required to have at least 12 kg of organic carbon, exclusive of surface litter, in the soil per square metre to a depth of 1 m or to a shallower lithic or paralithic contact. Often the exact value of bulk density is not critical in this calculation, but in marginal situations the measured values of bulk density must be used. Bulk density also appears in the definition of organic

soil material, and hence is used in the definition of Histosols.

The third physical property used in Soil Taxonomy is the water retained by soil material against a water tension of 15-bar. This is commonly abbreviated to "15-bar water". Plants extract water from soil by applying tensions (or suctions) to the soil water. It was thought that plants were able to extract water only until the forces holding the water in the soil exceeded 15-bar. Water bound more firmly than this was considered to be not available to plants. The modern techniques used to measure 15-bar water are probably measuring a property related in some way to the surface area of the soil particles. Fine particles have more surface area per unit mass than coarse particles. Thus, broadly, the 15-bar water content of a soil is correlated with the amount of clay present.

Water retained against a tension of 15-bar may be measured using soil which has been previously air-dried, or soil which is tested commencing at or near its natural water content. Some irreversible drying takes place when most soils are air-dried, but is usually significant only when the soil contains allophane or similar minerals. Soils with high organic matter content may also lose water irreversibly on air-drying. The magnitude of the change in 15-bar water content measured as a result of previously air-drying the soil is used in the proposed Andisol order to define some great groups and subgroups. Elsewhere in Soil Taxonomy, 15-bar water determined on air-dried soil is used to estimate the amount of clay present when the soil is difficult to disperse, or where the suspension used to measure particle size flocculates. There is generally a good correlation between 15-bar water measured on air-dry soil and the amount of clay measured in particle size analysis. Thus, the material in some oxic horizons does not disperse readily, and the amount of clay used to calculate the cation retention capacity per 100 g of clay is estimated by multiplying the 15-bar water value (determined on air-dry material) by 2.5.

The limited number of physical properties which are used as class limits, or as aids to classification, have been introduced. Some details of the techniques used to measure these properties will be discussed in a later session, and the significance of the properties and the way in which they are used will be examined in greater depth.

SOIL TAXONOMY - THE USE OF CHEMICAL AND MINERALOGICAL CRITERIA

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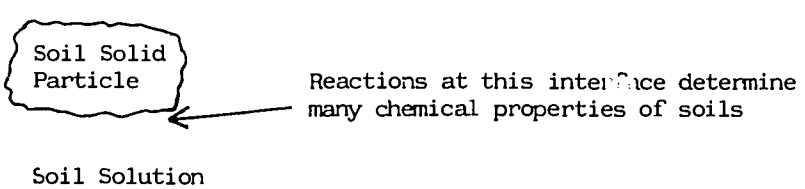
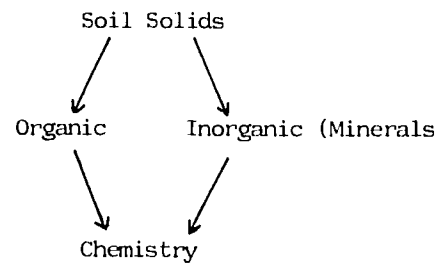
Soil Taxonomy is a utilitarian system for classifying soils. The principal practical application of soil classification is in the making and interpretation of soil surveys. Soil-survey interpretations provide predictions about the behaviour of a particular soil under given conditions. From an agricultural point of view, predictions about the likely levels of nutrients present, or the ability to retain and utilize added nutrients, or the ease of tillage are important. Predictions for a variety of purposes can be made. The chemical and mineralogical properties included in Soil Taxonomy provide essential information for the prediction of soil behaviour. Since this is an overview paper only some of the more important properties will be discussed and some generalizations will be made in order to simplify the discussion.

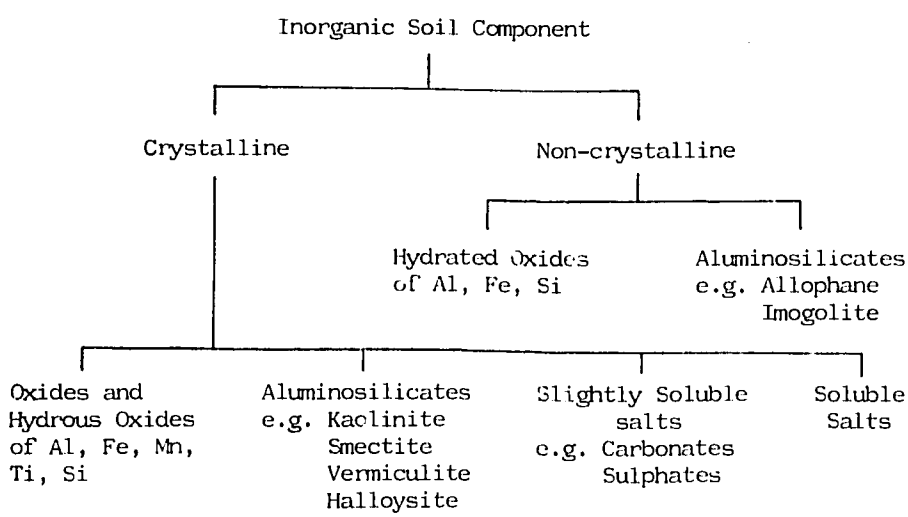
Soil chemistry is basically determined by reactions at the surfaces of soil particles. The nature of these surfaces is largely determined by the mineralogical properties. Since the smallest particles have the largest surface area per unit weight it is frequently reactions occurring at surfaces of clay size (colloidal) particles which are of greatest importance.



The soil solids may be organic or inorganic (or an intimate mixture) and thus the chemistry and mineralogy are very closely related as shown in the diagram below.



The inorganic soil component can be further subdivided as indicated.



The materials classified as 'Noncrystalline', are also referred to in the literature as 'X-ray amorphous' or 'short-range order' minerals.

It should also be noted that the nature and relative amounts of the organic and the different inorganic solid solids markedly influence the physical and engineering properties of the soil,

e.g.,bulk density, plasticity index, COLE.

Probably the single most important property determing soil behaviour is the surface area (or specific surface). Different minerals have different surface areas as shown in the table below and therefore the mineralogy is a virtally important factor controlling soil behaviour.

Mineral	Surface area m^2g^{-1}
Smectite (montmorillonite)	600 - 800
Kaolinite	10 - 50
Oxides (e.g. gibbsite, geothite, silica)	10 - 40

The surfaces of soil materials, whether of mineral or organic origin, are electrically charged. The materials can be divided into two main types depending on whether the surface charge is constant or variable. This division is not a rigid one because a single soil material can exhibit both types of behaviour and real soils commonly contain a mixture of constant and variable charge materials. The constant surface charge is produced by isomorphous substitutions within the mineral structure and is therefore independent of external factors such as the pH and composition of the soil solution. Constant charge materials are aluminosilicate minerals in which extensive isomorphous substitution occurs, e.g., smectite, illite, vermiculite and chlorite.

In variable charge materials the surface charge is determined by the interaction of surface hydroxyl groups with the soil solution as outlined below.

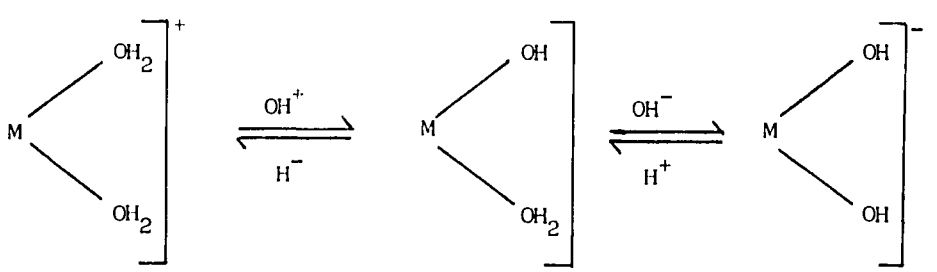


Table 1. Key to Mineralogy Classes used in Soil Taxonomy (Soil Survey Staff, 1975, p. 387).

Class	Definition	Determinant size fraction
	CLASSES APPLIED TO SOILS OF ANY PARTICLE-SIZE CLASS	
Carbonatic	More than 40 percent by weight carbonates (expressed as $CaCO_3$) plus gypsum, and the carbonates are >65 percent of the sum of carbonates and gypsum.	Whole soil, particles <2 mm in diameter whole soil <20 mm, whichever has higl percentage of carbonates plus gypsum.
Ferritic	More than 40 percent by weight iron oxide extractable by citrate-dithionite, reported as Fe_2O_3 (or 28 percent reported as Fe).	Whole soil, particles <2 mm in diameter.
Gibbsitic	More than 40 percent by weight hydrated aluminum oxides, reported as gibbsite and bohemite.	Whole soil, particles <2 mm in diameter.
Oxidic	Less than 90 percent quartz; <40 percent any other single mineral listed subsequently; and the ratio, percent extractable iron oxide plus percent gibbsite to percent clay,[1] is 0.20 or more. That is, $\frac{\text{extractable } Fe_2O_3\text{(pct.)} + \text{gibbsite(pct.)}}{\text{clay(pct.)}^1} \geq 0.2$	For quartz and other minerals, fraction 0.02 2 mm in diameter; for ratio of iron oxi and gibbsite to clay, whole soil <2 mm.
Serpentinitic	More than 40 percent by weight serpentine minerals (antigorite, chrysotile, fibrolite, and talc).	Whole soil, particles <2mm in diameter.
Gypsic	More than 40 percent by weight of carbonates (expressed as $CaCO_3$) plus gysum, and the gypsum is >35 percent of the sum of carbonates and gypsum.	Whole soil, particles <2 mm in diameter, whole soil <20 mm, whichever has high percentage of carbonates plus gypsum.
Glauconitic	More than 40 percent glauconite by weight.	Whole soil, particles <2 mm in diameter.
	CLASSES APPLIED TO SOILS THAT HAVE A FRAGMENTAL, SANDY, SANDY-SKELETAL, LOAMY, OR LOAMY-SKELETAL PARTICLE-SIZE CLASS	
Micaceous	More than 40 percent mica by weight.[2]	0.02 to 20 mm.
Siliceous	More than 90 percent by weight[2] of silica minerals (quartz, chalcedony, or opal) and other extremely durable minerals that are resistant to weathering. See weatherable minerals (ch. 3).	0.02 to 2 mm.
Mixed	All others that have <40 percent of any one mineral other than quartz or feldspars.	0.02 to 2 mm.
	CLASSES APPLIED TO SOILS THAT HAVE A CLAYEY OR CLAYEY-SKELETAL PARTICLE-SIZE CLASS	
Halloysitic	More than half halloysite[3] by weight and smaller amounts of allophane or kaolinite or both.	<0.002 mm.
Kaolinitic	More than half kaolinite, tabular halloysite, dickite, and nacrite by weight, smaller amounts of other 1:1 or nonexpanding 2:1 layer minerals or gibbsite, and <10 percent montmorillonite.	<0.002 mm.
Montmorillonitic	More than half montmorillonite and nontronite by weight or a mixture that has more montmorillonite than any other one clay mineral.	<0.002 mm.
Illitic	More than half illite (hydrous mica) by weight and commonly >4 percent K_2O.	<0.002 mm.
Vermiculitic	More than half vermiculite by weight or more vermiculite than any other one clay mineral.	<0.002 mm.
Chloritic	More than half chlorite by weight or more chlorite than any other clay mineral.	<0.002 mm.
Mixed	Other soils.[4]	<0.002 mm.

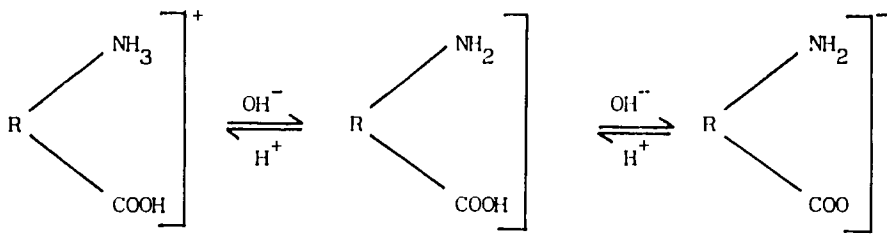
[1] Percentage of clay or percentage of 15-bar water times 2.5, whichever is greater, provided the ratio of 15-bar water to clay is 0.6 or more in half or more of the control section.

[2] Percentages by weight are estimated from grain counts. Usually, a count of one or two of the dominant size fractions of a conventional mechanical analysis is sufficient for placement of the soil.

[3] Halloysite as used here includes only the tubular forms. What has been called tabular halloysite is grouped here with kaolinite

[4] Sepiolitic, defined as containing more than half by weight of sepiolite, attapulgite, and palygorskite, should be named if found

The soil materials which show variable charge behaviour are the oxides, the non-crystalline aluminosilicates, kaolinite, halloysite and the organic matter. The variable nature of the organic matter surface charge is due to reactions of the type.



Thus for soils dominated by variable charge materials the surface charge and related properties, e.g., cation exchange capacity will be determined by the nature (pH and composition) of the soil solution. Soil Taxonomy therefore requires ion exchange parameters to be determined under specified conditions.

An indication of the sign and magnitude of the surface charge of soil materials can be gained from measurement of ΔpH where $\Delta pH = pH_{KCl} - pH_{H_2O}$ (Uehara and Gillman, 1980).

The chemical properties of soils, as determined by mineralogy and organic matter content, are included as differentiating characteristics at all levels in the hierarchy of Soil Taxonomy. Mineralogy is included specifically at the family level and fifteen mineralogical classes are designated (Soil Survey Staff, 1975, p. 387). These mineralogical classes (see Table 1) are based on the approximate mineralogical composition of selected size fractions of the same segment of the soil (control section) that is used for application of particle size classes.

The word approximate is included in the preceding sentence as the accurate quantitative determination of mineralogical composition is difficult. It is unusual for any soil to contain just one mineral component; mixed mineralogies tend to be the rule. In order to avoid the over-use of the mixed mineralogy class, Soil Taxonomy places strict boundaries on this class.

Useful interpretative clues for the prediction of soil properties can be obtained from the mineralogy classes. Ferritic and gibbsitic classes suggest possible ore sources of iron and aluminium. The soils tend to fix phosphorus in forms unavailable to plants. If not disturbed, the soils tend to be structurally stable and relatively permeable to water. Oxidic mineralogy indicates low fertility, but a structurally stable, permeable material in the undisturbed state

Serpentinitic, micaceous, chloritic, and vermiculitic classes suggest an unstable surface for construction of roads or buildings. Underlying rock materials are layered and mostly tilted. Landslides can be major problem. Serpentinitic or chloritic mineralogy also indicates low fertility. Magnesium or chromium toxicity or other secondary nutrient problems induced by high magnesium may be of concern. Vermiculitic mineralogy indicates potassium fixation and maybe a potential fertility problem.

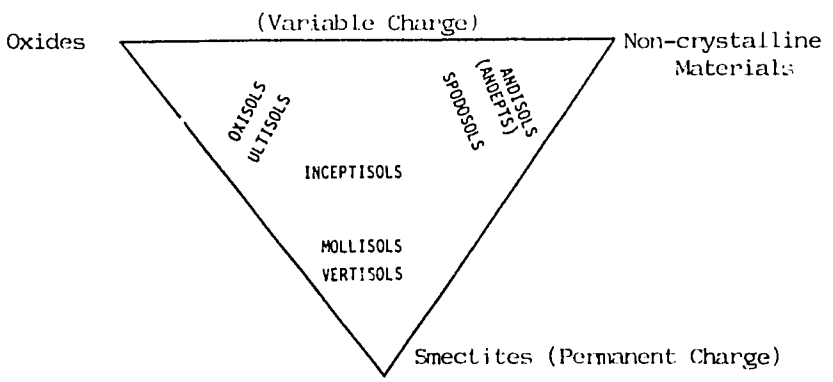
Glauconitic mineralogy indicates a high iron content. Siliceous mineralogy indicates low weatherable minerals and likely fertility problems. Halloysitic mineralogy indicates a humid climate and a high soil moisture regime - a soil that seldom, if ever, dries. Such soil materials are likely to be unstable for construction.

Kaolinitic mineralogy suggests highly weathered soil with a strong clay accumulation in the B horizon that may give permeability problems in septic tank fields. Fertility is probably low. Illitic mineralogy suggests the probability of adequate or nearly adequate supplies of potassium under natural fertility. If fertilizers are added, however, these soils may fix potassium.

Montmorillonitic mineralogy indicates susceptibility to shrink-swell as the soil wets and dries. An adverse effect on roads, fence posts, telephone posts, and small buildings may result. The shrink-swell problem is recognised in the Vertisols order and vertic sub-groups of the classification system. Hopefully, the most serious

problem soils are flagged in this manner. Montmorillonitic soils (especially if sodium saturated) hold more water than soils with other silicate clays. As a result, montmorillonitic soils are subject to creep and landslides in sloping areas.

In some situations, mineralogical class designations are not given as the mineralogy is implied by information included in the taxa,e.g.,Histosols tend to be dominated by organic matter. Since mineralogy plays such an important part in determining the behaviour of soils, key features employed to differentiate soils at the highest levels reflect the mineralogy. This is well illustrated by the diagram below (after Uehara and Gillman, 1980).



The chemical properties used in Soil Taxonomy are too numerous to include in total, but a number of the more important determinations are listed in Table 2 together with the situations in Soil Taxonomy where they are used and interpretative references. It should be noted that the use of chemical data cannot be made in certain situations without a knowledge of physical properties such as bulk density or particle size distribution. Further details of the laboratory measurements and data manipulations are given in the section on laboratory techniques.

Since the measurements listed (Table 2) represent the most important chemical criteria used in Soil Taxonomy, it can be seen that once a soil has been classified correctly, considerable information about the soil can be derived from the family designation. This

TABLE 2. Chemical Criteria used in Soil Taxonomy

	Measurement	Use in Soil Taxonomy	Inference
1.	Organic Carbon Content	Defining Histic, Mollic Anthropic, Umbric, Spodic horizons	Extent of accumulation of organic matter; contribution to CEC; N levels(?)
		Defining Humic Suborders and great groups	
2.	Cation Exchange Capacity (CEC)	Defining Oxic horizon and oxic subgroups Defining Andic subgroups (ratio of CEC to 15-bar H_2O)	Clay mineralogy; degree of weathering; nutrient storage capacity; engineering properties
3.	Base Saturation (%)	Distinguishing between Alfisols and Ultisols; distinguishing between Mollic and Umbric epipedons; distinguishing between Eutric and Dystric great groups	Degree of leaching; levels of available bases; in some situations inferences about pH can be made
4.	Exchangeable Bases and Exchange Acidity	Natric horizon ECDAM in definition of Andisols (Andepts) Allic subgroups Andic subgroups	High sodium levels: high variable charge mineral contents; high levels of soluble aluminium
5.	pH : ΔpH	Acric great groups of Oxisols	Positively charged surfaces
	pH(NaF)	Definition of Andisols and Andeptic subgroups	Presence of non-crystalline minerals

	pH < 3.5	Sulphuric horizon	Acid sulphate soils and likely toxicity problems
6.	% $CaCO_3$	Calcic and Petrocalcic horizons. Carbonatic mineralogy class	Chlorosis, zinc deficiencies, impedence of water movement
7.	% $CaSO_4$	Gypsic and Petrogypisic horizon. Gypsic mineralogy class	Sufficient sulphate to corrode concrete
8.	Soluble salt content	Salic horizon	Toxicity problems
9.	Phosphate retention	Definition of Andisols	Presence of non-crystalline materials
10.	Extractable Fe and Al	Definition of Spodic horizons, oxidic mineralogy class	Extend of weathering, quality of natural drainage, phosphate fixation
11.	Weatherable minerals	Cambic horizon (presence) Oxic horizon (absence)	Potential nutrient supply
12.	Citrate soluble P_2O_5	Defining Anthropic horizon	Very productive soils

information, if interpreted properly, gives a clear prediction of the properties of the soil and the likely response to particular management practices.

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SOIL PHYSICS : SPECIFIC LABORATORY PARAMETERS AND THEIR USE IN SOIL TAXONOMY

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Particle Size Distribution

Measurements carried out on the fine earth fraction of soils are considered first. Particle size analysis on material finer than 2 mm is carried out in two stages. Coarser particles, predominantly sand, are separated and subdivided by sieving. The size of finer particles, predominantly silt and clay, is usually assessed by measuring the rate at which they settle through water. Both stages, but particularly the latter, depend on the following processes:

1. Material tending to cause soil particles to cling or adhere together must be removed.

2. Particles which exist as aggregates must be physically separated.

3. A stable suspension of the fine particles in liquid must be formed.

4. Coarser particles are preferably removed from the suspension and sieved separately.

5. An indirect method which measures properties related to settling rate is required.

These steps are accomplished by procedures similar to those which follow:

1. Soils are treated with hydrogen peroxide to remove organic material.

2. The treated and washed soil is dispersed in water by shaking or stirring. Some more recent work has been carried out on soils dispersed by ultrasonic vibration.

3. During dispersion, chemicals are added to the water which discourage separated particles from forming clumps and adhering together. Sodium polymetaphosphate is commonly used, with the pH of the suspension adjusted to 8-9 with sodium carbonate.

4. The dispersed soil is poured on to a fine sieve and nearly all the sand removed. The material not passing the sieve is dried, weighed and passed through a series of coarser sieves.

5. The standard method (Soil Conservation Service, 1972) used to measure settling velocity uses a pipette to sample an originally uniform suspension at intervals at a known depth (Fig. 1). The concentration of soil particles in the pipette sample is measured and from these results the settling velocity and hence the size of the particles can be calculated.

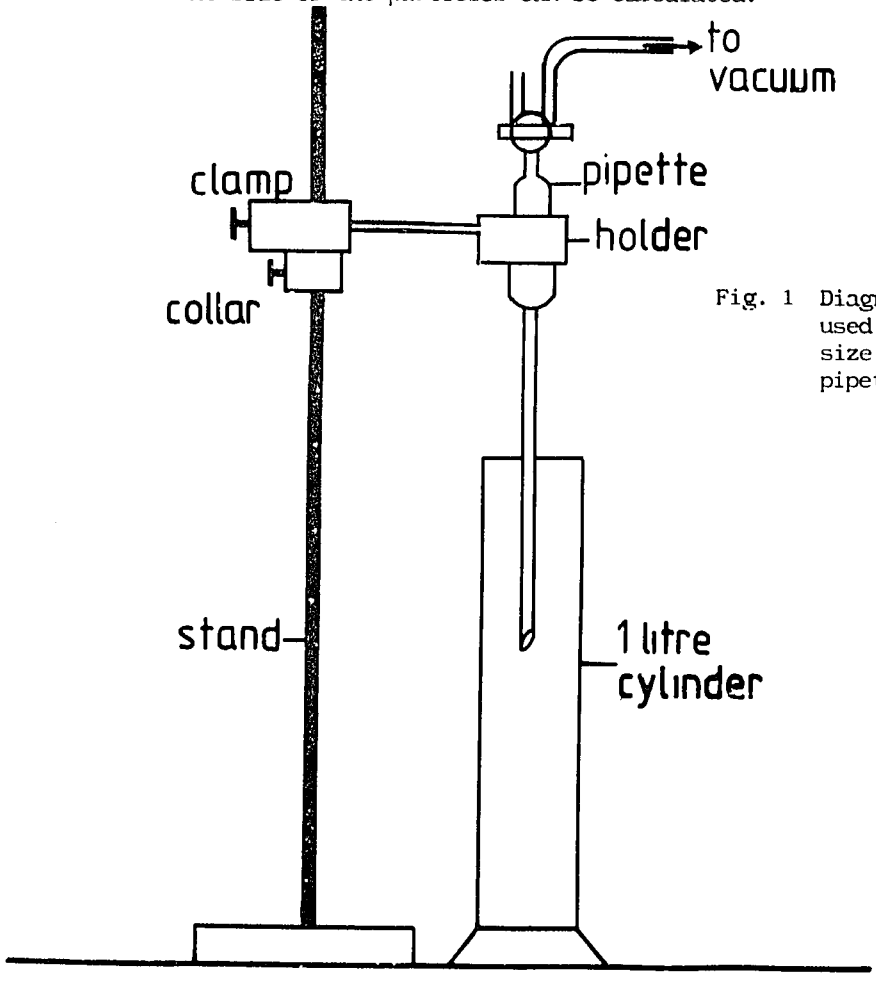

Fig. 1 Diagram of equipment used for particle size analysis using pipette method.

Other methods have been used instead of the pipette technique. For example, a hydrometer (Day, 1965) or a plummet balance (Hutton, 1955) can be used to measure the density of the soil suspension. A recent method (Hendrix and Orr, 1970) uses a beam of X-rays for the same purpose. All these methods need to be calibrated against the standard pipette method if results are to be comparable.

Results obtained from the fine earth fraction may be used in conjunction with data obtained on coarse fragments, where they are present, to obtain the particle size distribution of the whole soil. Data on coarse fragments is derived, sometimes, from field observations which will usually include estimates, on a volume basis, of the amount of gravel, stones and rock fragments present. It is now common, however, for the soil to be sieved on site through a coarse sieve, say 20 mm, and the finer and coarser fractions weighed immediately. Only material passing the sieve is sent to the laboratory for analysis.

Particle size data are used in many ways in Soil Taxonomy. Results on the fine earth fraction are used to determine textural classes, and in defining epipedons and other diagnostic horizons. Most notably, in addition to morphological evidence, the definition of the argillic horizon requires that its clay content must differ in specific ways from that in overlying or underlying horizons. Clay content is used also as an element in calculations of cation-exchange capacity/100 g of clay, to assist in the definitions of the spodic, cambic, and oxic horizons, and in many other places throughout the taxonomy.

As discussed in an earlier session Soil Taxonomy also makes use of particle size classes based on whole soil particle size distribution. The use of particle size class names to define families allows some broad statements to be made about the way in which water will be transmitted and stored in the soil. Soils with clayey particle size class are likely to have low infiltration rates, loamy and silty soils are likely to store reasonably high amounts of water available to plants, and loamy soils will be easily cultivated. Sandy soils

are likely to have a high infiltration rate but will store little plant-available water. In addition, some information of engineering significance is implied in the class name. Skeletal soils have high amounts of coarse fragments and fragmental soils have very little fine earth material. Their behaviour as engineering materials for road building or as foundations may be inferred. Clayey soils are likely to prove difficult to drain. Other interpretations may be made by considering the particle size class in conjunction with the soil moisture regime, and with other properties implied in the complete family name.

The choice of the particular limits used in defining particle size classes was made on the basis of criteria of importance in engineering and other fields. The limit of 18% clay between the fine- and coarse-loamy (and silty) classes reflects a perceived difference between plastic and non-plastic soil in an engineering sense. The ability to recognise a non-plastic soil is very important for engineering interpretations. Similarly, the 35% limit between loamy and clayey classes is based on a statistical relationship between clay content and the classification of soils for engineering purposes; the commonly used engineering classification systems are based mainly on their behaviour as construction materials.

Bulk Density

In order to measure the bulk density of soils which shrink and swell as their water content changes, a technique is used in which samples are allowed to reach equilibrium at a standard water tension before their volume is measured (Soil Conservation Service, 1972). This is the coated clod method (4A1). In the field, approximately fist-sized lumps are broken out of each horizon and immediately coated with a plastic resin. The resin is previously dissolved in a solvent, and the suspended clod is dipped quickly into the solution and withdrawn. The solvent evaporates leaving a very thin, flexible plastic skin coating the clod which holds it intact during transport to the laboratory. In the laboratory, a flat face is cut on the clod with a diamond saw. The soil is then

saturated, and the flat face is placed in contact with a porous surface in which water is held at a tension of 1/3 bar. When the clod has reached equilibrium it is removed, coated again with resin and weighed. Its volume is measured by immersion in water. The clod is then dried and weighed again and the bulk density at 1/3 bar is calculated.

In addition to this standard method, other older but less versatile techniques are used. Core samples are still frequently used to measure bulk density, but the method has a more restricted application. It cannot be used for soils which shrink and swell, and is unlikely to give satisfactory results when applied to soils which are dry, and are friable. In most situations it gives best results when the soil is near field capacity, when it provides a quick, simple and reasonably accurate method of measuring density. A cylindrical sampler, fitted with a sharp cutting edge, is used. It is pushed or driven into the soil and dug out intact. The cutting edge is removed and the faces of the soil cut to flat faces coinciding with the ends of the cylinder. The sample may be retained in the cylinder, or pushed out and stored in a plastic bag, for weighing later.

Other techniques are used in special circumstances, most of them consisting of excavating material from the soil, weighing it, and measuring the volume of the excavated hole. There are a variety of methods used for making the volume measurement.

In Soil Taxonomy bulk density is used in a number of ways, but primarily as one of the criteria for identifying soils for classification as Andisols. The critical density of 0.85 T/m^3 (g/cm^3) seems to have been selected because, apart from organic soils, there are comparatively few non-volcanic soils which have densities lower than this value. Most of the volcanic soils with low densities also meet the other criteria used to define the Andisols. There are, however, two related problems which have arisen, and which have not yet been resolved. There are a number of the soils, in particular some in N.W. United States and in East Africa, which meet all the criteria for Andisols except that they have densities

higher than 0.85 T/m^3. Consequently there have been suggestions that the limiting value should be increased, some have suggested to as high at 1.0 T/m^3. In addition, the necessity for the high precision implied in densities measured to two decimal places has been questioned. Thus, it seems possible that the limiting value may be increased to at least 0.9 T/m^3. The effect of such a change on the Andisol Order is still being assessed.

Water Retained at 15-Bar Tension

Plants growing in soil will thrive, there being no other adverse factors, so long as they have available and adequate supply of water which their root system can extract. When the water supply is exhausted the plants wilt. The water content below which plants can no longer extract water was measured originally by growing a particular indicator plant in soil in pots. When the plant wilted and was unable to recover overnight, the water content of the soil was measured. This was the definition of the wilting point of the soil. Later, experiments were carried out in which the wilting point was compared with the water contents obtained after water was extracted from the soil by applying direct tensions (or suctions) to the soil water. It was found that, for most of the soils examined, the wilting point was close to the water content obtained after a soil had reached equilibrium against a tension of 15-bar.

The usual laboratory method of applying such tensions is to create a pressure differential across a semi-permeable membrane on which the wet soil is placed. After equilibrium has been reached, the soil is removed and its water content measured. One form of the apparatus which is used at Soil Bureau (Gradwell and Birrell, 1979) is shown in Fig. 2.

Depending to some extent on the nature of the soil material, there is a good correlation between the 15-bar water measured on originally air-dry material and the clay content determined by particle size analysis. This suggests that the technique is

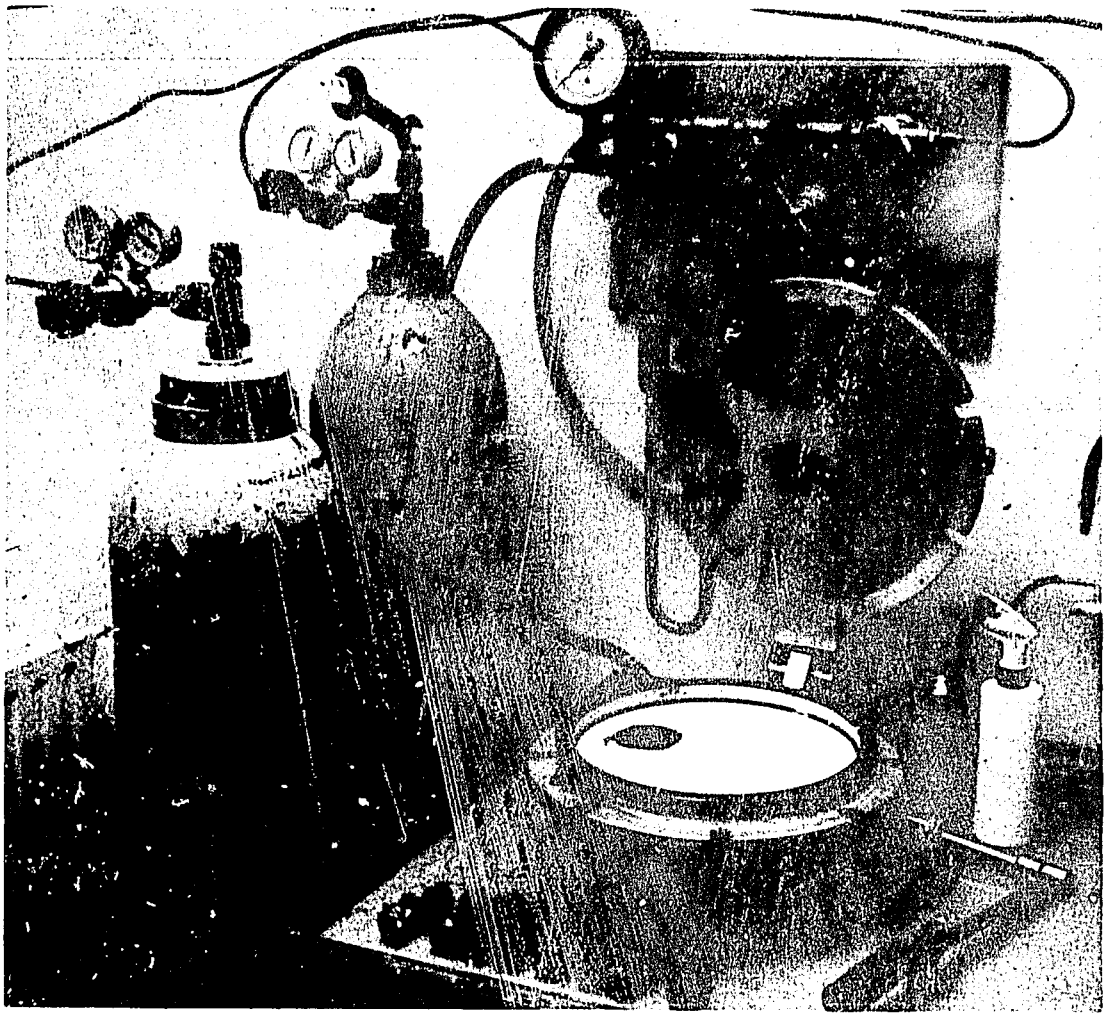

Fig. 2. Apparatus used to apply a tension of 15-bar to soil samples.

measuring a property related to the surface area of the soil particles. Some soils exhibit a large difference in the water content at 15-bar, depending on whether the soil has been previously air-dried or is taken for testing at near its field-moist condition. The difference between the 15-bar water measured on field-moist soil (15-bar FM) and the 15-bar water measured on soil which has been previously air-dried (15-bar AD) is usually only significant when the soil is derived from volcanic material, and seems to be related to the presence of allophane or related clay minerals.

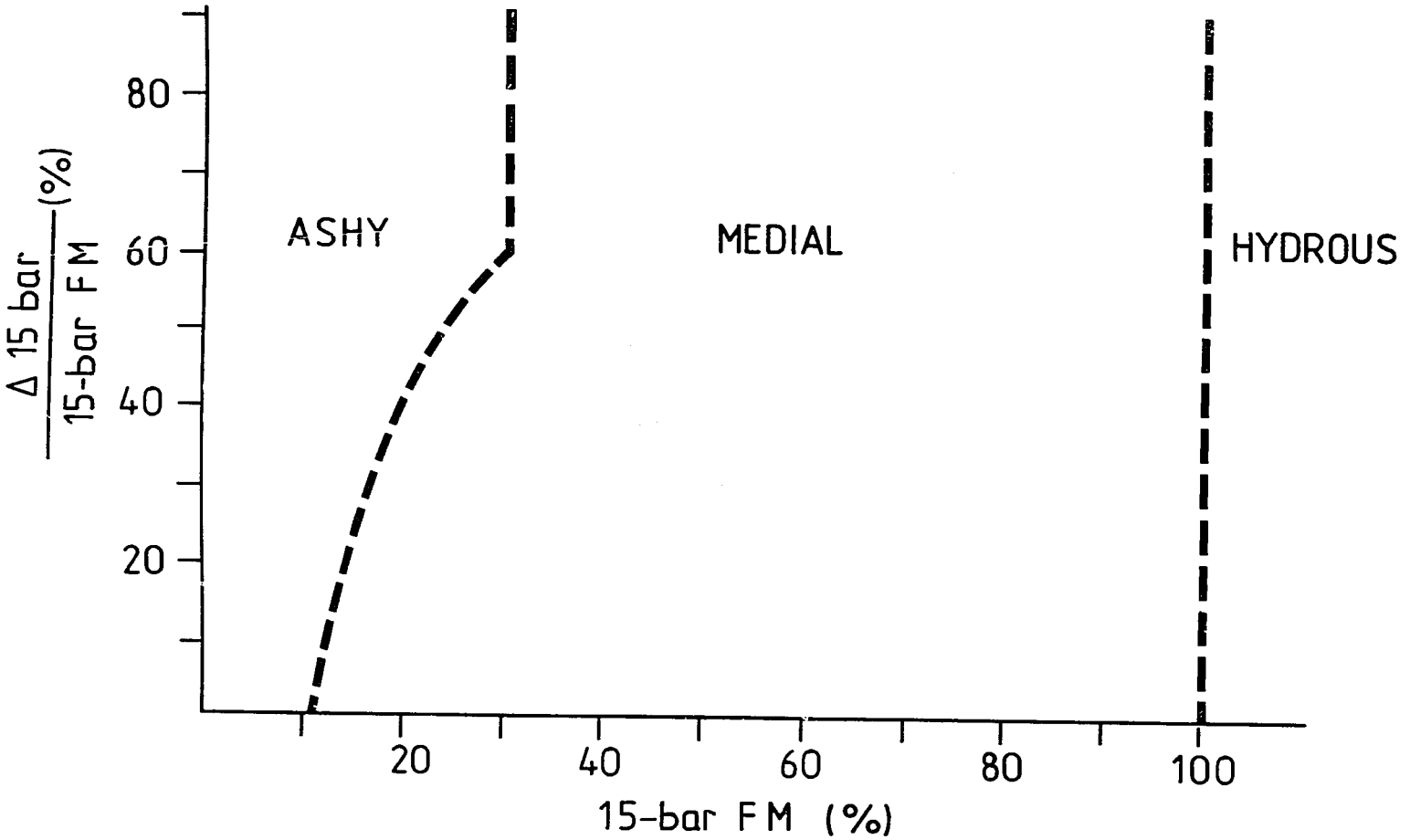

Fig. 3. Use of water retained against a tension of 15-bar to define combined particle size and mineralogy family criteria in the proposed Andisol order.

The methods proposed for determining if the exchange complex of a soil is dominated by "amorphous" material use 15-bar AD to ensure that only medial and hydrous material need meet the requirement for the pH in NaF to be $\geqslant$ 9.4.

Families in the proposed Andisol order are defined using combined particle size and mineralogy modifiers. Both 15-bar FM and 15-bar AD are used. Soils of ashy families are required to have 15-bar FM less than 30%, and 15-bar AD less than 12% when measured on the fine earth. Medial families have 15-bar AD greater than 12%, or have 15-bar FM greater than 30% but less than 100%. Hydrous families are required to have 15-bar FM greater than 100%. The relationships among these figures are shown in Fig. 3, where 15-bar FM is plotted against the difference between 15-bar FM and 15-bar AD, expressed as a percentage of 15-bar FM. There is some evidence from New Zealand soils that these limits may need adjusting, but there are not yet sufficient data to allow better limits to be defined.

Both 15-bar FM and 15-bar AD are used throughout the Andisols from order to family level, with the exception of suborder definitions. They are thus of primary importance in defining the classes of the order. In addition, 15-bar AD is used to estimate the amount of clay in some Andisols, and in some other orders where there may be some difficulty in measuring the clay content. In Oxisols, for example, whenever the ratio of 15-bar AD to measured clay exceeds 0.6 in the major part of the particle size control section, 15-bar AD may be used to estimate clay by multiplying its numerical value by a factor of 2.5.

Conclusions

This examination of methods used to measure physical properties, and the ways in which the properties are applied to the classification of soils in Soil Taxonomy, has been necessarily brief. Much work remains to be done to refine the use of physical parameters, to test the limits used, and to suggest other properties which may

be used to clarify the distinctions between classes and to assist interpretations of soils for land use. Soil Taxonomy thus provides a framework for much further work relating to basic soil physical properties and soil classification and interpretation.

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CHEMICAL CRITERIA : METHODS OF MEASUREMENT AND LIMITS USED IN SOIL TAXONOMY

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The chemical criteria used in Soil Taxonomy are summarised elsewhere in this Proceedings (see p. 90). These criteria are utilized at all levels in the hierarchy of Soil Taxonomy. In this paper, some of the more important laboratory methods used in obtaining the data are discussed and the reasoning behind some of the limits used in differentiating soils is outlined.

The determination of organic carbon has long been the subject of controversy and compromise. Recently, Metson et al. (1979) have reviewed the methods available for this determination and concluded that all the methods suffer from drawbacks or deficiencies of one kind or another.

There are two main types of method determining organic carbon, i.e., combustion and oxidation techniques, although both are based on the same chemical reaction the conversion of carbon to carbon dioxide. The extent to which this reaction occurs is monitored and the organic carbon content is thus determined. Two of the most widely used methods are the dry combustion (in air or oxygen) in a furnace, and the oxidation using chromic acid. In the furnace combustion technique a sample of soil is burnt at a high temperature and the CO_2 evolved is collected and measured (gravimetrically, volumetrically or titrimetically). The main drawback to the dry combustion techniques is that they are affected by the presence of carbonates or of elemental carbon as charcoal (little can be done about this latter material).

Carbonates present a problem because they decompose at high temperatures, evolving CO_2. This problem can be overcome by determining the carbonate content of the soil separately and its CO_2 equivalent subtracted from the value obtained for the whole soil. This assumes complete decomposition of the carbonate material during combustion which may not always occur.

The oxidation methods are based on the oxidizing power of acidified dichromate solutions (effectively chromic acid). The chemical reaction which is often used to describe the oxidation of organic carbon by acidified dichromate is:

$$2Cr_2O_7^{2-} + 16H^+ + 3C \longrightarrow 4Cr^{3+} + 8H_2O + 3CO_2$$

although this is obviously a simplification of what actually happens. The extent of reaction and hence the organic carbon content of the sample can be determined by measuring the amount of dichromate left after reaction is complete (Walkley, 1947), or the amount of Cr^{3+} formed (Blakemore et al. 1977) or the amount of CO_2 produced (Dalal, 1979).

The oxidation methods suffer from the deficiency that in many situations not all of the organic matter is oxidized. A correction factor, to compensate for unreacted carbon, must be used. This factor can be obtained by comparing the results of the oxidation and combustion techniques.

In Soil Taxonomy, soil organic carbon values are used in two ways: (a) as the experimentally determined values or (b) in the calculation of accummulation indexes, e.g., the amount of organic carbon in a square metre of soil to a depth of 1 metre or to a specified contact. Calculations of this latter type can be visualized in several steps.

(1) Multiply the %C for a horizon times the bulk density times the horizon thickness

(2) If course fragments are present, multiply by the volume fraction of the fine earth

(3) Multiply by 0.1 to convert to units of kg m^{-2} per horizon

(4) Sum the products to give the accumulation index

The accumulation index for organic carbon is used, for example, in defining the suborder Humox (Soil Survey Staff, 1975); the definition includes the statement "other Oxisols that have 16 kg or more organic carbon per square metre to a depth of 1 metre, exclusive of organic surface litter".

Some of the uses of organic carbon contents in Soil Taxonomy are listed in Table 1 below together with the limits applied.

Table 1. USE OF ORGANIC CARBON DATA IN SOIL TAXONOMY

Use in Soil Taxonomy	Limit set
Mollic Epipedon definition	>0.6% (with other criteria)
Umbric Epipedon definition	>0.6% (with other criteria)
Ochric Epipedon definition	<0.6% (with other criteria)
Histic Epipedon	>18% if mineral fraction is 60% or more clay (see p. 17 Soil Taxonomy)
Humic suborder of Ultisols and Oxisols	Humox >16 kg organic carbon m^{-2} to a depth of 1m
	Humults > 0.9% organic carbon in the upper 15 cm of the argillic horizon or > 12 kg organic carbon m^{-2} to a depth of 1m
Humic great groups	Humitropepts > 12 kg organic carbon m^{-2} to a depth of 1m
Fluventic subgroups	% does not decrease regularly with depth in profile

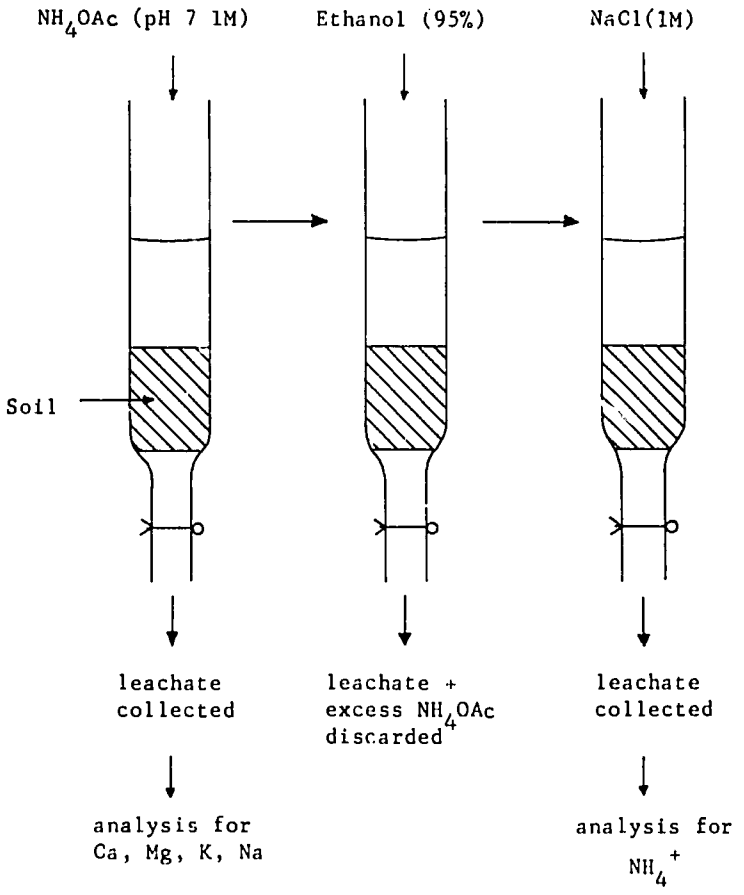
In general these limits are set to indicate the presence or absence of reasonable amounts of organic matter. This is important as organic matter levels influence the structural stability, ion exchange and nutrient cycling behaviour of soils. Questions have been raised about the relatively low requirement for the mollic epipedons. The reasons for this can be found in the rationale used in the development of Soil Taxonomy. A series of dark-coloured soils in the drier parts of the Great Plains of the USA are used for both grazing and winter wheat production. The soils under cultivation have relatively low levels of organic carbon because of oxidation and soil blowing; the low limit was set to avoid splitting the series where the major difference was caused only by management (G. Smith, personal communication, 1976).

The other chemical criteria widely used in Soil Taxonomy are related to the ion exchange properties of soils - cation exchange capacity, base saturation percentage, exchangeable acidity, sum of exchangeable bases plus aluminium and levels of individual exchangeable cations.

A number of methods are available for measuring the CEC of soils but only 2 are used in Soil Taxonomy:-

(1) Using NH_4OAc at pH 7 and (2) using $BaCl_2$ - triethanolamine ($BaCl_2$ - TEA) at pH 8.2 (SCS - USDA, 1972). Since the value of the CEC obtained will depend on the method used (because of variable charge nature of many soil materials) this strict adherence to specified methods is important.

One method of obtaining the NH_4OAc-pH 7 CEC is illustrated in the diagram below. A sample of soil is leached with the NH_4OAc solution (1 Molar, pH 7) and the leachate collected. NH_4^+ ions displace exchangeable cations from the exchange sites. The leachate is then analysed for the individual cations. The soil is then leached with ethanol to remove excess NH_4OAc solution, and finally with sodium chloride (1 Molar).



The Na^+ ions displace the NH_4^+ from the exchange sites and the NaCl leachate is collected and analysed for NH_4^+. The CEC is calculated from the NH_4^+ content of the NaCl leachate. Once the CEC and the amounts of the individual bases (Ca, Mg, K, Na) are known the base saturation can be determined since

$$\text{Base Saturation (\%)} = \frac{\Sigma \text{ Bases}}{\text{CEC}} \times 100$$

The CEC - Σ bases is referred to as the exchangeable acidity.

The measurement of the CEC using $BaCl_2$ - TEA at pH 8.2 is based on the separate determination of the exchangeable bases and the exchangeable acidity. The exchangeable bases can be determined as above using NH_4OAc. The exchangeable acidity is determined by

shaking the soil sample with the $BaCl_2$ - TEA reagent. The Ba^{2+} ions exchange with the bases and acidity (H^+ + Al^{3+}). The acidic cations react with the TEA and the amount of TEA reacted is determined by titration of the excess with standard acid. The exchangeable acidity is determined from the difference between the amount of acid required for the sample and the amount required for a blank sample of the $BaCl_2$ - TEA reagent (i.e.,one to which no soil has been added). Samples of the $BaCl_2$ - TEA extract can be analysed for the individual bases if desired.

CEC (pH 8.2) = Σ Bases + Exchange Acidity (pH 8.2)

Since soil surfaces generally get more negative as the pH increases (see p. 85) the CEC (pH 8.2) is higher than the CEC (pH 7). Thus the base saturation (%) calculated using CEC (pH 8.2) will be less than that calculated using CEC pH 7).

Two other ion exchange parameters used in Soil Taxonomy are the KCl extractable Al and the cation retention capacity (CRC). The former is obtained by shaking a soil sample with KCl (1 Molar) and determining the extracted Al by titration (Yuan, 1959). CRC is determined using a method similar to that for the NH_4OAc - pH 7 CEC except that unbuffered ammonium chloride is used instead of ammonium acetate in the first leaching step.

An alternative to the CRC is the sum of the bases extracted by NH_4OAc plus the KCl aluminium. Low values CRC or (NH_4OAc bases + KCl-aluminium) indicate that the "effective CEC" is low,i.e.,the CEC at or near the field pH is low and the soil is dominated by low activity clays. The use of CRC or (NH_4OAc-bases + KCl-aluminium) avoids the measurement of the high variable (pH dependent) charge found in some soils.

The ion exchange analyses need to be augmented in certain situations by physical data for use in Soil Taxonomy. Data are specified in terms of meq per 100 g clay rather than per 100 g soil. This necessitates a knowledge of the particle size

distribution. The change from meq per 100 g soil to meq per 100 g clay is made by the following calculation.

$$\text{meq/100 clay} = \frac{\text{meq/100g soil} \times 100}{\text{\% clay}}$$

CEC values are used specifically in Soil Taxonomy in the definition for the oxic horizon and oxic subgroups. One requirement for an oxic horizon is that it "has an apparent CEC of the fine earth fraction of 16 meq or less per 100 g clay by NH_4OAc unless there is an appreciable content of aluminium-interlayered chlorite". The CEC requirement for the oxic subgroups of Alfisols or Ultisols is that the CEC be less than 24 meq per 100 g clay (by NH_4OAc) in the major part of the argillic horizon. Low values of the CEC indicate highly weathered soils low in weatherable minerals and a low nutrient storage capacity. CEC values can also give an indication of the clay mineralogy and the consequent engineering properties of the soils. This is done by examining the CEC to clay ratio and using Table 2.

Table 2. RELATIONSHIP BETWEEN CEC/CLAY RATIO AND CLAY MINERALOGY

CEC (pH 7)/Clay Ratio	Likely Clay Mineralogy
>0.7	Montmorillonitic
0.5 - 0.7	Montmorillonitic or Mixed
0.3 - 0.5	Mixed
0.2 - 0.3	Kaolinitic or Mixed
<0.2	Kaolinitic

Another requirement of the oxic horizon and the oxic subgroups is that the CRC or effective CEC is low (< 10 meq per 100 clay for the oxic horizon, < 12 meq 100 g for the oxic subgroups). These low values again indicate highly weathered soils.

Base saturation values are used widely in Soil Taxonomy. The base saturation at specified depths (see later) is used to distinguish Alfisols from Ultisols; mollic and umbric epipedons are separated on the basis of the base saturation being greater or less than 50%

as are dystric (< 50% base saturation) and eutric (> 50% base saturation) great groups of the Inceptisols. Base saturation is also used in the definition of eutric great groups of the Oxisols. In some situations the limit is set as 50% at pH 7 or 35% at pH 8.2. This is related to the change in CEC with the method of measurement as discussed earlier. In general the base saturation value used should be that measured using the pH closest to the soil pH.

Base saturation values give an indication of the degree of leaching which has occurred in the soils and the levels of available bases (nutrients). In some situations, particularly when considering mollic/umbric epipedons, inferences about base saturation can be made from pH measurements as indicated in the Table below:

If pH in Epipedon is:	Then BS most likely is:
≥ 6.0	≥ 50%
≥ 6.0 but < 5 in underlying horizon between 5.0 & 6.0	≤ 50%
and ≥ 6.0 in underlying horizon between 5.0 & 5.7	≥ 50%
and pit drops in underlying horizon < 5.0	< 50%

The question has been raised as to why the limit between the Alfisols and Ultisols is the base saturation at specified but variable depths. The Ultisols, in the absence of soil amendments, can be farmed only under shifting cultivation, but the Alfisols can support a permanent agriculture. The Ultisols have few bases other than those cycled by plants and the base saturation, therefore, normally decreases with depth in and below the argillic horizon. In contrast, most Alfisols either have moderate or high base saturation and the base saturation increases with depth if there is any change.

During the development of Soil Taxonomy it was found that using the base saturation in the argillic horizon was insufficient to

distinguish the soils, and some "Ultisols" had relatively high base saturation values because of regular liming. In order to avoid splitting series because of differences induced by different management practices the depth of assessment of base saturation was set at 1.8 m (in uneroded soils) or 1.25 m below the top of the argillic horizon (for eroded soils). At these depths base saturation values should not be influenced by surface liming.

The levels of individual exchangeable ions are not used extensively in Soil Taxonomy. Sodium and magnesium levels are used in the definition of the natric horizon (Soil Survey Staff, 1975 p. 28) and aluminium levels are used in the definition of allic subgroups (Andisol proposal, 1978). In these situations high exchangeable sodium contents lead to low permeability and related problems while the high aluminium levels in the allic subgroups are indicative of likely toxicity problems.

The proportion of the CEC corresponding to the variable charge component is used in the definition of materials for which the exchange complex is dominated by amorphous materials (L.C. Blakemore, personal communication).

The chemical requirements for defining of spodic horizons are considered to be important criteria in many situations when providing laboratory information for Soil Taxonomy. The morphology of some spodic horizons is so marked (e.g.,ortstein thicker than 2.5 cm, cracked coatings and dark pellets in soils in sandy or coarse-loamy particle size classes) that soils with those features have generally been accepted as spodosols. If the soil lacks the above features but has a horizon which meets the colour requirements of spodic horizon, a series of laboratory tests are applied to test its placement in the Spodosol order.

The chemical analyses used for testing spodic horizon criteria were designed to indicate the presence of amorphous, organically-bound iron and aluminium. The spodic horizon is characterized by a dominance of these materials. Sodium pyrophosphate (pH 10) is

relatively specific for extracting organically-complexed materials and this is used to identify spodic horizons. Free iron and aluminium levels (as determined by citrate-dithionite extraction) theoretically include both the organically bound iron and aluminium and the hydrous iron and aluminium oxides and so are compared to the sodium pyrophosphate extractable levels when testing for spodic horizons. The chemical criteria are applied in a stepwise manner to the individual subhorizons to determine the presence or absence of a spodic horizon.

The other chemical criteria used in Soil Taxonomy will not be discussed here apart from two which are more recent introductions. P retention and pH in NaF are widely used in testing for the presence of amorphous materials. P retention is determined by adding a known amount of P solution to the soil and measuring the P retained by the soil after a period of contact. High values (> 90%) of P retention and indicative of the presence of substantial amounts of amorphous inorganic materials. The pH in NaF test is based on the reaction between fluoride ions and the surface hydroxyl groups of amorphous inorganic materials:

$$M - OH + F^- \longrightarrow M - F + OH^-$$

The OH^- produces an increase in the solution pH. If the pH increases to above 9.4 in 2 or 5 minutes it is indicative of the presence of significant amounts of amorphous materials.

From the discussion in this paper it is obvious that chemical criteria are important in Soil Taxonomy. These criteria are used at all levels in Soil Taxonomy and a significant amount of keying out can be completed using only the organic carbon contents and ion exchange properties as outlined above. It should be emphasized however that a knowledge of some physical parameters is necessary in certain situations and that the laboratory results will be of little consequence in the absence of good field descriptions and sampling.

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ALFISOLS AND ULTISOLS

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Introduction

Clay translocation and accumulation in soils is an important pedogenetic process, and evidence of accumulation through translocation is seen as clay-skins in pores or on ped faces. The concept of the argillic horizon (Soil Survey Staff, 1975) is based on the fact that under certain soil and environmental conditions, clays move and accumulate in specific horizons of the soil. Not all soils which show a clay increase in the subsoil have an argillic horizon, due to the fact that stratifications in the original sediment, erosion and preferential accumulation of coarse particles in the surface horizons and/or a differential rate of weathering may be responsible for the clay increase.

From the point of view of use and management of the soil, the presence or absence of an argillic horizon is important. The fact that clay moves or does not move may not be important, but on the other hand the fact that clay can or has moved is significant as it tells us of certain soil conditions. The latter does not seem to be well appreciated by some workers who have questioned the concept and tried to develop alternative proposals to the classification of Alfisols and Ultisols (Isbell, 1980).

For an argillic horizon to form, three sets of conditions have to be satisfied; the soil conditions in the surface horizons should be conducive to dispersion, the dispersed clay should be translocated and found in some subhorizon, the translocated clay should be able

to deposit and form clay skins. For these processes to operate, special soil conditions are necessary, and Eswaran and Sys (1979) have elaborated on them. Finally, the clay-skins that have been formed should not be disrupted and assimilated into the matrix of the soil by pedo-turbation processes. Consequently, if a soil has an argillic horizon, it implies that it has been or is subject to all these conditions.

Further, soils with an argillic horizon have ancillary properties which are significant for use and management of the soil. The lighter textured surface horizons provide favourable conditions for cultivation and for root proliferation. The heavier textured subsoil has the capacity to store moisture and nutrients.

The argillic horizon is thus an unique innovation in soil science. It is a concept that is ideal for a diagnostic horizon as it is important both from the genetic viewpoint and for the use and management of the soil. The problem is the field identification of the horizon and most of the discussions have arisen out of this.

Due to its significance, the argillic horizon is used as a differentiating criteria at different categoric levels in Soil Taxonomy. It is used at the order level (Alfisols, Ultisols), at the suborder level (Argids), at the great group level (Argiustolls), and implied even at the subgroup level (Ultic Haplorthox). This paper discusses the two orders - Alfisols and Ultisols - where it is used at the order level.

Attributes of the Orders

The two orders - Alfisols and Ultisols - share the common property of having an argillic horizon. In addition they have certain properties which distinguish themselves as a class and they lack other properties which separate them from other orders. The key to the orders prevents them from having properties which define Histosols, Spodosols, Oxisols, Vertisols and Aridisols but at the same time, some of these properties may be subordinate characteristics of the two orders and are used to define some of the lower categories.

Alfisols are differentiated from Ultisols by several features, the most important of which is the base saturation. Alfisols have a base saturation of 35% or more (by sum of cations) above the following critical depths:

1. If there is no fragipan and the argillic horizon in some part has a hue of 5 YR or yellower or has a colour value, moist, of 4 or more or a colour value, dry, more than 1 unit higher than the value, moist, the shallowest of

(a) 1.25m below the upper boundary of the argillic horizon,

(b) 1.8m below the soil surface, or

(c) immediately above a lithic or paralithic contact;

2. If there is no fragipan and the argillic horizon in all parts has a hue redder than 5 YR, has a colour value, moist, of 3 or less, and has a dry colour value no more than one unit higher than the value, moist, or if there is no fragipan and the epipedon has a sandy or sandy-skeletal particle-size distribution throughout and is >50 cm thick, the deepest of

(a) 1.25m below the upper boundary of the argillic horizon,

(b) 1.8m below the soil surface, or

(c) immediately above a lithic or paralithic contact.

The base saturation is expressed on CEC by sum of cations as most of the Alfisols and Ultisols have an important pH dependent component. In the Alfisols, which generally have a smaller pH dependent component, a base saturation of 35% by sum of cations is equal to 50% when expressed on CEC by NH_4OAc. The critical depth for the limit is taken as 1.5 or 1.8m due to the fact that the base saturation can be manipulated or changed through management. If the definition was based on surface horizons, classification would change with management and this is undesirable.

Suborders in Alfisols and Ultisols

Table 1 shows the suborders recognized in two orders.

Table 1. Suborders of Alfisols and Ultisols

Alfisols	Ultisols
Aqualfs	Aquults
Boralfs	--
Ustalfs	Humuults
Xeralfs	Udults
Udalfs	Ustults
	Xerults

There are some similarities and differences in the structure of the suborders. The wet soils form the 'aqu' suborder. The Boralfs have a frigid or cryic soil temperature regime and there is no equivalent in the Ultisols, as by definition the Ultisols have a mesic, isomesic or warmer soil temperature regime. The remaining three suborders in the Alfisols are based on the soil moisture regimes - ustic, xeric and udic.

A different approach is taken for the Ultisols. The Ultisols, where soil temperature may be a constraint, are those which occur at high elevations or high latitudes. Most of these soils have a high organic matter status and so this property is used to define the Humults. The remaining three suborders are based on the soil moisture regimes.

Great Groups

The great groups recognized in the two orders are listed in Table 2. Some suborders, such as the Aqualfs have a number of great groups while in others, such as the Xerults, only two great groups are recognized. Further, there are more great groups in the

Alfisols (37) than in the Ultisols (24). This is partly due to insufficient studies in the tropics where most of the Ultisols occur.

A brief discussion of each of the great groups follows.

Table 2. Great Groups in Alfisols (A) and Ultisols (U).

Sub-orders	Aqu		Bor	Hum	Ust		Ud		Xer	
Great Groups										
Plinth	A	U		U	A	U		U	A	
Natr	A		A		A		A		A	
Dur	A				A				A	
Trop	A	U		U			A	U		
Fragi	A	U	A				A	U		
Gloss	A		A				A			
Alb	A	U								
Umbra	A	U								
Ochra	A	U								
Pale		U	A	U	A	U	A	U	A	U
Cry			A							
Eutro			A							
Agr							A			
Ferr							A			
Fragloss							A			
Rhod					A	U	A	U	A	U
Hapl				U	A	U	A	U	A	U
Sombri				U						

- Plinth

In the plinthic great groups, the plinthite forms a continuous phase within 1.25m of the soil surface. Plinthite has the potential to harden and form ironstone and this potential constraint to soil use is brought out at a high level in the classification.

- Natr

Soils with natric horizons belong to this great group. By definition, high sodium saturation (base saturation) is not possible in Ultisols and so there are no natric great groups in Ultisols.

- Dur

Duripans form in soils which have a ready supply of silica and so are common in volcanic ash deposits. Ability to release silica is an indication of an ample supply which implies a large amount of weatherable minerals. In most Ultisols, such a supply of silica is not present and so Duripans and Durinodes are rare or absent in Ultisols.

- Trop

The trop prefix suggests that soil temperature is not a constraint to use of the soil. By definition, these soils have mean summer and winter soil temperatures which differ by less than $5^{o}C$. Note that there are no trop great groups provided for in the Ustalfs and Ustults as it was felt that the ustic soil moisture regime is more critical to crop growth than a temperature constraint.

- Fragi

The brittle sub-surface pan, the fragipan, is also a limitation and has been foreseen in the Aqu and Ud suborders. They are frequent in glaciated areas though they have also been reported in Brazil.

- Gloss

When there is a supply of organic acids due to the presence of an acid litter, complexation and removal of iron takes place in the surface horizons. In sandy material, this frequently leads to the formation of Spodosols. In heavier textured horizons, the early stages of bleaching is seen as white tongues penetrating the yellower or redder subsurface horizon. Such a morphology is termed as Glossic features. Further iron removal leads to an albic horizon and at a later stage a micro-spodosol may form in this albic horizon.

- Alb

Under fluctuating water-table conditions and aided by the presence of organic acids clay and iron can be removed from the soil surface leading to an albic horizon. Usually, the soils have a marked clay increase resulting in low hydraulic conductivities.

- Umbra

Due to moisture saturated conditions during some time of the year and in some cases coupled with slow temperatures, organic matter accumulates to give a mollic or umbric epipedon. If it is mollic, then in the Umbraqualfs, the base saturation drops to less than 50% (NH_4OAc) below the epipedon; in the Ultisols, the epipedon of the Umbraquults is frequently umbric.

- Ochra

An ochric epipedon is more common in the Aqualfs and Aquults of the tropics as decomposition of organic matter is rapid. Although organic matter tends to accumulate in wet conditions, if there is a rapid recharge of water-aeration, ochric, epipedons result.

- Pale

The central concept of the pale great groups is a soil with a thick argillic horizon and in addition, for the Ultisols, a low weatherable mineral content. This denotes a soil at an advanced

stage of weathering and soil formation. The pale Ultisols and some of the Alfisols conform to this concept.

There are a few other details which must be pointed out. First, the Paleudalfs cannot have iso soil temperature regimes. Such soils were not known at the time Soil Taxonomy was made and if such soils are reported, necessary adjustments can be made to the definition. Secondly the Paleustalfs and Palexeralfs may have a thick argillic horizon or may just have an abrupt textural change. This was also considered as a mark of advanced soil formation though frequently it is due to a lithological discontinuity. Thirdly, in the Alfisols, if they have a thick argillic horizon, they must also be red. Lastly, in both orders if the clay decrease does not meet the requirements but if the horizon where the clay decreased has more than 5% plinthite or has evidence to show clay eluviation (skeletans), then the soil is classified as belonging to the pale great group.

- Cry

The cryic great groups are only in the Boralfs and indicate the presence of cryic soil temperature regimes.

- Eutro

The Eutroboralfs have a base saturation of more than 60% (sum of cation) and are dry in some horizon for some part of the year.

- Agr

The agric horizon is a modified argillic horizon which has some illuvial organic matter. The staining of the clay skins is attributed to translocation of humus through long term cultivation. The Agrudalf is the only great group provided for, and such a soil has only been reported from Belgium.

- Ferr

The Ferrudalfs are soils with a degrading or degraded argillic horizon. The upper boundary of the argillic horizon is broken and

there is segregation of iron in the argillic horizon to form large concretions or coarse mottles. These soils are frequent in humid temperate areas.

- Fragloss

The Fraglossudalfs have both glossic features and a fragipan.

- Rhod

The rhodic great groups are distinguished by the bright red colours and are generally formed on limestones or basic rocks. They are a high free iron content and fix phosphates.

- Sombri

The sombric horizon is a dark subsurface horizon which forms at high elevations (iso-thermic, iso-mesic) in the tropical areas. This subsurface horizon is significant as it has a higher organic matter content and generally there is a slight increase of bases as compared to the overlying horizons.

- Hapl

These are the Alfisols and Ultisols which do not have the diagnostic properties defining the other great groups.

Subgroups

There are too many subgroups to permit a useful discussion of each. Subgroup names, with the exception of the typic, indicate that they are intergrades or extragrades. The soil may intergrade to another great group in the same suborder, in a different suborder or in other orders. The extragrades suggest that the soils have aberrant properties that are not characteristic of a class in a higher category of any order, suborder or great group. In some instances, multiple subgroups are provided to show that the soil intergrades between two given great groups.

Soil limitations from soil names

Soil names as given in Soil Taxonomy are devised so that several properties can be inferred from the names. This is one of the advantages of Soil Taxonomy. An example is an Orthoxic Tropudult. The order Ultisol, indicates that it is a soil with a clay increase with depth and low base saturation. The suborder, Udult, indicates that the soil moisture regime is udic, and that generally the crops are not subject to moisture stress. The great group, Tropudult, indicates that the soil temperature regime is iso or that there is little variation of soil temperature throughout the year. (The exact soil temperature is specified at the family level, e.g., isohyperthermic). The subgroup, Orthoxic Tropudult, indicates that the soil grades to an Oxisol or has a low cation exchange capacity.

In addition, one could also infer some of the major limitations that the soils could have. Eswaran (1977) lists the major limitations that each subgroup may have. The table does not show the degree of limitations as this is a function of the use of the soil; it only serves to warn of a potential constraint to use.

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ANDISOLS

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Soils formed from volcanic ash are classified in Soil Taxonomy as Andepts, which is a suborder of the Inceptisol order. Currently there is an International Committee called ICOMAND which is investigating the possibility of recognising a new order for soils from volcanic ash, an order called Andisols. The current definition of volcanic ash soils as Andepts is unsatisfactory for a number of reasons. Probably the main reason is that when Soil Taxonomy was compiled, the data base for soils from volcanic ash was very narrow, being confined to Hawaii, Alaska and the western seaboard of the United States of America. In fact, soils from volcanic ash cover 0.84% of the land area of the world and more than 50% of that area lies in tropical countries. Thus the information available when Soil Taxonomy was compiled was only a very small proportion of the information about the total range of volcanic ash soils. This illustrates the importance of generating more information about soils from tropical areas over the next few years, so that current revisions of Soil Taxonomy may reflect the total soil spectrum.

The Andept definition excluded many soils which should be included. Some of the particular problems with it were, firstly, that base saturation by ammonium acetate was used as a differentiating characteristic with a limit of 50%, the same limit used for mineral soils that have crystalline clays. The significance of this limit in Andepts is open to very serious question, because the clays are mostly amorphous and the cation exchange capacity is largely pH dependent. Secondly, thixotropy was used as a differentiating characteristic, but the decision that a given horizon is, or is not, thixotropic is very subjective and cannot be made uniformly. Thixotropy is partly a function of the water content and also partly a function of the stress applied. During the 1960 Chilean earthquake

road fills made from volcanic ash failed as a result of thixotropy, though no pedologist would have considered the soil to be thixotropic. A third unsatisfactory feature of the Andept definition was that the soil moisture regime was not used as a differentiating characteristic as it had been for all other soils. Interpretations for a given family cannot be made without the use of climatic phases. Fourthly, in Andepts, the darkness of the epipedon is weighted heavily in subgroup definitions, but in warm intertropical areas there seems to be little or no relation between colour and carbon content, degree of weathering or any other property. Many volcaniclastic materials are black when deposited and become lighter in colour with weathering. Another fifth feature was that for most mineral soils, a fragmental particle size class is provided, but it was not provided for Andepts. Coarse pumice falling from the air commonly has a basal layer without an appreciable fine earth fraction. And finally, inadequate emphasis was given to the unique moisture retention properties of volcanic ash soils. The irreversible effect of drying was used only to define the Hydrandepts. New data require reconsideration of the effects of drying. Consideration needs to be given to the possibility of substituting these properties for the present unsatisfactory property of thixotropy as well as the definitions of ashy and medial.

The identification of these taxonomic defects resulted in the preparation by Guy D. Smith of an unpublished document dated 10 April 1978 titled "A preliminary proposal for reclassification of Andepts and some Andic subgroups". In this document the name Andisol was introduced, this name rather than Andosol was proposed because the latter is currently used elsewhere with other definitions and because the connecting vowel 'o' is supposed to be restricted to Greek formative elements. Since the Andisol proposal was written, it has been tested at a number of gatherings and by correspondence between a number of people. The current thinking is that the definition of Andisols should be based on diagnostic soil properties. There would be two separate sets of these diagnostic soil properties. Vitric soil properties would characterise the younger volcanic ash soils and would be identified by having more than 60% of vitric

volcanic material and a pH in sodium fluoride greater than 9.2. Andic soil properties would characterise the more weathered volcanic ash soils and the possible criteria would be a pH in sodium fluoride greater than 9.4, a bulk density less than 0.85 g/cc, a P-retention value greater than 90, a detectable amount of variable charge and possibly a specific level of moisture held at 15-bar tension. These criteria and others are being tested and will continue to be tested over the next few years with the objective of compiling a final Andisol proposal for incorporation into a revised Soil Taxonomy.

The Classification of Andisols

Currently the suborders are defined in terms of moisture regime and temperature regime. The Aquands are the wet Andisols, Udands are formed in a udic moisture regime, Ustands in an ustic moisture regime, Xerands in a xeric moisture regime, and Tropands in iso-temperature regimes, isomesic or warmer. Great groups so far identified are vitric, with a high percentage of glassy material; melanic with deep, dark, organic matter rich epipedons; cryic in cold temperatures; placic with a placic horizon; duric with a duripan, and hydric with a high level of 15-bar water. It should be noted here that Andisols occupy a position in the weathering sequence between Entisols which are formed on very young volcanic ash recently erupted and other soil orders such as Oxisols, Ultisols or even Mollisols, which develop on volcanic ash after there has been sufficient time for the weathering to proceed beyond the stage where the soils are dominated by amorphous constituents.

A series of slides was then shown which illustrated many different types of Andisols from throughout the world.

ENTISOLS

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Entisols are extensive soils and found on most landscapes in the inter-tropical region. They are important soils for reason of the problems and challenges they invariably pose for land developers, problems such as wetness, moisture deficit, steep slopes, low fertility,etc.

In the inter-tropical region their temperature regimes include mesic, thermic and hyperthermic and iso-equivalents; their soil moisture regimes include the aquic, udic, ustic, xeric and torric.

The Entisol order embodies soils that lack diagnostic horizons, and if pedogenic horizons are present they are very weakly expressed or as fragments. Many Entisols have an ochric epipedon, or where modified by man, an anthropic epipedon. A few developed on sands have an albic horizon, and in coastal marshes, soils included with Entisols may have a histic epipedon and/or sulfidic materials.

The central concept of the order is a mineral soil, an AC profile organization, with no diagnostic B horizon of any type. The reasons for weak profile development vary. In many, time has been too short for horizons to have formed: coral sand beach strands, subject to hurricanes; flood plains of river systems; sloping surfaces below actively eroding hill slopes are examples of land forms that receive 'fresh' accretions of mineral material at frequent intervals. Buried epipedons are common in these situations and the order permits paleosols, if they are buried to depths of more than 50 cm, or more than 30 cm under specified conditions. Elsewhere erosion processes may remove surficial material from the site as fast as or faster than pedogenic horizons can form.

Some Entisols are very old, but due to the nature of the parent material, e.g., quartz and other minerals that are chemically stable, do not alter to form horizons.

Material presented in this paper is derived from p. 179-209 (inclusive) in Soil Taxonomy (Soil Survey Staff, 1975) and quotations are from that source. Entisols occurring outside of the Pacific Region of the inter-tropical zone are not included in the discussions.

Entisol Definition

Entisols are mineral soils that meet requirement 3 and either 1 or 2.

1. Have sulfidic material within 50 cm of the mineral soil surface; or

   Have an n value of more than 0.7; or

   Have more than 8 percent clay in all subhorizons between 20 and 50 cm below the mineral surface.

2. Do not have a diagnostic horizon; unless it is a buried horizon, other than an ochric epipedon, an anthropic epipedon, a histic epipedon consisting of organic materials, an albic horizon, or a spodic horizon that has its upper boundary deeper than 2 cm; or

   Do not have amorphous material that is dominant in the exchange complex; and may have any of the following subject to the requirements stated:

   (a) A salic horizon except that, if the soil is saturated with water within 1 m of the surface for 1 month or more in some years and has not been irrigated, the upper boundary of the salic horizon must be 75 cm or more below the surface;

   (b) If the soil is saturated with water within 1 m of the surface for 1 month or more, the sodium adsorption ration (SAR) may exceed 13% or 15% or more saturation with

Na in more than half of the upper 50 cm only if SAR increases or remains constant with depth below 50 cm;

(c) A calcic or gypsic horizon or duripan if its upper boundary is >1 m below the surface;

(d) If the texture is loamy fine sand or coarser to a depth of 1 m, plinthite may be present . a discontinuous horizon if it constitutes less than half the volume in all subhorizons;

(e) Buried diagnostic horizons may be present either if the surface of the buried soil is at a depth between 30 and 50 cm and the thickness of the buried soil is less than twice the thickness of the overlying deposits or if the surface of the buried soil is deeper than 50 cm; or

(d) Ironstone at any depth.

3. Have if the soil temperature regime is mesic, isomesic, or warmer and if there are cracks in most years as wide as 1 cm at a depth of 50 cm when not irrigated, Entisols, after the upper soil to a depth of 18 cm is mixed, have <30 percent clay in some subhorizon within a depth of 50 cm.

Limits between Entisols and Soils of other Orders

The definitions for Entisols must provide precise criteria for differentiating Entisols from all other orders. By order, the following identifies the principal differences.

1. Alfisols: Entisols cannot have an argillic horizon unless it is a buried horizon.

2. Inceptisols: Entisols must have one of the following:

(a) an n value >0.7 or

at least 8 percent clay in all subhorizons between a depth of 20 and 50 cm below the mineral surface

(b) sulfidic materials within a depth 50 cm below the mineral surface

Entisols do not have any of the following:

(i) A mollic, umbric, or plaggen epipedon;

(ii) A histic epipedon consisting of mineral rather than organic soil materials;

(iii) A calcic or petro-calcic horizon or a duripan if the upper boundary of any of them is within 1 m of the soil surface unless it is a buried horizon;

(iv) A cambic horizon or a fragipan;

(v) A sulfic horizon that has its upper boundary within 50 cm of the mineral soil surface; or

(vi) Sodium saturation that is >15 percent in more than half of the upper 50 cm, unless the sodium saturation increases or remains constant with depth or unless the soil is not saturated with water within 1 m of the surface for as long as 1 month at a season when the soil is not frozen in any part.

3. Histosols - Entisols must meet the definition for mineral soils.

4. Mollisols - Entisols must not have a mollic epipedon.

5. Oxisols - Entisols must not have an oxic horizon; must not have plinthite that forms a continuous phase within 30 cm of the soil surface, if the soil is saturated with water at sometime of the year within that depth.

6. Spodosols - Entisols must not have a spodic horizon that has its upper boundary within 2 m of the soil surface.

7. Ultisols - Entisols must not have an argillic horizon unless it is a buried soil horizon.

8. Vertisols - Entisols must meet one or both of the following requirements:

   (a) Must not have cracks that are as wide as 1 cm at a depth of 50 cm in most years; or

   (b) Either

      (i) After one surface soil to a depth of 18 cm is mixed, have <30 percent clay in some subhorizon above a depth of 50 cm; or

      (ii) Do not have gilgai, do not have slicken sides close enough to intersect, and do not have wedge-shaped peds that have their long axes tilted 10° to 60° from the horizontal.

So in summary, Entisols are permitted to include - ochric, albic, antrophic, agric, histic, salic >75 cm depth, sodium adsorption ratio (SAR) >13%; and spodic >2 m depth diagnostic features; but, are not permitted to include mollic, umbric, cambic, argillic, spodic, and fragipan diagnostic horizons.

Key to the Entisols of the Inter-tropical Region

In the order name Entisol, the formative element is ent. This is used as endings for the names of suborders, great groups, and subgroups.

Names for suborders comprise two syllables. The first endeavours to say something of the diagnostic properties of the soil, the second is the formative element from the name of the order. For example, the suborder of Entisols that comprise very young sediments are called Fluvents (Latin, fluvius, river with ent for Entisol).

The name of a great group consists of the name of a suborder and a prefix that consists of one or two formative elements that say

something further on the diagnostic properties. For example, Fluvents with an ustic moisture regime are called Ustifluvents (Latin, base of ustus, burnt, plus Fluvent).

The name of the subgroup consists of the name of the great group modified by one or more adjectives. The adjective typic is used for the subgroup that is thought to best typify the great group. Typic subgroups also have no additional properties indicating a transition to another great group. The Ustifluvents that typify the central concept of the great group are therefore called Typic Ustifluvents.

Intergrade subgroups are those that belong to one great group but that have some important properties of another order, suborder, or great group. They are named by a modifier which indicates the class to which the soil intergrades with. Thus, Ustifluvents that have many but not all the properties diagnostic of Mollisols are called Mollic Ustifluvents while those with properties indicative of wetness, but not having a true aquic moisture regime, are called Aquic Ustifluvents.

At the family level three further properties are added to complete classification. These are particle size class, mineralogy and temperature regime. An example of a complete classification for an Entisol could read as follows - Mollic Ustifluvent, fine loamy, mixed, isohyperthermic. To someone conversant with Soil Taxonomy this complete classification says a great deal about the properties of the soil and the environment in which it is forming:-

Isohyperthermic says the soil forms in a soil temperature regime where the mean annual temperature is >22°C and the difference between mean summer and mean winter temperatures is <5°C. Mixed mineralogy indicates that there is <40% of any one mineral, other than quartz or feldspar. Fine loamy particle size class indicates that by weight 15% or more of the particles are fine sand size with between 18-34% clay in the fine earth fraction.

Ustic says that the soil forms in a moisture regime where the SMCS* during the year can be dry (accumulated) for >90 days but moist for >180 days (accumulated).

Fluvent indicates the soil is likely to receive periodic accretions of 'fresh' alluvium and that organic carbon decreases irregularly down the profile.

Ent shows the profile to be weakly developed with no other diagnostic horizons other than an ochric epipedon.

Mollic indicates the epipedon is dark coloured, indicative of high organic matter, has a BS >50% but while intergrading to a mollic epipedon is too thin to qualify as mollic.

So the complete classification provides much data on the properties of the soil and therefore about the soil's potential land use.

The Entisol order comprises 5 suborders, 28 great groups, and 127 subgroups. However, in the inter-tropical region all 5 suborders are represented with 16 great groups, and 66 subgroups only. They are discussed below.

Entisol Suborders

Soil Taxonomy provides the full definitions for classes of the Entisol order, so only the salient features of the suborders are discussed. These are the Aquents, Arents, Fluvents, Orthents, and Psamments.

1. Aquents have an aquic moisture regime and are saturated with water for periods long enough to limit their use for most crops unless they are artificially drained. Aquents have low chromas or distinct mottles within 50 cm of the surface, or are

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*SMCS: soil moisture control section

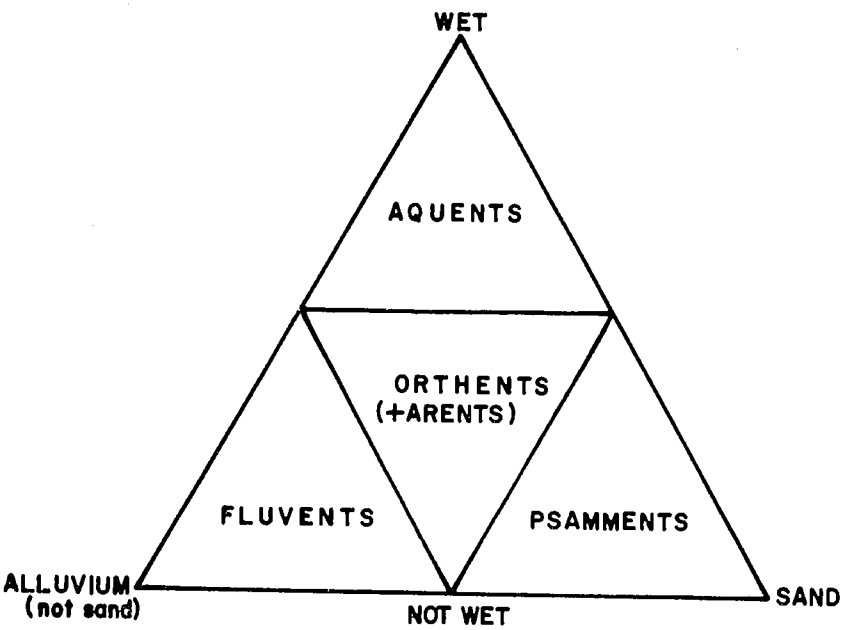

Fig. 1 Relationships between Entisol suborders (after Buol, Hole and McCracken, 1980)

saturated with water at all times. Some have sulfidic materials within 50 cm of the mineral surface. These wet Entisols may occur in tidal marshes, on deltas, floodplains, or in wet very sandy deposits. They are commonly in recent sediments.

2. Arents are better drained than Aquents and have elements of pedogenic horizons below a plough layer (Ap horizon) that have been deeply mixed by ploughing, spading or movement by man. Arents are not saturated with water for periods long enough to limit their use for most crops.

3. Fluvents form in recent loamy or clayey alluvial deposits, are usually stratified, and organic carbon decreases irregularly with depth. Fluvents are not saturated with water for periods long enough to limit their use for most crops.

4. Orthents commonly occur on recent erosional surfaces. They have textures of very fine sand or finer in the fine earth fraction, or textures of loamy fine sand or coarser and a coarse fragment content of 35% or more. Organic carbon decreases regularly with depth. Orthents are not saturated with water for periods long enough to limit their use for most crops.

5. Psamments have textures of loamy fine sand or coarser in all parts, have less than 35% coarse fragments, and are not saturated with water for periods long enough to limit their use for most crops. They are primarily soils in sands of shifting or stabilized sand dunes, cover sands, or in sandy parent materials. Psamments on old stable surfaces consist of quartz sands, so chemically stable that diagnostic horizons do not form. Gravelly and very gravelly sands are grouped with the orthents. Figure 1 diagrammatically shows the broad relationship between the Entisol suborders.

Entisol Great Groups and Subgroups

The great groups and subgroups of Entisols occurring in the inter-tropical region are listed in Table 1. The key criteria for the differentiation of great groups follows -

Great Groups	Characteristics
Sulfaquents	Sulfidic materials in top 50 cm
Hydraquents	n value >0.7; clay ≥8% in all subhorizons between 20-50 cm depth
Fluvaquents	Organic carbon >0.2% to 1.25 m and it decreases irregularly with depth; Have texture finer than loamy fine in some or all subhorizons to 1 m.
Tropaquents	Mean summer - mean winter, soil temperature <5°C at 50 cm.
Psamments	Sandy texture in all subhorizons between Ap or 25 cm and 1 m; mean summer - mean winter soil temperature ≥5°C at 50 cm.
Haplaquents	Other aquents.
Arents	No great groups.
Quartzipsamments	Sand fraction ≥95% quartz, zircon, tourmaline, rutile and other insoluble crystalline materials that do not weather to liberate Fe and Al.
Udipsamments	Udic soil moisture regime; mean summer - mean winter soil temperature ≥5°C at 50 cm.
Tropopsamments	Other psamments with udic moisture regime.
Ustipsamments	Other psamments.
Ustifluvents	Ustic soil moisture regime.

Great Groups	Characteristics
Tropofluvents	Isomesic, isothermic or isohyperthermic soil temperature regimes.
Udifluvents	Other fluvents.
Troporthents	Udic moisture regime; mean summer - mean winter soil temperature <5°C at 50 cm.
Udorthents	Udic moisture regime.
Ustorthents	Other orthents.

All subgroups (except Arents) have a typic subgroup which is applied to the subgroup that best fits the central concept of the great group. The other adjective used at subgroup class identifies intergrades to other classes irrespective of hierarchical class. Within the Entisols 20 such modifiers are recognised and defined. The following criteria are listed with the derivation of the modifier name to assist understanding. Reference can be made to Table 1 to see to which great group the modifier applies.

AERIC (Greek, aerios, air, brown and better aerated than Typic). Not that wet to be aquic, water table drops below 1 m for several months to allow oxidation and formation of mottles that have higher chroma than the typic subgroups.

ANDAQUEPTIC, ANDEPTIC. (The AND indicates presence of appreciable allophane). Terms are used for different great groups but both have a pyroclastic horizon 10 cm thick in the upper 75 cm of the profile.

ALFIC (ALF refers to an alluvial horizon of silicate clays and high base saturation,i.e., Alfisols). These subgroups have clay lamellae that meet criteria for an argillic horizon, except for thickness.

AQUIC. Have a shallower water table than the typic subgroup, is wetter than aeric but not that wet to meet criteria of an aquic moisture regime.

HISTIC. Have a histic epipedon.

HUMAQUEPTIC (Latin, humus, earth, presence of appreciable humus). Have low base saturation percent and are umbric-like in the epipedon except for thickness.

HAPLAQUODIC (HAPL, the simplest set of horizons and AQU as for aquic). Have an albic horizon and subhorizon that has weak accumulation of amorphous material (mainly humus); plus water table within 1 m of surface for 6 months in the year; and mean summer - mean winter soil temperature difference >5°C.

HAPLUDOLLIC (UD, udic, and OLL from mollisols). Have a udic moisture regime and fragments of a mollic epipedon.

LITHIC (Greek, lithos, stone). Have a shallow lithic contact.

MOLLIC. Have appreciable humus, high base saturation mollic-like epipedon, except for thickness.

ORTHOXIC. Have clay fraction that meets all requirements for oxic horizon but the amount of clay is too small to be an oxic horizon.

SPODIC. Have albic horizon and subhorizon that has a weak accumulation of amorphous material (mainly humus).

SULFIC. Have sulfidic materials within 1 m of the mineral soil surface.

THAPTO (Greek, thapto, buried). Have a buried soil.

TROPAQUODIC (TROP - no distinct winter or summer; moist and tropical; AQU as for aquic and OD from spodic). Mean winter - mean summer soil temperature <5°C. Have an albic horizon underlain by a horizon darker than above but the accumulation of amorphous material is too little to be spodic.

TROPIC. Soil temperature regime at 50 cm with difference between mean summer and mean winter <5°C.

UDALFIC (UD for udic and ALFIC). Have a udic moisture regime, and fragments of an argillic horizon with a base saturation >35%.

ULTIC (ULT for Ultisol). Have accumulated oriented clay as lamellae but too thin to be argillic; base saturation <35% at 1.25 m below uppermost lamellae.

USTOXIC. Have an ustic moisture regime; and have a clay fraction that meets all requirements for an oxic horizon, but the amount of clay is too small to be an oxic horizon.

TABLE 1 Suborders, Great Groups, and Subgroups of Entisols occurring in the Inter-tropical* Region

*Note classes not likely to occur in this Region are excluded from the table.

AQUENTS	SULFAQUENTS	Typic
	HYDRAQUENTS	Typic
	FLUVAQUENTS	Typic, etc. Aeric Aeric Tropic Andaqueptic Histic Humaqueptic Mollic Sulfic Thapto-Histic Thapto-Histic-Tropic Tropic Vertic
	TROPAQUENTS	Typic
	PSAMMAQUENTS	Typic Humaqueptic Lithic Mollic Spodic
	HAPLAQUENTS	Typic Aeric Mollic Sulfic
ARENTS	HAPLUDOLLIC	
	UDALFIC	
PSAMMENTS	QUARTZIPSAMMENTS	Typic Aquic Haplaquodic Lithic Orthoxic Spodic Tropaquodic Ustoxic

	UDIPSAMMENTS	Typic Alfic Aquic Lithic Spodic Ultic
	TROPOPSAMMENTS	Typic Aquic Lithic
	USTIPSAMMENTS	Typic Alfic Aquic Lithic
FLUVENTS	USTIFLUVENTS	Typic Aquic Mollic Vertic
	TROPOFLUVENTS	Typic
	UDIFLUVENTS	Typic Aquic Mollic
ORTHENTS	TROPORTHENTS	Typic Andeptic Lithic
	UDORTHENTS	Typic Andeptic Aquic Lithic
	USTORTHENTS	Typic Aquic Lithic Vertic

A series of slides was then shown which illustrated many different types of Entisols from Fiji, Cook Islands, Niue and Tonga.

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INCEPTISOLS

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The principal author of Soil Taxonomy, Guy Smith, remarked that "every taxonomy has a waste basket". In the development of Soil Taxonomy it became clear that certain groups of soils had properties or characteristics in common which justified their recognition as a group at the highest level of the taxonomy. Highly organic soils, Histosols, are readily distinguished. Soils with clays which expand when wet, and which are occasionally dry enough for deep wide cracks to form, the Vertisols, are clearly distinct from others. Mollisols are defined as soils with a thick dark epipedon with high base status. Ultisols and Alfisols have an argillic horizon, and are distinguished from each other by their base saturation at depth. Oxisols are highly weathered soils having a horizon in which there is a high concentration of hydrated oxides of iron and/or aluminium. Other groups were formed of soils having similarly clearly identifiable common properties. On the other hand there are soils which have no identifiable diagnostic horizons - the Entisols. Falling between the soils with clearly identifiable common properties and those with no significant horizon development lie a large group of soils which do not fit in any other order. These are the Inceptisols.

As defined in Soil Taxonomy the Inceptisols include at least one group of soils with many common properties or features. These are the soils derived from volcanic material. They are the subject of a proposed new order - the Andisols, which have been already discussed. However, even when these soils are removed from the Inceptisol order, there remains a large number of soils which form a group only because they do not fit anywhere else. The Inceptisol order is mainly defined by excluding soils whose properties meet the requirements of other orders. A soil is an Inceptisol because

it is not anything else. The problems of the order can be summed up in a sentence which appears in the introduction to the order in Soil Taxonomy: "The definition of Inceptisols is unavoidably complicated".

The order comprises soils which have altered horizons, but do not have evidence of translocation and accumulation of either silicate clay enriched with aluminium, or with an amorphous mixture of aluminium and organic carbon. Horizons of accumulation are permitted, provided they do not meet the requirements of any named diagnostic horizon of accumulation. The diagnostic horizon which most clearly expresses these concepts is the cambic horizon, which is, commonly, the key to the identification of a soil as an Inceptisol. Some Inceptisols may, however, have a sulfuric, calcic or petrocalcic horizon.

The cambic horizon is predominantly a horizon of alteration which occurs immediately below an epipedon, or at the surface of truncated soils. It does not have the dark colour, organic matter content and structure that would define a histic, mollic or umbric epipedon. It has a fine-earth texture which is very fine sand or finer. The cambic horizon usually has soil structure, or its original rock structure is altered or absent in at least half of its volume. In this context, rock structure includes fine stratification in unconsolidated sediments and pseudomorphs of weathered minerals in undisrupted saprolite. The cambic horizon contains some minerals capable of further chemical alteration. It does not meet the requirements for an argillic or spodic horizon, or for a duripan or fragipan. If carbonates are present in the parent material, the cambic horizon has less carbonate than the underlying layer. The upper boundary of the cambic horizon must be less than 50 cm from the surface and, unless the temperature regime is cryic or pergelic, its base must lie below 25 cm from the surface.

In general terms, therefore, it is possible to make some positive statements about soils which are classified as Inceptisols:

1. Soil moisture is available to plants more than half the year, or for more than three consecutive months during a warm season.

2. There is always at least one pedogenic horizon present (that is a horizon developed by soil-forming processes), formed by alteration or concentration of matter (but not including accumulation of translocated materials other than carbonate minerals or amorphous silica).

3. The soil texture is finer than loamy sand.

4. The soil contains some minerals capable of further chemical alteration.

5. The clay fraction of the soil has a moderate to high capacity to retain cations (bases plus aluminium).

These properties in combination uniquely define Inceptisols.

Inceptisols are found in a wide range of latitudes, provided that the requirements of the soil water budget are met (Item 1 above). Most are found on relatively young geomorphic surfaces, but in sub-arctic or alpine environments cold temperatures inhibit the chemical decomposition or minerals and therefore restrict soil development. In these locations, Inceptisols may be found on older surfaces. Inceptisols may also occur on recently accumulated alluvial sediments where soil-forming processes have proceeded sufficiently rapidly for distinct pedogenic horizons to develop. While they may have any kind of epipedon, the mollic epipedon is comparatively rare. The most common sequences of horizons are an ochric epipedon over a cambic horizon with or without an underlying fragipan, or an umbric epipedon over a cambic horizon with or without an underlying duripan or fragipan.

In considering the suborders within the Inceptisols, it has been assumed that Andepts need not be included. These soils are included in the proposed Andisol order. The factors which need

to be considered in defining suborders are illustrated in Fig. 1. Primary criteria are wetness, defining Aquepts; warm soil temperatures, defining Tropepts; and the presence of a dark, organic-rich acid surface horizon, defining Umbrepts. The Plaggepts include all freely drained soils with a plaggen epipedon - a deep humus-rich man-made surface horizon. Any soil underlying a plaggen epipedon is considered to be buried. Ochrepts are defined as the soils which do not meet the requirements of any other suborder.

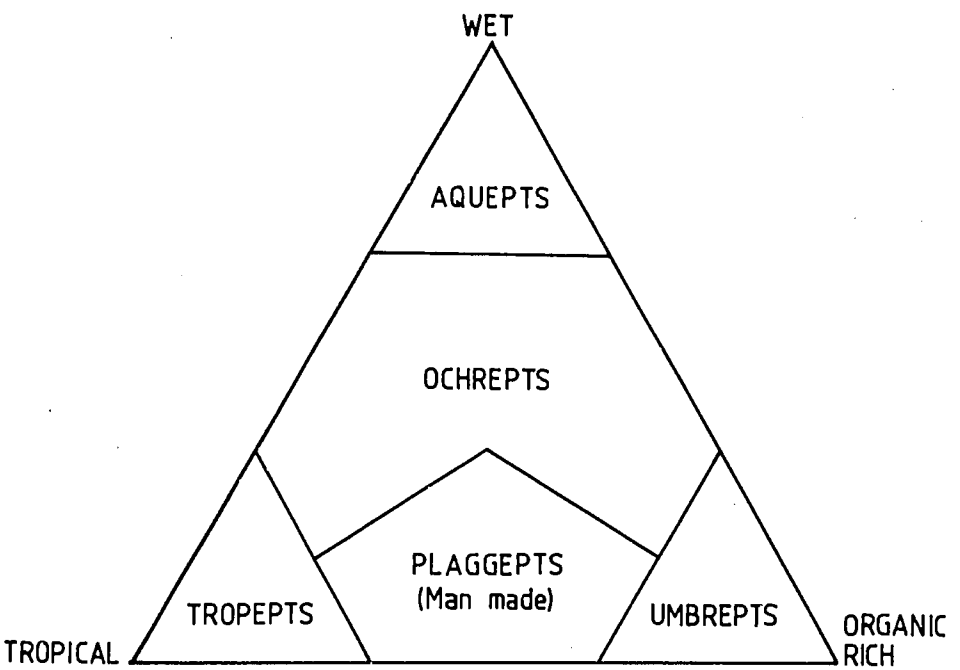

Fig. 1. Some relationships among suborders of the Inceptisols

Unless the soil is artificially drained, Aquepts are saturated with water at some period of the year. Commonly they have grey to black surface horizons underlain by a mottled or rusty-looking

grey subsoil. Most Aquepts have a cambic horizon and some have a fragipan. Their natural drainage is poor or very poor. Some Aquepts are used for agriculture after draining.

Tropepts have an isomesic or warmer iso- temperature regime, which implies that the difference between their mean summer and mean winter temperatures is less than 5°C. They are more or less freely drained and have predominantly brownish or reddish colours. Most have an ochric epipedon overlying a cambic horizon. They occur commonly on moderate to steep slopes where the regolith is usually relatively thin for humid tropical regions. Other Tropepts occur on gentle slopes or terraces. Umbric or mollic epipedons may occur, but the mollic epipedon is restricted to warm areas where the soil has a high content of clay with montmorillonitic mineralogy.

Umbrepts commonly have dark reddish or dark brownish colours, and are freely drained, organic-rich soils occurring in humid mid to high latitudes. Mostly they are found in hilly or mountainous regions with high precipitation, but a summer dry period is not unusual. They frequently support a coniferous forest at mid latitudes, but in higher latitudes or high elevations they have formed under grass or cold-climate shrub vegetation. This suborder is not likely to be of great interest in the tropical and subtropical South Pacific.

Plaggepts are the freely drained soils with a plaggen epipedon, that is, with a thick, organic-rich surface horizon composed of materials added by man over a very long period. They occur in Europe, parts of Asia and China, but are rare elsewhere.

As noted earlier, Ochrepts are defined mainly by their failure to meet the requirements of any other suborder. They are the mainly light-coloured, brownish, more or less freely drained Inceptisols occurring in mid to high latitudes. Most of them had or have forest vegetation except in colder areas. Most have an ochric epipedon

and a cambic horizon. Some may have a calcic horizon, a fragipan or a duripan.

Great groups in the Inceptisol order are formed using similar criteria to those used elsewhere in Soil Taxonomy. Thus the presence of a fragipan defines Fragiaquepts, Fragiochrepts, and Fragiumbrepts. Moisture and temperature regimes define Cryaquepts, Tropaquepts, Cryochrepts, Ustochrepts, Xerochrepts, Ustropepts, Cryumbrepts and Xerumbrepts. Dystropepts have lower and Eutropepts higher base status. Other great groups are defined similarly. Subgroup criteria follow the pattern found elsewhere in Soil Taxonomy.

In summary, Inceptisols are common soils of younger surfaces, and are likely to be found where temperature or time constraints have not permitted soil-forming processes to form horizons showing evidence of translocation and accumulation. However, evidence for the operation of soil-forming processes is found in recognisable pedogenic horizon development. In tropical and subtropical areas the suborders most likely to be encountered are the Aquepts and Tropepts. Where the soil temperature regime is cooler than isomesic, or there is a large difference between summer and winter soil temperatures, other suborders may be encountered, but in the inter-tropical region these will be restricted to high elevations.

MOLLISOLS

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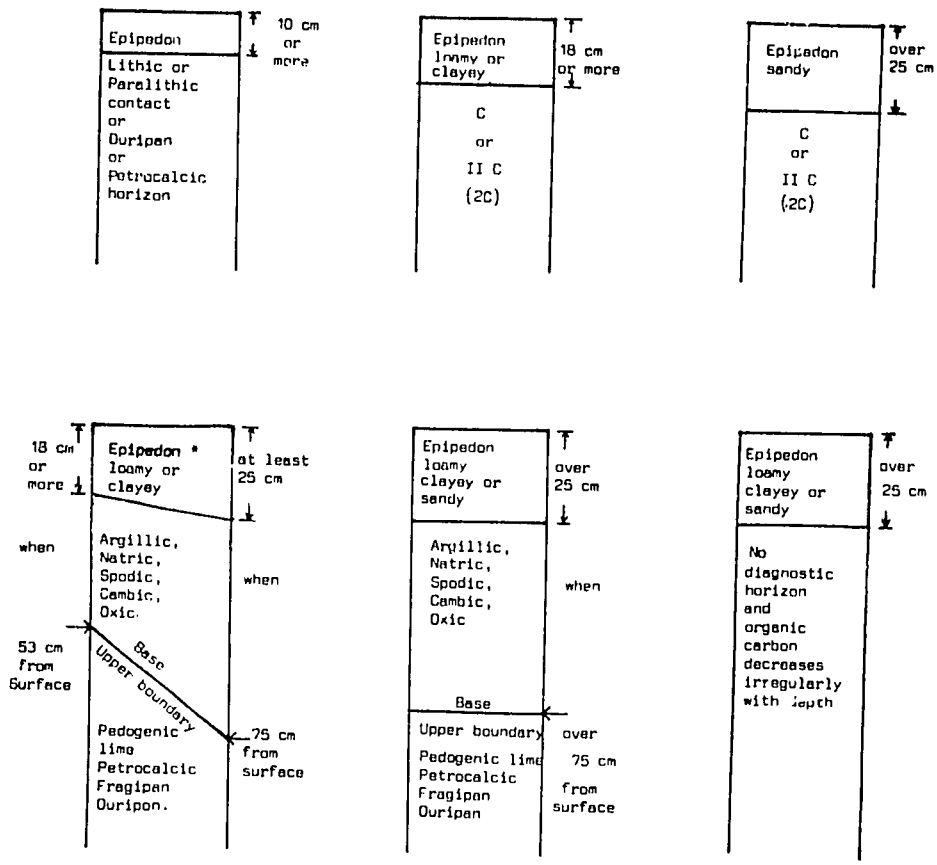
Mollisols can generally be defined as soils with thick, dark coloured humus rich surface horizons with moderate to high levels of bases. The mollic epipedon includes much of the A horizon and may extend into the Bt horizon, or argillic horizon.

In brief, a mollic epipedon must meet the following generalized criteria:

1. It must meet certain thickness requirements (Fig. 1).
2. It has soil structure, or is not both hard and massive.
3. It has a moist colour value of 3.5 or darker, a dry colour value of 5.5 or darker and a moist chroma of 3.5 or darker.
4. The base saturation (by NH_4OAc) is 50% or more.
5. It contains at least 0.6% organic carbon (or 1% organic matter).
6. The epipedon contains less than 250 ppm of P_2O_5 soluble in 1% citric acid.
7. It is moist in some part, when not irrigated for 3 or more months at a time during the year when temperature is favourable for growing crops.
8. The n value is less than 0.7.

There are exceptions to the above criteria, such as different colour and organic carbon requirements for soils with greater than 40 percent finely divided lime. These are covered in detail under the definition of the mollic epipedon, (Soil Taxonomy, pp. 14-16).



* If texture of epipedon is loamy fine sand or coarser throughout, the thickness must be greater than 25 cm.

Figure 1. Thickness Requirements for MOLLIC EPIPEDON

A number of the criteria such as organic carbon, base saturation, calcium carbonate equivalent and P_2O_5 soluble in citric acid require laboratory determinations for accurate placement (National Soil Survey Laboratory Staff, 1981). It must be remembered that it is neither feasible nor practical to conduct laboratory tests on every observation. Therefore, laboratory data should be made available on key, or dominant soils, - or Benchmark Soils as defined by the Soil Conservation Service (SCS) - and interpolated to other similar soils.

The late Dr. Guy Smith, in conversations with Dr. Michael Leamy, explained some of the thinking or logic used in developing the criteria to be used in defining the mollic epipedon.

In developing Soil Taxonomy, the authors gathered together all the soils they felt should be classified together. They studied all the descriptions and data available, and through considerable testing and trial and error settled on the criteria currently in Soil Taxonomy. The reasoning for the criteria for a mollic epipedon is generalized as follows:

1. The thickness requirements were selected to separate those soils that naturally supported enough vegetation to indicate they would also be suitable for non-irrigated cultivation - all other factors,e.g., temperature being favourable.

2. Structure and consistence were used to separate the non-calcic brown and similar soils of California and elsewhere from the Mollisols. The intent was that Mollisols could be dug fairly easily with an auger or spade.

3. The colour values are those that records and experience showed best separated the soils formed under grass cover - the intended Mollisols - from those formed under a forest cover - those soils to be excluded from the Mollisols.

4. A lower limit of 50 percent was set for the base saturation as all the available evidence showed the soils they wanted to classify together as Mollisols had a base saturation (by

NH_4OAc, the common test in SCS) ranging from 100% to a value approaching 50 percent, but not actually 50 percent or lower.

5. The data showed that all the soils that they wanted to classify together that eventually became Mollisols had an organic carbon content of at least 0.6 percent (or organic matter content of 1 percent). This correlated well with the soils that were considered suitable for non-irrigated cultivation.

6. The P_2O_5 requirement was selected to exclude historical village sites or other historical areas similarly disturbed or influenced by man. The Anthropic epipedon was set up to cover these soils.

7. Like the thickness and organic carbon criteria, the moisture requirement was used to separate out those soils in deserts because they were not suited to the growing of non-irrigated crops.

8. The n value was used to exclude the marshy soils (Hydraquents) from the Mollisols, even though they met all the other requirements of a mollic epipedon. These soils have considerably different engineering properties than the typical Mollisols.

Mollisols may have a large variety of subsurface horizons and/or diagnostic characteristics, or such horizons may be entirely absent. Some of the more common subsurface horizons in Mollisols are:

1) cambic horizon
2) argillic horizon
3) natric horizon
4) albic horizon
5) calcic horizon and
6) duripan

There are seven suborders of Mollisols - 5 of which are based on soil climate, i.e.,soil moisture or soil temperature regimes. These are:

Albolls - albic horizon
Aquolls - wet mollisols

Borolls - cold mollisols
Rendolls - high (> 40%) $CaCO_3$ equivalent
Udolls - moist
Ustolls - moist growing season
Xerolls - winter moist/summer dry

Not all soils with mollic epipedons are Mollisols. For instance, low bulk density soils formed in volcanic materials high in amorphous materials would classify as Andepts or Andisols as proposed.

Mollisols most often occur in subhumid and semi-arid climates, and less frequently in humid areas. By definition they are excluded from arid areas, or deserts. They occur on a wide variety of landforms and elevations. Temperature regimes range from isohyperthermic to cryic. They typically form under grass or grass-forb vegetation, and are most commonly thought of as being associated with prairies or steppes. Many Mollisols are calcareous, with the accompanying high base saturation.

In the warmer climates, where slopes permit, Mollisols are extensively cultivated. They are used to produce small grains and sorghum in the drier climates, and corn (maize) and soybeans in the warmer, more humid areas.

The developers of Soil Taxonomy tried to limit diagnostic criteria to only subsurface horizons rather than surface horizons. However, the mollic epipedon was the only horizon they could find that was common to all the "grassland" soils they wanted to group together. Thus it became necessary to use surface layers - or epipedons - as diagnostic at very high levels in Soil Taxonomy.

The danger of using surface layers as diagnostic is that they may be removed in areas of severe erosion, resulting in placing the soil in a different order. This has happened. In the United States a number of soils that were once Mollisols are no longer so because of erosion. It is common to have complex soil mapping units consisting of the original Mollisol and the eroded soil falling in another order. A typical soil mapping unit might include a Typic

WELOY Clayey-skeletal, mixed, isohyperthermic, Typic Argiudolls

Fig. 2

SAMPLED AS:

S 80TU-639 -002 SAMPLE NOS. 80P 788 - 790 DATE 10/20/81

YAP ISLAND, CAROLINE ISLANDS

GENERAL METHODS 1B1A, 2A1, 2B

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	TOTAL CLAY LT .002	TOTAL SILT .002 -.05	TOTAL SAND .05 -2	TOTAL FINE LT .0002	CLAY CO3 LT .002	SILT FINE .002 -.02	SILT COARSE .02 -.05	SAND VF .10 -.10	SAND F .10 -.25	SAND M .25 -.50	SAND C .5 -1	SAND VC 1 -2	COARSE FRACTIONS(MM) WEIGHT 2 -5	5 -20	20 -75	>2MM WT .1- 75	PCT OF WHOLE SOIL
				<- - - - - - - - - - - - PCT OF <2MM (3A1) - - - - - - - - - - - - - ->												<- PCT OF <75MM(3B1)->				
80 788	1S	0- 10	A1	24.1	49.4	26.5			30.3	19.1	15.0	5.6	2.1	0.9	2.9	2	TR	--	13	2
80 789	2S	10- 33	A3	24.9	43.8	31.3			28.2	15.6	14.1	3.8	2.1	2.9	8.4	4	1	12	31	17
80 790	3S	33- 56	B2	46.1	33.8	20.1			24.5	9.3	13.3	4.1	2.1	0.5	0.1	TR	--	--	7	TR

SAMPLE NO.	HZN NO.	ORGN C 6A1C	TOTAL N 6B1B	EXTR P 6S1A	TOTAL S 6R3A	DITH-CIT EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1	PI 4F	BULK DENSITY FIELD MOIST 4A3A	1/3 BAR 4A1D	COLE OVEN DRY 4A1H	WHOLE SOIL 4D1	WA. CONTENT FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2A	WRD WHOLE SOIL 4C1
		<- - - - - - -PCT OF <2MM - - - - - - ->									PCT <0.4MM		<- - G/CC - - ->			CM/CM	<- - -PCT OF <2MM - ->				CM/CM
80 788	1	4.25				3.8	0.	0.1	0.94	1.00											
80 789	2	0.83				6.3	0.5	0.2	0.84	0.69										24.0	
80 790	3	0.61							0.64	0.75										17.1	
																				34.8	

SAMPLE NO.	HZN NO.	NH4OAC EXTRACTABLE BASES CA 5B4A 6N2E	MG 5B4A 6Q2D	NA 5B4A 6P2B	K 5B4A 6Q2B	SUM BASES	ACIDITY 6H2B	EXTR AL 6G1E	CEC SUM CATS 5A3A	CEC NH4-OAC 5A8A	BASES + AL 5A3b	AL SAT 5G1	BASE SAT SUM 5C3	NH4 OAC 5C1	CO3 AS CACO3 <2MM 6E1A	RES. OHMS /CM 8E1	COND. MMHOS /CM 8I	PH CACL2 .01M 8C1E 1:2	H2O 8C1A 1:1
		<- - - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - - ->										<- - - - -PCT - - - ->							
80 788	1	7.4	5.2	0.3	0.1	13.0	11.0	--	24.0	22.7			54	57				5.8	6.1
80 789	2	6.7	7.8	0.1	--	14.6	6.5	--	21.1	20.9			69	70				5.5	6.2
80 790	3	8.3	12.7	0.2	--	21.2	9.8	--	31.0	29.5			68	72				6.0	6.1

SAMPLE NO.	HZN NO.	MINERALOGY CLAY X-RAY <2U 7A2B	7A2B	7A2B	7A2B	DTA <2U 7A3	7A3	TOTAL DOM RES 7B1A	WEATH 7B1A
		<- RELATIVE AMOUNTS ->				<- - - - -PCT - - - ->			
80 788	1	CL 2	KH 2	GE 1					
80 789	2	CL 2	KH 2	GE 1		KH17			
80 790	3	KH 2	VC 2	MT 1		KH39			

Hapludoll retaining the mollic epipedon, and a Typic Udorthent where the mollic epipedon has been eroded and the cambic horizon no longer meets the minimum thickness requirements.

In those areas where the soil classification changes, it is critical that sufficient data be collected during the field mapping to record this activity. It is equally important that the past erosion and its impact on the soil resource be discussed in the map unit description. This tells the user of the soils information that considerable erosion has taken place, and the soil must receive special management or treatment to prevent further deterioration.

Mollisols in the Tropics

Because of the typically high precipitation in tropical areas, Mollisols are not overly common. However, they do occur under certain conditions.

Many Mollisols in the tropics formed in calcareous parent materials such as coral or limestone. Others formed in parent materials that are very high in bases.

For instance, the Yaloy soil on the Island of Yap was classified as an Argiudoll. It formed in green chloritic and talc schist that are very high in bases. The parent rock is essentially massive with few fractures, thus inhibiting the downward movement of soil material into the bedrock. It is assumed this accounts in part for the high base status and illuviated clay in the argillic horizon. According to the National Soil Survey Laboratory Staff this soil has clay films and an apparent clay increase based on the 15 bar water distribution.

The data given in Figure 2 show that the organic carbon content ranges from 4.25 percent in the surface horizon to 0.61 percent in the argillic horizon. The base saturation (NH_4OAc) ranges from 57 percent in the surface to 72 percent in the argillic horizon. The P_2O_5 in citric acid was not determined but is assumed to be less

than 250 ppm. The soil has strong granular or blocky structure in the surface layers, and moderate blocky structure in the argillic horizon. Moist colours are dark enough to a depth of 33 cm. Dry colours were not given as these soils remain essentially moist throughout the year - with the possible exception that the immediate surface layer may dry out for short periods if cleared and left exposed. The soil is definitely moist more than 3 months each year as it occurs in a Udic moisture regime. The n value was not calculated as the clay did not disperse well, and the soil water content was not determined. However, it is assumed the n value was less than 0.7.

Experiences in the Pacific indicate a possible need to re-evaluate the great groups and subgroups of Mollisols. The question can be raised as to whether soil scientists are satisfied with separating tropical Mollisols at the family level, or should they be separated at some higher level in Soil Taxonomy. The answer will come only with a greater understanding of these soils in the inter-tropical region.

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OXISOLS

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Oxisols are red, yellow and occasionally grey soils of tropical or subtropical Regions. They are usually very deeply weathered and have undergone almost complete pedological transformation. Morphologically, apart from colour, they are characterised by sandy-loamy to clayey textures; medium to weakly developed blocky structures; in general, ferruginous and/or aluminous indurated elements; and by the absence of clear boundaries between horizons.

Weathering in removing the primary easily weatherable minerals has allowed formation of 1:1 clays of the kaolinitic family and of iron and aluminium oxihydrates. In addition, minerals resistant to weathering such as quartz and certain heavy minerals are commonly found.

Oxisols often develop on old geomorphological surfaces but they can also be found in relatively recent volcanic areas. They support forest or savannah vegetation. Their natural fertility is usually considered to be medium to poor.

1. Pedogenesis - Weathering

As Oxisols are generally linked with processes of deep weathering, examination of this process is appropriate. In hot, humid environments, (udic and ustic moisture regimes and isohyperthermic temperature regimes), the weathering process normally follows, schematically the following stages:

- the cations: sodium, potassium, magnesium and calcium as well as the more soluble elements of the rock are removed in solution simultaneously contemporaneously, silica from silicate minerals starts to be leached from the system; the silica, iron and aluminium which are liberated after the destruction of the primary minerals tend to reorganize in a more stable form - kaolinite, an aluminosilicate, with some iron substitution; as the silica continues to be progressively leached, some iron and eventually some aluminium (due to under-saturation in respect to silica) precipitate as oxides or hydroxides; and, the leaching of silica may progress, such that all silica is lost from the soil; at this stage only oxides and hydro-oxides of iron and aluminium remain in the soil.

This sequence of chemical change is very simplistic and in nature the processes operating are far more complicated. Some stages may be bypassed, for example, the formation of kaolinite or the sequence may never develop to the ultimate stage. Also, the paleo-climatic factors must be taken into account, for the formation of an Oxisol is a long process and it may have been initiated in a different climate than that prevailing at present. However, Oxisols by definition are soils which have reached the two last steps in the weathering process described.

2. The definition of the Oxic Horizon

This horizon is a deeply weathered subsurface horizon comprising a mixture of iron and aluminium oxihydrates, a variable amount of 1:1 lattice clays, with variable amounts of very insoluble minerals such as quartz or certain heavy minerals. It has neither an argillic nor a natric horizon.

In summary, the oxic horizon is defined as having:

- a minimum thickness of 30 cm;
- a fine earth fraction with 10 meq or less of bases (extractable with NH_4OAc plus aluminium extractable with 1N KCl) per 100g of clay;

- a CEC in the fine earth fraction of 16 meq or less per 100g of clay (by NH_4OAc at pH 7) unless there is an appreciable amount of aluminium interlayered chlorite;
- only traces of primary aluminosilicates such as feldspars, micas and ferromangnesium minerals;
- a texture finer than sandy loam and having more than 15% clay;
- less than 5% by volume that shows rock structure.

Classification of Oxisols:

Definition of the Order

Oxisols are mineral soils that meet one of these two requirements:

1. Have an aquic moisture regime and have plinthite that forms a continuous phase within 30 cm of the soil surface; or
2. Have an oxic horizon at some depth within 2 m of the soil surface but do not have a plaggen epipedon and do not have either a natric or an argillic horizon that overlies the oxic horizon.

Suborders

Five suborders are defined according to the key:

Aquox

Oxisols that have one or both of the following characteristics:

1. Plinthite that forms a continuous phase within 30 cm of the mineral surface of the soil and the soil is saturated with water within this depth at some time during the year; or
2. Either are saturated with water at some time during the year or are artificially drained, have an oxic horizon, and also have one or both of the following characteristics associated with wetness:

a. A histic epipedon; or

b. If free of mottles, immediately below any epipedon that has moist colour value of less than 3.5 there is dominant chroma of 2 or less; or if there are distinct or prominent mottles within 50 cm of the soil surface, the dominant chroma is 3 or less.

Torrox

Other Oxisols that have a torric moisture regime.

Humox

Other Oxisols that:

1. Have 16 kg or more organic carbon per square metre to a depth of 1 m, exclusive or organic surface litter;

2. Have a weighted average base saturation in the oxic horizon (by NH_4OAc) of <35 percent; and

3. Have an isothermic, thermic, or cooler temperature regime.

Ustox

Other Oxisols that have an ustic soil moisture regime and an isothermic, thermic, or warmer temperature regime.

Orthox

Other Oxisols.

Great Groups

Eight great groups have been defined in the different sub-orders (Table 1):

- Gibsi is defined for soils which have either cemented sheets containing 30% of gibbsite or have 20% or more by volume of gravel size aggregates containing 30% or more gibbsite within 1 m of the mineral soil surface, but do not have plinthite that forms a continuous phase within 30 cm of the

soil surface.

- Plinth is the great group which relates to soils which have plinthite that forms a continuous phase within 1.25 cm of the soil surface.

- Ochr are soils with an ochric epipedon.

- Umbr are soils that have either an umbric epipedon or ochric epipedon that has more than 1% of carbon in all subhorizons to a depth of 75 cm or more below the mineral surface.

- Sombri are Oxisols with a sombric horizon.

- Acr are Oxisols that have in some subhorizon of the oxic horizon a cation retention capacity of 1.5 meq or less per 100g of clay (from NH_4Cl), but do not have discernable structure in the oxic horizon or have only weak blocky or prismatic peds.

- Eutr are Oxisols that do not have an anthropic epipedon and have a base saturation of 35% or more in the epipedon and in all the subhorizons of the oxic horizon to a depth of at least 1.25 m.

- Hapl which is the central concept of the suborder, and applied to the Humox, Ustox and Orthox suborders.

Like the suborders the great groups are defined according to a key (Table 1).

Subgroups

The central concept of oxisol subgroups is the Typic, all other subgroups being considered intergrades or extragrades. The latter are listed in Table 1.

Table 1. List of suborder and great groups of the Oxisol in the order of the key and of the main subgroups.

Suborders	Great Groups	Subgroup
	(Gibbsiaquox	
AQUOX	(Plinthaquox	
	(Ochraquox	
	(Umbraquox	
TORROX		
	(Sombrihumox	
HUMOX	(Gibbsihumox	
	(Haplohumox	(Typic
	(Acrohumox	(Perroferric
	(Sombriustox	
USTOX	(Acrustox	
	(Eutrustox	(Typic
	(Haplustox	(Tropeptic
	(Sombriorthox	
	(Gibbsiorthox	(Typic
	(Acrorthox	(Haplic
	(	(Plinthic
	(	
	(	(Typic
	(	(Haplohumic
ORTHOX	(Eutrorthox	(Sombrihumic
	(	(Tropeptic
	(	
	(	(Typic
	(	(Aquic
	(	(Epiaquic
	(Haplorthox	(Plinthic
	(	(Quartzipsammentic
	(	(Tropeptic
	(	(Ultic

In brief, subgroups are as follows:

- Tropeptic having an oxic horizon that extends to a depth of more than 1.25 m and have moderate subangular blocky or prismatic structures.

- Petroferric subgroups are those with a petroferric contact within 1.25 m of the soil surface.

- Haplic subgroups are those which have a net positive charge in some horizon within 1.5 m of the soil surface.

- Haplo-humic subgroups with more than 16 kg of organic carbon per m^2 to a depth of 1 m and do not fulfil the other requirements for a Humox.

- Plinthic subgroups have more than 5% or more by volume of plinthite or gravel-size aggregates that are cemented by gibbsite in all subhorizons within a depth of 1 m from the soil surface and a net positive charge in some subhorizon within 1.5 m of the soil surface.

- Sombric subgroups are those with a sombric horizon which meet all the requirements of the sombric except the base saturation and 16 kg of organic carbon/m^2 to a depth of 1 m.

- Aquic subgroups are those which do not meet the criteria for an Aquox but have mottles that have chroma of 2 or less accompanied by red or dark red mottles within 1.25 m of the soil surface.

- Epiaquic subgroups are those which have hues less red than 10 YR in all parts of the upper 75 cm and that have a colour value, moist, of less than 4.

- Quartzipsammentic subgroups have a texture that is coarser than sandy clay loam in all parts of the oxic horizon within 1.25 m of the mineral soil surface.

- Ultic subgroups are Oxisols with a regular clay distribution in the oxic horizons and discernable structure in the major part of the oxic horizon.

The subgroups are not listed according to the key for Oxisols.

4. Oxisols in the South West Pacific and Problems of Classification

In the islands of the South West Pacific the oxisol order is widely represented. They are found mostly on volcanic material undersaturated in quartz, in areas which are somewhat geomorphologically

unstable. In this they differ from the majority of the Oxisols in Africa or in Latin America which develop in areas of 'old' stable granitic/gneissic rocks. Soil Taxonomy has made many improvements to the classification of Oxisols but many gaps and difficulties in classification remain.

(a) The creation of the Acr- great group has been an important step for the differentiation of the strongly weathered and oxidic rich Oxisols from the kaolinitic rich Oxisols. However, it is still incomplete and some differentiation at a high level of two categories within this great group appears necessary. These are:

(i) The soils with gibbsitic composition. These soils have been described in Lakeba, Fiji (Latham, 1978, and Leslie and Blakemore, 1978), in Vanuatu, Santo (Quantin, 1972-1978) and in Tahiti (Tercinier, 1974). They are deep red soils with a apparent non-existant CEC, a positive ΔpH and more than 40% of gibbsite. They cannot be clasified in the Gibbsi-great group because they have not gibbsitic sheets or gravels.

(ii) The soils with a ferritic composition which occur mainly on ultrabasic rocks. They are red (10 R), rich in hematite, to brown (7.5 YR), rich in geothite soils (Latham, 1981). They are found in New Caledonia but also in the Solomon Islands and Papua New Guinea.

These two categories of Oxisols are very different in regard to their characteristics and fertility status and should be differentiated at a higher level.

(b) The presence of very humiferous soils often with a mollic epipedon in a isohyperthermic temperature regime. These occur on the elevated atolls of the Loyalty Islands in New Caledonia (Latham, 1981). They are 40 to 80 cm thick overlying limestone and are very rich in calcium. The colour, carbon content,

structure and base saturation related closely to the criteria defined for a mollic epipedon. However, they cannot be classified as a Humox because of their base saturation and their temperature regime. Similar soils have been observed by P. Quantin (1972-1978) in Vanuatu.

(c) The presence of halloysite and meta-halloysite in many of the oxisols with lattice clays in the South Pacific. These clays are of the same family as those with a kaolinitic mineralogy class but have a slightly higher CEC. The CEC's of these soils are greater than the 16 meq/100g clay limit. They are very widespread in Vanuatu (Quantin 1972-1978).

(d) The presence of oxidic soil material over the oxic horizon is a problem in classifying some of the Oxisols in Vanuatu.

(e) The lack of any provision for soils with iron gravels or pisolithes. This characteristic is very important for the soils formed on ultra-basic rocks in the Region, in particular, New Caledonia (Latham, 1975). A pisolithic horizon of thicknesses greater than 50 cm can be formed, which overlies fine soil material. At present this feature classifies the family level as a fragmental to skeletal particle size class. It cannot be differentiated from quartz gravel or anything else. This characteristic is particularly important in other parts of the world such as Africa.

(f) Concerning the Eutr- great group that is described in the Region as developing on limestone (Leslie and Blakemore, 1978) the question can be asked as to whether they can be compared with Eutrorthox found, for example, under Savanah vegetation in West Africa. It can be asked whether the presence of limestone gravel is compatible with the definition of an oxic horizon.

Conclusion

The classification of the Oxisols presented in Soil Taxonomy (Soil Survey Staff, 1975) represents an important step toward the differentiation and the ordering of a pedological group of soils as yet little understood. In the South Pacific Region the classification shows some deficiencies and difficulties in its application. Many completely different soils will, by definitions prescribed, fall into the same not very distinctive classes of Typic- Acr- or Hapl- great groups of Orthox or Ustox and will have to be differentiated at the family level. Since the publication of the Soil Taxonomy in 1975, ICOMOX (International Committee for Oxisols) has been established to test, evaluate and prepare proposals for revision of the Oxisols order. Two new proposals have been made (ICOMOX, 1980 and ICOMOX, 1981) which present new proposals for consideration that seem more satisfactory for the Oxisols of the Region. It is hoped that the incorporation of new knowledge to these proposals will help to refine and improve the system so that it will reflect still better the Oxisol entity.

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SOIL TAXONOMY IN RELATION TO GENETIC SYSTEMS

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The major distinction between Soil Taxonomy and the many genetic systems of soil classification is that the latter use genetic theories as parameters. These theories may or may not be correct. Genetic systems also use environmental parameters, which in broad general concept are workable but are not easily able to be precisely defined. On the other hand, Soil Taxonomy uses genesis to choose the appropriate soil properties for use as taxonomic parameters.

A good example of a genetic system is the New Zealand system of genetic soil classification. It has seven categories: the first is the basal form of the soil profile; the second is the main energy status, derived from the latitudinal or altitudinal position; the third is the dominant soil forming process; the fourth is the development of horizons; the fifth is the state of enleaching; sixth is the parent material, and the seventh is the presence of specific surface or subsoil horizons. A typical nomenclature term in the N.Z. classification would be a strongly enleached, moderately clay alluvial surfulvic soil from strongly argillised greywacke. This classification has many strengths including a great degree of flexibility and a high effectiveness in explaining soil distribution patterns at reconnaissance scales. However, it has a number of weaknesses, which include a lack of exclusive definition of criteria; the difficulty of identifying a soil in the field with certainty without a knowledge of environmental parameters; the fact that chemical analyses for soil survey were not always relevant or helpful for classification; and a nomenclature which was not specific or precise.

The Russian system is also a genetic system and continues the approach commenced by Dokuchaiev. It has a strong genetic emphasis which evaluates soil properties and processes in relation to soil-forming factors. There are three main components of classifying soils in the Russian system. First, soil properties; second, soil forming processes; and third, factors of soil formation. Russian pedology is divided into two aspects - soil classification dealing with soil genesis on a broad scale, and soil systematics dealing with mapping problems. In the Russian system there are seven categories, the main one of which is the soil type which is about equivalent to the great soil group of Soil Taxonomy. The class is defined according to broad temperature zones; the subclass on broad morphology; the type has the same bioclimatic and hydrologic conditions and a similar basic soil morphology. The Chernozem, Krasnozem, Solonetz and Pdozol are examples of soil types. Subtype is separated on the intensity and kind of soil forming processes; the genera on the properties of the parent material; the species on the degree of development of main soil forming processes, and the variety is separated on the texture. The strength of the Russian system is that it is very effective at a broad mapping scale, particularly in Russia. The weaknesses are the lack of definition of the different taxa, and the dependence on environmental or genetic factors - not on soil properties.

The Genetic Implications of Soil Taxonomy

Soil Taxonomy assumes that many processes go on in any soil, and the horizons that are formed as a result of soil genesis reflect their relative strengths. If a given set of processes have been dominant for a significant time, they will have left their marks on the soil in the form of distinctive horizons. These horizons can be defined in terms of measurable or observable properties though the definitions may be more difficult to apply than the features are to recognise in the field, just as there is no problem in recognising a dog or a cat at a glance, but there may well be difficulty if we were to write specific definitions to separate dogs from cats. Nevertheless, if the definitions are properly written and carefully applied, competent pedologists

should arrive at the same classification of a given soil even though they hold widely different views about genetic processes. Genesis by itself cannot be used to define taxa and meet this objective. The processes that go on can rarely be observed or measured - they vary with the season and the year - they leave their marks in the soil, but the marks may persist long after the processes that produced them have ceased to act. Thus, mottles in the lower soil horizons may be the marks of groundwater that is currently present at some season or of groundwater that disappeared some hundreds or thousands of years ago. The marks are always the results of processes that existed in a past which may be recent or distant. The genesis of most soils must, therefore, be inferred. It happened in the past. Beliefs about it differ between individuals with varying experiences and change with new knowledge. Nevertheless, the genesis of soils is extremely important both to the taxonomy of soils and to the mapping in the field. The genesis is important to the classification partly because it produces the observable or measurable differences that can be used as differentiating characteristics. These normally have some known accessory properties and probably have others that are important but are still unknown. Genesis is also important to mapping. The mapper uses his knowledge of genesis to extend his very limited sampling observations to the whole landscape. He knows that he can expect the soils to differ where one of the soil-forming factors differs. Genesis does not appear in the definitions of the taxa, but lies behind them. It was the intention to keep soils of similar genesis in the same taxa to the maximum extent possible by using properties that either result from or control soil genesis. The use of diagnostic horizons that are the result of soil genesis brings the genesis indirectly into the definition of the taxa, even though the processes that produced the horizons are unknown. Some diagnostic horizons, such as the silica cemented duripan, can be formed in the presence of other widely different sets of processes. It was thought that if these other processes differed greatly, their effects would be reflected by the presence of other diagnostic horizons or features. Thus, some duripans overlie a spodic horizon, others underlie an argillic horizon. The genesis of the duripan in such different soils probably is not

the same and the associated diagnostic horizons keep the soils separated in the taxonomy. If soils of unlike genesis were grouped in one category, an attempt was made to distinguish them in the next lower category. For instance, Aridisols are dry soils; the Argids include soils formed on young land surfaces and soils formed on very old land surfaces. These are distinguished at the next lowest level as Haplargids and Paleargids. Most of the important genetic differences were thought to have been sorted out as taxa in the subgroup category.

The reason emphasis was given to diagnostic properties produced by soil genesis or affecting genesis was that these would have the greatest number of accessory properties. The aim of Soil Taxonomy was to devise taxa about which the largest number of important statements could be made. Statements that were important to the purposes of the soil survey were interpretations about the use and management of the soils, not about their genesis. A classification intended to reflect genesis alone could be very different from Soil Taxonomy.

Knowledge about soil genesis lags far behind knowledge and experience with soil behaviour. The definitions of Soil Taxonomy focus attention on the particular diagnostic horizons and features that were selected. There is danger that this will detract attention from their accessory properties or from other properties still undefined. If two soils arrive at the same combination of diagnostic properties through different genetic routes, differences normally exist between them but can easily be overlooked. We all tend to see what we have been trained to see. Even the obvious can be overlooked until someone points it out to us. Because of the bias against properties that were not selected for use as differentiating characteristics, the definitions must be continually tested by the functioning of the soils grouped together. Taxonomy is not simply a process of applying definitions. It requires some thought about the objects that are grouped. Does the grouping that results permit the greatest number of the most important

statements for the purposes of the classification about the objects that are grouped? This is the central problem of taxonomy. For Soil Taxonomy, these statements concern the interpretations about responses to use and management. Genesis plays its role indirectly.

THE FAO/UNESCO SOIL MAP OF THE WORLD LEGEND

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Historical development

Before discussing the details of the FAO/UNESCO legend (1974) per se some historical review of how and why this legend was developed is necessary. In 1956, during The International Congress of Soil Science in Paris, it was decided that a commissioner of the International Soil Science Society (ISSS) would investigate and report on the problems of world soil classification and soil correlation. Soil maps at the scale of 1:5,000,000 and 1:10,000,000 were presented to the ISSS Congress in 1960. D'Hoore (1960) presented a soil map of Africa, Bramao and Lemos (1960) one for South America and Lobova and Kovda (1960) one for Asia. However, these soil maps were different in their conception and some level of standardization was obviously required.

In 1961 it was decided to prepare an international soil legend. A first draft of the soil legend was presented in 1966 and the overall philosophy and basic principles for the legend were finalized in 1968. This legend was prepared with L. Bramoa, then L.D. Swindale and finally R. Dudal as coordinators. It was published in 1974.

Purpose of the FAO/UNESCO Legend and the World Soil Map

The purpose of the legend was to establish a soil map of the world with the following objectives:

- To provide a first evaluation of the world soil resources;
- To provide a scientific basis for the transfer of technology between regions with similar environments;

- To develop a soil classification system acceptable to the world soil science community at large;
- To establish a common framework for more intensive research in developing countries;
- To serve as a basis for educational, research and development activities;
- To reinforce international contacts in the field of soil science.

Principles of the FAO/UNESCO Legend

The legend comprises 106 soil units. It is a legend for a soil map and not a classification system. The soil units were chosen on the basis of existing knowledge on the formation, characterization and distribution of the soils in all parts of the world. Subdivisions have been proposed which do not relate to equivalent categories in other soil classification systems, but, in general, it is possible to make comparisons at the great group level.

To allow for identification and reliable correlation between widely separated countries, the definition of the units relies on field observable and measurable properties. The characteristics of the soil themselves constitute the criteria for differentiation. Thus, the system is a natural scheme. The main characteristics have been chosen according to the universally agreed principles of soil formation and genesis. These have been combined into diagnostic horizons, and since many relate to land use, they have practical application.

The list of soil units is a monocategorical classing and not a taxonomic system. However, it is not only a simple listing of elements. The legend tends to make possible a creative synthesis and a concrete inventory of the soil properties and characteristics for both practical and scientific purposes.

Determination of the Soil Units

The soil units of the FAO/UNESCO legend are determined following a description of the soil profile and laboratory analyses. There are two steps; first, determination of the main profile horizons in the

field; and second, recognition of a diagnostic horizon(s).

In describing the soil in the field, the initial step is to separate the different horizons and to describe their characteristics. The principal horizon designations are by capital letters A, B, C, etc., and numerals are used for subhorizons. In the FAO scheme horizons are defined as follows:

- H horizon: an organic surface horizon;
- A horizon: a mineral surface or subsurface horizon (buried soil) rich in organic matter and with well expressed pedological development;
- E horizon: a mineral horizon which is marked by an eluviation of clay and an increase in sand and silt content;
- B horizon: a mineral horizon where rock structure has virtually disappeared and in which one of the following properties is recognised;
    - a clay, iron, aluminium or humus enrichment either separately or in combination;
    - a degree of sesquioxide accumulation;
    - a degree of weathering of the original material with the formation of clays; the formation and separation of oxides; and, the development of a granular, blocky or prismatic structure;
- C horizon: a mineral horizon made up of unconsolidated materials from which the solum has formed;
- R horizon: the hard continuous rock.

Transitional horizons are recognised when they present characteristics of two different horizons, such as AE, EB, BC, etc. Letters, suffix and prefix figures are used to indicate certain pedological characteristics, subdivision of the main horizons, and lithologic discontinuities.

Diagnostic Horizons

Thirteen diagnostic horizons are defined to express the soil characteristics and to define the soil units. The diagnostic horizons have defined quantitative properties. Their definitions are similar to those of Soil Taxonomy from which they have been taken. They are:

- the Histic horizon
- the Mollic A
- the Umbric A
- the Ochric A
- the Argillic B
- the Natric B
- the Cambic B
- the Spodic B
- the Oxic B
- the Calcic horizon
- the Gypsic horizon
- the Sulphuric horizon
- the Albic E

In addition to the diagnostic horizons some additional diagnostic characters have been defined in order to distinguish some soil units or to divide them. However, these characters are not as well defined as the diagnostic horizons. They are:

- a thin iron pan which is normally a black to dark red indurated layer 2 to 70 mm thick;
- soft powdery lime;
- ferrallic character used for Cambisols with a CEC lower than 24 meq/100 g of clay;
- hydromorphic character;
- takyric character for clayey soils which crack with polygonal symmetry;
- vertic properties;
- abrupt textural change;
- soils with an exchange complex dominated by amorphous material;
- high salinity;
- interfingering;
- albic material;
- sulphuric material;
- gilgai microrelief;
- percentage weatherable minerals;
- tonguing;
- permafrost;
- plinthite;

- aridic moisture regime;
- high organic matter content in B horizons;
- smeary consistence.

Soil Units

Twenty-six main units have been defined for the FAO/UNESCO legend. They are:

- Fluvisols which are recent alluvial soils, often with some hydromorphic characteristics;
- Gleysols, are soils with well expressed hydromorphic features;
- Regosols, are soils formed on unconsolidated material except for recent alluvial deposits;
- Lithosols are very thin soils formed on hard rock;
- Arenosols, are soils with albic, argillic, cambic or oxic horizons but not well expressed;
- Rendzinas are thin soils with a mollic A horizon over limestone;
- Rankers, are thin soils with an umbric horizon;
- Andosols, are soils where mineral constituents are dominated by amorphous materials and allophane;
- Vertisols, are clay rich soils, normally black, with vertical cracks and slickensides;
- Solontchaks, are soils with high salinity;
- Yermosols, are pale coloured soils of the arid regions;
- Xerosols, are the other aridic soils;
- Kastanozems;
- Chernozems;
- Phaeozems;
- Greyzems, are the soils of the great Russian plain;
- Cambisols, are like Inceptisols with little profile differentiation except for a cambic horizon;

- Luvisols, are soils with an argillic horizon, and a base saturation greater than 50%;
- Podzoluvisols, are soils with an argillic B and a deep tonguing of an E horizon into the B horizon;
- Podzols, are soils with a spodic horizon;
- Planosols, are soils with an albic E over a weakly permeable subsoil;
- Acrisols, are soils with an argillic B horizon and a base saturation less than 50%;
- Nitosols, are soils with an argillic B but with only a slight increase of clay in the profile;
- Ferralsols, are soils with an oxic horizon;
- Histosols, are soils with a histic A horizon.

These main units can be further subdivided according to other soil parameters, also by textural classes, slope classes, or into phases which indicate characteristics important for land use, and recognising climatic factors.

Conclusion

The soil map of the world has been completed. In the Region 2 sheets cover Australia, New Zealand and some of the Pacific Islands (FAO/UNESCO, 1976). However, the map scale is 1:5,000,000 so the soils expressed are very generalised. As the system is simplistic and the names euphonic, some attempts have been made to use the system at larger scales. ORSTOM used the FAO legend for the UNESCO/UNFPA project in the outer islands of Fiji, and two maps have been drawn at scales of 1:50,000 and 1:25,000 (Denis, in press; Latham and Denis, in press). The system is easy to work with and can be easily understood by many people. However, at larger scales it lacks sufficient differentiae and could be easily subdivided to be utilised as a taxonomy.

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FRENCH SOIL CLASSIFICATIONS AND THEIR APPLICATION IN THE SOUTH PACIFIC ISLANDS

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The French soil classification (C.P.C.S.*, 1976) is derived from the genetic principles inherited from the early Russian pedologists, to which morphological and physico-chemical facts have been added in order to define taxonomic units. It is the result of several approximations of which the most important are the soil classification scheme of Aubert and Duchaufour (1956) and further modifications by Aubert (1965), Aubert and Segalen (1966) and Duchaufour (1970-1977). As there are still many unclarified areas in our pedological knowledge it exists only in mimeograph form. At present it is the subject of continuing discussions as to its rearrangement (work of the C.P.C.S.), the complete reconstruction (Soil Classification Scheme by Segalen et al., 1979) or statements about other ways of expressing pedological facts (Typology : Chatelin, Martin, 1972; Beaudou, Chatelin, 1976). In this paper the C.P.C.S. (1967) classification will be presented in as much detail as possible, together with the Segalen's soil classification scheme.

THE C.P.C.S. (1967) CLASSIFICATION AND ITS APPLICATION IN OCEANIA

The principle of this classification is "morphogenetic". The soils are classified after their morphological characteristics, according to their formation processes.

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*C.P.C.S.: Commission de Pédologie et de Cartographie des Sols.

The C.P.C.S. classification is subdivided into higher units : classes and subclasses, and lower units : groups, subgroups, families and series. The classes and subclasses express (Aubert, Boulaine, 1971) :

- the degree of soil evolution and profile development;
- the mode of weathering defined by the type and amount of free sesquioxides and by the abundance of certain types of clay;
- the type and the distribution of organic matter; and,
- certain fundamental evolutionary processes such as hydromorphy or soil development in the presence of salts.

The subclass characterizes the morphological features due to the pedo-climate. The groups and subgroups are defined according to morphological characters corresponding to soil development processes while the family is concerned with petrographic material and the series with edaphic characteristics.

The main field of application of the C.P.C.S. classification in the Region has been in Vanuatu where general maps on a scale of 1:50,000 and 1:100,000 have been made, and in New Caledonia where surveys on a scale of 1:1,000,000, 1:200,000, and 1:50,000 have been made. Apart from these, more limited studies have been conducted in Tahiti, Wallis, Fiji, Solomon Islands and Papua New Guinea.

The C.P.C.S. classification includes twelve classes :

1. Raw mineral soils:

Raw mineral soils are those which contain only a small trace of organic matter in the upper 20 cm of the profile, and in which the mineral horizons have not undergone any significant pedological development. A Regional example is furnished by the soils formed on very recent volcanic material (cinders, lava, and transported material) around the active volcanoes in Vanuatu (Quantin, 1975). These soils are uncommon in the humid tropics because of the rapidity and intensity of weathering. In Soil Taxonomy they are classified as Entisols.

2. Weakly developed soils

Weakly developed soils are those with a marked humiferous horizon but with little sign of geochemical alteration in the mineral matter or of pedological differentiation. This class contains four subclasses:

- weakly developed soils of glacial zones;
- weakly developed humiferous soils;
- weakly developed soils of dry zones;
- weakly developed soils of non-climatic origin.

In this Region, high altitude very humiferous alpine Rankers and non-climatic weakly developed soil, due to erosion or deposition, can be found.

Among the eroded soils, are classed those which have been truncated by erosion like those on altered basalt or schists in New Caledonia.

Deposition soils can be of two kinds:

- recent soils of river alluvium or colluvium. In this Region, these soils are common on all Holocene river terraces. They are very important because of their agricultural value, though they are not extensive. In Soil Taxonomy, they are classified as Fluvents;

- soils of recent volcanic deposits which are related to Vitrandepts (Vitritropands).

The concept of evolution and weathering in these soils is rather complicated, because the deposited material may have been subject to weathering before its deposition. Some eroded soils may have been deeply weathered under humid paleo-climates then truncated. Thus it is difficult to determine that part of the profile resulting from present processes of soil development,

and therefore the degree of pedological organisation of the profile appears to be a more suitable criterion.

3. Vertisols:

Vertisols are dark-coloured clay soils, dominated by swelling clays with a high exchange capacity (35-40 meq/100 g). They show shrinkage cracks in the dry season, obliquely striped slikensides indicating that they are affected by internal movements, which can produce a gilgai microrelief on the surface. The criteria for their classification are comparable to those used at the highest level (Vertisols) in Soil Taxonomy. For lower levels drainage capacity and the structure of the upper 15 cm in the profile are taken into account.

Typic Vertisols are common on the west coast of New Caledonia on the piedmont of basaltic hills and in the alluvial plains. Some vertic brown soils appear also on the west coast of the greatest and oldest islands of Vanuatu (Santo, Malekula). They are rare elsewhere in the Pacific Islands because the climate is too wet.

4. Andosols:

These soils constitute a group characterised by the dominance in the mineral fraction of the poorly ordered hydrated alumino-silicate called allophane associated with variable but often high percentage of organic matter. The classification of Andosols has been developed since the C.P.C.S. and at present provides for subclasses dichotomy between Andosols with weakly differentiated profiles and those with well differentiated profiles. The former corresponds in part to the separation of Vitrandepts from other Andepts. Andosols with a well differentiated profile are more common in the South Pacific islands and they include Eutrandepts, Dystrandepts and Hydrandepts. These soils are well represented in Vanuatu, Fiji, and Papua New Guinea.

5. Calcimagnesic soils:

These are the soils in which the morphological characteristics of the upper horizons are determined by the effect of alkaline earth ions (Ca, Mg). The lower part of the solum, where it exists, shows neither the characteristics of Vertisols nor those of Isohumic soils. The supply of bivalent ions is assured by a carbonate or other very basic types of underlying rocks.

In this Region the following soils are classified in this unit:

- Rendzinas on calcareous sand of coastal plains or atolls (French Polynesia, Fiji Loyalty Islands, Vanuatu);
- Brown calcareous soils with an aluminium rich facies;
- soils derived from volcanic pumice on uplifted atolls of Loyalty Islands, Kabara, and Niue.

These soils are classified in Soil Taxonomy as Mollisols under the suborder Rendolls.

6. Isohumic soils:

Isohumic soils are those which have a moderate or weakly differentiated profile, showing high percentages of organic matter at the surface that decreases slowly with depth. They are steppe soils: Brunizems, Chernozems, Chestnut soils, Brown soils, Maroon soils (cinnamonic). These soils are uncommon in the islands of the South Pacific. Certain soils with a calcareous crust on the west coast of New Caledonia (encrusted Maroon soils) can be classed among them. In Soil Taxonomy these Brown lime encrusted soils would be classified as Calciustolls.

7. Brown soils:

These soils are characterized by a humus of mull type in which the characteristics are similar to that defined for a mollic horizon, and by a well differentiated profile. Most of the iron liberated

by weathering is allied to the humus - clay complex. These soils would be classified in Soil Taxonomy as Mollisols, Inceptisols and Alfisols. In tropical environments eutrophic Brown soils, either weakly developed, or vertic, or ferruginised have been defined. These soils, which generally are not deep, have been observed in New Caledonia, Vanuatu, and Fiji, on volcanic uplands and on limestones. They are related to the Eutropepts described in Soil Taxonomy. Quantin, in order to take into account the incomplete mineral modification of some weakly developed acid soils in Vanuatu and New Caledonia,proposed that they should be classified as dystrophic or unsaturated Brown soils which could be related to Dystropepts.

8. Podzolized soils:

Podzolized soils are sometimes characterized by an A_2 horizon which is eluvial, very white and extremely impoverished in clay, iron and cations and always by an illuvial B horizon in which the characteristics are those of a spodic horizon rich in Al and Fe complexed humus. True Podzols are uncommon in this Region. They can be seen on very siliceous rocks, phtanites or siliceous alluvium in New Caledonia. On the other hand, the podzolisation with the formation of a bleached A_2 horizon is a common process in New Caledonia where it affects the upper fersiallitic part of ferallitic soils, also in Fiji in red and yellow podzolic soils and in Tahiti at high altitude.

9. Iron sesquioxide or fersiallitic soils:

These soils are characterised by the separation of iron or manganese sesquioxides which give a red-ochre or red colour to B horizons. In addition to kaolinite, their principal clay mineral, they contain a certain amount of 2:1 clay and are usually lacking in gibbsite. The concept of a fersiallitic soil, which has hitherto been restricted to ferruginous tropical soils and red or brown mediterranean soils, has been enlarged to include fersiallitic soils of low base saturation. In the Region such soils have been

observed in New Caledonia, Vanuatu and Fiji. These soils may undergo secondary podzolic evolution in the A_2 horizons. These low base saturation fersiallitic soils encountered in the Region would be classified in Soil Taxonomy as Ultisols or Alfisols for those leached in clay, or with Inceptisols, Eutropepts, Dystropepts for those which are not leached.

10. Ferrallitic soils:

Ferrallitic soils are characterized by an almost complete weathering of primary minerals except for quartz, muscovite and a few heavy minerals, and by the synthesis of kaolinite (or halloysite), aluminium hydroxides and iron sesquioxides. They are the typical soils of the humid tropics. They are subdivided at the level of subclass according to base saturation criteria. But in order to take into account the existence of soils composed uniquely of metallic sesquioxides the creation of a new subclass of oxidic soils has been proposed into which allitic soils rich in aluminium hydroxides, and ferritic soils, rich in iron sesquioxides, could be placed.

In Soil Taxonomy, ferrallitic soils correspond principally with Oxisols, but certain leached ferrallitic soils have been included among the Ultisols. Some halloysite rich ferrallitic soils, from volcanic materials, would be classified as Inceptisols (Tropepts, Andepts). These humid tropical soils are very common in Pacific Islands.

11. Hydromorphic soils

The class of Hydromorphic soils was created to characterize the soils in which pedogenesis is dominated by water saturation due to a temporary or permanent waterlogging of part or the whole of the profile. The following are classified as Hydromorphic soils:

- peats which in Soil Taxonomy are classified as Histosols. These soils are frequent in the subcoastal or inland marshes

which do not receive too much alluvium. They can be found in New Caledonia, Fiji, Vanuatu, Papua New Guinea, Tahiti and in many other areas;

- soils with moderate or small amounts of humus and with gley or pseudogley features, which correspond to the Aqu- suborders in Soil Taxonomy.

12. Sodic soils:

These are the soils in which the evolution is dominated by:

- the presence of soluble alkaline salts in solution of which the conductivity is above 7 mmhos.
- the presence of exchangeable sodium together with the appearance of a massive and diffuse structure.

They correspond mainly with Aridisols having a sodic or natric horizon. Limits in concentrations of soluble salts or exchangeable sodium are lower in the 1967 edition of C.P.C.S. than in Soil Taxonomy.

Within this Region these soils are uncommon, except in mangrove areas and on the west coast of New Caledonia where they are under the influences of a very dry climate, sodium rich parent rocks, and sea sprays, and where some solontchacks and solonetz are found.

Discussion

Thus, in the upper subdivisions of the French classification, most emphasis is placed on the major pedogenetic processes which are as follows:

- development under different types of humus (brunification, podzolization, iso-humization);
- ferruginization;
- andosolization;
- vertisolization;
- calcium-carbonate (or sulphate) illuviation;
- allitization, ferritization, ferralitization;
- waterlogging;
- alkalization;

In its principal features the French classification is logical and corresponds to the major world ecopedological units. However, it has been much criticized in recent years for various, sometimes contradictory, reasons. The following remarks have been made:

- It lacks precision. The abse ce of precise diagnostic features and well defined limits, sometimes leaving too much open to personal interpretation. But, this allows a certain flexibility in areas as yet unknown.
- It is incomplete. Numerous soils are not easily fitted into the system and it is therefore necessary to propose new taxa which then pile up over a number of years.
- Imprecise references are given to climate, which also do not account adequately for palaeoclimates.

However, the general principles of the system have apparently received the assent of the French Pedological community and a new edition of the C.P.C.S. following these principles is in progress.

SOIL CLASSIFICATION PROJECT (Segalen *et al.*, 1979)

Other classification projects have been undertaken recently and among these the most complete by far, is that of a group of ORSTOM pedologists led by P. Segalen. This project marks a break

with the French genetic classification and attempts to be a more objective classification. Like Soil Taxonomy it classifies soils first by their own characteristics and according to diagnostic horizons. Two fundamental types of data are taken into consideration:

- mineral and organic constituents,
- soil morphology as expressed in the horizons.

The choice of the main mineral and organic constituents as primary taxa in the classification follows from the important properties that they have and from their permanent character. In addition the soil constituents summarize the effect of the factors and processes of their formation. But the morphological features are not undervalued, even though they are used at the second level.

Four levels of classification have been made:

- level I (class and subclass) is determined by the constituents or groups of main constituents;
- level II (groups to families) is determined by the diagnostic characteristics of the organic, humiferous, and mineral horizons;
- level III (genus, series) is determined by the chemical and edaphic characteristics of the horizons;
- level IV (phase, variant) is determined by special characteristics of the pedon and environmental data, relevant to land use or soil genesis explanation.

Ten classes are thus defined:

- primarosols which have no notable pedological development and where, if it is present, the organic horizon is less than 18 cm thick;
- organosols in which the organic horizon is more than 3/4 of the soil profile if that is less than 60 cm thick, or

more than 45 cm if the soil is more than 60 cm thick;

- selsols which contain chloride, sulphide, sulphate and carbonate salts;

- andosols in which the mineral matter is mainly composed of secondary amorphous and/or poorly ordered minerals which are very hydrated and form stable organo-mineral complexes with humic acids;

- bisialsols composed of 2:1 and 1:1 clay minerals, in variable proportions;

- ferbisialsols characterised by the presence of 2:1 clay minerals and iron oxides or hydroxides associated in variable proportions with 1:1 clay;

- monosialsols characterised by 1:1 clay minerals and possibly aluminium hydroxides;

- fermonosialsols in which the mineral horizons are constituted of 1:1 clays associated with metallic sesquioxides (iron, aluminium, titanium...);

- oxidisols are constituted mainly of iron, aluminium, titanium and other sesquioxides with very small amounts of clay minerals;

- podzols characterised by the degradation in the upper part of the pedon of clay minerals and iron and aluminium sesquioxides, and by the formation of more or less mobile complexes between organic matter and iron and aluminium hydroxides;

In the absence, as far as we know, of application, we may ask if this project can fulfil the aims of its subscribers, that is:

- comprehensive, allowing for all criteria to find their own place,

- natural, as it is based on naturally limited criteria,
- coherent, as it is based on a hierarchy of criteria where each criterion is treated at a special taxonomic level independently of the idea of the observer,
- universal, valuable for all times and in all countries allowing to add any new soil unit we can observe.

We may answer as follows:

- comprehensive: it includes morphological, chemical and mineralogical criteria;
- natural: the idea of natural limits is very often difficult to establish and much progress has still to be made towards their definition;
- coherent: the system's coherence need not be tested;
- universal: treating soil as an object in itself no external considerations are taken into account, for the high levels of classification, but they are, at the lower level, for land use evaluation or genesis explanation;

The main difficulty of the project is that much work is needed in the laboratory in order to define the main units. Therefore, there is some divergence between pedologists who prefer to classify their soils in the field with a minimum of analytic data because their laboratory support is limited, and those with access to good laboratory facilities who look for a more sophisticated system.

CONCLUSION

The 1967 edition of the French Soil Classification has served as a basis for most of the tropical soil surveys undertaken by ORSTOM during the last fifteen years. However, it has not always proved adequate for all the pedological units encountered and a revision of the classification is in progress. As well as the

studies in typological language (Beaudou, p.201), two different ways of thought have now emerged.

- one prefers to stay in the French morphogenetic tradition, revising the existing classification and making it more accurate;
- the other influenced by Soil Taxonomy prefers to build an entirely new, more objective and logical system. This project, conducted by a group of pedologists led by P. Segalen, is based on the definition of diagnostic horizons and on the creation of new units defined at the highest level by the organo-mineral constitution of the soil according to the main pedological processes.

If the C.P.C.S. members pursue and improve the first method of classification to a new edition, as it now appears, it is desirable that the authors should take into account the precise and logical concepts which Chatelin et al., and Segalen et al., have brought to pedology.

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THE TYPOLOGICAL LANGUAGE*
A NEW METHODOLOGY FOR SOIL AND ENVIRONMENTAL STUDY

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The first part of a soil scientist's work is the understanding of soils and the processes responsible for their formation at different map scales both in space and time.

The second, and equally important part of his work, is undertaken after the information has been collected. It concerns the transmission of this information. Transmission can either be a horizontal communication between different scales of observation or a vertical communication between different scientific disciplines.

There are several ways of transmitting such information:

first by classification and second, through language and typology.

Classification and language can be based on the simple principle of diagnosis. Soil scientists are continually making diagnoses. Each elementary factor represents a diagnosis. These diagnoses can be classified very easily. These are the elementary morphological diagnoses (pedological observations) and elementary analytical diagnoses (laboratory results). This elementary level is usually insufficient,

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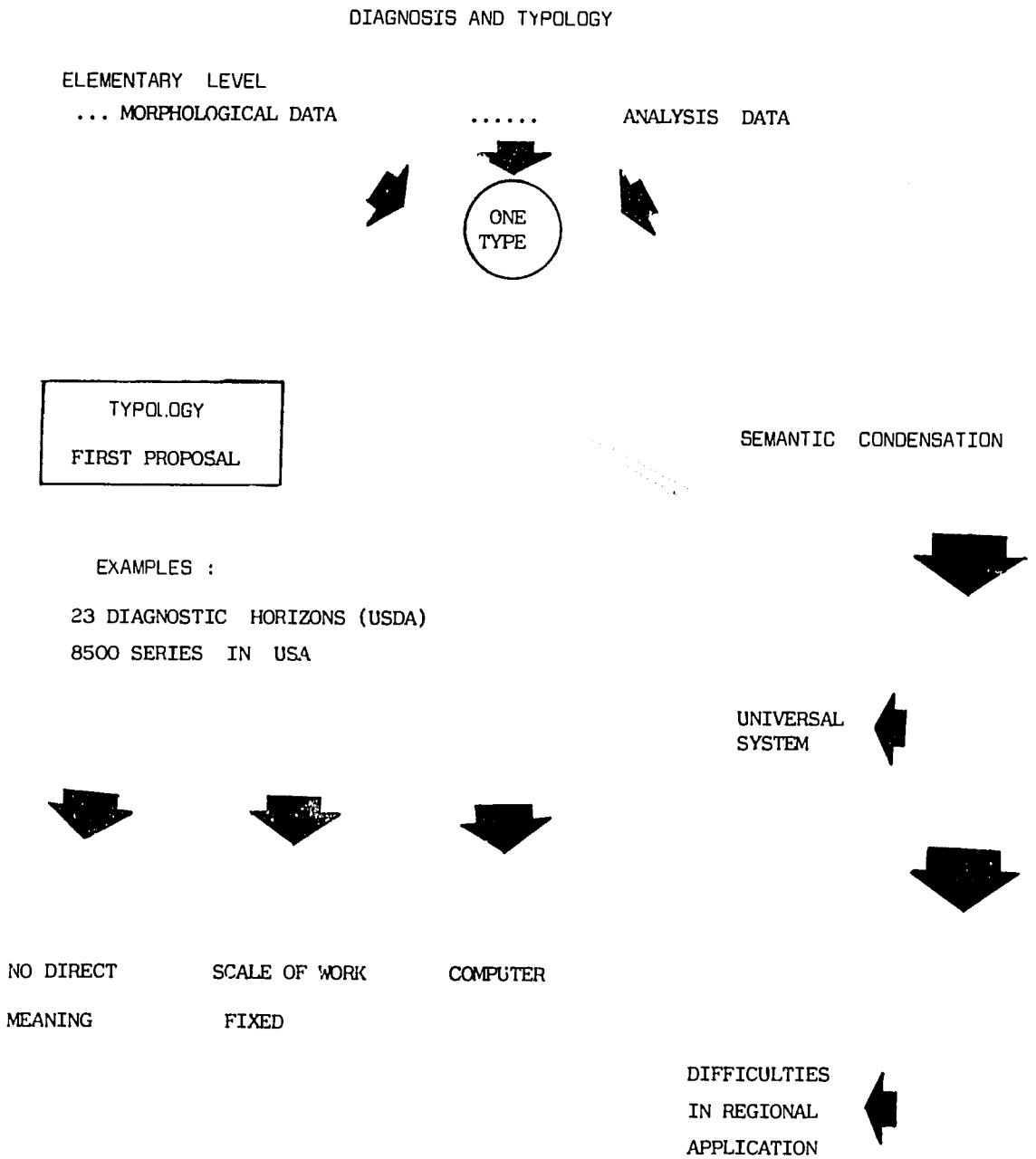
*Although this paper does not strictly relate to the main theme of the Forum, it was presented for discussion purposes and is therefore included in the Proceedings.

Figure 1


DIAGNOSIS AND TYPOLOGY
ELEMENTARY LEVEL
... MORPHOLOGICAL DATA
.....
ANALYSIS DATA
ONE TYPE
TYPOLOGY
FIRST PROPOSAL
SEMANTIC CONDENSATION
EXAMPLES :
23 DIAGNOSTIC HORIZONS (USDA)
8500 SERIES IN USA
UNIVERSAL SYSTEM
NO DIRECT MEANING
SCALE OF WORK FIXED
COMPUTER
DIFFICULTIES IN REGIONAL APPLICATION

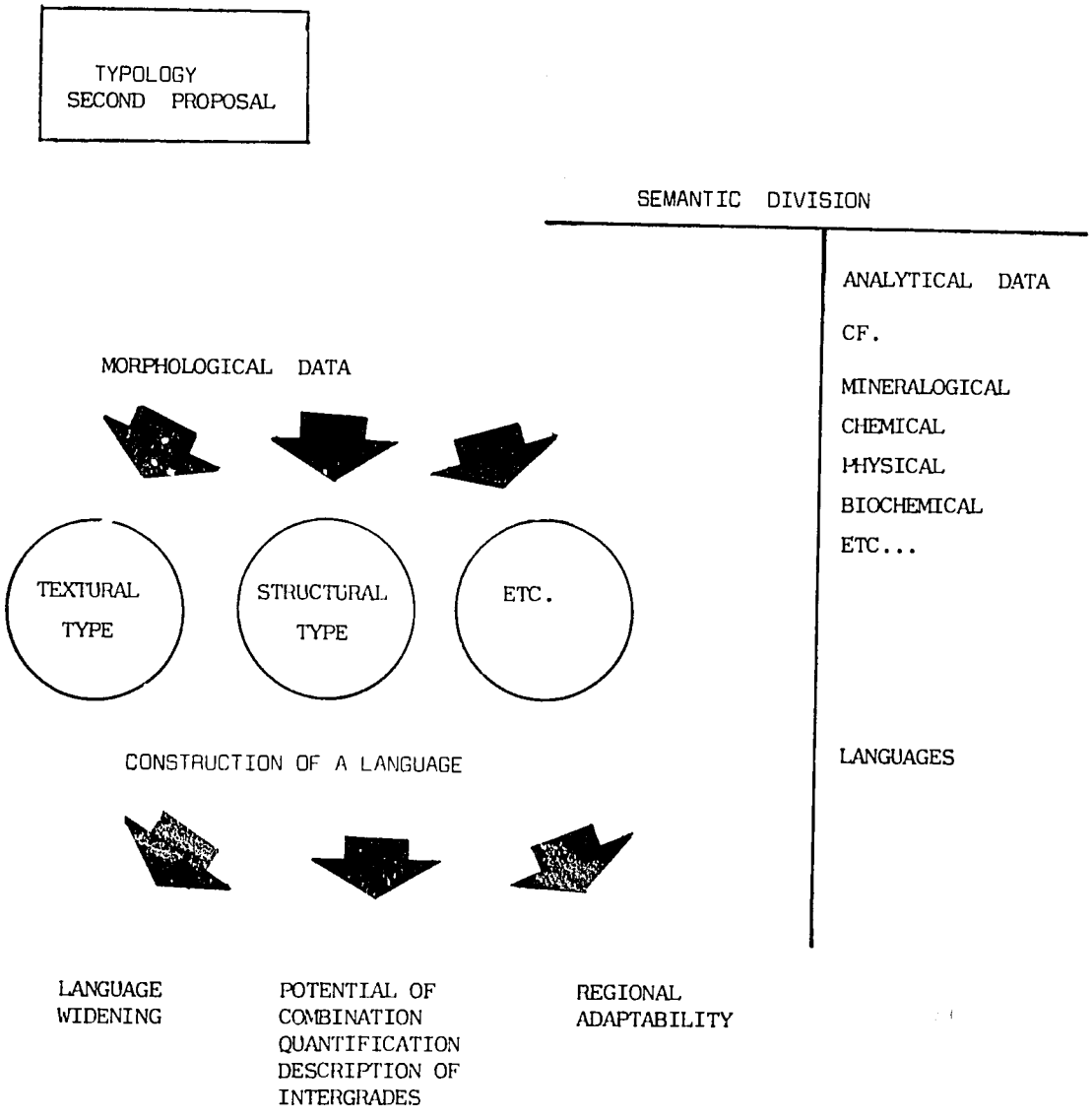
and scientists have to envisage a higher level of synthesis. In general a pedologist passes from an elementary diagnosis to one which is expressed by very general and abstract genetic concepts. This final synthesis involves a good deal of interpretation and leaves some parts uncertain. Therefore it is not strictly an objective way to treat information.

Between the elementary and the final genetic level there are other levels of synthesis which can be called compound diagnoses. These compound diagnoses constitute a typology. Two principles are used:

First, that of semantic condensation: (Fig. 1). Each type is defined by a large number of elementary data which are very different from each other (e.g., colour, texture, nature of clays, structure, percentage of organic matter etc.,.....). This process of semantic condensation has the special capacity of giving rise to classifications with a finite number of taxa. A classification must take into account the problems of memorizing it. An example is provided by Soil Taxonomy (Soil Survey Staff, 1975) in which a number of diagnostic horizons are included which are as easy to memorize by name and in their definitions. But the semantic condensation is much larger for the definitions are supposed to be applicable to all the world's soils. In any classification the number of great groups and subgroups is always relatively limited. If a classification includes a large number of taxa it cannot be memorized. Also, the citation by name of the classification's units falls short in accounting for all soil characteristics that should be considered, and especially so when the name is based on toponymy, for it loses much of the pedological information.

Second, that of semantic division: (Fig. 2). This process does not lead to a classification but to a language. In this system diverse factors concerning morphology, physics, chemistry and mineralogy are not brought together in highly synthesised taxonomic units. On the contrary, establishing a semantic division means that one gives a precise and limited meaning to a word. Thus, in such a system

Figure 2


TYPOLOGY
SECOND PROPOSAL
SEMANTIC DIVISION
ANALYTICAL DATA
CF.
MINERALOGICAL
CHEMICAL
PHYSICAL
BIOCHEMICAL
ETC...
MORPHOLOGICAL DATA
TEXTURAL TYPE
STRUCTURAL TYPE
ETC.
CONSTRUCTION OF A LANGUAGE
LANGUAGES
LANGUAGE WIDENING
POTENTIAL OF COMBINATION QUANTIFICATION DESCRIPTION OF INTERGRADES
REGIONAL ADAPTABILITY

several levels of diagnosis will exist. Each one of these concerns a precise subject. Let us take soil structures for example. The diagnosis concerning soil structures receives a name (amérode, pauciclode...) which has only one structural significance (it does not take into account mineralogy nor geochemistry nor colour, etc.). The term pauciclode for example is defined as follows: within a continuous horizon there are planes and angular edges. They practically never separate out into really well formed angular blocky aggregates. Natural faces and artefacts derived from breakage yield angular blocks of variable size.

Thus each time one wants to characterise a given soil several diagnoses and therefore several words must be used. As the diagnoses are semantically independent the language is infinitely open and it can assimilate new diagnoses translated by new words without being disturbed. This is contrary to what happens in classifications where the addition of new knowledge necessitates basic rearrangements.

However, the number of words is limited and has to stay limited so that it does not exceed the capacity of memorization. In fact it is by the multiplicity of possible combinations between the different terms that the language is able to describe various soils without needing a large vocabulary.

The Establishment of Several Levels of Diagnosis. (Fig. 3)

These different levels of diagnosis are not graded according to their greater or lesser genetic significance.

1. The first diagnostic level (major diagnosis) is based on directly observable morphological characters. These characters must fulfil two conditions: first, they must immediately serve to identify all components of a soil; and second, they must apply at all levels of observation (from a thin microscope section to a landscape).
   Thus, the first level must constitute a comprehensive structural canvas on which all the rest can be grafted. Let us take the term STRUCTICHRON: it concerns a soft, friable, porous, homo-

Figure 3

COMPOSED DIAGNOSIS	FIRST LEVEL OF DIAGNOSIS AND VARIATIONS	SECOND LEVEL OF DIAGNOSIS	THIRD LEVEL OF DIAGNOSIS
APEXOL	APPUMITE STRUCTICHRON		COLOUR TEXTURE MINERALOGY BIOLOGICAL CHARACTERISTICS ETC.
INFRASOL	GRAVOLITE GRAVELON STERITE RETICHRON ALTERITE	AMERO PAUCI ANGU ALIA PSAMMO CLODE	

GROUPING IN:

DEVELOPMENT : ORTHO - BRACHY - LEPTO

SITUATION : EPI - HYPO

DEFINITION : ORTHIC - PARORTHIC

Figure 4

TYPOLOGICAL QUANTIFICATION

X : 0% OF A	Two phases
X-STIGMEA : 0-5 % OF A	STRUCTICHRON
X-PHASE A : 5-15 % OF A	ALTERITIC STIGME STRUCTICHRON
X-A : 15-30 % OF A	ALTERITIC PHASE STRUCTICHRON
(A)-X : 30-45 % OF A	ALTERITIC STRUCTICHRON
X-A OR A-X : 45-55 % OF A	ALTE - STRUCTICHRON
	ALTERITE - STRUCTICHRON

genous, brightly coloured mineral horizon. It is homogenous in the sense that all the particles of clay or sand, ferruginous or not, are intimately bound up with each other. This definition uses only those criteria available from simple morphological observation and follows well the principle of semantic division.

2. The second diagnostic level (secondary diagnosis) concerns the structural organisation of the soil of which the terms amérode, anguclode, aliatode are examples (see appendix). Structural diagnosis such as is defined here goes further than the usual reference to geometric forms and so, in fact, corresponds to a more synthetic level of diagnosis than that of the elementary diagnosis. Let us take for an example the typological diagnosis anguclode. It is concerned with the planes of the separation faces, the presence of sharp edges, the presence of isolated aggregates and, equally, allows for the existence of a certain number of incompletely formed aggregates.

3. The third level of diagnosis (complementary diagnosis). It regroups the traditional diagnoses of pedology. It is concerned with colours, textures, chemical, biochemical and mineralogical parameters, etc. The diagnoses and terminologies have been in existence for a long time.

It needs to be understood that the first two of the diagnostic levels fill a gap in the standard descriptive system used in pedology. This gap prevents the establishment of a comprehensive structural framework of soils.

All these diagnoses can be very easily associated when they are properly designated. For example, one can speak of a structichron anguclode, red, clayey, kaolinitic gibbsitic, unsaturated,etc.

Altogether this constitutes a scientific terminology adapted to the study of world pedology. The language thus formed possesses a certain number of linguistic capacities allowing for a good adaptation to the objects treated. This language must be a real working tool,

that is to say it must be a means to treat information already acquired and, equally, be a means of discovering new information. For this it must give combinative characters. Then it is possible to identify, classify and compare varied soils having all sorts of associations and intergradings.

Let us now examine the different applications of this language:

- It is possible to create several descriptive categories:

o in definition: horizons and soils will be orthique when they correspond closely to their central concepts and parorthique when the resemblance is less;

o in location: the use of prefixes epi - or hypo - allows the horizon to be localised in a profile;

o in development: this concerns the upper part of the soil: the apexol. It is possible to distinguish lepto - (slightly thick), brachy - (medium thick) and ortho - (very thick) - apexols.

- In addition, like all languages this one is grammatical and its terms have a capacity of derivation which allows them to be associated together. For example we can present a structichron or a retichron (nouns), express a structichrome (adj.) phase, a process of retichromation (derived noun),etc. Equally we can describe a structi-retichron, a structichrome retichron,etc.

- The capacity of the language can be enlarged further by quantification (Fig. 4). The rules of writing have been established. They are flexible enough to adapt themselves to a variable number of classes determined according to environmental characters or to the detail and level of observation. The rules allow mixtures or juxtapositions of 2, 3, 4 or more elements to be described quantitatively. In practice quantification is most necessary,for pedological materials are never simple.

Figure 5.

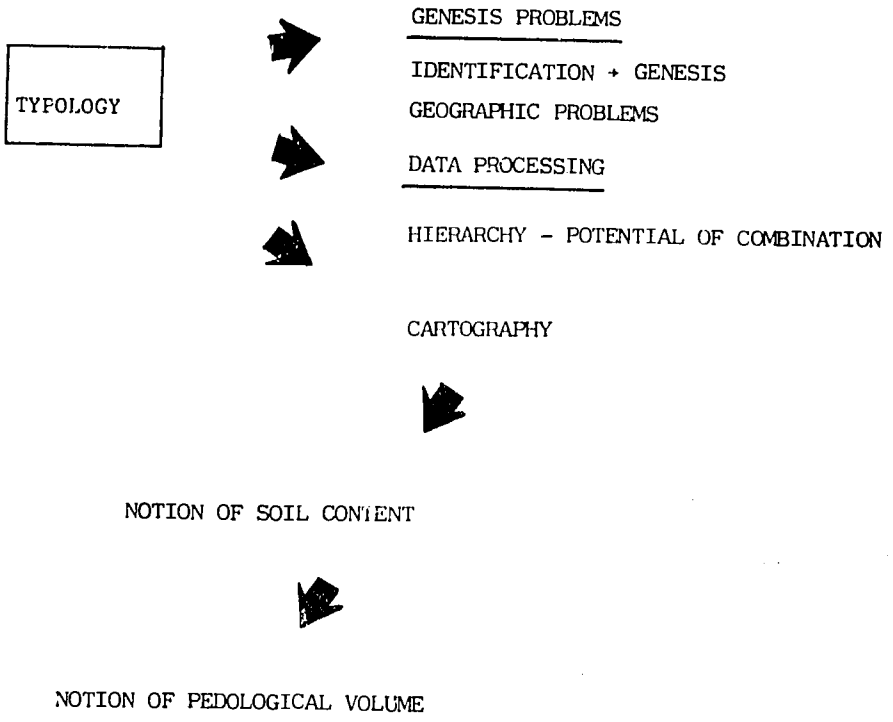
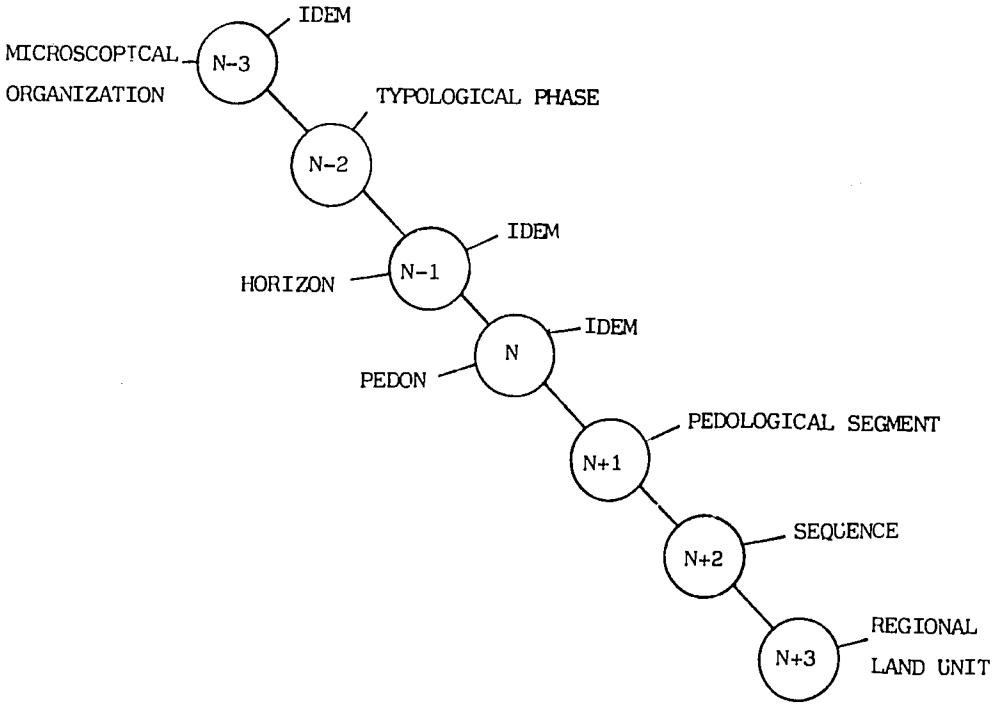


Figure 6. Pedological Volumes



Thus, the descriptive system which we have constructed copies, in a way, the multitude of natural combinations. It is a grammar for the treatment of scientific information (Fig. 5).

The whole system follows closely practical realities, especially at the level of soil survey. Soil maps using this system have been prepared for West Africa and Central Africa (Beaudou and Chatelin, 1977; Beaudou and Collinet, 1977).

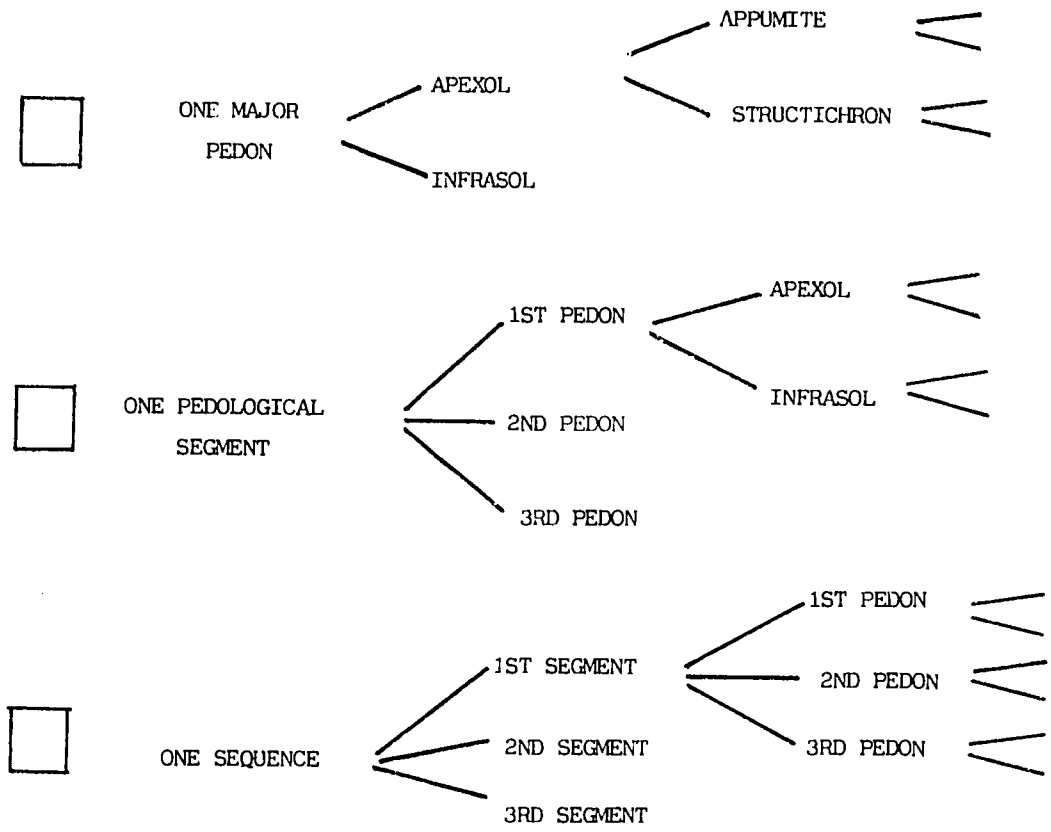
Typology allows all the observed characters found in a variety of spatial units (for example region, landscape, soil) to be expressed in a sufficiently concise and accurate way. In this way the variable development of soft horizons (apexols) is quickly translated by the use of lepto -, brachy -, ortho-apexols. In the same way a given apexol may top a heterogenous infrasol of sterite, steri-retichron, gravolite, etc. Typologic terminology thus takes account of multiple characteristics without however, masking the dominant morphogenetic characters. It is therefore a new way of developing the notion of the contained soil in a given spatial unit.

Typology has unified the means of description at the microscopic and field levels. Equally it allows for a greater or lesser complexity in the contained soils to be expressed. This said, we can now turn to the definition of some pedological spatial units. Several of them are already in current use (e.g., horizon, pedon), others are new. From the smallest to the largest the following spatial units can be named: microscopic, typological phase, horizon, pedon, pedological segment, pedological landscape and region. These are encoded as the following expressions, starting with the smallest, and in order of size: n-3, n-2, n-1, n, n+1, n+2, n+3. These different spatial units are contained within one another (Fig. 6). Thus several pedons (n) constitute a segment (n+1), several segments a landscape (n+2), etc. Figure 7 shows the degree of organisation of pedological groups.

Finally, for natural mappable soils the contained soil must be distinguished from its physiographic cover. A complete interfluve corresponds to the physiographic cover of a landscape. When the

Figure 7

SURVEY UNITS



pedological mantle can be analysed into several segments, the contents, like the cover, correspond well to that which has been defined as size n+2. But there also exist cases where the pedological cover is little differentiated. The cover then corresponds to a landscape (n+2) but the contained soil can be at the level of a segment (n+1) or even a pedon (n).

Figure 8 is an example of the representation of a cartographic unity. It shows the association of three semantic fields:- that defining the forms of relief; that of the typology of the soils; and, finally that of pedogenetical concepts.

This system has been used on the Ivory Coast. Maps (5 degree squares) have been made and the contained soils have been represented with the aid of a typological system. From these initial soil maps (segments and landscapes) other interpretative maps have been made to show the potential for the north of the country. These new maps are in fact the maps of land suitability for agriculture and include features such as slopes, hollows, rock outcrops, iron crust development, etc.

To conclude this overview I will briefly re-state the salient points covered. I have tried to explain an approach which has led us from the idea of diagnosis to the construction of a typology, then through to the notion of contained soils, and lastly the idea of pedological spatial units. In other words, it is about the path from theoretical reflection to practical utilisation. This approach has been made possible by concentrating research at the level of means of expression and from this to the transmission of information from specialist to user. Information transmission is carried out with the aid of a structural language which allows all the information collected in the field to be utilized.

Through these concepts of diagnoses, type, language, semantic division, combination, quantification, contained soil, physiographic cover, a new systematic methodology for the study of soils has been presented.

Figure 8

EXAMPLE OF A SIMPLIFIED LEGEND
GIVEN TO A PEDOLOGICAL SEGMENT

MORPHOLOGY - LANDFORM	SOIL - CONTENT
CONVEXO-CONCAVE SUB-LEVELLED HILL-TOPS	- LEPTO-APEXOLS AND BRACHY-APESOLS WITH RED STRUCTICHRON, SANDY-CLAY, PAUCICLODE. - INFRASOLS WITH STRUCTI-ALTERITE AND ALTERITE.

PEDOGENETIC CONCEPTS

FERRALLITIZATION, REJUVENATION BY EROSION

PEDOPLASMATION

Some of the advantages of this methodology have been stressed. It is important to emphasise that the approach has an interdisciplinary base (an identical language exists for studying plant structures, the forms of relief, landscapes). One final point must be made: the soil classifications (FAO/UNESCO (1974), Soil Taxonomy) are presented as work tools to be used on a world scale. Certain principles are imposed with the objective of making the transfer of information easier between countries. The new methodology presented here is founded on a language which also has a universal value. Also, it allows a certain independence, thus facilitating work performed at a regional scale. The diagnoses used can be adapted to particular areas or to various subjects, without restrictions. Pedogenetic concepts from one school of thought are not rejected but can be easily added according to the principle of semantic division. Finally, this language allows for conceptual diversity.

APPENDIX

Typological Language: Some Definitions

1) The first diagnostic level

STRUCTICHRON: mineral material, soft, relatively homogenous, having the structural organisation of a true soil, dissimilar to the material of origin. Thus, it is characterized by its colour and structure. Two variants can be identified.

DYSCROPHE STRUCTICHRON: is characterized by addition of organic matter which gives it a dull colouration. The dyscrophe structichron will be homogenous if the colouration is evenly distributed or heterogenous if the organic matter occurs as mottles or stripes (value 3 to 5 - chroma 3 to 5 in 10YR and 7.5YR hues; the chroma varies 3 to 6 in 5YR and 2.5YR hues, the value staying unchanged).

STRICT STRUCTICHRON: is characterized by the absence of organic matter and by bright red or yellow colours (value 4 to 6 - chroma 5 to 8).

GRAVOLITE: indicates a large concentration of nodules of metallic sesquioxides (>45%). This diagnosis is always associated with another (structichron, retichron, etc). The form of the nodules is variable. Sometimes the nodules consist of pseudomorphosed minerals or rocky fragments, or of altered material, strongly impregnated by metallic sesquioxides.

STERITE: represents hard and continuous formations of metallic sesquioxides. Sterites are rarely homogenous and show a very great variation in colour and facies. Two variants have been distinguished according to their hardness:

PETRO-STERITE: is very hard and cannot be broken without use of a spade.

FRAGI-STERITE: is not hard and can be broken up more or less easily in the hand.

RETICHRON: designates a usually soft material, yellow or beige in colour, mottled or marbled with red and red-ochre. This colouration may be reversed so that mottles and marbling are yellow or beige on a red or red-ochre background. In general the mottles or marblings make an alveolar or reticulate design in which the mesh measures several centimeters. It is an evolved mineral combination having no macroscopic analogy with its parent rock. A variant has been defined:

DURI-RETICHRON: This variant is characterized by slight hardening of the coloured mottles.

2) The second diagnostic level

ANGUCLODE: The planes of the separation faces and sharp edges constitute a structure of well defined angular aggregates. The anguclode type can include the polyhedric, prismatic and cubic pure types or associations of these. The basic units are of variable size.

PAUCICLODE: is characterized by cracks and angular edg s. They practically never separate out into really well formed angular blocky aggregates. Natural faces and artefacts derived from breakage yield angular blocks of variable size.

AMERODE: indicates massive and continuous structure but which can have rare fissures which are angular on splitting.

ALLATODE: indicates "floury", "powdery" or "degraded" structures. Elementary descriptive schemes are poorly adapted to accommodate these structures. The very fine elements (micro-aggregates) are distributed near continuously and without fissures. It is very porous and friable under pressure but it withstands erosion very well.

APEXOL: It is formed by assemblage of the humic and structichrome horizons. When the structichron is well developed only the upper part, directly allied to biological processes and fertility, belongs to the apexol. The transition to the lower part of the structichron where colouration is more pronounced and the pedo-climate is more regular, is very gradual. Thus, the limit between the upper structichron and the lower structichron is very difficult to define and has been fixed arbitrarily at 150 cms. This is also the lower limit of the apexol.

Several categories of apexols have been recognised according to their development:

LEPTO-APEXOL: It is comprised of one only humite, appumite, or melanumite.

BRACHY-APEXOL: It is formed of one humite, appumite or melanumite, and a structichron. Two degrees of development can be recognised.

- o BRACHY-APEXOLS PEU DEVELOPPES: They are composed of a humite, melanumite or appumite and a dyscrophe structichron.

- o BRACHY-APEXOLS STRICT: They are composed of a humite or appumite with a dyscrophe structichron and a strict structichron. But the combination is always less than 150 cms thick.

ORTHO-APEXOL: It is composed of a humite or appumite, a dyscrophe structichron and a strict structichron. The combination is at least 150 cms thick.

INFRASOL: It is composed of gravelly, retichrome, steritic and alteritic, regolic, psammitic horizons. A structichron can also be found in the infrasol. It can be derived from the structichron of an ortho-apexol, where it will be a deep structichron. If it appears under a gravolite, sterite, or gravelon it will be a hypo-structichron.

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SOIL TAXONOMY AND SOIL SURVEY

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Soil Taxonomy is one of the most valuable innovations in soil science for soil surveyors. It is one of the most important tools available for field survey and rates in importance and value with the spade, auger, colour book and field maps. Without Soil Taxonomy, the soil scientist cannot efficiently classify, interpret, and correlate the soils.

Looking back over my 25 years as a soil scientist I am amazed at the quality of the work completed without a classification system that facilitated both a better and faster completion of the job. With Soil Taxonomy we can be both more efficient and effective in field survey activities.

Using Soil Taxonomy, we can say more about the soils we map, but more importantly, Soil Taxonomy helps us know why we separate soils. For instance, today we recognize the difference between the Alfisols and Ultisols based on the base saturation of the argillic horizon at the stated depths. In the past we might not have separated these soils, or separated them without knowing why, except that they respond differently to similar kinds of management.

Soil Taxonomy provides many answers to field problems. It does not provide all the answers, however, as it is a dynamic system open to amendment or adjustment as more information about soils becomes available. It is this dynamic concept that will make Soil Taxonomy truly international, especially as pedologists from around the world help us better understand soils outside the United States.

I want to cover some generalized and simplified procedures for making a soil survey. First the soil scientist gathers together all the data available on the area to be surveyed. Such information includes previous soil surveys if available, and other resource data available on geology, landforms, vegetation, climate, etc. The soil scientist also meets with representatives of the potential land users to try and determine the anticipated uses for the survey. These people then work together to design the types of map units to be used in making the survey. This is important as it assures that the potential users of the survey will feel they are an integral part of the survey. In designing map units to meet user needs we need to be flexible. That is, we need to use different kinds of map units with different levels of input for different land uses.

Soil Taxonomy is very important to this process. Soil map units can be designed as phases of various levels or taxa in Soil Taxonomy. For instance a map unit can be the phase of a series, a phase of a family, a phase of a subgroup and so on up to the order level.

At this point it is necessary to define some basic terms used in soil surveys. First there are four basic kinds of soil mapping units. These are the consociation, association, complex and undifferentiated units.

Consociation is a coined term meaning a soil that is in association with itself, or what used to be called a monotaxon or single taxon unit. The consociation bears the name of the soil or taxon that dominates the unit. This taxon name can be anything from a series to an order. In very general terms a consociation contains at least 85 percent of the named or very closely similar soils, and 15 percent of contrasting soils.

An association contains two or more usually different soils or taxa occurring in a fairly regular or defined pattern, but the soil surveyor chose not to separate them, at the mapping scale and for the intended use. The association is named for up to three dominant taxa in the unit.

A complex contains two or more, usually different, soils or taxa that either occurred in such small bodies or were so intermingled that it was not feasible to map them separately at the mapping scale. They are also named for the up to three most dominant taxa in the unit.

In both the association and the complex, the defined major components occur in all delineations of the soil mapping unit bearing that name and usually in a somewhat similar pattern.

The undifferentiated soil mapping units contain two or more very similar soils that do not occur in any defined or recurring pattern. The taxa providing the unit name may or may not occur in all delineations. All taxa in the undifferentiated unit have similar interpretations, land use and management for the intended use of the survey.

Two other terms need clarification. These are taxonomic unit and soil mapping unit. A taxonomic unit is identified by the pedons or polypedons that fall within the limits of the taxon, regardless of where it falls within the classification scheme. For instance, at the series level, all polypedon that fall within the range of characteristics for that series, and that carry the name of that series are a taxonomic unit.

A soil mapping unit on the other hand includes all of the polypedons within a given delineation regardless of their taxonomic classification (which taxonomic unit they are in). A soil mapping unit may and usually does contain more than one taxonomic unit. It contains inclusions of other taxonomic units. A soil mapping unit is not only a single delineation on the map, but is also a collection of all delineations bearing the same phase name.

Thus, a taxonomic unit is the same as far as consisting entirely of pedons or polypedons that fall within the taxa providing the name for the unit. The soil mapping unit on the other hand consists of (1) all the taxonomic units that fall within a single delineation on the map, and (2) all the delineations or map units bearing the same name. The dominant taxonomic units (up to three) within a soil

mapping unit provide that map unit with its name.

The last term to be defined is phase. A soil phase is a management unit and is vital to the proper use of soil surveys. A phase consists of the map unit name plus other properties or characteristics that make it different or unique in use and management from other map units bearing the same taxonomic unit name. For instance we may have non-stony and stony phases of the same taxa (series, family, etc.) or different degrees of slope. These are phases as they directly affect use and management.

With these concepts in mind, the initial field soil map legend discussed earlier can be taken into the field and tested as a part of the soil survey.

In most modern surveys the soil scientist first selects representative areas and conducts a detailed transect of the areas. Aerial photographs or other base maps are interpreted before entering the field. The transect aids the testing of the air photo interpretation and the selection of sites for further observations. During the transect process, detailed descriptions of all the soils observed and records of all the observation sites are made. Depending upon the intensity of the survey, and the detail of mapping, the information learned from the transect is transferred to other similar areas. In very detailed areas of highly intensive land use and management, the soil scientist will transverse the entire area, enter as many delineations as possible and observe the soils. In areas of less intensive land use more reliance will be placed on air photo interpretation and transfer of transect data and less on detailed field observations.

This type of soil survey activity would not be either effective or efficient without a classification system like Soil Taxonomy. Because Soil Taxonomy has such strictly defined parameters it is usually not particularly difficult to classify a given pedon. Once a soil has been classified it is much simpler to compare the soil against other soils as the same taxa.

Soil Taxonomy also allows us to map soils at different levels of intensity by using different levels of taxa for soil mapping unit names - or put another way, defining soils at different taxonomic levels.

Listed below are some examples of taxonomic levels, taxonomic units, soil mapping units and phases. For ease of presentation the soil mapping unit and phase have been combined.

Taxonomic Level	Taxonomic Unit	Soil Mapping Unit (Phase)
Series	Suva	Suva silt loam, level
Family	clayey, mixed, isohyperthermic	clayey, mixed, isohyperthermic
	Typic Haplorthox	Typic Haplorthox, stony, steep
Subgroup	Typic Haplorthox	Typic Haplorthox, clayey, steep
Great group	Haplorthox	Haplorthox, clayey, steep
Suborder	Orthox	Orthox, steep
Order	Oxisol	Oxisol, steep

As is apparent, Soil Taxonomy allows us more latitude in designing and defining map units, and makes it considerably easier to compare taxonomic units. It has additional advantages in correlating and interpretating soil surveys (see p.227). The fact that Soil Taxonomy greatly assists in the correlation and interpretation processes makes it all that much more of a valuable tool in the soil survey process.

SOIL TAXONOMY AND SOIL CORRELATION

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What is soil correlation? Soil correlation is the procedure by which a high standard of quality in making and interpreting soil surveys is maintained. The correlation of soils within a specific area includes the development of recommendations about the naming of mapping units, or combinations of mapping units; careful review of these recommendations and modifications where necessary to place the soils properly in a nationwide system of soil classification. The ultimate usefulness of soil maps is greatly effected by the accuracy of soil classification and correlation, which includes comparisons of local classification units with those already defined and named in the nationwide system, and the grouping of these units into classes in higher categories. Soil correlation procedures normally encompass a series of meetings. The initial meeting is held prior to the commencement of the soil survey and includes an assessment of the logistics required for the survey to proceed effectively. Then there is a field correlation at an intermediate stage of the survey and a final correlation at the end of the survey to check that the units mapped are all fully defined and understood and matched with known units, or defined as new units.

What does soil correlation do for us? Well, soil correlation permits comparisons between soils within one country, for instance, within New Zealand. It permits comparisons between soils on different islands within one country, for instance, between Rarotonga and Aitutaki in the Cook Islands. It permits comparisons of soils on different islands in different countries, for instance,

between Tonga and Vanuatu and Hawaii. And it permits comparison between soils in totally different parts of the world, for instance, between Rwanda and Indonesia. These comparisons can be used as valid prediction of soil productivity only if they are based on a scientific, accurate soil classification system.

Problems of a Uniform Soil Classification

The various nationals involved in soil surveys in the South Pacific have tended to use the soil classification systems of their own country, and this has tended to inhibit the transfer of information between countries. Soil scientists lack a common classification whereby they can compare, group and correlate soils over the Region, and agronomists find it difficult to transfer information on such things as the results of fertilizer and crop trials between countries. The Suva Conference of 1976 (see p. 251) recommended that there was a need for the updating of earlier surveys to give better characterisation of the soils so that more basic data and soil properties (physical, chemical, mineralogical, agronomic) is available to potential users. Development of a common international soil classification system is considered crucial so that the results of fertilizer and agronomic trials can be more readily shared amongst the different countries. Of the systems available, Soil Taxonomy is by far the most effective in correlating soils and thus in enabling experience with soils to be transferred realistically. More detailed soil characterisation and reclassification of the South Pacific Region could be a long process, and it has been proposed that initially there should be a concentration on the soils of Research Stations in the Region. This is the basis of the current co-operative programme between the Governments of Fiji and New Zealand. Characterisation and classification of the soils in the more important and representative stations could enable the establishment of Benchmark sites. These would enable the results of soil and agronomic studies to be fully shared among the different countries of the Region. Ultimately, some linkage may be possible with the Benchmark Soils Project

administered by the University of Hawaii. Such linkage would tap a vast pool of information that is being derived by the Benchmark Soils Project on the agronomy of tropical soils.

The Impact of Soil Taxonomy on Soil Correlation

In New Zealand under the genetic soil classification system used up until the mid 1970s, there were many problems in correlating or comparing soils:

1. There was considerable difficulty in fitting surveyed soil units into ill-defined classes.

2. Soil series were never defined specifically.

3. Intergrades between soil units were overworked, for example, the Warepa series was classed in some surveys as a yellow-grey earth, and in others as an intergrade to a yellow-brown earth. It was uncertain whether the concept of the Warepa series had been stretched too far, or whether the different pedologists involved had different concepts of the boundary between the yellow-grey earths and the intergrades. Using Soil Taxonomy the Warepa series was clearly a Fragiaquept and there were no more arguments. This is an illustration of the powerful effectiveness of a precisely defined taxonomy in soil correlation.

Pacific Application - the Cook Islands

A modern example of the application of Soil Taxonomy to soil correlation is contained in a report by J.G. Bruce about to be published entitled "Soil Pattern and Classification of the Soils of the Southern Cook Group". In this report soils on different islands can be correlated with confidence, which means that valid productivity predictions derived from trials on Rarotonga can be applied to a number of other islands.

Conclusion

Soil Taxonomy provides the only practical and comprehensive system for transferring knowledge about soil similarities and therefore soil performance from place to place, region to region, country to country. It is not a simple system. The soil is not a simple system. The discipline required to use Soil Taxonomy is both superficially alarming and fundamentally convincing. To those of you who are sceptical, to those of you who have doubts, to those of you who are confused, my plea is to keep an open mind; to try the system in real situations and to be encouraged by the conclusions of others, that in a system of apparently overwhelming complications there is, indeed, an overriding simplicity.

AGRONOMIC/LAND USE IMPLICATIONS OF SOIL TAXONOMY

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Soil Taxonomy was developed not strictly as a scientific classification scheme, but as a scientific classification scheme that also has practical application in the use and management of soils. Soil Taxonomy makes it easier to map, describe, interpret, and use similar kinds of soils. It makes the technology learned about one soil much easier to transfer to another similar soil, or to a soil in another place.

Whereas soil surveys in the USA place major emphasis on the soil series, and phases of soil series, there is considerable interest in the agrotechnology research of the Benchmark Soils Project for here agrotechnology is being transferred at the family level. In order to bring the various elements of previous papers into perspective, it is appropriate to take a very generalized look at certain aspects of Soil Taxonomy and their agronomic and land use implications.

First, some of the key diagnostic horizons are reviewed, starting with the surface horizons or epipedons:

The Mollic epipedon is a mineral surface horizon that is dark coloured, friable, high in bases and high in organic matter. It is very fertile.

The umbric epipedon is like the mollic epipedon in all aspects, except it is low in bases. It responds well to applications of plant nutrients.

The histic epipedon is an organic surface horizon that is saturated with water for at least short periods and is extremely high in organic matter.

The ochric epipedon is one that does not meet the requirements for the other defined epipedons. It may meet all the requirements for a mollic or umbric epipedon but is too thin or too light coloured to qualify. It may be dark or light coloured, high or low in bases or organic matter, soft and friable, or hard and firm and massive.

Now a brief look at some of the diagnostic subsurface horizons:

The cambic horizon is one that shows slight evidence of weathering or alteration. This alteration is evidenced by redistribution or removal of carbonates, removal of bases, reaction of iron oxides giving rise to redder or brighter colour, or gleyed colours in combinations of other specified properties.

The argillic horizon is the horizon of maximum clay accumulation. It represents a more advanced stage of weathering than the cambic horizon, but still contains lattice clays that may or may not be high in bases. A natric horizon is an argillic horizon high in sodium.

The oxic horizon represents the most advanced stage of weathering. The lattice clays are weathered and sesquioxides have accumulated. It is very low in bases and differs from the cambic horizon in this respect. The oxic horizon differs from the argillic horizon by lacking clay films and by lacking an increase in clay with increasing depth.

Pans, such as a duripan, petrocalcic horizon, placic horizon, are subsurface horizons that are cemented by a variety of materials including iron, aluminium, calcium carbonates, silica or any combination of these materials. They restrict the downward movement of both roots and water.

At this point, a general review of some of the orders and how their properties relate to agronomic and other land use decisions is presented. Exceptions can always be found for most statements. A more generalized review will be of most value at this stage. Detailed criteria are included in Soil Taxonomy, hence more specific agronomic and other land use decisions can be inferred.

The Entisols are essentially the very young soils formed on recent alluvial fans, or flood plains; unstable soils on mountaintops; or soils whose geologic erosion is in equilibrium with soil development. Some Entisols are so young or so 'raw' it is difficult, even questionable, to call them soil. Entisols have a very wide range of soil moisture and temperature regimes, texture, mineralogy, slope, vegetative cover, and landform. They are deposited by wind, water, or gravity; are nearly level to extremely steep; and are excessively drained to very poorly drained and ponded.

Since about the only characteristic the Entisols have in common is their lack of genetic soil horizons, it is extremely difficult to make generalizations about their potential for use and management - at the order level at least. Much more can be said about Entisols at the suborder or lower taxa levels. For instance, the Aquents are wet Entisols whose use and management are limited by a periodically high water table. Fluvents are Entisols on flood plains whose use and management is limited by periodic flooding with its associated scouring and deposition of new materials. Psamments are the sandy Entisols with low available water capacity and nutrient retention capacities, high soil blowing hazard, low bearing capacity when dry, and rapid permeability.

The Vertisols have not been discussed formally. However, they warrant a quick review. The Vertisols, like the Entisols, lack diagnostic horizons. Here, however, is where the similarity ends. Vertisols are the high shrink-swell clayey soils. They swell or expand when wet, and shrink when dry, and form deep wide cracks. They have high bulk densities, typically have a high percentage of organic matter and bases and low permeability. Temperature regimes

range from isohyperthermic to frigid. They have torric to udic moisture regimes but not aquic. Vegetation is typically grass or savannah, although desert shrubs are common on the Torrerts. Vertisols are typically clayey with the clay fraction dominated by montmorillonite.

Vertisols are used for livestock grazing and for crop production. They are excellent soils for rice or cotton production. They have a much higher energy requirement for tillage than do the Entisols. They have limited available moisture contents for some crops due to a relative lack of pores although they have high water storage capacities. When they can be successfully manipulated, they should not be tilled if either too dry or too moist. The Vertisols respond favourably to applications of the major plant nutrients. The Vertisols have severe limitations for engineering and urban uses. The high shrink-swell and low strength of these soils make them poor choices for use as construction materials or as foundation material for structures.

Inceptisols are characterised by some evidence of alteration within the soil profile as suggested by weak pedogenic horizon development. They may have mollic, umbric, ochric or histic epipedons but lack illuvial horizons, such as the argillic horizon. They are roughly intermediate in weathering between the Entisols and the Alfisols. Inceptisols cover a wide range of soil moisture and temperature regimes, landforms and vegetation. However, they do not have an aridic (torric) moisture regime. They dominantly have loamy textures and mixed mineralogy.

In general, Inceptisols are well suited to both irrigated and non-irrigated crop production. The loamy texture and mixed mineralogy make them fairly easy to manipulate. They respond favourably to applications of nitrogen, phosphorus and potassium but may require applications of trace elements and lime in some areas. They typically have favourable available water capacities.

Inceptisols as a general rule are suited to most engineering and urban uses. The primary exception is those with an aquic moisture regime. They are a fair to good source for construction materials and provide fair to good foundations for structures.

The Alfisols follow the Inceptisols on the weathering scale. They have silicate clay enriched illuvial horizons that are moderate to high in bases. Typically they have ochric epipedons with the argillic horizon. They are higher in bases than the Ultisols but may be lower than the Mollisols, more weathered or strongly developed than the Inceptisols, generally lower in organic matter than the Mollisols and more moist and lower in bases than the Aridisols. Alfisols formed mostly under either forest or savannah vegetative cover. They are on relatively stable landscapes that are moderate to old in age. The Alfisols are basically loamy or clayey with mixed or montmorillonitic mineralogy. Some, however, have kaolinitic mineralogy. They occur in aquic, udic, ustic, and xeric moisture regimes, and all temperature regimes.

The Alfisols are suited to either irrigated or non-irrigated agriculture. Typically the Alfisols are less permeable than the Inceptisols of similar texture, as they contain illuvial clay in some or all pores thus restricting water movement. They respond to applications of nitrogen, phosphorus and potassium, and to some minor nutrients, especially sulphur and lime. They are suited to most urban and engineering uses, except for the clayey, montmorillonitic Alfisols that are poorly suited to these uses.

The Mollisols do not fit the weathering sequence of the Entisols-Inceptisols-Alfisols, etc. because they may have almost any diagnostic subsurface horizon, or may lack such horizons entirely. The common element of the Mollisols is the presence of a mollic epipedon, i.e., they have dark coloured, friable, base and organic matter rich surface horizons. The Mollisols were established to provide taxa for the grassland soils of prairies and steppes. They were intended to recognize those soils that have a good potential for non-irrigated crop production. The Mollisols have a wide variety of soil moisture

and temperature regimes although the aridic (torric) moisture regime is expressly excluded. They cover a wide range of soil texture and mineralogy (except sesquioxide).

Although the only property Mollisols have in common is the mollic epipedon, it is possible to make some generalized statements about their use and management. The Mollisols, by intent, are well suited to non-irrigated opland, e.g.,small grains, sorghum, maize (corn) and soybeans, and for livestock grazing. Many Mollisols are also suited to irrigated crop production. Because of the friable epipedon, most Mollisols are easy to manipulate with fairly low energy requirements. They also respond favourably to applications of nitrogen, phosphorus, and potassium. Many Mollisols are suited to a variety of engineering and urban land use. However, their suitability may be dependent upon the texture and mineralogy of the subsurface horizons and moisture regime (Aquolls). Mollisols are a good source material for topsoil. When they are disturbed for various urban or engineering uses, the surface layer is often stockpiled for re-use as topsoil after the manipulation has been completed.

Aridisols are rare in the tropics although a few do occur at the extreme margins and in the rain shadow of high mountains. They are much like the Mollisols, except for the lack of dark colours and high organic matter in the surface layer (ochric epipedon) and have an aridic (torric) moisture regime. They essentially cover the full range of temperature regimes. Aridisols are mostly formed under a desert shrub-grass vegetation on relatively young to ancient landscapes. They are usually high in calcium and may also be high in soluble salts and sodium because of incomplete leaching of the soil profile due to limited precipitation. They may have horizons of silicate clay accumulations (argillic horizon), horizons of alteration (cambic horizon) or lack these horizons. Duripan, petrocalcic, calcic, salic or gypsic horizons are not uncommon. Aridisols cover a wide range of texture and mineralogy.

Aridisols are used mostly for livestock grazing. They are used for cropland only where water is available for irrigation. Their suitability for irrigation depends upon the type of subsurface horizon present, and on the presence of excess sodium or salts. These properties can be inferred by lower taxa names. For instance, a Nadurargid would be an Aridisol with a natric horizon high in sodium underlain by a duripan. Aridisols require some nitrogen and phosphorus, but generally have adequate amounts of potassium. Aridisols have a variable suitability for urban uses, depending upon the kind of subsurface horizon present, texture and mineralogy, and the presence of excess soluble salts, gypsum and sodium.

Ultisols represent an advanced stage of weathering. They have relatively thick silicate clay-enriched argillic horizons. They typically are high in extractable aluminium and very low in calcium. They are more weathered and lower in bases than Alfisols and less weathered and higher in bases than the Oxisols. Ultisols are formed under a forest vegetation on relatively old stable landscapes. They have mostly loamy and clayey textures with mixed or kaolinitic mineralogy. They are more permeable than the Alfisols as they are more highly weathered and are dominated by 1:1 lattice clays. Where Ultisols are marginal to Oxisols, they are often difficult to separate.

Ultisols are used for a variety of crops. They require large amounts of nitrogen, phosphorus, potassium and calcium for maximum production, and to maintain optimum productivity. They can also require additions of trace element fertilizers. They respond favourably to applications of organic matter such as compost or manures. Power requirements for soil manipulation are generally lower than for Alfisols of comparable textures. Ultisols are generally suited to most engineering and urban uses. However, they do cause severe corrosivity problems for concrete and uncoated steel due to their high acidity. The argillic horizon in Ultisols is less expansive, i.e., has lower shrink-swell potential, than in Alfisols.

Probably less is known about the Oxisols than any of the orders already discussed. They are absent or rare on the continental United States, and USDA experience is limited to relatively small areas in Hawaii and Puerto Rico. The Oxisols represent the extreme or ultimate in weathering. They typically have weathered to great depths, and have weakly expressed horizonation. They are more rapidly permeable in relation to the clay content, when compared to other orders, as the Alfisols, Mollisols, Ultisols, and Vertisols. The Oxisols are generally formed under tropical forests on ancient stable landscapes. Most Oxisols are clayey, and are dominated by sesquioxides. Typical mineralogy is ferritic, oxidic, or gibbsitic.

Oxisols typically have low productivity for cultivated crops unless large amounts of both major and minor nutrients are applied. Applications of organic matter are also important in maintaining the productive capacity of these soils. Many areas of Oxisols are bare and probably never will produce vegetation without help from man. As a result they are source areas of sediments because of the severe erosion problem. In some instances the soils have been subjected to sufficient sheet erosion that concretions have been concentrated and now completely cover the soil surface. The Oxisols have unique engineering properties that are not fully understood. They are, however, generally fairly well suited to most engineering and urban uses.

As stated earlier, less is known about Oxisols. The USDA is relying very heavily on the knowledge and experience of the international soils community to help fill in the blanks, and to strengthen the weak spots in their classification.

Histosols are of considerable significance to this Region, even though they are of minor extent. It is important that land users and planners be aware of their extent and locations because of their unique properties. Histosols are organic soils, as contrasted to soils of other orders, which are mineral soils. Histosols are mostly saturated with water, though some are not. The wet Histosols formed under a cover of water-tolerant plants.

They are commonly formed in mangrove swamps in the Pacific Region. The non-wet Histosols are formed under tropical forest. All have low bulk densities.

Histosols are suited to a wide variety of crops. In the wet areas, if used for water-tolerant crops, such as some taro varieties, little management of the water table is needed. However, if water sensitive vegetables, some root, grain or tree crops are grown, management of the water table is critical. If lowered too much, the soils will subside through oxidation of the organic matter, and if not lowered below the root zone the plants will not produce well or will die. These soils are also subject to severe wind erosion if left exposed. The drier Histosols, i.e., the Folists, are suited to a variety of crops but they, too, need to be protected from wind erosion. Histosols are generally unsuited to most engineering and urban uses. They have very poor bearing capacities and do not support foundations or equipment. Normal engineering procedures call for the complete removal of these materials, or expensive specialized design to overcome their very poor load-bearing capacity.

The last order to be discussed is the Andisols. This is not presently a recognized order in Soil Taxonomy, but is a proposed order that appears to have an excellent chance of being adopted. The Andisol order will include most if not all of the "Andepts" suborder of Inceptisols and the "Andic" subgroups of several other orders.

Andisols are formed in volcanic ash and other vitric pyroclastic materials. They are characterised by low bulk densities, high cation exchange capacities, and a high organic matter content. They support a wide variety of vegetation although commonly forest. Andisols are characterized by amorphous materials and many still contain unweathered or devitrified volcanic glass. In areas of "recent" volcanic activity these soils often have layers of ash that has not yet weathered.

Andisols are in general well suited to the production of a variety of crops. They are typically deficient in phosphorus and nitrogen. Some are also deficient in lime, and trace elements. They have high phosphorus retention. Andisols have low-bearing strength and are poorly to fairly suited to most engineering uses or as construction materials. The majority are subject to a severe piping hazard when used in water retention structures. Some even liquify when subjected to compaction by heavy equipment as in harvesting of crops or construction (Hydrandepts).

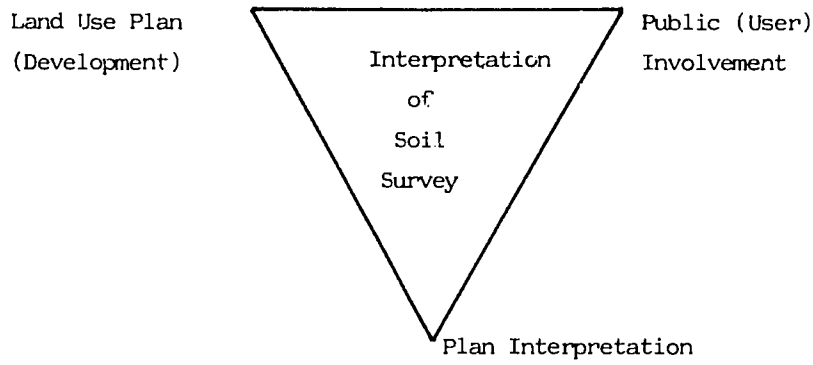
Discussion has centered almost exclusively on applying Soil Taxonomy to land use decisions at the order level. The discussion has also, of necessity, been generalised. The same concepts used in this discussion can be applied to any taxa - order, suborder, great group, subgroup, family, or series. The key is to know and understand the terminology or nomenclature. By understanding the formative element, the definitions of the various diagnostic horizons, the other diagnostic characteristics and the family criteria, certain broad statements can be made about most soils at some higher taxa. For instance, it is known that Psamments are sandy Entisols - the element psamm coming from the Greek psammos meaning sand, and ent being the element for Entisols.

Soil Taxonomy at first glance appears to be very complicated and difficult to use. Taxa names are awkward and can be very long, especially at the family level. However, with a little patience and study those awkward looking names can be, and in fact will be, very meaningful and will serve as a valuable tool for land use planners. Remember, Soil Taxonomy was developed to provide the field soil scientist and the user of soil surveys with a viable and most useful tool in making land use planning decisions.

LAND USE PLANNING

Land use planning can be considered as a triangle with soil surveys and interpretations as its heart. One point is the land use plan or the development of the plan; the second point is an

informed community or user, vital to the success of any plan; and third is the implementation of the plan. Even the most well thought out and presented plan is of little value if it is not implemented.



Before proceeding two questions need to be answered:

(1) What is a soil survey and how do we interpret it?

(2) How do soil surveys affect land use planning?

A soil survey gathers basic facts about the soil and its environment.

Slope

Climate	Erosion
Vegetation	Overflow

Soil Factors

Permeability	Salinity
Depth	Texture
Water	Nutrients

After the soil factors have been gathered, the next step is to determine the type of interpretation needed. Once this is determined basic assumptions must be agreed upon and specific criteria developed. Criteria must be developed by an inter-disciplinary team of specialists who understand the land use and its soil-related problems.

Soil interpretations can be divided into three broad groups:

Single Factors	Soil Groupings	Soil Ratings
Texture	Land Capability	Limits or Suitability
Depth	Irrigation/Non-irrigation	Filter Fields
Slope	Range	Shrink-swell
Erosion	Woodland/Timber	Corrosivity
Permeability	Wildlife	Topsoil
Flooding	Hydrologic	Sand/Gravel
Water Table	Unified	Roadfill
Nutrients		
Drainage		

In developing criteria, the major soil characteristics are determined and definite parameters determined for each degree of suitability or limitation. For instance for shrink-swell potential:

Soil Property	Limitation Low	Medium	High
% Clay	0 - 18	18 - 35	> 35
COLE (in/in)	0 - 0.03	0.03 - 0.06	> 0.06

Soils falling in the high category above will contain large amounts of 2:1 lattice clays and form large deep cracks when dry and seal over when wet. Vertisols - one order of high shrink-swell clays-are usually unstable and on steeper slopes may tend to move down slopes.

Criteria for limitations for septic tank filter fields are even more complicated. Soil characteristics considered could include permeability, depth to water table or restrictive layer, slope, flooding, and drainage class.

Wet soils (aquic) are poorly suited to septic tank filter fields as effluent will not filter through the subsoi'.

Highly stratified soils with strata of contrasting textures, or soils with dense clayey subsoils are also unsuitable for filter

fields because of restricted downward movement of water and effluent.

Planning or development of land can be either desirable or undesirable. For instance under undesirable development, the best farm lands are developed for non-farm uses, leaving nearby marginal agricultural soils standing idle. However, under desirable land use good farm lands are retained for agriculture, and marginal farm lands are used for non-farm developments.

Single purpose interpretative maps can be developed for any group of interpretations - e.g.,for single factors we could have permeability, slope, erosion or other maps. These maps would show graphically where the slight moderate and severe erosion hazards occur in a given area. Similar maps can be developed for range sites, for building sites or any of the other numerous interpretations that are made.

By using Soil Taxonomy we can take any soil map and prepare a specified area plan giving the best locally adapted uses for that area. A knowledge of locally adapted crops, community needs, the chemical and physical limitations of the soils (through the classification), will help achieve a better result in land use planning. This is done by matching crops and land uses to a suitability of soils as much as possible.

Soil Taxonomy provides a dynamic tool that greatly assists the transition from soil survey to land use, development, and management.

DATA STORAGE AND RETRIEVAL

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Soil surveys and computers were made for each other. Thus, in the USA many of our soil survey activities either are, or will be, computerised. This paper discusses some of the ways the U.S. Soil Survey Programme uses computers to assist soil scientists do their work more effectively and more efficiently.

The National Soil Survey Laboratory in Lincoln, Nebraska makes considerable use of computers. In fact some of their tests are so highly mechanized and computerized that the technician is really not required from the time the test is first set up until after the computer prints out the final results. The computer weighs, measures, records, mixes, and calculates the results. Depending upon the programme, it will recalculate in desired formats.

Probably the most popular or well known computer programme is the soil survey interpretation programme. This programme is maintained at the Iowa State University Statistical Laboratory, Ames, Iowa. In this programme field soil scientists complete the soil properties part of the Form SCS-Soils-5. The scientists estimate the percent of the soil passing through various sieves, and other properties such as permeability (or hydraulic conductivity), available water capacity, depth, duration, and period (in months) of a water table, depth to bedrock or duripan and other soil properties that directly affect use and management. Using these properties the computer was programmed to estimate the degree of soil limitations for a variety of land uses. These soil limitations are currently the keys to specific types of land use planning and management decisions. The next logical step is to convert soil limitations to soil potential

ratings based on the current state of the art in technology and economics.

In the western United States, the USDA has developed a computer programme to assist authors in writing their soil survey manuscripts. Called Computer Assisted Writing (CAW), it allows authors to format their text from pre-edited statements. Briefly, the author sends discrete statements about the soil to the Technical Service Center (TSC). There the editor edits the statement, assigns it a unique code and 'feeds' it into the word processor. When authors write their soil series descriptions and map unit descriptions, they submit a work sheet with all the codes in proper sequence. If variable data such as elevation, precipitation, depth, etc. are required these are shown on the work sheet in appropriate format. Upon receipt of the work sheet, the TSC editor reviews it, and then turns it over to the word processing operator who, in a matter of a very few minutes, provides the author with a completed map unit description, which can be easily revised and updated as needed. This procedure is being used in the majority of survey areas in the western United States, with favourable results and considerable savings in time.

Another use of computers that is gaining in popularity is the use of digital computers to develop families of interpretive or single purpose maps based on the soil map. First the basic soil map is digitized or 'fed' into the computer. The various soil properties and interpretations are then processed by map units on the soil map. From this basic data, the computer produces various types of interpretive maps such as limitation ratings for residential sites or suitability as a source of topsoil, single purpose maps such as location of soils with high shrink-swell potential or with flooding problems, or soil properties maps such as slope, surface textures, depth to rock, etc. These in turn are used by land use planners or managers in helping to visualize specific problem/ suitability areas.

Another way that computers play a vital role in the soil survey programme is the digital image processing and analysis of Landsat imagery and reflectance spectra. By using the computer to interactively manipulate a Landsat scene and analyze the reflectance pattern, geologic formations, vegetative cover and broad soil associations can be determined. In addition, analysis of Landsat data provides us with a tool to monitor cropping systems, land use patterns, irrigation efficiency and soil moisture conditions. Thus, computer technology has assisted the field of soil science in numerous ways.

A large variety of other computer programmes are used in the U.S. For instance there is a programme which schedules all phases or steps in the 'life' of a soil survey from the initial field review and approval of the memorandum of understanding (work plan) through to the actual publication of the survey. Another programme gives estimates of soil moisture and temperature regimes based on at least 30 years of records of climatic data. All soil series in the USA, their clarification and the State responsible for the description, plus additional data make up another programme. Yet another programme is a file of all map units correlated after a given date, and includes acreages of each, range sites, flooding potentials, interpretation record numbers, class determining phases (those unique phase names that interpret differently from the model for the named series), surface texture, and similar data. There are numerous additional programmes, but those discussed above give some idea of the variety of soil survey activities that are currently computerized.

What does the future hold? Inevitably, more exciting and useful computer programmes will be developed.

For instance,a programme is being developed in the U.S. to input all official soil series descriptions into the computer for quick retrieval at both State and local levels. This would dramatically reduce printing costs and workload. The second phase of this project is to develop a programme to evaluate the validity of each

series through testing selected soil series criteria. A third phase could be to test both Soil Taxonomy and our soil interpretation criteria by combining information from the soil series file being developed and the existing laboratory data file and soil interpretations files. This will facilitate the testing of the theory that Soil Taxonomy is in fact based on, or biased towards, soil interpretations. To many, this programme is long overdue, and soil scientists in the Western USA are giving this concept high priority during the 1981 fiscal year.

Another programme long overdue in the U.S., but which New Zealand soil scientists are already working on, is the computerization of Soil Taxonomy. Among the many applications such a programme would have are (1) it would allow us to finally test the existing criteria in Soil Taxonomy; (2) it would permit us to test any proposed revisions to Soil Taxonomy, and (3) it would allow us to determine all parts of Soil Taxonomy that would be affected by any revisions and/or additions to the system. Certainly there are several other applications of a programme that analyses all the criteria used in Soil Taxonomy.

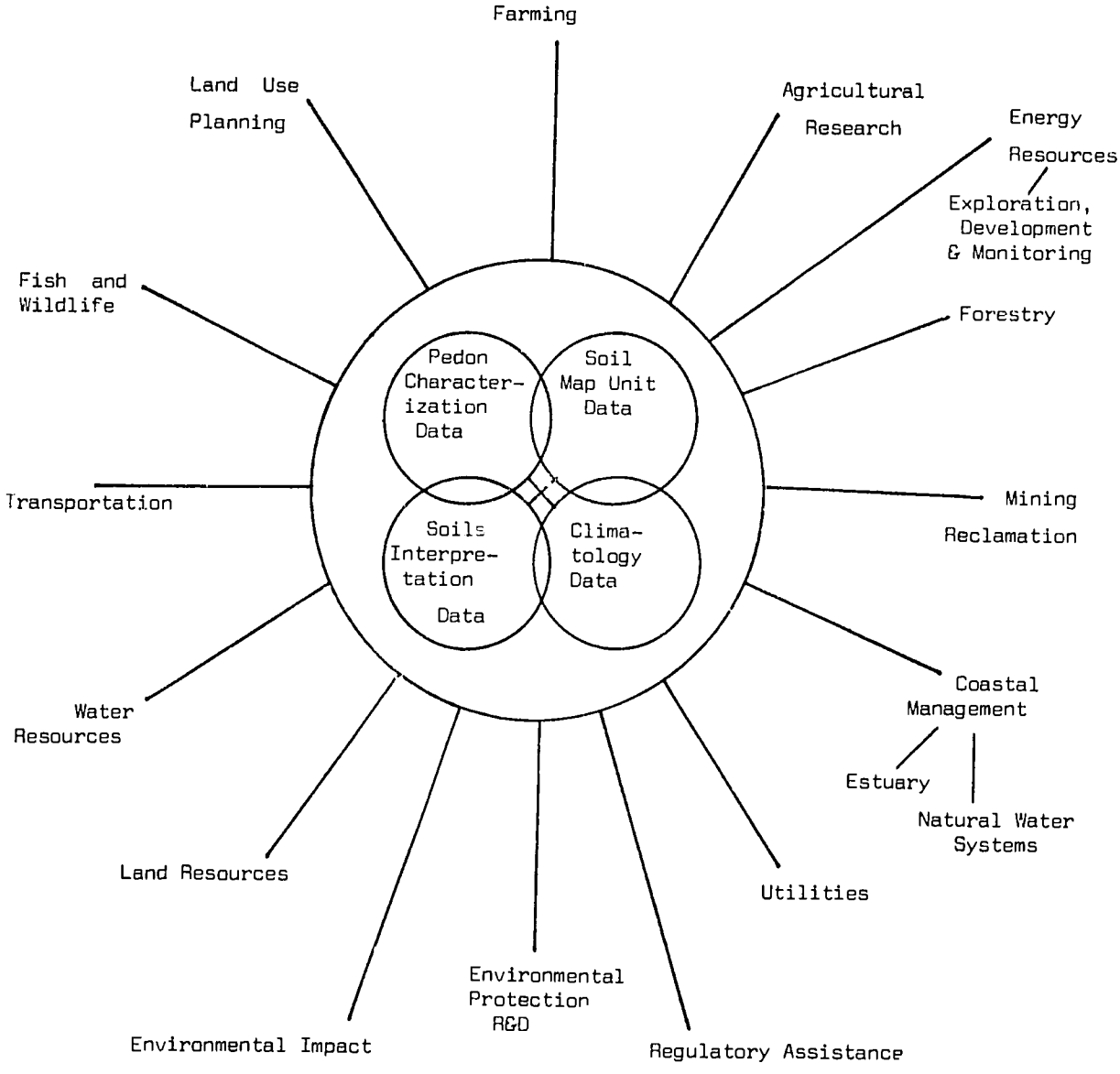
A logical next step to specific programmes is the development of Soil Information Systems.

Basically, information systems are designed to access, examine, and analyze information for specific purposes. An integrated information system gathers data from all available sources. It might include information on soils, climate, geology, vegetation, economics and demographics, to develop a land use programme that best fits the needs and desires of the local community. A number of soil information systems are in existence today. The agrotechnology transfer implications of the Benchmark Soils Project provides a good example (Uehara p.

Another project is the Soil Resource Information System (SRIS). This is a cooperative project between the Colorado State University Department of Agronomy, the Laboratory for Information Science in

Figure 1

Soils Resource Information System



Soils Survey Data Component Organization and Displays

Agriculture (LISA), the College of Agricultural Sciences and the USDA, Soil Conservation Service. The goals of this programme are:

1. Identify and obtain data and information concerning soil resources from relevant suppliers of soils data.

2. Integrate and create compatibility and coordination among key suppliers of data.

3. Identify the necessary features of soil information systems required by the community of current and potential users.

4. Develop a demonstratable pilot segment of SRIS emphasizing required features.

5. Develop a work plan for the comprehensive implementation of SRIS.

The heart of this programme - or the major components - are Soil Survey Data; Soil Interpretation Records (SCS-Soils-5's); National Pedon Data System; and Climatological Data. Some sample displays already available or planned include Land Use Planning, Agriculture, Agricultural Research, Forestry, Mining Reclamation, Coastal Management, etc. (Fig. 1).

The implementation work plans will be tested, or developed for the uses planned at the start of the project. Pilot plans are being developed and tested for additional displays such as range. Additional information including progress reports and work plans are available from Colorado State University, College of Agriculture.

Comments in this paper have been confined to data manipulation in the United States, by the Soil Conservation Service. I'm sure Dr. Leamy, Dr. Uehara and other resource persons at this Forum could elaborate on what their organizations are doing in the field of data storage and retrieval.

EVALUATION OF THE RECOMMENDATIONS OF THE 1976 SPC REGIONAL TECHNICAL MEETING ON SOIL SCIENCE AND LAND USE

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Recommendation No. 1

In an analysis of soil surveys completed in the Region, it was noted that while extensive coverage existed there were still some gaps. The Meeting recommended that Governments plan to complete at least reconnaissance scale (about 1:250,000) soil surveys of all productive land in the Region over the next three years. Detailed surveys (scale about 1:5,000) should also be conducted of all agricultural research stations in the Region. This will allow full use to be made of available information in all aspects of land use planning.

This recommendation was advised to Governments. It is a good opportunity to ask participants if this recommendation was applied in the Pacific countries.

Recommendation No. 2

In the analysis of the availability of information on climate, geology, vegetation and topography, and of cartographic and air-photo resources, which are necessary for effective soil survey operations and subsequent land use planning, it was noted that coverage in many areas is still inadequate. The Meeting recommended that Governments review their programmes of basic resource surveys to provide effective back-up for soil and related land use surveys.

This recommendation was advised to Governments. Participants could inform the Regional Forum in Soil Taxonomy if their own Governments have already reviewed (or started to review) their programmes of basic resource surveys to provide effective back-up for soil and related land use surveys.

Recommendation No. 3

> In a review of the use of soil information in the Region, it was noted that much valuable information was not being fully used in government policy-formation and decision-making processes. The Meeting recommended that Governments actively encourage closer co-operation and regularly scheduled meetings between soil scientists and planners to make full use of soil information available in national planning processes.

As far as we know, soil scientists and planners have had closer co-operation to make full use of soil information available in national planning processes and national rural development.

Recommendation No. 4

> The Meeting noted that few participants were fully aware of soil studies being carried out in other countries in the Pacific. The Meeting recommended that Librarians of institutions responsible for soils work develop, in co-operation with the South Pacific Commission, active exchange of published material in the Region.

Limited exchange of published soils material is being carried out, but there are serious obstacles to a better flow of information. These are:

(1) In many countries, such publications are not normally sent to the institutional, departmental, national or university libraries, or to the South Pacific Commission Library. They are therefore not recorded and not made available to a wider public.

(2) In many countries, libraries are run by untrained staff with insufficient educational qualifications and, even in countries which have libraries staffed by professional librarians, these libraries are understaffed and under-equipped to acquire, organize and disseminate all relevant publications in their field or published in or about the Pacific.

It is therefore unrealistic to expect marked improvement in the exchange of soil science publications (or any other publications) unless:

(i) writers and publication services ensure that their publications are sent to relevant libraries at least in their own countries and preferably also to a regional institution with an organized library service, e.g., the South Pacific Commission and the Library of the University of the South Pacific;

(ii) scientific workers campaign for improved library services in their own countries and for the development of regional information services, such as in the South Pacific Commission, the South Pacific Bureau for Economic Co-operation and the Regional Bibliographic Centre.

The Regional Bibliographic Centre is at present staffed by the Library of the University of the South Pacific. It was set up in 1980 at the request of the Standing Conference of Pacific Libraries, comprising libraries in Australia, New Zealand, Hawaii, the Cook Islands, Fiji, Guam, Kiribati, Papua New Guinea, Solomon Islands, Tuvalu, Western Samoa, SPEC and SPC, who agreed to co-operate in the collection of publications for the preparation of bibliographies and indexes. The

Centre is at present preparing submissions to funding agencies in order to develop and extend its formation services which would necessarily include soil science.

The need to organize and disseminate soil science information is therefore part of the wider problem of information services in the South Pacific Commission area. Scientists and librarians need to co-operate more closely in finding solutions and funding to overcome the deficiencies.

Recommendation No. 5

The Meeting noted that no uniformity in soil classification or soil correlation procedures exists in the Region. It further noted that lack of uniformity was preventing useful exchange of information between countries of the Region and between the Region and other parts of the world. It was recommended that an active programme of characterization, classification and correlation be established with the objective of completing coverage of research stations, important agricultural areas, development areas and areas of special interest within the next three years.

The Meeting called on the South Pacific Commission to approach Governments and Territorial Administrations in the region to co-operate in a 3-year characterization, classification and correlation programme. It is requested that participating Governments support a small team of experienced soil correlators to make a few visits within the Region each year. Such support should include limited laboratory services. Soil classification should be in terms of international soil classification systems which are in extensive use throughout the world - the U.S. Soil Taxonomy and the French Soil Classification.

In order to implement this recommendation in connection with recommendations No. 1 and No. 11, the SPC Tropical Agriculturalist personally took action with a Soil Scientist from ORSTOM Noumea

during the Fifth Regional Conference of Permanent Heads of Agriculture, Livestock Production and Fishery Services which was held in Noumea, New Caledonia, from 21st to 25th March 1977: "The Meeting called on the South Pacific Commission to approach Governments and Territorial Administrations in the Region to cooperate in a 3 year characterization, classification and correlation programme".

The ORSTOM representative referred to recommendation Nos. 1, 5, 8 and 11 made by the Regional Technical Meeting on Soil Science and Science Use. As these recommendations called for implementation at Government level, it was clearly difficult to discuss them at the meeting. "Interested researchers should nonetheless remain in contact and determine to what extent the recommendations can be implemented". (Cf. Report, page 29, item 88).

On the 16th October 1977 a meeting took place at SPC Headquarters, Noumea, with the Director of Programmes (Mr G. Motha), Mr. D.M. Leslie, Soil Scientist - DSIR,New Zealand, Mr. Marc Latham, Soil Scientist - ORSTOM, Noumea, and the SPC Tropical Agriculturalist. At this time, a representative from the Commonwealth Fund for Technical Co-operation, London, was visiting SPC Headquarters. It was suggested that the Tropical Agriculturalist draft a project to be submitted to this C.F.T.C. representative. The proposal was drafted as follows:

"In order to implement recommendations which are of main interest for agronomists, agricultural extension officers and farmers, and referring mainly to Recommendations 1, 5 and 11, it is proposed that a soil scientist team from DSIR - New Zealand (Soil Bureau), ORSTOM Noumea, and the University of Hawaii visit the following territories: Fiji, French Polynesia, New Hebrides, Niue, Western Samoa and American Samoa. This team will -

(i) carry out detailed surveys (scale about 1:5,000) of most of the agricultural stations. This will allow full use to be made of available information in all aspects of land use planning;

(ii) make soil classification and correlation in terms of international soil classification systems which are in extensive use throughout the world - the U.S. Soil Taxonomy and the French Soil Classification;

(iii) collect agronomic information which exists in these countries that would be of regional value. This information should be recovered and evaluated in terms of soils and crops, and of fertiliser recommendations, for farmers.

Summary of Detailed Expenditures

(Based on one soil scientist from the following countries:- New Zealand, New Caledonia and Hawaii)

	A$
- Duty Travel	4,000
- Per diem allowances (40 days x 30 x 3)	3,600
- Unforeseen events	400
	8,000

- Government and Local Administrations will provide local transportation and field support.

Note: Report of these three soil scientists will be published in both languages - English and French - by the South Pacific Commission."

The C.F.T.C. never supported this proposal and the SPC Secretariat did not put this item on the proposed budget.

Recommendation No. 6

The Meeting noted the successful operation of the University of Hawaii's Benchmark Soil Programme in Asia and Africa. It was pleased to learn of the availability to countries of all technical information related to the

project. The Meeting recommended that:

(a) territories and countries with important soils in the soil families covered by the Benchmark Soil Programme consider taking part in the programme and thereby drawing on the wide range of knowledge of these soils now becoming available from other parts of the world;

(b) the concept of a regional Benchmark Soil Programme on soils important to the Region using crops important to the Region, be accepted as the basis for a follow-up soils and land use programme. This programme should follow the soil classification and correlation phase but initial planning could be started now in some countries. Territorial Administrations and Governments are requested to support this work.

The soil classification and correlation programme was not applied; Territorial Administrations and Governments were requested to support this work. It is very interesting to get comments from participants of the present meeting.

Recommendation No. 7

The Meeting noted that many different methods of chemical soil and plant analysis were used in the Region and that the results were expressed in many different ways. It was recommended that a survey of methods be undertaken and welcomed the offer of the University of Guam to undertake the survey. The results should be discussed with laboratory staffs in an effort to rationalise procedures so that analysis data can be more readily exchanged and understood throughout the Region.

It was an offer from the University of Guam. SPC did not receive any confirmation of this offer by the University of Guam. However, a letter from Mr D. Leslie indicated that "I had written personal, unofficial letters to Kato Tama, Tomasi Simiki, Satish

Chandra, Nusi Muala and Jef Demeterio asking them to encourage their respective Governments to write official letters to SPC requesting adoption and implementation of some, if not all the 1976 Soils and Land Use Conference recommendations."

Recommendation No. 8

The Meeting noted difficulties experienced by the South Pacific Commission in obtaining regular information on soils and agronomy. It recommended that an active research worker in soils or agronomy in each country be appointed as Liaison Officer to correspond with the South Pacific Commission and to keep it informed of changes and developments in each country.

SPC did not receive any nominations of Liaison Officers.

Recommendation No. 9

The Meeting was pleased to learn of the comprehensive bibliographic services now being offered by the University of Hawaii. It noted the desire of the University of Hawaii to include in its files reports that now have only local distribution. It further noted a request that such documents include in the title or reference the key words needed for complete indexing in the bibliographic system. The Meeting recommended that Territorial Administrations and Governments ensure that published or unpublished reports of more than local interest be indexed and deposited in the SPC Library from where they will be included in the University of Hawaii system.

The SPC Library has received 9 reports in the last five years:- 2 on Cook Islands, 1 on Tonga, 1 on Fiji, 1 on New Caledonia, 1 on New Hebrides, 1 on the Solomon Islands and 2 on French Polynesia.

Of these, only the New Zealand Soils Bureau reports on Tonga and the Cook Islands came automatically. The others had first to be discovered and then requested from the originators. There must be many others which we do not know.

The Hawaiian and Pacific Collection of the University of Hawaii, and the Library of the University of the South Pacific have both been notified via library accession lists,etc.,of the existence of these reports.

Our remarks on Recommendation 4 apply also to Recommendation 9.

Recommendation No. 10

> The Meeting noted that the South Pacific Commission is maintaining a Directory of Agricultural Research and Experimentation in the South Pacific. The value and the need to regularly update this Directory was stressed. It was recommended that this now be reissued with the co-operation of the Liaison Officers (Recommendation No. 8) and then be updated at approximately one yearly intervals. It was further recommended that the Directory be cyclo-styled and that it be brief, including only a list of people and a list of their experiments with title, objectives and current state of progress. Basic soil and crop data should be included.

The last Directory of Agricultural Research and Experimentation in the South Pacific was published in 1975 (Information Document No. 36, 1975). No further directories have been published.

At the Fifteenth South Pacific Conference held in Noumea in September-October 1975, and at the Sixteenth South Pacific Conference held in Noumea in 1976, it was decided that "greater emphasis has to be placed on training at the grass roots level through an increased number of territorial and sub-regional training courses". At the same time, consideration has been given for presentation

of an integrated three-year rolling work programme. Therefore it was too difficult to collect information on objectives and results of agricultural research and experimentation in order to draft an up-to-date directory.

Recommendation No. 11

The Meeting noted that large amounts of agronomic information exist in most countries and territories that would be of regional value. This information should be recovered and evaluated in terms of soils and crops and of fertiliser recommendations for farmers. It was recommended that an experienced agronomist be attached to the soil correlation team (Recommendation No. 5) to collect and asses this data as a preliminary to the Benchmark field trial programme.

As far as the soil correlation team could not be formed, the experienced agronomist was not required.

Recommendation No. 12

To ensure the practical usefulness of the considerable amount of research on fertilizer trials that has been conducted or is currently being conducted within the Region, the Meeting recommended that each territory or country publish as soon as possible a bulletin on its recommended fertilizer practices. These bulletins should include a list of known nutrient deficiencies and fertilizer recommendations for the different major soils and major crops of each territory or country wherever this data is available. The Meeting agreed that these bulletins will be of immediate benefit to extension workers and farmers locally and will also prove of considerable value in other parts of the Region where similar soils occur and the same crops are grown.

Participating Governments are requested to aid the territories and countries in conducting the research needed for these bulletins where this has not already been done, and to aid in the publication and distribution of the bulletins.

Technical bulletins and magazines are published in many countries in the South Pacific Commission's area. They can include known nutrient deficiencies and fertilizer recommendations for the different major soils and major crops in the country.

The list of these bulletins and magazines could be given by participants.

Recommendation No. 13

The Meeting recommended the development of a system which would ensure that basic resource data currently being collected in an uncoordinated manner are effectively used in crop production terms for the socio-economic benefit of the country or territory concerned.

In this respect it strongly recommended that the appropriate authorities of each territory or country within the SPC area give very careful consideration to the example of a 3-phase agricultural development model.

Furthermore, it requested that the considered opinion of the Pacific Governments and Territorial Administrations be collected into an overall response in the form of an expression of opinion concerning the possible value and use of this approach and its adoption. It is recognised that the detail of each country's requirements may differ, and may differ at each level of the 3-phase development plan, and considered comment on each phase is requested.

This is a problem of Agricultural Research and Information. This will also be an agricultural extension problem in each country as soon as the guideline for national rural development has been approved.

Recommendation No. 14

The Meeting discussed the urgent need for training in the new methods of soil classification which will be the basis of future activities in experimental agriculture. It was recommended that a training workshop be planned by the Department of Agronomy and Soil Science in the University of Hawaii for staff with some responsibility for, and experience in, soil survey, soil fertility or land use in the Region. The purpose of the course would be to explain the principles of soil classification for use in soil surveys and in soil fertility work. The course should take the form used in the successful SPC-sponsored courses on agricultural research methods, i.e., with an initial workshop in Hawaii followed within two years by a refresher workshop within the SPC region.

A training workshop on soil science and agriculture research was organized by the University of Hawaii (Department of Agronomy and Soil Science) from 27 July to 2 September 1973. This initial workshop in Hawaii was followed by a refresher workshop in Koronivia Research Station, Fiji, from 17 to 21 March 1975. SPC paid part of expenses (consultants and participants). The present recommendation was taken because of these very useful and successful workshops in Hawaii and Fiji in 1973 and 1975.

Recommendation No. 15

The importance of regular reviews of the programme was stressed. It was recommended that a second meeting be held in three years' time to assess progress of the correlation programme and to plan continuing work on the field trial programme and on applications in crop production.

South Pacific Conferences held over the past four years did not put a high priority on the Regional Technical Meeting on Soil Science and Land Use. Therefore, because of budgetary restrictions, such a meeting was not listed on the SPC work programme.

STATUS OF SOIL RESOURCES INFORMATION IN THE SOUTH PACIFIC REGION*

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Ministry of Agriculture and Fisheries,
Fiji.

During the Forum, Regional participants presented prepared reports on the current status of soil resources information for their respective countries. Participants commented on organizational factors relating to soil research and land-use studies; soil survey coverage and soil mapping scales; level of soil characterization for the important soil series; soil classification systems adopted; level of soil interpretation and interpretative schemes employed; proposed or current programmes in soil resources; and, in general terms, an overview of the adequacy of the existing soil resources data in relation to land-use planning, and as a basis for increasing agricultural productivity.

This paper endeavours to synthesize this information, both in a Regional and national context, and summary listings have been prepared by country (Table 1). The format of the table follows that presented at the 1976 SPC Soil Science and Land Use Conference, Suva. The report is based on the best available information, and is self-explanatory.

However, the interpretation of Table 1 deserves analysis and discussion, i.e., to assess the adequacy of soil resources information; the degree of Regional standardization in soil survey method, correlation, classification and interpretation; and availability of

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*Refers to those countries served by the South Pacific Commission (SPC), see Fig. 1, p. 276.

TABLE 1. Summary of the current status of Soil Resources information for the South Pacific Region

COUNTRY OR TERRITORY	SOIL SURVEY COMPLETED	MAPPING SCALE	KINDS OF UNITS	OTHER KINDS OF MAPS	SOIL CHARACTERIZATION	CLASSIFICATION SYSTEMS	INTERPRETATIVE CLASSIFICATIONS	RESEARCH STATIONS (no. mapped)	SOIL SURVEY (PUBLISHED) Ref. Bibliography	AREA
American Samoa	70%	1:100,000	Series	None	None	NZ/Hawaiian	None	Taputimu (12 ha)	Wright, 1963	197 km^2
	100%	1: 24,000	Series		Full	Soil Taxonomy	Interpretative Tables		USDA (in prep)	
Cook Islands	95%	1: 15,000 for Atiu, Mauke, Aitutaki, Mangaia, and Mitiaro; 1:10,000 for Rarotonga; and 1:5,000 for Manuae. Southern Cook Islands Group 1:31,680	Series with phases	Interpretative maps for groups of crops in preparation	Complete chemical, clay, mineralogy; some physical, micromorphological, biological and fertility (both glasshouse and and field) work	NZ, FAO, Soil Taxonomy	Tabular suitability ratings for groups of specific crops	Totokoitu (20 ha) (1:2376)	Grange & Fox (1953) Bruce (1972) Leamy et al (1975) Leslie (1980) Campbell (1981) Wilson (1981) Wilde (1981) Webb (1981) Milne (in prep)	240 km^2
Fiji	100%	1:126,720 (note: 1:50,000 in progress)	Soil sets and series	Land Classification (1:126,720)	For major soils, chemical, some fertility and mineralogy	Modified NZ/ Hawaiian	Land classification and land use capability	Koronivia (168 ha) (1:3,000) Nawaicoba (396 ha) (1:3000); Legalega (42 ha) (1:1500); Wainigata (200 ha) (1:3000); and Seaqaqa (100 ha) (1:3000)	Twyford & Wright (1965) Adams (1968) Hunting Technical Services Ltd (1969) Chandra (1971) Chandra (1972a,b,c) Twyford (1972). FAO/ UNDP (1972). Chandra (1973a,b). Chandra (1974). Leslie and Blakemore (1978). Denis (1979). Latham (19[illegible])	18,234 km^2
	10%	42 surveys at scales < 1:25,000 (unpublished)	Series	Land classification and land use capability	Some chemical analyses					
	20%	9 surveys at scales < 1:50,000 (unpublished)	Great groups							
	2%	1:25,000 for Rotuma Lakeba and Part Taveuni Research Stns at scales <1:5,000	Series with phases		Chemical, physical and mineralogy anlyses, and for some fertility work	Soil Taxonomy, FAO and some CPCS (French)	Some suitability ratings for groups of specific crops	Note: Sigatoka, Wainidradra, Dobuilevu and Naduruloulou Research Stations to be surveyed 1982		

TABLE 1. Summary of the current status of Soil Resources Information for the South Pacific Region (continued)

COUNTRY OR TERRITORY	SOIL SURVEY COMPLETED	MAPPING SCALE	KINDS OF UNITS	OTHER KINDS OF MAPS	SOIL CHARACTERIZATION	CLASSIFICATION SYSTEMS	INTERPRETATIVE CLASSIFICATIONS	RESEARCH STATIONS (no. mapped)	SOIL SURVEY (PUBLISHED) Ref. Bibliography	AREA
French Polynesia	10%	1:40,000	Subgroups, families	None	Chemical, mineralogy and some physical analyses	CPCS (French), FAO	General land classification	Papeete (Tahiti) 10-20ha Taravao (Tahiti) 90 ha, Opunohu (Moorea) 25ha I.R.H.O (Rangirea, Tuamotu Chain)	Tercinier, 1955-1969; Jamet and Stein, 1980	4,000km^2
	2%	1:10,000	Subgroups, families	None	Full chemical, mineralogy and physical analyses	CPCS (French)				
Guam	100%	1:25,000	Series	Land use capability	Chemical, and some mineralogy	Local system	Engineering		Stensland, 1952	544km^2
Kiribati	None									719 km^2
Nauru	None	-	-	-	Analyses on a restricted number of profiles for chemistry, mineralogy and some physical	Soil Taxonomy (restricted profiles only)	None	None	None	226 km^2
New Caledonia	100%	1:1,000,000	Great groups	Land suitability for agriculture	Full chemistry and mineralogy with some physical and micromorphology analyses	CPCS (French)	Suitability ratings for specific land uses	Nessadiou (Bourail) 200ha (1:5000) IFCC (Ponerihouen) 30ha	Denis et al (1971) Latham et al(19?!) Denis (1979). Latham (1981a) Latham (1981b)	18,653km^2
	20%	1:200,000 (1:10,000 for small areas)	Families							
	15%	1:25,000 1:50,000	Families and series							
Niue	100%	1:63,360	Series with phases	None (extended legend)	Chemical and mineralogy. Some fertility	New Zealand	Potential land use (crops best adapted)	Vaiea (1:50,000) Vaipapahi (1:50,000)	Wright and Van Westerndorp (1965) Leslie (in prep)	259km^2
	100%	1:50,000	Subgroups, families, series	Soil radiation anomalies; trace elements	Some biological. Chemical, physical mineralogy, and fertility (glasshouse) work	Soil Taxonomy	None			
Norfolk	100%	1:50,000	Great soil groups, series and types	Drainage	Chemical, physical and mineralogy	Australian	None		Stephens and Hutton (1954, 1956)	34.5 km^2

TABLE 1. Summary of the current status of Soil Resources information for the South Pacific Region (continued)

COUNTRY OR TERRITORY	SOIL SURVEY COMPLETED	MAPPING SCALE	KINDS OF UNITS	OTHER KINDS OF MAPS	SOIL CHARACTERIZATION	CLASSIFICATION SYSTEMS	INTERPRETATIVE CLASSIFICATIONS	RESEARCH STATIONS (no. mapped)	SOIL SURVEY (PUBLISHED) Ref. Bibliography	AREA
Papua New Guinea	40% 60% (extrapolation)	1:250,000	Associations with Series	Land capability	Chemical. Restricted number of mineralogy and physical analyses. Some fertility studies	Soil Taxonomy, FAO	Ratings for various crops, land use capability ratings for arable cropping, pasture and tree crops	Not known	Graham & Baseden (1956); Hartley, Aland, Searle (1972); Holloway et al (1974); Nicholson (1980); Van Wijk (1959); Van Wijk (1963); Zijsvelt and Torlach (1976); Zijsvelt (1977); Haantjens et al (1967); Ford (1973)	462,243km^2
	1%	1:20,000 to 1:50,000	Series with phases							
Pitcairn	None				Analyses on a restricted number of profiles	None		None		4.5 km^2
Solomon Islands	100%	1:250,000	Associations Great groups	Land Systems; Physiographic regions; land use	Chemical, physical and mineralogical analysis of selected profiles	Soil Taxonomy	Delineation of of agricultural opportunity Areas	Dodo Creek (30ha) and 2 substations (Tenaru and Onelafa, each 20ha) Current mapping and soil characterization programme	Ballantyne (1961) Hansell and Wall (1974, 1975, 1976a, 1976b); Wall and Hansell (1974, 1975, 1976a, 1976b) Wall et al (1979)	28,530km^2
	1%	1:10,000	Series, with phases and complexes	None	Full chemical physical and mineralogy		Tabular suitability ratings for various land uses			
	<0.1%	1:2000 to 1:5000	Series with phases	None						
Tokelau	None				None			None	Reynolds (1971) provides the only information	10 km^2
Kingdom of Tonga	20% (Tongatapu)	1:100,000	Soil types	None	Chemical, and mineralogy	NZ FAO Soil Taxonomy	None	Vaini (1:5,000) Note: Research Stations at Vava'u (40ac) and Ha'apai (12ac) - no detailed soil maps available	Gibbs (1976); Orbell (1971). Four further reports in preparation	699km^2
	90%	1:25,000	Series with phases	None	Chemical, physical, mineralogy and fertility (both glasshouse and field)	NZ Soil Taxonomy	Tabular ratings for groups of crops, forestry and pasture			
	<1%	1:5,000								
Trust Territory of the Pacific Islands	Islands of Truk, Yap, Palau, Ponape, Kosrae	1:10,000	Series	None	Full	Soil Taxonomy	Interpretative tables	Not known	USDA (in prep)	1833 km^2

TABLE 1. Summary of the current status of Soil Resources information for the South Pacific Region (continued)

COUNTRY OR TERRITORY	SOIL SURVEY COMPLETED	MAPPING SCALE	KINDS OF UNITS	OTHER KINDS OF MAPS	SOIL CHARACTERIZATION	CLASSIFICATION SYSTEMS	INTERPRETATIVE CLASSIFICATIONS	RESEARCH STATIONS (no. mapped)	SOIL SURVEY (PUBLISHED) Ref Bibliography	AREA
Tuvalu	None				None			Elisefou		26 km^2
Vanuatu	100%	1:500,00	Great group	Land capability	Full chemical, and mineralogy for major soils only	CPCS (French) FAO	None	Tagabe (Vate)	Quantin (1976) Quantin (1981)	14,700km^2
	100%	1:100,000 and 1:50,000	Phase of Great groups	Vegetation, relief, geology land capability	Full chemical, physical, trace elements, and mineralogy	CPCS (French) FAO, Soil Taxonomy	Land capability	IRHO (Saraotou, Santo) 400ha		
Wallis and Futuna	In progress	1:20,000	Series	Land suitability for agriculture (in preparation)	Chemical	CPCS (French)	Various land use suitability ratings		Beaudou and Latham (in preparation)	125km^2
	90% (Wallis only)	1:100,000	Great group	None	Partial chemical	Locality derived from French	n.a.		Tercinier (1960)	
Western Samoa	100%	1:31,680 (Upolu) 1:100,000 (Savaii)	Series, with types and phases	Land classification (1:100,000)	Almost complete analyses for major soils	Modified NZ/ Hawaiian	Potential land use (crops best adapted)	Asau (2,500ha) 1:20,000; Tegitogiga (400ha) 1:10,000; Alafua (31ha) 1:4,000) and Moamoa (7ha); Laloanea (40ha); 2 at Nu'u (48ha and 25ha); Vaea (48ha); Avele (15ha) Nafanua (7ha); and Le Mafa (240ha) all at 1:40,000 scale	Hamilton and Grange (1938); Wright (1963); Seelye et al (1938)	2,952km^2

expertise in soil science within the Region. This is of particular importance should the recommendation for a Pacific Regional Benchmark Soils Project be implemented. Table 2 is the author's own summary and assessment, and the following discussion elaborates further on that information embodied in the table.

(i) National reconnaissance soil mapping and soil characterization:

Soil mapping at scale of ≥1:100,000 is adequate for the majority of countries in the Region. The exceptions are the larger nations where reconnaissance mapping is inadequate: Papua New Guinea (40% coverage at 1:250,000, the remainder based on extrapolation) and New Caledonia (only 20% coverage at 1:200,000). The level of soil characterization for the initial reconnaissance surveys is generally adequate, and where limited, these countries have often had more detailed modern soil surveys conducted with a higher degree of characterization for major soil series.

(ii) National semi-detailed soil mapping and soil characterization:

Only 4 nations have modern national soil surveys (≤1:50,000 scale) with full characterization of the major soil series. These are: Cook Islands, Tonga, Niue and part of Vanuatu. However, it is pleasing to report that current soil surveys are being conducted at this scale for Fiji, French Polynesia, New Caledonia, Wallis and Futuna, American Samoa and several states in the Federated States of Micronesia (Truk, Yap, Kosrae, Ponape, Palau). The level of soil characterization for all these surveys is high.

More detailed soil surveys are urgently needed for Papua New Guinea, part Solomon Islands, and part Western Samoa.

(iii) Soil Classification:

Of the 20 countries/territories within the Region, 14 have a national soil map, but for these soil surveys various soil

TABLE 2: An analysis of the adequacy of soil resources information for the South Pacific Region

	American Samoa	Cook Islands	Fiji	Fr. Polynesia	Guam	Kiribati	Nauru	New Caledonia	Niue	Norfolk Island	Papua New Guinea	Pitcairn	Solomon Islands	Tokelau Island	Tonga	Trust Territory of the Pacific Islands	Tuvalu	Vanuatu	Wallis and Futuna	Western Samoa
Reconnaissance national soil map	2	1	1	x	3	x	x	2	1	2	3	x	2	x	1▽	1*	x	1	1▽	1
Level of soil characterization at reconnaissance scale	3	2	2	x	3	x	3*	2	1	3	3	3	2	x	3	1*	3*	2	3	2
Detailed (≤1:50,000) national soil mapping	x	1	3*	3*	x	x	x	3*	1	x	x	x	x	x	1	1*	x	1▽	1*	x
Level of soil characterization at ≤ 1:50,000 scale	x	1	3*	3*	3	x	x	3*	1	x	x	x	x	x	1	1*	x	1▽	1*	x
Classification																				
a. Soil Taxonomy	x	✓	▽	x	✓	x	✓*	x	✓	x	✓	x	✓	x	✓	✓	x	✓	x	x
b. FAO	x	✓	▽	✓	x	x	x	x	✓	x	✓	x	x	x	✓	x	x	✓	x	x
c. French	x	x	▽	✓	x	x	x	✓	x	x	x	x	x	x	x	x	x	✓	✓	x
d. Local	✓	✓	✓	x	x	x	x	x	✓	✓	x	x	x	x	✓	x	x	x	x	✓
Interpretative classifications																				
a. land capability	x	x	✓	✓	✓	x	x	✓	x	x	✓	x	✓	x	x	✓	x	✓	x	x
b. suitability groups of crops	x	✓	x	x	x	x	x	✓	✓	x	x	x	✓	x	✓	✓	x	x	✓	x
c. crop specific	x	x	x	x	x	x	x	x	x	x	x	x	✓	x	x	✓	x	x	x	x
No. Research Stations	1	1	10	4	x	1	x	2	1	x?	?	x	3	x	3	?	1	2	x	11
No. mapped in detail (≤ 1:5,000)	x	1	6	x		x		1	x		?		3*		1	?	x	x		1
Representativeness of soils on R.S's	?	1▽	1	?		1		?	1		?		2†		2	?	1	?		2
Level of soil characterization for R.S's mapped	3	1	1▽	x		x		2▽	2		?		3*		1	?	x	x		3
Level of soil survey expertise	x	x	3	?		x	x	?	x	x	1		x		x	x	x	x	x	x
Level of local laboratory supportive services for soil survey	x	x	1	x	2	x	x	1	x	x	3	x	3	x	2?	x	x	x	x	3

✓ yes x no or none * current programme ▽ in part † not local ? not known

1 very adequate
2 adequate
3 inadequate

classification systems have been used. Seven countries are classified accordingly to Soil Taxonomy, four to the French System (C.P.C.S.), five to FAO, seven to local systems. Some countries have their soils classified to more than one system,e.g.,Vanuatu (Soil Taxonomy, CPCS and FAO). The local systems are in general in addition to either Soil Taxonomy or FAO. These systems are the NZ genetic (for Tonga, Niue, Cook Islands); modified NZ/Hawaiian (Fiji, Western Samoa, American Samoa); Northcote (part PNG); and a specialist engineering classification only, for Guam.

(iv) Soil Interpretation:

The level of soil interpretation for all countries in the Region is generally very weak, and there are virtually no interpretative maps produced. Interpretative tables do accompany Soil Survey Reports. These in the main give broad use-capability ratings only, and for some surveys there are suitability groupings for crops with common growth characteristics. Only the Solomon Islands has soil/crop specific interpretative tables available, although Fiji is currently preparing similar tables.

(v) Agricultural Research Stations:

Should a Pacific Regional Benchmark Soils Project be established, the network of trial sites would centre on established research stations. Table 2 has included columns to indicate the level of knowledge for the soils on research stations in the Region. It is apparent that many countries do not have a research station (understandable considering the size of some) but of those that do, few have detailed soil surveys or an adequate level of soil characterization. The exception is Fiji which is currently preparing to establish its own national benchmark soils network. The 10 Fijian research stations, with supporting laboratory data,will be mapped and classified by the end of 1982.

(vi) Expertize in Soil Science:

The general lack of trained local soil scientists in the Region is disturbing. There is only one Regional pedologist actively working in soil survey in the Region (Fiji). Governments of the Region have relied on expatriate soil survey teams to conduct the national soil surveys,e.g.,N.Z. DSIR (Tonga, Niue, Cook Islands, Samoa's, Fiji); ORSTOM (Vanuatu, New Caledonia, Wallis and Futuna, and French Polynesia); CSIRO (Papua New Guinea) and LRD/DOS (Solomon Islands).

The level of laboratory support for soil survey operations and for soil testing for general agriculture is more encouraging. Several countries (Guam, Fiji, Western Samoa, Tonga, Papua New Guinea) have laboratories in which research and routine analytical work on soils are carried out.

Fiji has two main laboratories at the University of the South Pacific (USP) and at Koronivia Research Station (MAF) plus other laboratories with more restricted or specialist capabilities (Fiji Sugar Corporation, Public Works Department). The laboratory at Koronivia is mainly to support general agriculture but has assisted with some national soil survey work. The USP (Fiji) laboratory is equipped to carry out a full range of soil characterization analyses but so far its facilities have not been called upon to assist in national soil survey operations. The laboratory has supported a number of small private surveys and is currently conducting soil characterization for a limited number of soils from Solomon Islands, Kiribati, Nauru and Tuvalu. ORSTOM operate a large, well-equipped laboratory in Noumea which supports soil surveys in the French Territories. The University of Guam has a laboratory adequate for general agricultural purposes and a restricted number of soil characterizations. Tonga has a new laboratory, again functioning in support of agriculture, rather than for soil survey operations. Western Samoa (USP, Alafua Campus) has recently established the

Institute for Research Extension and Training in Agriculture (IRETA) with the objective of servicing the South Pacific Region. However, the soil laboratory establishment in 1970 by FAO has suffered from inadequate funding during the 1970's, so has at present a limited capability to undertake full soil characterization, and support soil surveys. Apart from some agronomic oriented research its main function is in the area of soil testing for general agriculture.

(vii) Conclusions:

Assuming a Pacific Regional Benchmark Soils Project is established, considerable preparatory work needs to be undertaken to produce detailed soil maps for the research stations, and new ones which should be selected not only for the network, but in the interests of national agriculture. Soil characterization, correlation and classification need to be included with these soils surveys.

The logical follow-on from a Benchmark Soils Programme is extroploation of data from research stations to national soil maps, i.e.,transfer of crop/soil management technology. Thus, national soil maps at 1:50,000 scale are a pre-requisite stage for such transfers. Governments must be encouraged to support more modern detailed soil mapping and characterization programmes.

Standardization of soil correlation procedures, a common soil classification, and a level of uniformity in soil interpretations are real Regional needs. These can only come about through greater Regional contact between soil researchers from the various countries and even through some loose Regional association whereby data of mutual interest can be shared and exchanged in some organised manner. But, it is in the Regions' interests that some uniformity in the methodologies employed come about.

As more, and larger, development projects for agricultute and forestry are implemented, in particular in the larger nations (PNG, Solomons, Vanuatu, Fiji and Western Samoa), the desirability of having national expertise in soil science (particularly, soil survey as the laboratory capabilities are in most cases adequate) cannot be stressed enough. Thus, a training programme for pedologists should be given immediate priority by Governments. Indeed the Institute which organized this Forum should be encouraged to establish a post-graduate programme in soil survey as soon as possible. Reliance on 'foreign' expertise, when the inevitable soil, related problems arise in development projects, is no longer valid for the larger Pacific countries.

From the list of participants it can be seen that not all countries of the Region were represented. However, sufficient information was obtained to give here an objective overview of the status of soil resources information in the South Pacific.

A BENCHMARK SOILS PROJECT FOR THE SOUTH PACIFIC - THE POTENTIAL AND POSSIBLE CONSTRAINTS

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Developments in the world economy would indicate that countries of the South Pacific Region will be required to produce a greater portion of their own food and fibre requirements, i.e., the Region will be obliged to progress more rapidly (than at present) towards self-sufficiency. The rate of this change will be determined to a large extent by the type and efficiency of development and sound utilization of the Region's soil resources. This is particularly important since the resources of the Region are limited to the sea, the land and the people. Further development of the marine resources will involve significant technical innovations and therefore development of the land resources is even more crucial.

Before efficient development can occur an evaluation of the soil resources of the Region is required. In this context the USDA Soil Taxonomy (Soil Survey Staff, 1975) is of paramount importance; Soil Taxonomy provides for a guide for making and interpreting the necessary soil surveys.

In Soil Taxonomy a comprehensive classification system is developed that groups soils with similar chemical and physical features that affect their properties and use. The parameters used to differentiate soils give information about the climate, moisture status, nutrient status and depth of soil penetrable by roots, i.e., parameters based on land use experience. A knowledge of the soil resources of the Region based on Soil Taxonomy immediately gives us an evaluation of those soil resources in terms of the potential for agricultural production.

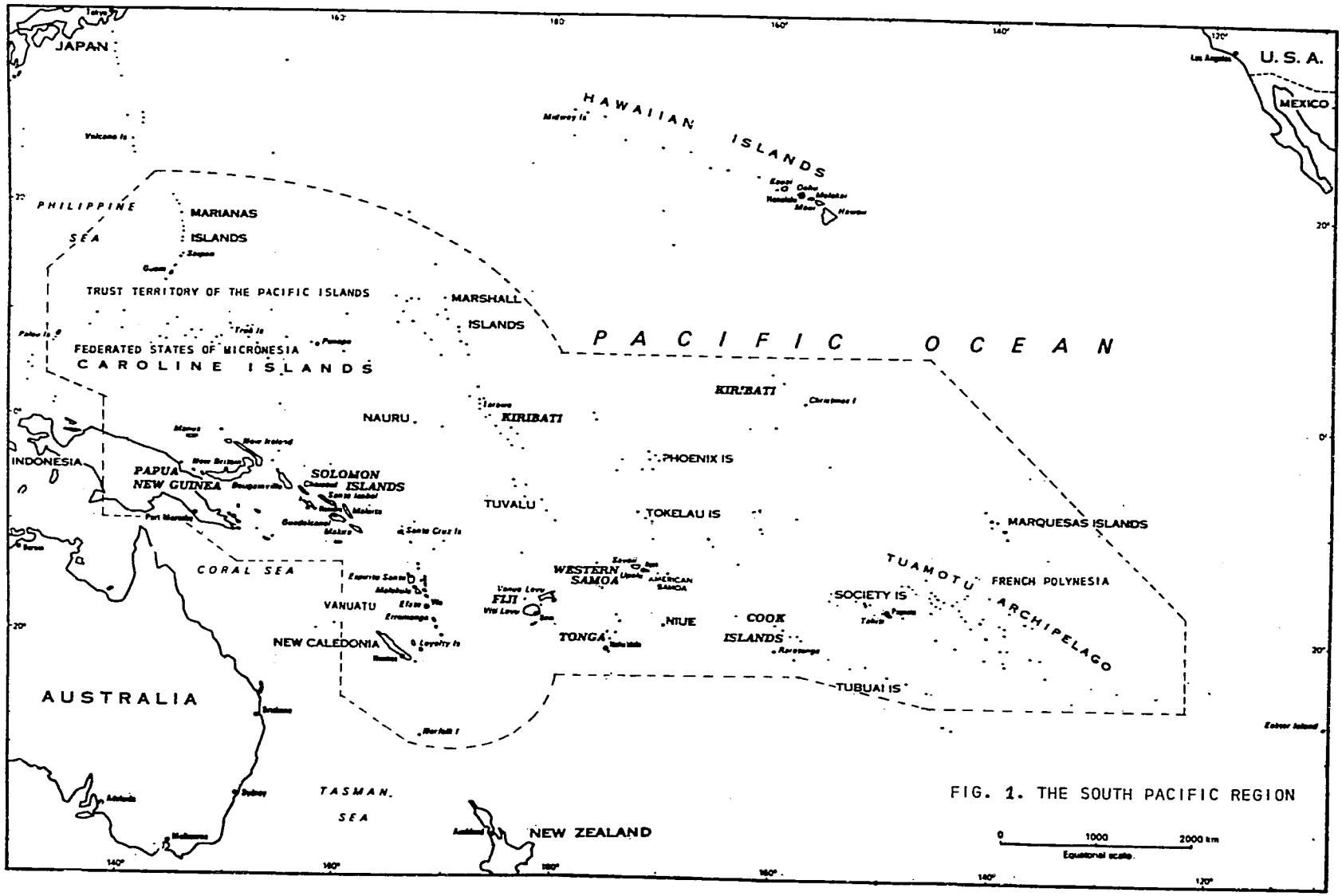

FIG. 1. THE SOUTH PACIFIC REGION

Soil Resources of the South Pacific Region

For the purpose of this paper we will consider South Pacific Region as the area served by the South Pacific Commission which stretches from the Trust Territory of the Pacific Islands in the north-west to French Polynesia and the Cook Islands in the south-east (Fig. 1). The area involved is greater than 20 million km^2, but the total land area of just over 500,000 km^2 is relatively small. Of the land area some 80% is occupied by Papua New Guinea, 15% by the large island groups of the Solomon Islands, Vanuatu, New Caledonia and Fiji, and the remaining 5% by innumerable small islands ranging in size from several thousand km^2 to much less than 1 km^2. The Region therefore consists basically of 20 small countries or territories separated by substantial stretches of ocean. The large distances between territories and the limited population (approx. 5,000,000) pose significant problems for the Region in terms of transport, communication and inter-regional cooperation. A detailed discussion of the consequences of the small size and large separation of Regional countries is given in Ward and Procter (1980).

The islands of the South Pacific are either continental in their geology,e.g., Papua New Guinea, or oceanic high islands (volcanic peaks rising as great domes of basalt, extruded from the sea bed),e.g., Upulo, W. Samoa, or coral islands,e.g., Niue and atolls,e.g., Manuae, Cook Islands. Since the volcanic high islands frequently have fringing or barrier coral reefs and some coral islands often have deposits of volcanic ash, mixed lithologies are common and the soils in many areas are derived from a diversity of parent materials.

The continental and larger oceanic high islands are dominated by very rugged landscapes with hilly or steep slopes. The extent of flat or gently rolling land on these islands is relatively small. In general, within the Region there is a dominance of weakly formed soils and stony phases are common but on the continental 'like' islands the most weathered and developed soils of the Region are found.

The coral islands are mainly low atolls created by the protection of a reef by accumulation of comminuted coral sands. Soils are generally shallow, immature, of low productivity, supporting only coconuts.

There is a substantial amount of resource information available about the soils of the Region (see Appendix 4). Most countries had reconnaissance soil surveys and some detailed surveys made; the details of the survey information available are given by Leslie (this Proceedings p. 263). However, the agricultural development varies from quite highly developed,e.g., Fiji to partly developed,e.g., W. Samoa, Tonga to poorly developed,e.g., Niue. The level of agricultural development normally coincides with the general level of development of the countries as this general development provides much of the infrastructure (roads, markets, education) necessary for agricultural development. Agricultural research activity also varies considerably, but can generally be related to the size of the country; the larger the country the more extensive the agricultural research programme. This in turn can be related to the resources available in terms of manpower and finance.

The Concept of Agrotechnology Transfer

The main agricultural goal of soil classification and soil survey is the assessment of the land resource in terms of plant productivity. Information (i.e., agrotechnology) transfer is one of the processes used in the prediction of productivity. Information is transferred from experimental stations or farms to analogous areas as defined by soil (or land) classification. This method of predicting productivity is based on the hypothesis that if two soil sites are similar they will respond in a similar way to prescribed agricultural practices, e.g., crop varieties, management. The concept of similarity presents a major problem. Similar means being alike or approaching identity to some degree: the degree is variable and frequently unknown. Soil classification, whose role is to group similar soils together, lies at the heart of the matter.

The only classification that has so far achieved world-wide coverage is the FAO/UNESCO Soil Map of the World (FAO/UNESCO, 1974). Unfortunately, however, this legend applies to the accompanying maps at a scale of 1:5,000,000 and is therefore of limited practical use for small island nations. Soil Taxonomy (Soil Survey Staff, 1975) although it has not been applied universally, is gaining increasing acceptance (particularly in developing countries); because of the more extensive taxonomic hierarchy and potential for detailed soil surveys this system is much more useful for agricultural purposes. The differentiating characteristics used are quantitative and explicit at all levels in the multicategoric system, the majority of these characteristics being based on land use experience.

The Benchmark* Soils Project initiated by the University of Hawaii in 1974, has been testing the premise that soils belonging to the same soil family as defined in Soil Taxonomy are sufficiently similar to allow for succesful transfer of agrotechnological information. The soil family is the fifth level of subdivision in Soil Taxonomy (see this Proceedings p. 54) and has been described by Uehara (1978) as "a condensed statement of what we know about a soil".

In the University of Hawaii - University of Puerto Rico Benchmark Soils Project three soil families have been studied (Hydric Dystrandepts, Tropeptic Eutrustox, Typic Paleudults) and the three experiments used are transfer, variety and management. A number of primary sites (> 5 ha) at which all experiments are conducted and a number of secondary sites (1-2 ha) where the transfer experiments are conducted have been established. The primary sites receive major inputs while the secondary sites have minimal inputs and are designed to confirm

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*Benchmark soils are those that, because of their large extent, their key position in the classification system, or their occurrence in critical areas, are important to our understanding of soils.

results derived at primary sites. Full details of the transfer, variety and management experiments are given by Beinroth et al., (1980).

Once it has been demonstrated that management systems implemented successfully on a soil of a particular family can be transferred to another soil of that family, then an acceleration of agricultural development will occur. This will be accompanied by a decrease in the cost of the development.

There are many agricultural stations in the stations in the South Pacific Region (see Table 2, p.269) involved in research aimed at increasing food production. In many cases these stations have been selected to act as "soil windows" for the neighbouring areas and results of trials on these stations have been used to develop agricultural practices for the surrounding areas. It is likely that many of these stations, in the different Regional countries, have similar physical environments. Many research stations in the tropical areas outside the South Pacific also have similar environments (the identification of similar environments is made possible by soil surveys and soil classification). As a consequence research projects may have already been completed on a similar soil, for the same crop, at other stations either within or outside the Region. Thus a correlation of the soil resources of the agricultural research stations (initially within the Region and later with other areas) would provide a basis for communication and information exchange. Soil correlations would not eliminate the need for field experimentation but researchers would have the benefit, in many situations, of the results of others, e.g., once the major soil families in an area are known,experience elsewhere with soils of the same families can be used to determine which crops are likely to do well in that area. These crops would be trialled at the experiment station and local practices developed for communication to farmers of the area.

A Regional Benchmark Soils Project in the South Pacific

The establishment of a South Pacific Regional Benchmark Soils Project would take place in stages. Initially a feasibility study

must be made. A small technical team (with pedological emphasis) selected by an appropriate Regional group, e.g., the Regional Directors of Agriculture, would be recruited to carry out the initial study.

This team would collate all the soils and crop information available in the Region. This would include soil survey and classification details, results of trials carried out at research stations within the Region and information on traditional farming experiences. Information on likely related soil and land systems in other areas of the tropics would also be collected. Individual governments would be encouraged to rationalize their soil resources data and, if possible, attempt to have detailed soil surveys of research stations or other important development areas completed.

The team would draw up plans for the development and implementation of the Regional Benchmark Soils Project. These would be presented to the Regional governments for their approval and their support in obtaining the necessary funding (from aid sources) for the implementation of the project.

There are three major requirements for the implementation of a Regional Benchmark Soils Project:

1. A small group of people assuming Regional responsibility for coordination of the project. This group would be directly responsible to the Regional governments.

2. Financial support.

3. A willingness on the part of Regional governments to be involved and their full participation in the project.

For the project to be successful it must encompass the Region as a whole, i.e., the administrative group must come under a Regional umbrella. If a project is established the coordinating group could be joined for a limited period (up to 3 years) by a Project Coordinator who has been involved in Benchmark-type projects elsewhere in the tropics. The Project Coordinator could assist with the development of

the necessary administrative infrastructure as well as the provision of technical advice.

Once the network design has been prepared and accepted by Regional governments a second technical team, responsible for the implementation of the project, would be appointed. This technical team would be responsible for the organization of field trials at suitable research stations with the aim of developing field practices suitable for application in the area. Before commencement of the trials, information would be sought about similar trials (if any) elsewhere; this would avoid some duplication of research effort. On completion of the trials extension officers would then coordinate the transfer of the technology from the research station to the farm.

Research and planning teams in the Region would call upon the team to provide information on the best land use or cropping systems for particular areas. Obviously for reasonable advice to be given the team would require good soil survey information. On receipt of the possible alternatives the research and planning teams in the individual territories would decide on the most suitable alternatives for the particular situation.

In a few instances it may be necessary to establish a number of secondary transfer sites outside the present research stations (primary transfer sites) to provide information about some of the major soil families of the Region. A special problem arises with the atoll situations, where the opportunity for land use diversification is limited and there has been only limited agricultural research and development. A major thrust of the project could well be the development of agricultural systems for the atoll situations, but much is known world-wide about atoll soils and the transfer of information for this situation would be the most reliable at present.

Some agrotechnology transfer has already taken place within the Region, e.g., coffee information from PNG to Fiji, pine technology from Fiji to Tonga and Guam, but there are a number of constraints to further development.

Some countries have an adequate pool of personnel trained in various aspects of agriculture while others are not so fortunate. A number of research officers capable of conducting the necessary trials (and communicating the results) and an adequate group of extension officers is required. Few countries have any expertise in soil survey work, but many countries already have detailed soil surveys. There is only a very limited number of people conversant with Soil Taxonomy.

The soil resources of the Region provide considerable potential for further development. There is a considerable diversity of soils allowing for diversification in crops. The current level of knowledge about the soils is generally good (see p.264).

A considerable amount of agricultural research has been carried out in the Region. There is, however, much duplication of research activity in the various Regional countries and the introduction of a Benchmark project would, hopefully, reduce this duplication. Several aspects of this research activity require further comment. Some of the research projects have been poorly planned, e.g., incorporating too many variables, lack of reference plots, poor selection of sites or crops. Some very good research has not been developed either because of poor research reports or (more commonly) because the results have not been extensively publicized. Many projects are written up as departmental reports which do not receive wide circulation. In many cases the successful projects are not written up for publication in Regional or international publications.

Many fertility trial and crop evaluation projects have, in the past, been of limited value because of inadequate site characterization, i.e., landscape position climatic, variability. The soils have often not been identified by soil series or classified to any system; this has led to considerable difficulty in correlating results and therefore transferring the data within a country or the Region. It is essential that detailed research reports include detailed site descriptions, e.g., soil characterization (description, physical,

chemical and mineralogical properties, classification using Soil Taxonomy), climatic data, management practices.

Traditional farming experiences developed successfully over centuries by shifting cultivators are not widely reported in the literature. These experiences can be of considerable significance in land use planning.

Other constraints which involve more discussion that the length of this paper permits are:

(i) lack of continuity of research personnel due to, e.g., departure of expatriate officers, promotion of local officers out of research sectors;

(ii) limited personal contact between agriculture workers in the Region;

(iii) land tenure problems (variable Regionally);

(iv) too much specialization both at Regional meetings and on the job, e.g., extension/research officers tend to be, the cocoa expert, the goat expert, the root crop expert;

(v) population trends (rural to urban) and age structure;

(vi) variation of economic feasibility of agriculture programmes within the Region.

Financial Requirements

The financial support for a Regional Benchmark Soils Project would initially have to be obtained from aid funds. Once a Regional body has been convinced to act as the Regional 'umbrella' a planning grant could be obtained for the feasibility stage. This would be followed by a major submission to aid agencies, e.g., FAO, EEC, World Bank, Ford Foundation, USAID, ADB, for funding for a period of 5-10 years

to get the implementation team fully established and operational. After this period the continuation of the project would be funded through a Regional body by governments in the usual way.

Once the Project is established and the implications (see below) made apparent to Regional governments, it is highly likely that their full involvement and participation will follow.

Implications of a Regional Benchmark Soils Project

Once a successful Benchmark Soils Project is established in the South Pacific Region a number of immediate benefits will be obtained:

1. A structure will be established for the sharing of research information and the planning of research. Associated with this -

2. Agricultural research should become better coordinated both within the Region and within countries of the Region. This should lead to less duplication of research activities and the subsequent saving of time and money.

3. It is anticipated that the Regional Benchmark Soils Project would link with the University of Hawaii Benchmark Soils Project and with other international research institutes, e.g., IRRI, IITA, CIAT leading to increased soil/crop information being made available to Regional agriculturalists.

4. The establishment of a system of cooperative research and agro-technology transfer should produce benefits to the individual farmer. Research and planning staff will be better informed and as a consequence the selection of crops, farming systems, etc., will be less subject to error. This in turn should lead to more appropriate land and soil use practices with more regular and higher incomes for farmers. With increasing confidence in cash crop agriculture systems agriculture would become more diversified and maximum use of the soil resources would be made. This would minimize the problems that are occurring at present with more piecemeal, luck of the draw systems.

5. With a more rational use of the soil resources countrie of the Region would not only increase their food production but planning should also improve with more accurate forecasting of likely production levels.

6. Implementation of the Regional Benchmark Soils Project would involve a substantial educative/training component. Agricultural scientists, extension staff, and planners would be given the necessary training to fulfil their roles in the development of the project. The rationale and benefits of the project could be introduced to farmers and students, thus increasing the general agricultural awareness of the people of the Region.

Conclusion

Countries of the South Pacific Region are faced with the problems of increasing population, increasing costs of imported food-stuffs and a general demand for better living standards (including nutritional standards). Faced with these problems a concerted Regional effort must be made to increase agricultural production, develop suitable crops as substitutes for imported materials and utilize the meagre land resources as efficiently as possible. A successful Regional Benchmark Soils Project will prove a major asset in moving towards these goals.

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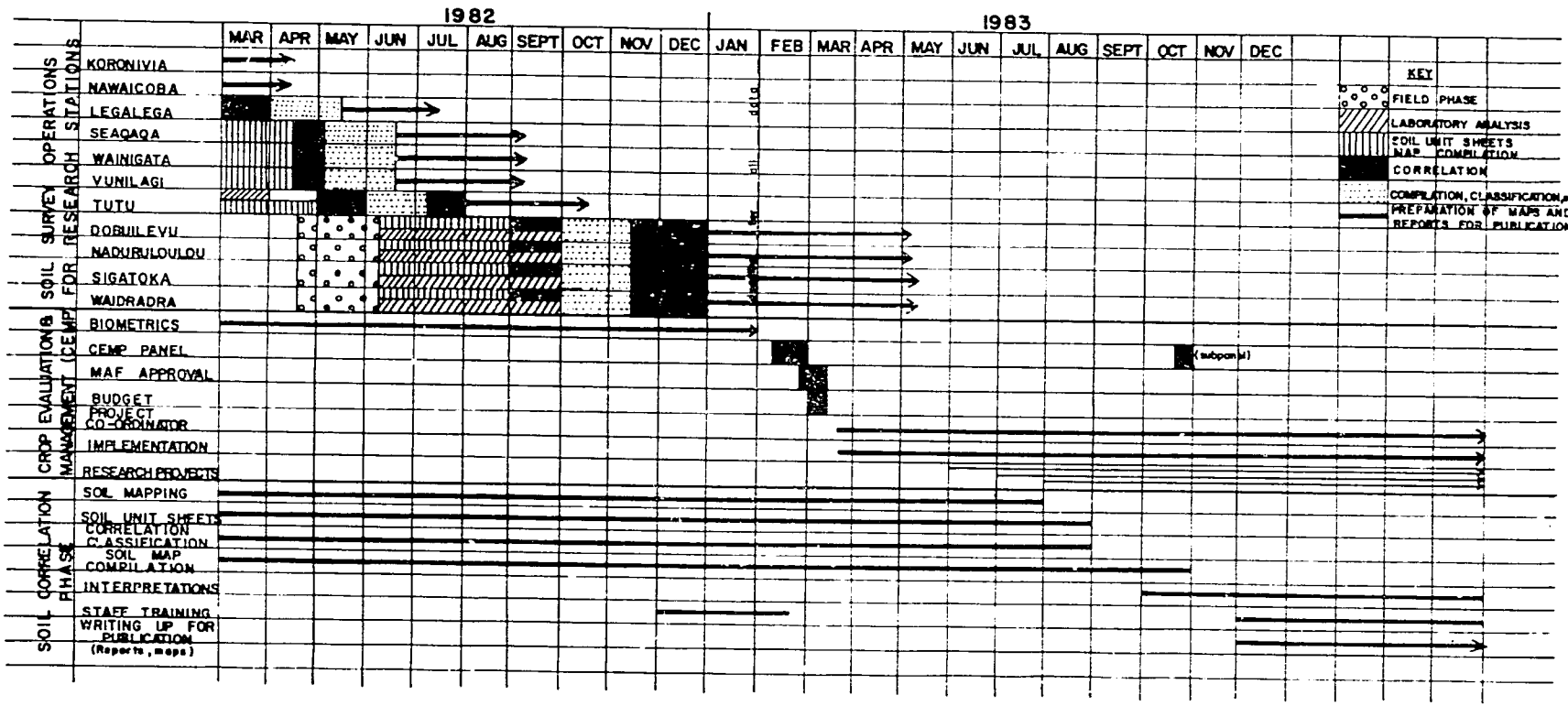
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SEAQAQA
WAINIGATA
VUNILAGI
TUTU
DOBUILEVU
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SIGATOKA
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INTERPRETATIONS
STAFF TRAINING
WRITING UP FOR PUBLICATION (Reports, maps)
KEY
FIELD PHASE
LABORATORY ANALYSIS
SOIL UNIT SHEETS
MAP COMPILATION
CORRELATION
COMPILATION, CLASSIFICATION, etc.
PREPARATION OF MAPS AND REPORTS FOR PUBLICATION

THE FIJI SOIL CLASSIFICATION, CROP EVALUATION AND MANAGEMENT PROGRAMME (1980 - 1985)

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During the last 20 years most major land development projects in Fiji have been based on the comprehensive national soil survey undertaken in the 1950's (Twyford and Wright, 1965), and subsequent land use capability mapping performed by the Land Use Section, Ministry of Agriculture and Fisheries, which has based its work on that of Twyford and Wright. The soil maps of Twyford and Wright were of scale 1:126,720.

The system of soil classification used by Twyford and Wright was a 'local' one similar to, and following that developed for Hawaii (Cline, 1955). A major disadvantage of a 'local' classification has been the difficulty of correlating Fiji soils with those of other countries. This has meant that agrotechnological information from more advanced countries, for example - information on high yielding crops, soil specific fertilizer requirements, soil/crop management systems,etc., could not be readily transferred to Fiji. In turn, Fiji has invested a great deal in agricultural research over the last 20 years, an investment when measured against results, has been costly in terms of manpower, time and money.

Fiji was aware of these problems, but it took a meeting of soil scientists in Suva (South Pacific Commission, 1976), to emphasize the need for a Regional standard of soil classification and correlation For Fiji, subsequent bilateral aid discussions with New Zealand during 1979 have seen the implementation of a 5 year (1980 - 1985) broad based, and we trust, far-reaching soil resources programme, for the country. It is the programme that is the subject of this paper.

SOIL CORRELATION PROGRAMME

In June 1981, a Soil Correlation Unit was established at Koronivia Research Station to handle the soil correlation of Fiji soils. At present, the unit comprises a pedologist on a 2 year secondment from the New Zealand Soil Bureau and a local counterpart, but with plans for two University of the South Pacific graduates to join the unit by 1983.

A major initial objective of the unit is to classify existing soil series, and further new series, according to Soil Taxonomy (Soil Survey Staff, 1975). Concurrent with the correlation/classification, national soil maps will be prepared at 1:50,000 scale. During 1983, discussions will be held to design trials for the 10 agricultural research stations. Data from these will be extrapolated as they become available, to the soil interpretative tables which will accompany the 1:50,000 national soil maps.

Soil Survey Phase

Detailed soil surveys will be confined to selected representative landscapes. Such areas will include all agricultural research stations, major land development areas, and other 'windows' in landscapes of special interest. These areas will also be representative of our major physiographic regions. The soils of the research stations will alone represent approximately 25 per cent of the original soil series established by Twyford and Wright (1965).

Soil surveys on research stations started in July, 1980. Areas which have been surveyed to date are:

(i) Rotuma Island (4400 ha) - an island of young volcanic ash soils, some 650 kilometres north of the main Fiji group. This is a development project of special interest, because of the special effort to undertake evaluation of the land resources through to crop establishment, in a logical manner. In brief, the soil survey (Laffan and Smith, in press) was a follow-up on a socio-economic/infra-structural study, and will be followed by a study of crop options, market

opportunity and food processing prospects for the island. The approach is similar to the 3-phase model by the New Zealand Soil Bureau for their work in Tonga, Niue and the Cook Islands (Leslie 1977), and that proposed by Adams (1970).

(ii) Legalega Research Station (42 ha) - adjacent to Nadi International Airport, the station represents the older floodplain systems of the lowland dry zone of Western Viti Levu. The research emphasis is on pulses, peanuts, mango, citrus, macadamia and pineapples. The soil survey (Laffan and Leslie, in press) is at a scale of 1:3000.

The soils were expected to be all Oxisols but some Ultisols have been identified since. Two common soils of the station are:

- Typic Eutrustox, fine loamy, oxidic, isohyperthermic
- Oxic Haplustults, fine loamy, kaolinitic, isohyperthermic

(iii) Nawaicoba Quarantine Station (397 ha) - 30 kilometres south of Nadi International Airport and represents a slightly higher altitude area of complex hill country soils. The research emphasis is on pasture, sheep and cattle management, but in the district many of the soils are extensively used for sugarcane and other horticultural crops. The soil survey (Leslie and Laffan, in press) is at a scale of 1:3000.

The soils of Nawaicoba are mainly Ustropepts, Eutropepts, Ustorthents, Tropudalfs, Haplustalfs, Rhodustults and Vertisols.

(iv) Koronivia Research Station (210 ha) - the principal agricultural research station where the headquarters for the Research Division and laboratory facilities of the Ministry of Agriculture and Fisheries are located. Koronivia represents the alluvial floodplain and low coastal hill country systems of the wet zone of south-eastern Viti Levu. Field crops research is carried out on rice, bananas, tubers, cocoa and dairy pastures, all of which are important land uses in the wet zones of Fiji.

The soil survey (Leslie, in press) is at a scale of 1:3000. The soils of Koronivia are mainly Tropofluvents, Tropaquents, Tropaquepts, Eutropepts and Tropohumults, in areas of mineral soils. Mineralogy classes are kaolinitic for the hill soils.

There are also organic soils (Histosols) where fluvaquentic subgroups of Tropofibrists, Tropohemists and Troposaprists have been differentiated.

(v) Seaqaqa Research Station (102 ha) - representing a raised plateau area in the dry zone of Fiji's second biggest island, Vanua Levu. Like Legalega, the research emphasis is on dry zone crops.

The soil survey of Seaqaqa (Laffan, Furdie and Shepherd, in preparation) has tentatively suggested that the soils of Seaqaqa are mainly Dystropepts/Ustropepts, Eutrustox, Umbraquox, Rhodustults and Paleustults with mineralogy being either oxidic or kaolinitic. Analyses are still in progress. The soil map scale will be 1:3000.

(vi) Wainigata Research Station (120 ha) - representing complex hill country soils in the south-east of Vanua Levu. This is an area of intermediate rainfall where the emphasis of research is on cocoa and coconuts.

The soil survey of Wainigata (Purdie, Laffan and Shepherd, in preparation) has just been completed. With laboratory analysis as yet incomplete the soils are expected to be Eutropepts, Humitropepts, Aquepts with some Mollisols.

(vii) Vunilagi Estate - a special interest area in terms of the plantation scale coconut industry, where soils are developed in the main, from saline marsh sediments, recent coastal sands and coralline detritus. Sites for characterization were located along a single traverse from the coast to the hill country inland of the property. This is merely a soil characterisation study (Shepherd, in preparation) and no soil map per se is proposed.

Soils at Vunilagi are mainly Psamments, Sulfaquents, Sulfaquepts, Tropaquepts and Tropohumults.

Research stations yet to be surveyed include:

(viii) Tutu Estate (480 ha) - another area of special interest in terms of young volcanic ash and lava flows, on Fiji's third largest island, Taveuni. The Ministry of Agriculture proposes to lease a part of the estate for crop trials and a soil survey to select that area is currently in progress.

The main soils are likely to be Typic, Altic and Hydsic sub-groups of Haplotropands with smaller areas of Vitritropands with a wide range of particle size classes, plus restricted areas of Oxic Tropudalfs and Dystropepts developed on the older ashes and flows.

(ix) Sigatoka Research Station (328 ha) - a representative station in the intermediate climatic belt of Viti Levu. It is a complex of hill country adjacent to an alluvial flood plain.

The Sigatoka area is very important to Fiji as a source of high quality vegetables, and has often been called the 'Salad Bowl' of Fiji for this reason. Other important crops are passionfruit, tobacco, cassava, potatoes, maize and pasture together with cattle and goat breeding.

The important soils of Sigatoka are expected to be Ustalfs, Humitropepts, Aquepts and Tropofluvents.

(x) Dobuilevu Research Station (49.6 ha) - representing another alluvial flood plain and hill country complex in the intermediate climatic belt, but located in the north east of Viti Levu. Field crops research is on pasture, tubers, vegetables, rice, bananas and cocoa.

The soils at Dobuilevu are expected to be mainly Tropofluvents, Humitropepts, Aquepts, Ustalfs, with smaller areas of Oxisols.

(xi) Waidradra Research Station (206 ha) - representing a higher altitude area of the wet zone. It is a complex of alluvial flood plains and steeply rising hill slopes. Field crop research is directed mainly at tree crops such as banana, cocoa and tubers. Waidradra rises to 270 metres compared to Koronivia which has a maximum altitude of 45 metres.

The soils of Waidradra are likely to be mainly Tropofluvents, Humitropepts, Eutropepts and Aquepts.

(xii) Naduruloulou Research Station (90 ha) - representing another wet zone locality, which is intermediate in character to Koronivia and Waidradra. Research emphasis is on cocoa.

Soils at Naduruloulou are expected to be mainly Eutropepts, Humitropepts, Aquepts and Tropohumults with small areas of Histosols.

The field phase of the soil surveys of the foregoing 12 properties will be completed by June, 1982, with laboratory data available by September, and draft maps with accompanying reports by the end of 1982.

Land Systems Approach

Upgrading a national soil survey to 1:50,000 scale is a formidable task for a small team in 3 years. However, a great deal of soil survey work has been completed since the Twyford and Wright survey. Much of the work has involved soil surveys of specific parts of the country as a basis for assessing land suitability for various forms of land development, embracing agriculture, forestry, town planning, land subdivisions for real estate purposes and environmental studies. Apart from projects surveyed by officers in the Ministry of Agriculture, some excellent soils characterisation work has been undertaken by private development consultants: (Huntings 1970); United Nations agencies (FAO 1972); ORSTOM (Latham, 1979); Royal Society of New Zealand (Leslie and Blakemore, 1978); to name a few. The Land Use Section at Koronivia has received soil reports for about 30 different areas across Fiji.

Because of the existence of such valuable data, it has been decided to employ a land system approach, which would better define soil/landscape relationships. This approach has been successfully used in a few places, for example in New Guinea (CSIRO, 1968), Western Australia and Northern Territory (CSIRO, 1970), and more recently in the Solomon Islands (Land Resources Division, 1976).

The land system approach identifies tracts of country which are relatively homogeneous in terms of lithology, landform, vegetation and climatic factors. It provides an appropriate base for the differentiation and field characterisation of Fiji soils, but only as a complement to the 'windows' which will be mapped in greater detail. It is estimated that Fiji may have at least 20 land systems.

The approach lends itself to illustrative diagrammatic representation of the results, which would be an enormous improvement, because, even though there is considerable amount of data in the original work of Twyford and Wright (1965) the text is poorly indexed, difficult to read and lacking in illustrative/diagrammatic information. Thus, its usefulness in extension or planning, by personnel with no formal training in soils, is limited.

'Windows' in Unrepresented Areas

Once the Fiji land systems are established and the post-Twyford and Wright soil survey work of various areas (approximately 40 per cent) superimposed on them, the gaps in soil survey coverage will become apparent. In such gaps, 'windows' or sample areas would be located and surveyed. Each would be approximately 3 km^2 in area.

For each 'window' the soil pattern will be mapped, selected profiles described, and sampled for chemical and mineralogical analyses. Emphasis would be placed on relating soil profiles to their position in the landscape, and thereby explaining the variability that is known to exist within many of the soil units established in the original classification (Twyford and Wright, 1965). Catena and soil sequences will be the basis of characterisation.

The 'window' areas would complete the correlation phase of the soil programme, as the information gained through them can be extrapolated to remaining areas, with a high level of confidence. This would, therefore, enable the Unit to correlate the remaining 35 per cent of existing soil units, finishing in 1984.

SUITABILITY OF SOILS FOR SPECIFIC CROPS

Fiji recognises that all soil units must be rated for their suitability for individual crops. This is a fundamental follow-up to the soil survey which is performed concurrently with soil correlation and classification. A questionnaire has been prepared and forwarded to agronomists, horticulturists and foresters, for specialist response on more than 75 crops, grasses, legumes and trees, to ascertain soil/climatic requirements to attain ootimum yields. The data from the agronomists etc., specifying what crops require for optimum growth will be collated with a table of soil limitations which evaluates 19 parameters, e.g.,slope, susceptibility to flooding, erosion and waterlogging, effective rooting depth, permeability, salinity, etc.

The unit is also working closely with climatologists in order to obtain meaningful agro-climatology interpretations.

THE CROP EVALUATION AND MANAGEMENT PROGRAMME (CEMP)

After the soils of Fiji have been correlated and classified, selected soils on the research stations will be chosen as benchmark trial sites. Crops which are known to be commonly viable for Fiji, plus crops new to Fiji will be evaluated by way of various management, fertility, varietal etc. trials. New crops to be evaluated will be selected from countries known to grow them successfully, and transfer will be on the basis of the soil family, of Soil Taxonomy.

Trial designs will be determined by a panel scheduled to meet February, 1983. Fiji would encourage the Benchmark Soils Project, administered by the University of Hawaii, to co-operate in this programme and assist with technical advice.

OBJECTIVES OF THE OVERALL PROGRAMME

So far the limitations of our existing classification, and the general framework of our current effort to adopt and apply Soil Taxonomy has been outlined. In summary, the principal objectives of the 5 year programme are to produce the following:

(a) New Soil Maps at 1:50,000 scale

Each map will have both a physiographic and soil classification legend. Established soil series names will be preserved where possible, although many new names will inevitably be created through more detailed field characterisation and refinement of the soil pattern. The short term assignments characterising the soils of the research stations are an important part of this phase.

(b) A National Soil Classification Map

This would be published at the scale 1:100,000, with units expressed at subgroup category of Soil Taxonomy.

(c) A Soil Correlation Report

Soils series will be tabulated in this report, together with their correlative equivalents in the Twyford and Wright, FAO/UNESCO and Soil Taxonomy systems of soil classification.

(d) Soil Unit Sheets

All available information for each soil mapping and taxonomic unit will be embodied in a more technical reference report. It will include site data (parent material, climatic data, slope position, etc.), profile features (physical, chemical, mineralogical and their

variability) plus other basic soils information which users of soil reports can refer to. These soil unit sheets also form the basis for soil correlation procedures.

(e) Soil Specific Crop Specific Interpretation Tables

The suitability of specific soils for specific crops would be shown in the tables. They will be upgraded from time to time as new information becomes available, for use by extension workers. When reliable crop data is fully available the production of single factor interpretative maps may be possible. The maps would rate specific soils against their yields under certain defined management levels. Ratings would be in terms of high, moderate, low and unsuitable.

DATA STORAGE AND RETRIEVAL

At present no data storage/retrieval system exists, and soils information cannot be easily obtained by potential users. One aim of this programme is to establish a simple system at Koronivia Research Station in which the major considerations are likely to be point data on maps of 1:50,000 scale, showing profile descriptions and laboratory references; soil unit sheets for all soil series; soil interpretation card index by soil series; soil monoliths; photographic records on air photos and colour slides.

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CLOSING ADDRESS

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Mr. Chairman, ladies, and gentlemen

It gives me great pleasure to give this closing address. This Forum on Soil Taxonomy was organised with one objective in mind; i.e., to inform the soil scientists of the Region on Soil Taxonomy, to make them familiar with the system, and to show the applicability of the system. The Forum, as you know, was the outcome of a recommendation adopted in 1976 at a meeting of soil scientists in the Region and sponsored by the South Pacific Commission.

In the last 2 weeks I believe that we have had an exciting time. When I gave my first lecture and watched your reactions, all I saw was a number of blank faces. Some were confused, others perplexed, a few disappointed, and I am sure some of you thought that you made a mistake coming to this meeting. These are natural reactions whenever you are exposed to a new subject, whenever you are told that you have to change and adopt something new. However, as the days progressed there was a distinct metamorphism. Probably, initially this was due to curiosity and early this week, during our field trip, we were glad to see a genuine interest. People were beginning to use Soil Taxonomy terms. Participants were sharing their experience. It became really evident yesterday when the lectures on the application of Soil Taxonomy were given. Though it was late in the afternoon, everybody was alert. It was clear that most people had seen the light at the end of the tunnel. Your comments yesterday evening clearly showed that we had achieved what we set out to do.

Your comments also showed that there was some dissatisfaction. This is inevitable. The organizers do realize that the interpretations and applications are very important. However, we cannot have this until you have an appreciation of the system and this is what we wanted to achieve in this particular forum.

Dr. Uehara has repeatedly told us that Soil Taxonomy promises us two things - economy of action and economy of time. The countries of the South Pacific Region do not have the time, money, or personnel to develop a classification system of their own or to do the research that is needed to provide the interpretations that are necessary. They have to use a system that is developed and tested but which is applicable to the Region. We have tried to show that Soil Taxonomy can and will serve this purpose. We have also talked about agro-technology transfer. The Region needs this badly. No one country can afford the time or money to do all the agricultural research to support its agriculture. Research has to be shared and research results have to be communicated and Soil Taxonomy provides the vehicle for this communication. If you can take this message to your planners and decision makers, you have made a contribution to your country and to the Region.

Our next question is where do we go from here. We should not lose the momentum that has been started. Your recommendations today indicate that you are all conscious of the problems and needs of not only your respective countries but also of the Region as a whole. We should strive to work more closely together for the common goal of seeking self-sufficiency in food and fibre production in the Region. The resource personnel and the international organizations represented here will assist you where ever possible. The fact, however, remains that it is your task and your responsibility. Without your initiative and efforts, we cannot progress much.

This Forum would not have been possible if not for the pain-staking work of one person. I still do not know how he became enthusiastic about Soil Taxonomy but you all will agree that we are happy that he is. This Forum was postponed by almost a year

as he had great difficulty in trying to obtain funds to organize it. Through perseverance, he has succeeded and we are very grateful to him. I hope you will join me in showing our deep appreciation to Dr. John Morrison and also to his wife Maggi for not only seeing this Forum to a successful conclusion, but also in their hospitality.

We are also grateful to the University of South Pacific and the School and Institute of Natural Resources in particular for all the facilities that they have provided. The logistics of the workshops were handled by a number of people and organizations in Fiji. We greatly appreciate the work of Mr. Dave Leslie, Mr. Vilitati Seru, Mr. Kafoa, and all staff of the Department of Agriculture and their research stations. We also appreciate the support and information provided by the staff of the Fiji Sugar Corporation and the Fiji Pine Commission.

The quality of a forum is strongly dependent on the quality of the resource personnel and we are fortunate to have an excellent group here. Drs. Mike Leamy and Fletcher Thomas from the Soil Bureau DSIR, Drs. Marc Latham and Alain Beaudou of ORSTOM, Monsieur Michel Lambert of the South Pacific Commission (SPC). We are also fortunate to have two outstanding scientists from the U.S. One is an academician and that is Goro Uehara and the other is a practitioner and that is Dick Kover.

Finally, it is my pleasant duty to thank the several organizations who directly or indirectly funded this Forum, apart from USP. One is the New Zealand Government and the other is USAID through their Soil Management Support Services (SMSS). As programme leader of SMSS, on behalf of SMSS I would like to express our thanks to all the collaborators in this Forum and we are grateful to USP for inviting SMSS to cooperate in this effort.

In conclusion, we look forward to the 1982 Forum and we hope it will be as successful as this one.

RECOMMENDATIONS OF THE FORUM

1. Analytical Services

Proposed by L. Chase (Solomon Islands), seconded by M. Purea (Cook Islands).

This Forum recognises that an increasing use of Soil Taxonomy and the growing intensity of soil survey throughout the Region will severely strain the existing analytical facilities, and strongly recommends that these existing facilities be adequately supported in terms of both skilled personnel and funding.

2. Training

Proposed by J. Lilino (Fiji), seconded by H. Eswaran (USA).

This Forum recommends that the countries of the South Pacific promote the training of personnel in soil classification, making and interpreting soil surveys for agrotechnology transfer and agricultural development. It also recommends that the existing tertiary educational institutions (i.e., Fiji Institute of Technology, Fiji College of Agriculture, the University of the South Pacific Laucala and Alafua Campuses, Papua New Guinea University of Technology (Lae), Lae Technical College, University of Papua New Guinea and the University of Guam) develop curricula in these subject matter areas. The purpose of these training programmes is to enable the trainees to use a common language for sharing agricultural knowledge and experience gained in different parts of the Region.

3. Communication

Proposed by P. Taufatofua (Tonga), seconded by M. Latham (New Caledonia).
Recognising that improved communication among people working in the field of soils and land use will increase the efficiency of research activity and result in mutual benefits for all countries in the South Pacific Region. The Forum recommends that a newsletter be established which will be circulated to all interested parties. It is further recommended that editorial responsibility be placed initially on the group of soil/land use people based in Suva, and that identified correspondents from each country should contribute. It is further recommended that the use of PEACESAT should be encouraged as a means of communication among soils/land use workers in the Pacific Region.

Note: As a result of improved communication, it is expected that a South Pacific Regional Soils Association will be formed which will seek affiliation with the International Soil Science Society.

4. Next Regional Meeting

Proposed by F.F. Kafoa (Fiji), seconded by M. Siri (Papua New Guinea).
Realizing that the major constraints to efficient utilization of the soil resources of the South Pacific Region are time, money and a lack of trained personnel and appreciating the fact that Soil Taxonomy provides a common language and can act as the vehicle for agrotechnology transfer between the countries, the participants of the Forum strongly recommend that a second Forum be organized in the region in 1982.
This Forum will focus on the use and management of soils of the Region and evaluate the interpretation of soil surveys.
To standardize the methodology and descriptive terminology among the soil scientists of the Region, it is also recommended that the Forum address these aspects in greater detail.

The Forum recommended that the 1982 meeting be held in Papua New Guinea.

5. Regional Benchmark Soils Project

Proposed by I. Huria (Papua New Guinea), seconded by P. Taufatofoa (Tonga).

This Forum recognises the value of the Benchmark Soils Project concept and recommends that a panel be convened to investigate the strategy for implementing a South Pacific Regional Benchmark Soils Project. This panel should comprise members from University of Hawaii, Soil Management Support Services, the University of the South Pacific, ORSTOM, and New Zealand Soil Bureau and would report to the 1982 Papua New Guinea Forum.

APPENDIX 1

SOUTH PACIFIC FORUM ON SOIL TAXONOMY (2-13 Nov. 1981)

PROGRAMME

Monday 2.11.81

Session 1.	Chairman Dr J.Morrison
9.00 - 10.30 am	Opening Ceremony - SNR Lecture Theatre Welcome Dr J.Maraj, Vice-Chancellor, USP Official Opening Minister of Agriculture, Fiji Overview Paper, Prof G.Uehara Forum Details Dr J.Morrison
11.00 - 12.00 noon	Dr M.Leamy History of the development of Soil Taxonomy and the need for an International Soil Classification System
12.00 - 1.00 pm	Prof G.Uehara Implications of Soil Taxonomy for agrotechnology transfer - the Benchmark Soils Project
	Lunch at USP for Participants and Invited Guests
Session 2.	Chairman Mr R.Kover
2.15 - 3.30 pm	Introduction to Soil Taxonomy The Basic Concepts and philosophy of Soil Taxonomy (Eswaran) 30 minutes Diagnostic horizons (Leamy) 45 minutes
3.45 - 5.00 pm	Moisture and temperature regimes (Leslie) 15 min. Laboratory information Chemistry and Mineralogy (Morrison) 30 minutes Physics including particle size classes (Thomas) 20 minutes Flow diagrams (Thomas) 10 minutes

Evening Social Function at USP (Hosted by Institute of Natural Resources)

Tuesday 3.11.81

8.00 - 12.00 noon	Field trip to Koronivia Research Station Alluvial soil sequence and terrace site, 4 soils (Leslie)
Session 3.	Chairman Dr M.Leamy
1.30 - 3.30 pm	Specific laboratory parameters; techniques and background to taxonomic limits
	Eswaran 40 minutes
	Thomas 40 minutes
	Morrison 40 minutes
3.45 - 5.00 pm	Discussion of keying out using Soil Taxonomy (Eswaran)

Wednesday 4.11.81

Session 4.	Chairman Mr F.F.Kafoa Soil Orders of Importance in the South Pacific (each section will include time for discussion)
8.15 - 9.00 am	Alfisols and Ultisols (Eswaran)
9.00 - 9.45 am	Andisols (Leamy)
9.45 - 10.30 am	Entisols (Leslie)
10.45 - 12.00 noon	Discussion groups
Session 5.	Chairman Prof G.Uehara
1.30 - 2.15 pm	Inceptisols (Thomas)
2.15 - 3.00 pm	Mollisols (Kover)

3.00 - 3.45 pm	Oxisols (Latham)
4.00 - 5.00 pm	Discussion groups

Thursday 5.11.81

8.00 - 12.00 noon	Field trip to Koronivia Research Station Hill country catena, 4 soils (Leslie)
Session 6.	Chairman Mr V.Seru Soil Taxonomy in relation to other classification systems
1.30 - 2.15 pm	FAO Soil Map of the World Legend (Latham)
2.15 - 3.00 pm	French System(s) (Beaudou and Latham)
3.15 - 4.00 pm	Genetic Systems (Leamy)
4.00 - 5.00 pm	International Technical Assistance through the Soil Management Support Services (Eswaran)

Friday 6.11.81

Session 7.	Chairman Mr D.M. Leslie
8.30 - 9.00 am	Soil Taxonomy and soil survey (Kover)
9.00 - 9.30 am	Soil Taxonomy and soil correlation (Leamy)
9.30 - 10.00 am	Soil Taxonomy and soil interpretation (Uehara)
10.00 - 10.30 am	Data storage and retrieval (Kover)
10.45 - 12.00 noon	Benchmark Soils Project (Uehara) including time for discussion
Session 8.	Chairman Mr D.M. Leslie
1.30 - 3.00 pm	Regional reports (lead speaker Leslie) updating the data of the 1976 SPC Conference on Soil Science and Land Use.

3.15 - 3.45 pm	A Benchmark type project for the South Pacific? The potential and likely problems (Morrison)
3.45 - 4.15 pm	Fiji Soil Programme (Seru)
	Evening Social Function (Hosted by D.M. Leslie)
Monday 9.11.81	
8.30 am	Depart Suva for Sigatoka
1.00 - 4.30 pm	Field trip - Sigatoka Valley 3 profiles with land use (Partridge, Leslie, Morrison)
Tuesday 10.11.81	
8.00 - 12.00 noon	Field trip - Nawaicoba - 3 profiles with land use (Drysdale, Leslie, Morrison)
1.30 - 4.30 pm	Legalega Research Station 4 profiles (Leslie and Thomas)
6.30 pm	F.I.A.S. (Western Branch) "Social Implications of Soil Taxonomy" (Uehara)
8.00 pm	Function arranged in collaboration with FIAS
Wednesday 11.11.81	
8.30 - 12.30 pm	Soil use in the Lautoka area - 2 profiles (Sugrim, Drysdale, Leslie, Morrison)
1.30 - 5.30 pm	Return to Suva via the Monasavu inland road
Thursday 12.11.81	
Session 9.	Chairman Dr J Morrison

8.30 - 10.00 am	Review of field-trip
10.15 - 11.15 am	Evaluation of Recommendations of 1976 SPC Conference on Soil and Land Use (Lambert)
11.15 - 12.00 noon	Potential links between South Pacific countries and the Benchmark Soils Project (Uehara, lead speaker)
Session 10.	Chairman Dr M.Leamy
1.30 - 2.30 pm	Agronomic/Land Use implications of Soil Taxonomy (Kover)
2.30 - 3.15 pm	Soil Taxonomy and Crop Performance (Eswaran)
3.30 - 4.00 pm	Forum review discussion (Leamy, Lead speaker)
	Evening Social Function
Friday 13.11.81	
	Chairman Mr D.M.Leslie
8.30 - 11.30 am	Discussion of Forum recommendations
11.30 - 12.00 noon	Closure

APPENDIX 2

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NOTES FOR FIELDTRIPS

Tuesday 3 November

Koronivia Research Station

Pedon KN 05

Pedon KN 08

Pedon KN 11

Pedon KN 30

Thursday 5 November

Koronivia Research Station

Pedon KN 17

Pedon KN 18

Pedon KN 19

Pedon KN 20

Monday 9 November

Sigatoka Research Station

Pedon SIG 1

Pedon SIG 2

Pedon SIG 3

Tuesday 10 November

Nawaicoba

Pedon NWC 1

Pedon NWC 2

Pedon NWC 3

Legalega Research Station

Pedon LL 1

Pedon LL 29

Pedon LL 9

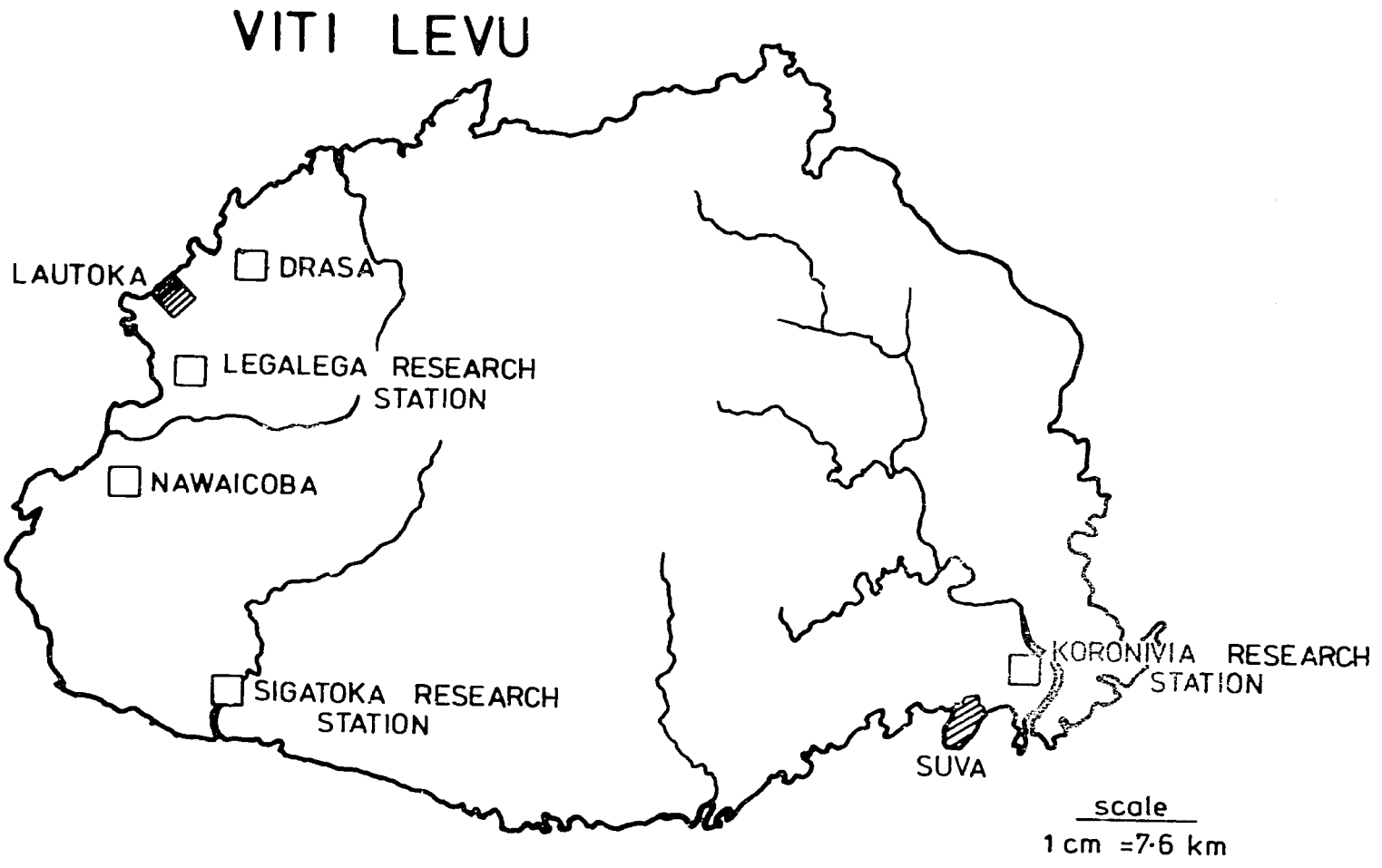
Pedon LL 30

Wednesday 11 November

Drasa

Pedon DRS 3

Pedon DRS 4


VITI LEVU
LAUTOKA
DRASA
LEGALEGA RESEARCH STATION
NAWAICOBA
SIGATOKA RESEARCH STATION
KORONIVIA RESEARCH STATION
SUVA
scale
1 cm =7·6 km

Appendix 3 presents profile and site descriptions with classifications for the pedons visited during the field trips.
NOTE: Profile descriptions follow Soil Survey Method (Taylor and Pohlen, 1970) with horizon designations after the legend of the Soil Map of the World (FAO/UNESCO, 1974). The laboratory analyses were carried out using standard methods. The MAF phosphorus values were obtained by shaking soil samples with 0.025 Molar sulphuric acid (soil solution ratio 1:100) for 1 hour and then analysing the solution for phosphorus (Department of Agriculture, Fiji, unpublished).

The following summarizes why certain pedons were selected for the field trips and the main points of discussion at these sites with an emphasis on any problems encountered in keying - out the soils. This has been included more for the benefit of the Forum participants and is not a full summary of all the discussions.

Pedons KN 05, 08, and 11 were selected to demonstrate soil processes operating on a 'youthful' alluvial flood plain in an udic moisture regime, and how Soil Taxonomy assists with not only the differentiation of the taxa but through the nomenclature with an appreciation of the principal physical and chemical features of the pedons.

Rewa series (Pedons KN 05) develops on a levee which receives periodic accretions of alluvium at a rate that generally keeps pace with soil development. However, the paleosol in the profile indicates that past flood events have deposited larger volumes of sediment at the site. Here soil development is required to restart from the initial position, i.e., as an Entisol. Such major flood events are considered to be 1 in 100 year events. The pedon has a weakly expressed cambic diagnostic horizon, and discussion centred on

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FAO/UNESCO, 1974. Soil Map of the World. Volume 1, Legend. UNESCO, Paris, 62p.

Taylor, N.H. and Pohlen, I.J., 1970. Soil Survey Method. N.Z. Soil Bureau Bull. 25, 242p.

this feature as the differentiating criterion between Entisols and Inceptisols (which are recognized closer to the river).

The other feature of the profile was the well expressed paleosol (Ab horizon) which, as the organic carbon figures confirm, causes an irregular decrease in carbon content down the profile, i.e., the fluventic subgroup criterion for Eutropepts.

Some discussion was generated by the relatively high values of the CEC for a soil having a kaolinitic mineralogy. Recent studies have shown that in some soils of this area an inter-stratified kaolinite-smectite is found and this may account for the high CEC/clay ratio in this case.

Navua (KN 08) and Nausori (KN 11) series occur in sequence further from the river, are finer textured and though they flood regularly, do not receive significant amounts of "fresh" alluvium. However, both pedons experience seasonal high water tables and the oxidation and reduction features, i.e., gleying and mottling, typical of 'wet' soils were explained in the context of the aquic moisture regime. The importance of differentiating at the suborder level soils with aquic moisture regimes was discussed as were mottle colour criteria in differentiating subgroups of Tropaquepts - in this case the Navua series (Aeric) from the Nausori series (Typic).

Koronivia (KN 30) series develops on marine planated surfaces that have been weathering in situ for a long period of time. Profile development is therefore well expressed. The pedon was included to show the features of the argillic horizon, i.e., clay coatings to peds, the clay distribution figures and the general principles of illuviation. Also discussed were the BS% figures, which were low in the argillic horizon and below indicating that this series must be classified as an Ultisol rather than an Alfisol; how the relatively high amounts of organic carbon made this soil a Humult at the suborder level (with an isohyperthermic temperature regime, a Tropohumult); and because of the low CEC values into the Humoxic subgroup, i.e., intergrading to the Oxisol order.

Pedons KN 17 to 20 form a hill sequence and were selected to show the variability that can occur in the hill country, and the importance of understanding soils in the field in relation to slope and topographic position. The pedons were studied in order from ridge crest to toe-slope.

Domonuku (KN 17) and Waila (KN 18) series: discussion centred on whether or not there were truncated argillic horizons. There was discussion of the possibility that such truncation had occurred at the time of bush clearance in the 1920's. It was decided that the pedons had cambic horizons and on temperature data were classified as Tropepts. Chemical data showed less than 50% BS, and with the high organic carbon figures, they were classified as Humitropepts, and Typic.

Sarava (KN 19) series: developed on an old landslide scar, the shallow profile was used to explain criteria used for identifying lithic and paralithic contacts.

Davuilevu (KN 20) series occurs on toe-slopes at the bottom of the slope sequence. The site receives all the runoff from the slopes above and seasonal waterlogging occurs as indicated by oxidation and reduction features. The pedon was compared to the Navua series (affected by ground water table) where gleying processes occur in the reverse direction in the profile to the Davuilevu.

The Sigatoka Research Station sites are located in an area at the dry end of the udic moisture regime.

Pedon SIG 1: discussions at this site centred on clay skin criteria in the identification of argillic horizons, and the requirement of having backup particle size data where cutans are not well expressed. All horizons gave a positive NaF test indicating the presence of some reactive aluminium species in the profile.

Pedon SIG 2 was discussed in relation to the Rewa (KN 05) series. Both are young soils on a floodplain, but SIG 2 is of coarser texture and has no cambic horizon. For Entisols developed on alluvium, irregular decrease in carbon content down the profile is to be expected and therefore keys out at the suborder rather than at the subgroup level as in the Inceptisols. Whether or not the epipedon was mollic was discussed. It meets the BS, organic carbon and depth criteria, but fails to meet the colour criteria.

Pedon SIG 3 was selected to explain the concept of the pedon as 2 different taxa were described within the allowed dimensions of the pedon. That described and analysed classifies as a Typic Haplustoll although considerable discussion centred on whether or not an argillic horizon was present. The particle size figures suggest a clay bulge, but in consideration of the 15 bar moisture retention data and the montmorillonitic mineralogy, the consensus view dismissed the argillic horizon possibility. Vertic features (polished surfaces and cracking) were explained, but these were of insufficient thickness to qualify for a vertic subgroup.

The Nawaicoba, Legalega and Drasa Pedons all develop in an ustic moisture regime.

Pedon NWC 1 was selected to show the features of a Vertisol, i.e., vertical cracking, tilted peds, slickensides and polished surfaces. Differences between cutans and polished surfaces were explained. The weakly expressed surface gilgai features were discussed as another criterion for recognition of Vertisols of vertic subgroups of other orders.

Pedon NWC 2 though classified the same as NWC 1, was ued to reinforce properties of Vertisols, but in addition, features of initial clay translocation were shown. Some discussion followed on the irregular decrease of organic carbon in relation to fluventic subgroups of other orders. It was explained that since many Vertisols were

formed in lower slope positions where accumulation of run off material occurred, these fluventic features were common.

Pedon NWC 3: at this site initial discussion centred on whether or not the epipedon was mollic. It was explained that because of COLE (too high) and structure (massive and hard when dry) the epipedon could not be mollic. Also, it was shown that apparent structures were, in fact, cracks. The cambic B horizon was recognised on the basis of being of redder hue than the underlying horizon. The difference between cutans and stress features was reiterated.

A soil sequence of pedons developed on 'old' alluvium in a subdued landscape on Legalega Research Station was selected to expose participants to strongly weathered soils and their associated properties. Four pedons comprised the caten.

Nadi (LL 1) series: the features of the oxic horizon were introduced at this site. It was agreed after discussion that though the epipedon was mollic, Oxisols key out first, and that oxic horizons are not permitted in the Mollisol order. Examination of the data presented in the table for this pedon shows that the CRC as determined by the sum of the exchangeable bases plus aluminium just exceeds the limit required for an oxic horizon (28 - 54 cm horizon). This was explained as being the result of the relatively high exchangeable calcium levels caused by the extensive liming history of the area. Direct determination of the CRC using ammonium chloride gave a value which met the required limits for an oxic horizon.

Mocambo (LL 29 and LL 9) series: though both pedons had been mapped in the same series, Soil Taxonomy showed them to be different at the family level (mixed and kaolinitic mineralogies), but otherwise similar in all properties. They are duplex profiles comprising sediments of similar origin to the material for the Nadi series overlying the so-called Legalega sediments. The question of plinthite in the subsoil was raised, but could not be resolved on the day, requiring drying over a period of time before it could

be dismissed, i.e., no irreversable drying occurred. The features of an argillic horizon were again demonstrated as was the use of the chemical (CEC) data to show these pedons intergrade to Oxisols.

Legalega (LL 30) series: at this site the question of plinthite presence was again raised (and subsequently disproved). The presence of white mottles (gibbsite?) in subsoils was raised to indicate possibly an aquic moisture regime. On the basis of colour chromas, an aquic regime was dismissed. The pale - concept applied to 'old' soils was discussed.

The Drasa 3 site, comprising 3 taxa within the pedon was selected in this degraded landscape, common in the so-called 'dry' zone of western Viti Levu to reinforce the pedon concept and the need to observe pointers to landscape stability and instability.

Profile 3A: here rock structure made up more than 50% of the subsoil horizons (pedologically altered) so no cambic horizon was recognised. This placed the soil in the Entisol order. A positive NaF test in all horizons, relatively high 15 bar moisture retention and exchangeable aluminium led to a discussion of the possibility of an andeptic subgroup which is provided in the Udorthents but not in the Ustorthents. It was decided that (considering the 3 profiles) the decrease in 15 bar moisture retention on drying was insufficient for an andeptic subgroup.

Profile 3B was similar to the 3A, but with a different particle size class and a paralithic contact at 36 cm.

Profile 3C was similar to 3A, but the epipedon had been recently buried by a shallow layer of erosion products, i.e., too recent to be considered as a paleosol.

Drasa 4: at this site considerable discussion was generated as to whether the diagnostic horizon was argillic or oxic. Clay skins were described for deep in the profile and the particle size data

indicated an argillic horizon. Based on BS% values the pedon keyed out as an Ustult. The physical properties and field descriptions indicated strong oxic affiliations and the chemistry confirmed the pedon intergrading to Oxisols, being oxic at the subgroup level.

NOTE ADDED IN PROOF (p327)

Since the Proceedings went to press a computer analysis of climatic data for Fiji has been completed by USDA-SMSS. This analysis concluded that the soil moisture regime for all of Fiji was UDIC, contrary to local estimations which had indicated that some areas in the drier zones of the larger islands had USTIC moisture regimes. The USDA-SMSS computer analysis uses the Thornthwaite method for determining potential evapotranspiration (PET). The Thornthwaite method has been shown to give good results for temperate continental areas but deficiencies have been observed when it is applied to other situations. The Penman method of determining PET has been found useful in many non-continental situations and the use of this method gives an USTIC soil moisture regime for the driest parts of the Fiji islands.

The conclusion that all the soils of Fiji have an UDIC moisture regime causes some concern in terms of the relationship between classification and land use, as there are marked differences in the agriculture between the wetter and drier zones of the islands. This problem may be resolved with the introduction of the proposed subdivisions of the moisture regimes as proposed by the International Committee on Soil Moisture Regimes in the Tropics (ICOMMORT).

As a result of the use of the present criteria and methods given in Soil Taxonomy, the soils of the Nawaicoba, Legalega and Drasa sites must be reclassified as follows:

NWC 1	Typic Pelludert
NWC 2	Typic Pelludert
NWC 3	Paralithic Vertic Eutropept
LL 1	Tropetic Eutrothox
LL 29	Orthoxic Tropudult
LL 9	Orthoxic Tropudult
LL 30	Typic Paleudult
DRS 3	Andeptic Troporthent
DRS 4	Orthoxic Tropudult

Pedon KN 05

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-18	5.6		1.4			35			14.8
18-28	5.7		1.2			14			16.5
28-77	6.0		1.4			5			21.7
77-108	6.0		0.7			10			23.9
108-123	6.0		1.2			5			21.2

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-18	26.7	19.9	75	13.1	6.5	0.1	0.2		11	49	40
18-28	28.0	22.0	79	14.3	7.3	0.2	0.2		11	46	43
28-77	32.6	25.7	79	16.6	8.7	0.2	0.2		3	44	53
77-108	32.9	28.7	87	18.1	10.1	0.2	0.3		1	49	50
108-123	28.6	22.8	80	13.9	8.5	0.1	0.3		2	46	52

Pedon KN 05 (Rewa Series)

Classification:	Fluventic Eutropept, clayey, kaolinitic, isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Levee; altitude 19 m a.m.s.l.; hummocky microrelief
Drainage:	Moderately well drained
Vegetation:	Cocoa (for 10 years)
Parent Material:	Alluvium derived from quartz-poor rocks
Ap1 0-18 cm	horizon slightly moist; dark brown 10 YR 3/3 (ped face); 10 YR 3/3 (rubbed); silt loam; weakly developed fine nut structure plus weakly developed medium crumb; non-sticky, non-plastic, friable; many fine roots; no stones; diffuse smooth boundary,
Ap2 18-28	horizon slightly moist; dark brown 10 YR 3/3,(ped,face); 10 YR 3/3 (rubbed); silt loam; few fine faint dark brown, 7.5 YR 4/4 mottles; weakly developed coarse blocky structure breaking to weakly developed fine nut; non-sticky, non-plastic, friable; common fine roots; no stones; indistinct smooth boundary,
Bw 28-77	horizon slightly moist; dark yellowish brown 10 YR 4/4 (ped face); 10 YR 4/4 (rubbed); silt loam; weakly developed fine nut structure; non-sticky, non-plastic, friable; few fine roots; no stones; indistinct smooth boundary,
B/C 77-106	horizon moist; yellowish brown 10 YR 5/6 (ped face); dark yellowish brown 10 YR 4/6 (rubbed); silty clay loam; few weakly developed coarse nut structure breaking to very fine nut; non-sticky, non-plastic, friable; few, very fine Fe/Mn concretions (5 YR 2/2); few fine roots; no stones; distinct smooth boundary,
Ab 106-126	horizon moist; dark brown 10 YR 3/3 (ped face); 10 YR 3/3 (rubbed); silt loam; weakly developed fine nut structure; non-sticky, non-plastic, friable; few fine roots; no stones.

Pedon KN 08

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) AAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-20	5.7		2.2			16			23.5
20-33	5.8		2.0			18			23.3
33-49	5.9		1.0			2			24.5
49-64	5.9		1.3			<2			24.5
64-93	5.9		0.8			6			23.4
93-143	6.1		0.6			2			24.8

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-20	30.6	20.3	67	11.4	8.3	0.2	0.4		2	42	56
20-33	30.7	21.7	71	12.2	9.0	0.1	0.4		2	40	58
33-49	25.5	18.5	73	9.3	8.8	0.1	0.3		1	39	60
49-64	25.0	18.6	74	8.8	9.4	0.1	0.3		3	39	58
64-93	21.2	17.1	81	8.1	8.6	0.1	0.3		3	38	59
93-143	22.9	18.6	81	8.0	10.2	0.1	0.3		6	30	64

Pedon KN 08 (Navua Series)

Classification:	Aeric Tropaquept, clayey, kaolinitic, isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Floodplain, flat microrelief; altitude 19 m a.m.s.l.
Drainage:	Imperfectly drained
Vegetation:	Para grass pasture
Parent Material:	Alluvium derived from quartz-poor rocks
Ag1 0-20 cm	horizon moist; olive grey, 5Y 5/2 (ped face); dark greyish brown, 10 YR 4/2 (rubbed); silt loam, profuse, medium, prominent olive brown, 2.5 YR 3/4 mottles; weakly developed coarse blocky structure breaking to weakly developed fine nut; slightly sticky, non-plastic, friable; abundant fine roots; no stones; indistinct smooth boundary,
Ag2 20-33	horizon moist; olive grey 5Y 5/2 (ped face); very dark greyish brown, 10 YR 3/2 (rubbed); silty clay loam; profuse, medium, prominent olive brown, 2.5 YR 3/4 mottles; weakly developed medium nut structure breaking to single grain; slightly sticky, non-plastic, friable; abundant fine roots; no stones; distinct wavy boundary,
Bg 33-49	horizon moist; brown, 10 YR 4/3 (ped face); yellowish brown, 10 YR 5/4 (rubbed); silt loam; many, medium, distinct olive grey 5Y 5/2 mottles; weakly developed coarse blocky structure breaking to weakly developed fine nut; slightly sticky, non-plastic, friable; many very fine roots; no stones; distinct smooth boundary,
Agb 49-64	horizon moist; olive brown, 2.5Y 4/4 (ped face); dark brown, 10 YR 3/3 (rubbed); silty clay loam; many, coarse, distinct yellowish red 5 YR 4/6 mottles; weakly developed fine structure plus weakly developed medium crumb; non-sticky, non-plastic, friable; common very fine roots; no stones; distinct smooth boundary,
Bgb 64-93	horizon very moist; yellowish brown, 10 YR 5/6 (ped face); 10 YR 5/6 (rubbed); clay loam; many, coarse, distinct olive grey 5Y 5/2 mottles; massive breaking to weakly developed coarse blocky structure; slightly sticky, non-plastic, friable; no roots; no stones; diffuse smooth boundary,

B/Cr	93-143	horizon wet; yellowish brown 10 YR 5/6 (ped face); 10 YR 5/6 (rubbed); clay loam; profuse, coarse, prominent light olive grey, 5Y 6/2 mottles; massive breaking to weakly developed coarse blocky structure; slightly sticky, non-plastic, friable; no roots; no stones.

Pedon [illegible]

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) NAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-16	5.1		4.0			28			26.1
16-28	5.2		2.4			3			26.7
28-43	5.5		0.9			5			22.0
43-93	5.6		0.9			<2			18.4
93-119	5.2		0.5			5			14.4

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-16	29.3	14.3	49	8.6	5.2	0.2	0.3		2	39	59
16-28	26.0	12.8	49	7.7	4.9	0.1	0.1		0	37	63
28-43	20.3	12.4	61	7.1	5.1	0.1	0.1		0	48	52
43-93	20.6	13.2	64	7.3	5.6	0.1	0.2		·	57	42
93-119	16.2	8.2	51	4.4	3.5	0.1	0.2		35	28	37

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Pedon KN 11 (Nausori Series)

Classification:	Typic Tropaquept, clayey, kaolinitic, isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Floodplain; flat microrelief; altitude 16 m a.m.s.l.
Drainage:	Poorly drained
Vegetation:	Setaria grass, Para grass, Centrosema
Parent Material:	Alluvium derived from quartz poor rocks
Ap 0-16 cm	horizon slightly moist; very dark greyish brown 2.5Y 3/2 (ped face); 2.5Y 3/2 (rubbed), silty clay loam; few fine, faint dark brown, 7.5 YR 4/4 mottles; weakly developed fine nut structure plus weakly developed medium nut; non-sticky, non-plastic, friable; common fine roots; no stones; indistinct smooth boundary,
A/B 16-28	horizon slightly moist; olive grey 5Y 4/2 (ped face), olive brown 2.5Y 4/4 (rubbed) silty clay loam; many, fine, distinct 7.5 YR 5/6 mottles; weakly developed fine nut; non-sticky, non-plastic, friable; firm; no cutans; common fine roots; no stones; distinct smooth boundary,
Bg 28-43	horizon slightly moist; olive grey 5Y 4/2 (ped face); olive 5Y 5/4 (rubbed), clay loam; profuse, fine, distinct, strong brown, 5 YR 5/8 mottles; massive, breaking to weakly developed coarse blocky structure; slightly sticky, non-plastic, friable; few medium roots; no stones; diffuse smooth boundary,
B/Cg 43-93	horizon very moist; light olive grey 5Y 6/2 (ped face); pale olive 5Y 6/4 (rubbed), clay loam; profuse, coarse, prominent, yellowish red, 5 YR 5/8 mottles; massive breaking to weakly developed coarse blocky; sticky, plastic, firm; few very fine roots; no stones; indistinct smooth boundary,
Cr 93-118	horizon wet; greenish grey 5BG 5/1 (ped face); greenish grey 5GY 5/1 (rubbed), fine sandy clay; common, coarse, distinct, yellowish red, 5 YR 5/8 mottles; massive breaking to single grain; sticky, slightly plastic, friable; no roots; no stones.

Pedon KN 30

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-18	5.4		2.6						11.3
18-41	5.6		1.8						13.4
41-73	5.1		1.0						27.4
73-100	5.0		0.6						29.1
100-125	5.1		0.3						23.9

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-18	10.6	6.4	60	5.0	1.0	0.2	0.2		46	22	32
18-41	8.6	5.2	60	4.4	0.7	tr	0.1		42	17	41
41-73	10.1	4.5	45	3.6	0.9	tr	tr		19	12	69
73-100	11.4	1.2	11	0.7	0.4	0.1	tr		11	13	76
100-125	13.9	1.1	8	0.5	0.3	0.1	0.2		13	25	62

Pedon KN 30 (Koronivia Series)

Classification:	Humoxic Tropohumult, clayey, kaolinitic, isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Surface of moderately dissected terrace
Topography:	Flat microrelief; altitude 62 m a.m.s.l.
Drainage:	Imperfectly drained
Vegetation:	Para grass pasture
Parent Material:	Strongly weathered in situ basic tuff of the Suva marl type
Ap 0-18 cm	horizon slightly moist; dark brown 10 YR 3/3 (ped face), 10 YR 3/3 (rubbed) silt loam; weakly developed fine nut structure plus weakly developed very fine granular; non-sticky, non-plastic, friable; many fine roots; few, unweathered, rounded gravels; indistinct smooth boundary,
Au 18-41	horizon slightly moist; olive brown 2.5Y 4/4 (ped face), yellowish brown 10 YR 5/8 (rubbed) silt loam; common, medium, distinct, yellowish red 5 YR 4/6 mottles; weakly developed very fine nut structure plus weakly developed very fine granular; non-sticky, non-plastic, friable; common fine roots; few, unweathered, rounded gravels; sharp wavy boundary,
Bt 41-73	horizon moist; yellowish brown 10 YR 5/8 (ped face), 10 YR 5/8 (rubbed) clay loam; few medium, prominent, dark red 10R 3/6 mottles; weakly developed coarse blocky structure breaking to weakly developed very fine blocky; sticky, slightly plastic, firm; few, faint, dark yellowish brown, 10 YR 4/6 clay cutans; few very fine roots; no stones; indistinct smooth boundary,
Btg 73-100	horizon moist; yellowish brown 10 YR 5/8 (ped face), 10 YR 5/8 (rubbed) clay loam; profuse, medium, prominent, dark red 10R 3/6 mottles; massive breaking to weakly developed medium blocky structure; sticky, slightly plastic, firm; no cutans; no roots; no stones; indistinct smooth boundary,
B/C 100-125	horizon moist; very pale brown 10 YR 7/3 (ped face), 10 YR 7/3 (rubbed) silty clay loam; few, medium, distinct red 2.5 YR 5/8 mottles; massive; slightly sticky, non-plastic, firm; no roots; no stones.

Pedon KN 17

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-6	5.5		8.6			97			30.2
6-19	5.2		4.5			38			26.5
19-31	5.2		2.2			7			25.4
31-43	5.3		1.1			<2			25.3
43-58	5.5		0.9			<2			23.9
58-98	5.6		0.4			<2			25.6
@ 120	5.8		0.3						21.5

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-6	38.7	27.4	71	15.5	10.9	0.5	0.5	0.2	3	34	63
6-19	29.2	18.3	63	10.7	7.0	0.3	0.3	1.0	4	33	63
19-31	26.3	13.6	52	8.4	4.8	0.2	0.2	3.7	4	31	65
31-43	25.4	11.8	46	7.4	4.0	0.2	0.2	6.6	2	36	62
43-58	19.9	8.4	42	5.7	2.5	0.1	0.1	3.4	4	39	57
58-98	26.7	12.0	45	8.8	2.8	0.2	0.2	8.3	3	37	60
@ 120	18.6	9.0	48	6.6	2.1	0.1	0.2	2.7	9	43	48

Pedon KN 17 (Domonuku Series)

Classification:	Typic Humitropept, clayey, kaolinitic, isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Summit interfluve site on narrow hill crest
Topography:	Slope 1° N facing; altitude 100 m a.m.s.l.; flat microrelief
Drainage:	Imperfectly drained
Vegetation:	Navua sedge, Mile-a-minute, Yellow primrose
Parent Material:	Moderately weathered in situ marls and siltstones of basic and intermediate composition
Ah1 0-6 cm	horizon slightly moist; dark brown 10 YR 3/3 (ped face), 10 YR 3/3 (rubbed) silty clay loam; moderately developed very fine nut structure; non-sticky, non-plastic, friable; many very fine roots; no stones; indistinct smooth boundary,
Ah2 6-19	horizon slightly moist; dark greyish brown 10 YR 4/2 (ped face), dark yellowish brown 10 YR 4/4 (rubbed) silty clay loam; few, fine, distinct, strong brown 7.5 YR 5/6 mottles; weakly developed fine nut structure plus weakly developed very fine granular; slightly sticky, non-plastic, friable; common very fine roots; no stones; diffuse smooth boundary,
AB 19-31	horizon slightly moist; yellowish red 5 YR 5/6 (ped face), 5 YR 5/6 (rubbed) clay loam; weakly developed fine nut structure plus weakly developed fine granular; sticky, non-plastic, friable; few fine roots; no stones; indistinct smooth boundary,
Bw 31-43	horizon slightly moist; yellowish red 5 YR 5/6 (rubbed) clay loam; common, medium, distinct 2.5Y 6/4 mottles; moderately developed coarse blocky structure plus moderately developed fine blocky; sticky, non-plastic, friable; few faint yellowish red 5 YR 4/6 clay cutans; few very fine roots; no stones; distinct smooth boundary,
Bs 43-58	horizon slightly moist; dark yellowish brown 10 YR 4/6, dark yellowish brown 10 YR 4/4 (ped face), 10 YR 4/6 (rubbed) clay loam;

		weakly developed medium blocky structure breaking to single grain; slightly sticky, non-plastic, firm; few very fine roots; no stones; distinct smooth boundary,
B/Cs	58-98	horizon slightly moist; light brownish grey 2.5Y 6/2 clay; massive; slightly sticky, non-plastic, firm; no roots; no stones; sharp smooth boundary,
C	98-104	horizon slightly moist; yellowish red 5 YR 5/6 clay loam; massive; non-sticky, non-plastic, friable; no roots; no stones; sharp smooth boundary,
Cs	104-114	horizon slightly moist; light brownish grey 2.5Y 6/2 clay; massive; slightly sticky, non-plastic, firm; no roots; no stones.

Pedon KN 18

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-11	5.2		4.5						26.5
11-21	5.3		2.9						25.1
21-41	5.3		1.4						27.5
41-67	5.2		0.9						26.8
67-121	5.3		0.8						25.9

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-11	28.8	15.0	52	9.4	5.1	0.3	0.2		4	31	65
11-21	25.5	12.8	50	7.8	4.7	0.2	0.1		4	28	68
21-41	27.1	11.3	42	6.7	4.3	0.2	0.1		3	29	68
41-67	27.8	9.1	33	5.6	3.2	0.2	0.1		4	40	56
67-121	28.3	6.7	24	3.9	2.4	0.2	0.1		2	37	61

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Pedon KN 18 (Waila Series)

Classification:	Typic Humitropept, clayey, kaolinitic, isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Planar-convex backslope in strongly dissected hill country
Topography:	Slope 22° facing N; altitude 90 m a.m.s.l.; terracettes
Drainage:	Moderately well drained
Vegetation:	Batiki blue grass, Desmodium, Navua sedge, Mimosa, Tar weed
Parent Material:	Colluvium derived from weathered marls and siltstones of basic and intermediate composition

Ah	0-11 cm	horizon slightly moist; dark brown 10 YR 3/3 (ped face), dark yellowish brown 10 YR 4/4 (rubbed) silty clay loam; moderately developed fine nut structure plus moderately developed very fine nut; non-sticky, non-plastic, friable; abundant medium roots; few, strongly weathered, subangular gravels; indistinct smooth boundary,
A/B	11-21	horizon slightly moist; dark yellowish brown 10 YR 4/4 (ped face), 10 YR 4/4 (rubbed) silty clay loam; moderately developed fine nut structure plus moderately developed very fine granular; non-sticky, non-plastic, friable; many medium roots; few, strongly weathered, subangular gravels; indistinct smooth boundary,
Bw	21-37	horizon slightly moist; yellowish red 5 YR 5/6 (ped face), strong brown 7.5 YR 5/6 (rubbed) clay loam; weakly developed coarse blocky structure, non-sticky, non-plastic, friable; few, faint, strong brown 7.5 YR 5/6 cutans; many fine roots; no stones; distinct wavy boundary,
B/C1	37-63	horizon slightly moist; pale yellow 2.5Y 7/4 (ped face), 2.5Y 7/4 (rubbed) clay loam; massive; non-sticky, non-plastic, firm; few, faint, strong brown 7.5 YR 5/6 cutans; common fine roots; no stones; diffuse smooth boundary,
B/C2	63-118	horizon slightly moist; pale yellow 2.5Y 7/4 (ped face), 2.5Y 7/4 (rubbed) clay; massive; slightly sticky, non-plastic, friable; few, faint, strong brown 7.5 YR 5/6 cutans; no roots; no stones.

Pedon KN 19

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-18	5.6		2.9			7			20.1
18-31	5.9		1.6			<2			19.1
31-121	6.9		0.4			77			15.4

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-18	32.4	24.2	75	16.8	7.0	0.2	0.2	0.9	11	39	50
18-31	33.1	26.9	81	19.0	7.4	0.2	0.3	0.8	7	43	50
31-121	30.6	30.0	98	23.2	6.3	0.3	0.2	0.2	10	51	39

Pedon KN 19 (Sarava Series)

Classification:	Lithic Eutropept, clayey, kaolinitic isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Planar-concave midslope in strongly dissected hill country
Topography:	Slope 40° facing NW; altitude 55 m a.m.s.l.; terracettes
Drainage:	Moderately well drained
Vegetation:	Batiki blue grass, Navua sedge, Desmodium, Carpet grass
Parent Material:	Shallow colluvium over weakly weathered in situ siltstone of basic-intermediate composition
Ah 0-18 cm	horizon slightly moist; very dark greyish brown 10 YR 3/2 (ped face), 10 YR 3/2 (rubbed) silt loam; moderately developed fine nut structure plus moderately developed fine granular; non-sticky, non-plastic, friable; many fine roots; no stones; indistinct smooth boundary,
A/B 18-31	horizon slightly moist; dark yellowish brown 10 YR 4/4 (ped face), 10 YR 4/4 (rubbed) silt loam; common, medium, distinct, reddish brown 5 YR 4/4 mottles; weakly developed very fine nut structure plus moderately developed fine granular; non-sticky, non-plastic friable; many fine roots; few, strongly weathered, subangular stones; sharp wavy boundary,
R 31-121	horizon dry; olive 5Y 5/3 (ped face), 5Y 5/3 (rubbed) very fine sand; many coarse, distinct, yellowish brown 10 YR 5/8 mottles; massive; non-sticky, non-plastic, very firm.

Pedon KN 20

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-13	5.5		4.1			<2			20.2
13-32	6.0		2.1			<2			19.7
32-58	6.3		1.0			4			21.6
58-83	6.6		0.5			<2			20.3
83-103	7.0		0.1			157			18.0

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-13	30.8	21.5	70	14.4	6.6	0.2	0.3	0.7	5	40	55
13-32	31.3	24.4	78	16.2	7.7	0.2	0.3	0.4	3	39	58
32-58	36.3	31.4	87	21.4	9.5	0.3	0.2	0.2	3	40	57
58-83	34.1	31.6	93	21.9	9.1	0.3	0.3	0.1	3	44	53
83-103	35.0	34.5	99	25.7	8.1	0.4	0.3	0.1	4	54	42

Pedon KN 20 (Davuilevu Series)

Classification:	Aquic Eutropept, clayey, kaolinitic, isohyperthermic
Location:	Koronivia Research Station, Viti Levu, Fiji
Physiographic Position:	Concave toeslope in strongly dissected hill country
Topography:	Slope 18° facing NW; altitude 25 m. a.m.s.l.; terracettes
Drainage:	Imperfectly drained
Vegetation:	Batiki blue grass, Navua sedge, Desmodium, Mimosa
Parent Material:	Colluvium derived from marls and siltstones of basic and intermediate composition

Ah	0-13 cm	horizon slightly moist; dark brown 10 YR 3/3 (ped face), 10 YR 3/3 (rubbed) silty clay loam; developed fine nut structure plus moderately developed fine granular; non-sticky, non-plastic, friable; abundant fine roots; no stones; indistinct smooth boundary,
A/Bg	13-32	horizon slightly moist; dark yellowish brown 10 YR 4/4 (ped face), 10 YR 4/4 (rubbed) silty clay loam; common, fine, faint, olive grey 5Y 5/2 mottles; weakly developed coarse blocky structure breaking to weakly developed fine nut; non-sticky, non-plastic, friable; abundant fine roots; no stones; indistinct smooth boundary,
Bg	32-58	horizon moist; yellowish brown 10 YR 5/6 (ped face), 10 YR 5/6 (rubbed) silty clay loam; many, fine, distinct, olive 5Y 5/3 mottles; weakly developed fine blocky structure; slightly sticky, non-plastic, friable; many fine roots; few, strongly weathered, subangular gravels; distinct smooth boundary,
B/Cg	58-83	horizon moist; yellowish brown 10 YR 5/8 (ped face), 10 YR 5/8 (rubbed) silty clay loam; many,medium,distinct olive grey 5Y 5/2 mottles; massive; non-sticky, non-plastic, firm; many fine roots; distinct smooth boundary,
R	83-103	horizon dry; yellowish brown 10 YR 5/4 (ped face), 10 YR 5/4 (ped face) fine sand; massive; non-sticky, non-plastic, extremely firm; no roots.

Pedon SIG 1

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	6.4	4.9	5.41	0.24	22	38	<1	18	16.8	6.8
20-25	6.5	4.7	1.06	0.08	13	18	<1	29	25.6	18.4
40-50	6.6	4.6	0.44	0.04	11	15	<1	25	17.4	17.6
70-80	6.7	4.5	0.26	0.02	13	45	<1	16	20.2	17.4
140-150	6.8	4.6	0.20	0.01	20	614	<1	17	23.4	20.4

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-10	27.5	23.4	85	12.3	10.2	0.9	<0.1	0	46	47	7
20-25	29.5	24.8	84	8.3	15.8	0.6	0.1	0	47	37	16
40-50	32.3	25.4	79	7.8	16.3	0.3	1.0	0	44	42	14
70-80	24.1	26.0	(100)	8.4	17.5	<0.1	0.1	0	54	34	12
140-150	53.9	40.0	75	18.4	21.1	0.2	0.3	0	65	29	6

Pedon SIG 1

Classification:	Typic Tropudalf, clayey, mixed, isohyperthermic
Location:	Sigatoka Research Station, Viti Levu, Fiji
Physiographic Position:	Convex backslope in strongly dissected hill country; altitude 100 m a.m.s.l.
Topography:	Microrelief flat with major terracettes; slope 12° facing west
Drainage:	Moderately well drained
Vegetation:	Grasses and reeds
Parent Material:	Thin colluvium derived from basalt flow rock over in situ rock of the same origin
Ah 0-19 cm	slightly moist; very dark greyish-brown (10 YR 3/2) slightly gritty silt loam; moderately developed fine nut structure with moderately fine granular and crumb; non-sticky; non-plastic; very friable; abundant, fine and medium roots; few, weakly weathered, sub-angular stones; indistinct, smooth boundary,
AB 19-32	slightly moist; 70% dark brown (10 YR 3/3), 30% yellowish-red (5 YR 5/6) rubbed, dark yellowish-brown (10 YR 3/4) silty clay loam; moderately developed fine nut structure with some moderate fine granular; non-sticky; non-plastic; friable; many, very fine roots; common, moderately weathered subangular stones; indistinct smooth boundary,
Bt1 32-58	dry; stones yellow (10 YR 7/6) and matrix, brown (7.5 YR 4/4), rubbed, brown (7.5 YR 4/4) stony clay loam; weaky developed medium blocky structure breaking to weak to moderate fine nut and crumb; non-sticky; non-plastic; friable; uncemented; soft to firm penetration; few, distinct, dark reddish-brown (5 YR 3/4) clay coatings (to stones only); many fine roots; many, moderately weathered subangular stones; diffuse, smooth boundary,

Bt2 58-81	dry: yellowish red (5 YR 5/6), rubbed strong brown (7.5 YR 4/6 - 5/6) gravelly clay loam; weakly developed coarse blocky structure breaking to moderate fine-nut structure; non-sticky; non-plastic; friable to firm; uncemented; stiff penetration; common, distinct, dark brown (7.5 YR 4/4) clay coatings; many, fine roots; abundant, moderately weathered subangular stones; distinct, smooth boundary,
BC1 81-151	dry; pale olive (5Y 6/3) weathered in situ rock; massive; very firm; uncemented; hard penetration; many, prominent, dark reddish-brown (5 YR 2/2) Fe/Mn coatings; few, fine roots; distinct smooth boundary,
BC2 151-166	dry; yellowish-brown (10 YR 5/8) fine sandy clay loam; massive; firm; uncemented; firm penetration; many, distinct, olive grey (5Y 5/2) clay coatings.

Pedon SIG 2

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	6.5	4.9	1.58	0.23	7	382	<1	14	17.9	8.9
25-30	6.3	4.6	0.74	0.10	7	239	<1	16	n.d.	7.4
35-40	6.7	4.9	0.80	0.10	8	259	<1	17	17.4	13.0
55-65	6.8	5.8	0.57	0.07	8	265	<1	14	16.0	16.0
75-85	6.5	5.2	0.70	0.08	9	390	<1	17	20.9	16.1
95-105	6.9	5.0	0.55	0.06	9	396	3	14	n.d.	n.d.
125-135	7.0	5.0	0.22	0.04	5	418	7	12	14.3	8.3

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-10	32.2	29.6	92	21.2	6.0	2.5	<0.1	n.d.	56	25	19
25-30	32.0	28.4	89	22.6	5.0	0.5	0.3	n.d.	55	31	14
35-40	32.1	30.6	95	24.7	5.3	0.2	0.4	n.d.	45	37	18
55-65	31.5	29.2	93	23.6	5.0	0.2	0.4	n.d.	45	44	11
75-85	37.1	33.7	91	26.9	6.0	0.4	0.4	n.d.	20	52	28
95-105	33.9	32.6	96	26.0	5.8	0.5	0.3	n.d.	28	56	16
125-135	30.9	29.5	95	23.3	5.6	0.4	0.2	n.d.	66	21	13

Pedon SIG 2

Classification:	Typic Tropofluvent, coarse loamy, mixed, isohyperthermic
Location:	Sigatoka Research Station, Viti Levu, Fiji
Physiographic Position:	Levee on terrace surface; altitude 10 m a.m.s.l.
Topography:	Flat, planar site
Drainage:	Well drained
Vegetation:	Tree crops with grass ground cover
Parent Material:	Alluvium derived from rocks of mixed mineralogy
Au1 0-19 cm	slightly moist; dark brown (10 YR 3/3), rubbed, brown (10 YR 4/3) very fine sandy loam; moderately developed fine and medium nut structure, with single grain; non-sticky; non-plastic; friable; many fine and medium roots; indistinct, smooth boundary,
Au2 19-33	slightly moist; dark brown (10 YR 3/3) fine sandy loam; weakly developed fine and medium nut structure with single grain; non-sticky; non-plastic; friable; many fine and medium roots; indistinct, smooth boundary,
Au3 33-49	slightly moist; 80% very dark greyish-brown (10 YR 3/2), 20% yellowish brown (10 YR 5/4), rubbed, olive brown (2.5Y 4/4) very fine sandy loam; few, fine, faint dark reddish-brown (2.5 YR 3/4) mottles; weakly developed, fine nut structure with single grain; non-sticky; non-plastic; friable; common fine and medium roots; indistinct, smooth boundary,
C 49-70	slightly moist; olive brown (2.5Y 4/4) with 10% worm casts of very dark greyish-brown (10 YR 3/2), rubbed dark brown (10 YR 3/3) fine sandy loam; single grain, with weakly developed fine cast granular structure (10%); non-sticky; non-plastic; very friable; common, fine and medium roots; distinct, smooth boundary,

Ab1	70-91	slightly moist; very dark greyish-brown (10 YR 3/2), rubbed dark brown (10 YR 3/3) loam; weakly developed fine and medium nut structure; non-sticky; non-plastic; friable; common, medium roots; indistinct smooth boundary,
Ab2	91-111	slightly moist; very dark greyish-brown (2.5Y 3/2) with 15% brown (10 YR 4/3), rubbed dark brown (10 YR 3/3) very fine sandy loam; weakly developed fine nut structure; with single grain and weak fine crumb; non-sticky; non-plastic; friable; common, medium roots; indistinct smooth boundary,
C	111-141	slightly moist; dark brown (10 YR 3/3) fine sandy loam; single grain; non-plastic; non-sticky; loose; few medium roots.

Pedon SIG 3

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	6.3	4.6	2.78	0.19	15	43	2	26	29.0	16.8
28-35	6.6	4.8	0.88	0.08	11	16	<1	34	29.7	16.8
45-50	6.8	4.7	0.30	0.06	5	16	2	19	31.0	15.5
58-65	6.8	4.8	0.13	0.04	3	19	4	6	34.0	17.3

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Ca	Exch.Al	Sand %	Silt %	Clay %
0-10	64.0	58.3	91	46.4	10.2	1.4	0.3	0	48	38	14
28-35	60.7	57.3	94	50.1	6.8	0.2	0.2	0	23	42	35
45-50	59.9	54.5	91	47.1	6.9	0.1	0.2	0	45	34	21
58-65	58.0	56.3	97	47.6	8.1	0.1	0.5	0	48	33	18

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Pedon SJG 3

Classification:	Typic Hapludoll, clayey, montmorillonitic, isohyperthermic
Location:	Sigatoka Research Station, Viti Levu, Fiji
Physiographic Position:	Concave toeslope in moderately dissected hill country; altitude 110 m a.m.s.l.
Topography:	Slope 10°, facing east; microrelief, terracettes
Drainage:	Moderately well drained
Vegetation:	Nadi blue grass
Parent Material:	Colluvium derived from andesitic tuff over *in situ* rock of the same origin

Ah	0-25 cm	slightly moist; very dark greyish-brown (10 YR 3/2 - 2.5Y 3/2) with 15% parent material flecks of yellowish-brown (10 YR 5/6), rubbed, very dark greyish brown (10 YR 3/2) clay loam; moderately developed fine and medium blocky with nut structure; slightly sticky; non-plastic; friable to firm; many, fine and very fine roots; distinct, smooth boundary,
Bt	25-43	slightly moist; brown (10 YR 4/3) and very dark greyish-brown (10 YR 3/2) with 20% parent material flecks of yellowish-brown (10 YR 5/6) clay loam; strongly developed medium prismatic structure breaking to strong medium and coarse blocky; slightly sticky; slightly plastic; firm; many prominent, dark greyish-brown (10 YR 4/2) clay (pressure) coatings; common very fine roots; few, strongly weathered subangular gravels; distinct, smooth boundary,
BC	43-57	moist; yellowish-brown (10 YR 5/6) sandy clay; massive, breaking to weakly developed medium blocky structure; slightly sticky; slightly plastic; firm; many prominent olive grey (5Y 4/2 and 5/2) clay coatings; common, very fine roots; abundant, moderately weathered, sub-angular gravels and stones; indistinct, smooth boundary,
C	57-65	slightly moist; yellowish-brown (10 YR 5/6) sandy loam; massive; non-sticky; non-plastic; extremely firm; common, prominent olive grey (5Y 4/2 and 5/2) clay costings; no roots; *in situ* rock.

Pedon NWC 1

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	5.6	4.9	4.70	0.32	15	15	48	50	39.5	21.2
40-50	6.5	5.6	1.38	0.11	15	11	4	41	39.6	30.2
90-100	7.3	6.4	0.94	0.08	12	9	21	36	40.8	30.0

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-10	53.5	47.0	88	29.6	14.2	1.1	2.1	0	20	32	48
40-50	54.8	54.9	100	29.2	24.9	0.3	0.5	0	26	33	41
90-100	54.2	53.5	99	27.0	25.1	0.2	1.2	0	31	20	49

Pedon NWC 1

Classification:	Typic Pellustert, clayey, montmorillonitic, isohyperthermic
Location:	Nawaicoba, near Nadi, Viti Levu, Fiji
Physiographic Position:	valley surface in rolling country; concave toeslope; altitude 35 m a.m.s.l.
Topography:	slope 3° facing NE; flat microrelief
Drainage:	poorly drained
Vegetation:	inferior grasses and miscellaneous weeds for goat grazing; exotic pines; previously ploughed
Parent Material:	colluvium
Ap 0-20 cm	dry; black (5 YR 2/1) clay; strongly developed coarse blocky structure, with strong fine blocky structure in upper 3 cm; slightly sticky; slightly plastic; firm; common, faint, black (5 YR 2/1) polished surfaces to peds; fine and medium live roots; common, weakly weathered sub-rounded fine grits; indistinct smooth boundary,
Bw 20-60	moist; black (5 YR 2/1) clay; moderate to strongly developed coarse blocky structure; slightly sticky; slightly plastic; very firm; common, distinct, black (5 YR 2/1) slickensides and polished surfaces; structural aggregates tilted at 20-60°; few, fine and medium roots; common, weakly weathered, sub-rounded very fine gravels; indistinct, smooth boundary,
BC 60-110	moist; black (5 YR 2/1) and dark brown (10 YR 3/3) clay; few, fine, faint reddish brown (5 YR 4/4) and yellowish red (5 YR 5/6) mottles; massive; slightly sticky; slightly plastic; firm; common, distinct, black (5 YR 2/1) slickensides and polished surfaces; common, weakly weathered, subrounded, very fine gravels.

Pedon NWC 2

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-8	6.0	5.4	4.65	0.30	16	108	5.8	17	29.3	14.3
20-30	6.3	5.2	1.80	0.11	16	25	6.1	25	39.2	20.2
43-47	6.8	5.8	0.42	0.06	7	15	19.6	28	36.1	18.1
50-55	6.9	5.7	0.64	0.07	9	13	7.6	14	32.0	16.0
90-100	7.1	6.1	0.24	0.05	5	10	<1	32	55.2	35.5

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-8	60.9	56.4	93	35.1	20.5	0.4	0.4	0	18	49	33
20-30	69.8	62.9	90	37.6	24.8	0.3	0.2	0	22	34	44
43-47	42.4	45.0	(100)	23.5	21.2	0.2	0.1	0	21	35	44
50-55	49.8	53.6	(100)	28.5	24.3	0.3	0.5	0	35	31	34
90-100	59.3	53.6	90	24.4	28.0	0.5	0.7	0	12	37	51

Pedon NWC 2

Classification:	Typic Pellustert, clayey, montmorillonitic, ischyperthermic
Location:	Nawaicoba, near Nadi, Viti Levu, Fiji
Physiographic Position:	hill surface in rolling country; concave mid-slope; altitude 50 m a.m.s.l.
Topography:	slope 6° facing NE; flat microrelief
Drainage:	moderately well drained
Vegetation:	exotic forest, inferior grasses; previously ploughed
Parent Material:	colluvium

Ap	0-8 cm	dry, black (7.5 YR 2/0) clay loam; moderately developed fine and medium nut plus moderate medium blocky structure; slightly sticky; non-plastic; very friable; churning; many, fine and medium roots; few moderately weathered, subangular gravels; indistinct, smooth boundary,
Bt	8-40	dry; black (2.5 YR 2/0) clay; strongly developed coarse blocky structure; slightly sticky; non-plastic; firm; distinct black (5 YR 2/1) slickensides and polished surfaces; few, very fine roots; few, moderately weathered, sub-angular gravels; distinct, smooth boundary,
BC		slightly moist; dark brown to brown (10 YR 4/3) clay loam; common, fine, faint strong brown (7.5 YR 5/6) mottles; massive breaking to weakly developed coarse blocky structure; slightly sticky; non-plastic; friable; few, faint dark greyish brown (10 YR 4/2) polished surfaces and slickensides; few, very fine roots; few, weakly weathered, subangular gravels; distinct, smooth boundary,
Ab	49-57	slightly moist; very dark greyish brown (2.5Y 3/2) clay loam; common, fine, faint dark yellowish brown (10 YR 4/4 and 10 YR 4/6) mottles; massive, breaking to weakly developed very fine blocky structure; slightly sticky; non-plastic; friable; few, faint, very dark grey (10 YR 3/1) polished surfaces; distinct, smooth boundary,
BC	57-120	slightly moist; olive (5Y 5/3) clay; common, fine, distinct dark yellowish brown (10 YR 4/4 and 10 YR 4/6) and olive grey (5Y 5/2) mottles; massive; sticky; slightly plastic; friable; few, faint, dark yellowish brown (10 YR 4/4) polished surfaces.

Pedon NWC 3

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	5.4	4.4	4.76	0.32	15	26	<1	49	29.6	18.6
17-20	5.7	5.0	0.42	0.06	7	11	<1	46	28.9	17.1
30-40	7.8	5.8	0.44	0.05	9	9	<1	38	33.9	31.6
50-55	7.7	6.0	0.22	0.02	11	9	<1	33	16.9	16.8

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-10	54.9	45.8	83	24.1	20.6	0.5	0.6	0	30	36	34
17-20	45.5	40.6	89	20.2	19.8	0.1	0.5	0	56	17	27
30-40	60.[illegible]	----------	free lime	-------	24.6	0.2	0.4	0	36	22	42
50-55	39.9	----------	free lime	-------	20.1	<0.1	0.5	0	55	27	18

Fedon NWC 3

Classification:	Paralithic Vertic Ustropept, clayey, montmorillonitic, isohyperthermic
Location:	Nawaicoba, near Nadi, Viti Levu, Fiji
Physiographic Position:	hill surface in rolling country; convex backslope; altitude 53 m a.m.s.l.
Topography:	slope 5° facing NE; flat microrelief
Drainage:	moderately well drained
Vegetation:	exotic forest, inferior grasses, previously ploughed
Parent Material:	colluvium over weathered in situ rock (andesite ?)
Ap 0-13 cm	dry; dark reddish brown 5 YR 3/2) clay loam; vertical cracking; moderately developed fine and medium nut structure, non-sticky; non-plastic; friable; many fine and very fine roots; distinct, smooth boundary,
Bw 13-25	slightly moist; dark reddish brown (5 YR 2/2) gritty clay loam; many, distinct fine and medium brownish yellow (10 YR 6/6) parent material mottles; weakly developed medium blocky structure; non-sticky; non-plastic; friable to firm; common very fine and fine roots; many, weak to moderately weathered subangular gravels; distinct smooth boundary,
Bt 25-50	slightly moist; dark reddish grey (5 YR 4/2) clay; common, distinct fine and medium yellowish red (5 YR 4/6) mottles; vertical cracks and stress oriented features; moderate to strongly developed coarse blocky structure; slightly sticky; slightly plastic; firm; common, distinct dark reddish grey (5 YR 4/2) polished surfaces; few, fine roots; few, strongly weathered, subrounded very fine gravels; sharp smooth boundary,
BC 50-75	dry; light brownish grey (2.5Y 6/2) very fine sand; massive; non-sticky; non-plastic; extremely firm; very stiff penetration; weathered in situ rock.

Pedon LL 1

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-28	5.4	4.7	0.9	0.07	13			27	9.3
28-54	6.5	5.8	0.4	0.04	10			28	11.3
54-109	6.8	6.1	0.3	0.04	8			26	9.0
109-140	7.2	6.5	0.2	0.01	20			30	12.7

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch. Al	Sand %	Silt %	Clay %
0-28	5.1	2.9	59	2.4	0.3	0.2	<0.1	0.1	63	8	29
28-54	4.1	3.4	84	3.1	0.3	<0.1	<0.1	<0.1	61	8	31
54-109	3.8	3.6	95	3.3	0.2	<0.1	0.1	<0.1	77	7	16
109-140	3.7	3.5	95	3.4	0.1	<0.1	<0.1	<0.1	60	13	27

Pedon LL 1 (Nadi Series)

Classification:	Typic Eutrustox, fine loamy, mixed, isohyperthermic
Location:	Legalega Research Station, near Nadi, Viti Levu, Fiji
Physiographic Position:	Upper surface of fluvial terrace in flat country; altitude 16 m a.m.s.l.
Topography:	Planar
Drainage:	Well drained
Vegetation:	Fallow (previously in pulses)
Parent Material:	Weakly weathered sediments derived from siliceous Tertiary rocks and basic volcanics

Ap	0-28 cm	horizon dry; dark reddish brown 5 YR 3/3, 5 YR 3/3 (ped face), 5 YR 3/3 (rubbed) silt loam; no mottles; weakly developed very fine blocky structure breaking to moderately developed very fine crumb; non-sticky, non-plastic, very friable; few fine roots; no stones; diffuse smooth boundary,
Bw1	28-54	horizon dry; dark reddish brown 5 YR 3/4, 5 YR 3/4 (ped face), 5 YR 3/4 (rubbed), silt loam; no mottles; weakly developed medium blocky structure breaking to weakly developed very fine crumb; slightly sticky, non-plastic, very friable; few fine roots; no stones; diffuse smooth boundary,
Bw2	54-109	horizon slightly moist; reddish brown 5 YR 4/4, 5 YR 4/4 (ped face), dark reddish brown 5 YR 3/4 (rubbed) silt loam; no mottles; massive breaking to single grain plus fine crumb structure; slightly sticky, non-plastic, very friable; no roots; no stones; distinct wavy boundary,
B/C	109-141+	horizon slightly moist; strong brown, 7.5 YR 5/8; 7.5 YR 5/8 (ped face); 7.5 YR 5/6 (rubbed) loamy sand; no mottles; massive breaking to single grain with fine blocky structure; non-sticky, non-plastic, friable; no cutans; no roots; no stones.

Pedon LL 29

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-24	5.2	4.2	0.9	0.08	11			24	7.8
24-69	5.8	5.4	0.3	0.03	10			30	13.6
69-145	4.9	4.1	0.2	0.02	10			38	17.9
145-180	4.5	3.8	0.2	0.03	7			53	23.6

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-24	5.2	2.0	38	1.5	0.2	0.2	0.1	0.7	67	6	27
24-69	4.9	3.6	75	2.9	0.7	<0.1	<0.1	<0.1	58	6	36
69-145	10.0	2.3	23	0.9	1.4	<0.1	<0.1	10.0	44	11	45
145-180	13.0	2.0	15	0.6	1.4	<0.1	<0.1	13.0			

Pedon LL 29 (Mocambo Series)

Classification:	Oxic Haplusult, fine clayey, kaolinitic, isohyperthermic
Location:	Legalega Research Station, near Nadi, Viti Levu, Fiji
Physiographic Position:	Side of fluvial terrace in rolling country; altitude 15 m a.m.s.l.
Topography:	Slope 2° facing NW; microrelief flat
Drainage:	Imperfectly drained
Vegetation:	Fallow
Parent Material:	Old alluvium from siliceous and basic volcanics, overlying siliceous alluvium
Ap 0-24 cm	horizon dry; dark reddish brown, 5 YR 3/3, 5 YR 3/3 (ped face), 5 YR 3/4 (rubbed) coarse sandy loam; no mottles; massive, breaking to weakly developed very fine crumb structure; non-sticky, non-plastic, very friable; few fine roots; no stones,
Bt1 24-69	horizon slightly moist; yellowish red 5 YR 5/8 (rubbed) clay loam; no mottles; weakly developed medium blocky structure breaking to weakly developed very fine crumb; slightly sticky, slightly plastic, very friable; few faint yellowish red 5 YR 5/8 clay cutans; few fine roots; no stones,
Bt2 69-109+	horizon moist; yellowish red 5 YR 5/8 (rubbed), gravelly clay; many fine prominent mottles; moderately developed medium blocky structure breaking to moderately developed very fine nut; sticky, plastic, friable; common distinct light yellowish brown 2.5Y 6/3 clay cutans; no roots; many, unweathered, subrounded gravels.

Pedon LL 9

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-27	5.2	4.4	0.8	0.07	11			18	7.1
27-67	5.8	5.2	0.5	0.05	10			27	11.3
67-107	5.3	4.7	0.3	0.03	10			31	17.8
107-180	4.7	4.0	0.2	0.02	10			37	13.9

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-27	4.3	2.2	52	1.6	0.3	0.2	0.1	0.5	70	8	22
27-67	4.1	3.0	75	2.6	0.3	0.1	<0.1	<0.1	62	7	31
67-107	7.1	5.1	71	4.1	1.0	<0.1	<0.1	0.1	48	10	42
107-180	6.7	1.1	16	0.4	0.7	<0.1	<0.1	3.8	57	10	33

Pedon LL 9 (Mocambo Series)

Classification:	Oxic Haplustult, fine loamy, mixed, isohyperthermic
Location:	Legalega Research Station, near Nadi, Viti Levu, Fiji
Physiographic Position:	Lower middle surface of fluvial terrace in terrace system; altitude 14 m a.m.s.l.
Topography:	Planar
Drainage:	Imperfectly drained
Vegetation:	Fallow (ex-peanuts)
Parent Material:	Alluvium derived from siliceous sedimentary rocks

Ap	0-27 cm	horizon dry; dark yellowish brown 10 YR 3/4, 10 YR 3/4 (ped face), 10 YR 3/4 (rubbed) fine sandy loam; weakly developed fine blocky structure breaking to moderately developed fine crumb; non-sticky, non-plastic, friable; no roots; no stones; distinct smooth boundary,
Bt1	27-67	horizon slightly moist; yellowish brown, 10 YR 5/8, 10 YR 5/8 (ped face), 10 YR 5/8 (rubbed) fine sandy clay loam; weakly developed fine blocky structure breaking to weakly developed fine crumb; non-sticky, non-plastic friable; common, distinct, very dark greyish brown 10 YR 3/2 clay cutans; no roots; no stones; diffuse smooth boundary,
Bt2	67-107	horizon slightly moist; yellowish brown 10 YR 5/6, 10 YR 5/6 (ped face), 10 YR 5/6 (rubbed) clay loam; common, medium, distinct dark red 2.5 YR 3/6 mottles; massive, breaking to weakly developed medium blocky structure; non-sticky, non-plastic, friable; few, faint, dark brown 7.5 YR 4/4 clay cutans; no roots; no stones; indistinct smooth boundary,
B/Cg	107-137+	horizon moist; white 5Y 8/2 loamy coarse sand; many, medium, distinct strong brown 7.5 YR 5/8 mottles; massive breaking to weakly developed medium blocky structure; non-sticky, non-plastic, friable; no roots; no stones.

Pedon LL 30

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	P(ppm) MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention %
0-30	4.9	4.2	0.8	0.05	16			13	3.2
30-68	4.9	3.9	0.5	0.04	13			40	18.3
68-125	5.1	3.9	0.2	0.02	10			43	19.5
125-180	5.1	3.9	0.2	0.02	10			40	17.6

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-30	3.0	0.4	13	0.4	<0.1	<0.1	<0.1	1.1	86	5	9
30-68	8.7	2.8	31	2.4	0.4	<0.1	<0.1	4.3	50	7	43
68-125	11.0	2.1	18	1.1	1.0	<0.1	0.1	6.8	44	11	45
125-180	9.4	1.1	12	0.4	0.7	<0.1	<0.1	9.4	48	11	41

Pedon LL 30 (Legalega Series)

Classification:	Typic Paleustult, clayey, kaolinitic, isohyperthermic
Location:	Legalega Research Station, near Nadi, Viti Levu, Fiji
Physiographic Position:	Lower surface of fluvial terrace in flat country; altitude 12 m a.m.s.l.
Topography:	Planar
Drainage:	Poorly drained
Vegetation:	Peanuts
Parent Material:	Highly siliceous alluvium
Ap 0-30 cm	horizon dry; dark brown 10 YR 3/3, 10 YR 3/3 (ped face), 10 YR 3/3 (rubbed) sand: massive breaking to single grain with very fine crumb structure; non-sticky, non-plastic, loose; few fine roots; distinct smooth boundary,
Btg1 30-68	horizon moist; dark red 2.5 YR 3/6, red 2.5 YR 5/8 (rubbed) clay; profuse, fine, prominent 2.5Y mottles; moderately developed coarse blocky structure breaking to weakly developed very fine nut; sticky, plastic, friable; common, distinct, dark red 2.5 YR 3/6 clay cutans; few fine roots; indistinct smooth boundary,
Btg2 68-118+	horizon moist; dark red 2.5 YR 3/6 (rubbed) clay; profuse, fine, prominent mottles; strongly developed coarse blocky structure breaking to moderately developed very fine nut; sticky, plastic, friable; common distinct red 2.5 YR 4/8 clay cutans; no roots.

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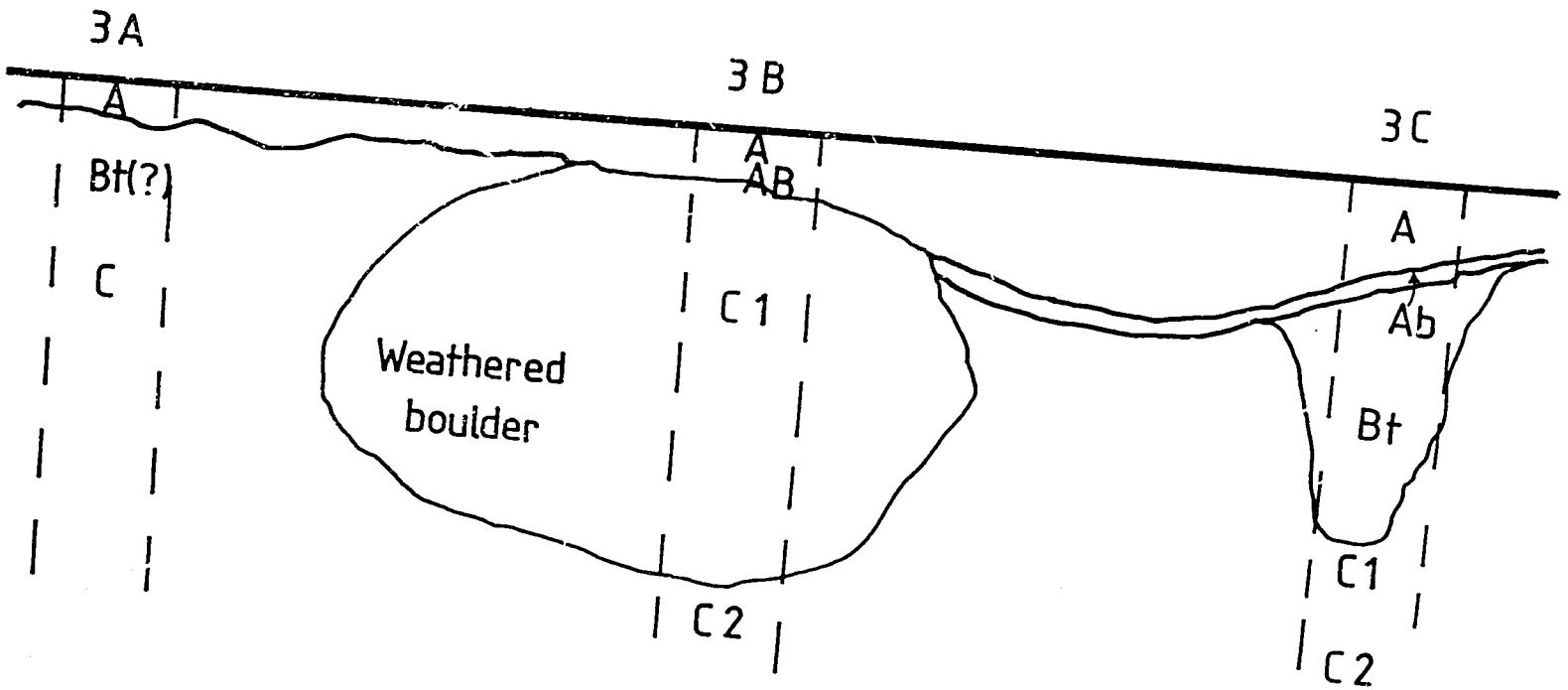
DRASA PEDON : Vunadoi Road



Pedon Drasa 3A

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-7	4.1	3.2	0.87	0.06	15	29	2	68	33.9	31.2
15-20	4.4	3.3	0.31	0.04	8	25	<1	74	38.6	31.9
35-40	4.6	3.5	0.03	0.03	1	27	2	74	38.2	32.2
120-125	4.7	3.6	0.01	0.03	0.3	29	1	61	41.7	33.2

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-7	21.6	4.2	19	1.6	2.2	<0.1	0.4	10.3	19	31	50
15-20	18.9	2.0	11	0.5	1.3	<0.1	0.2	10.6	24	37	39
35-40	23.1	1.9	8	0.9	0.9	<0.1	0.1	11.3	37	29	34
120-125	14.0	3.6	26	0.9	2.1	<0.1	0.6	8.2	26	46	28

Pedon Drasa 3

Location:	Vunadoi Road, Drasa Estate, near Lautoka, Viti Levu, Fiji
Physiographic Position:	Planar midslope; altitude 70 m a.m.s.l.
Topography:	Microrelief uneven; slope 8° facing north
Drainage:	Well drained
Vegetation:	Pine forest with ground cover of ferns and poor grasses
Parent Material:	Volcanic derived colluvium over in situ basic volcanic rock

Profile 3A

Classification:		Typic Ustorthent, clayey, mixed, isohyperthermic
Au	0-7 cm	slightly moist; dark reddish-brown (2.5 YR 3/4) clay loam; weak to moderately developed fine nut structure with weak, fine crumb; sticky; slightly plastic; friable; fine and medium roots; colour variegated (very fine) particles of parent material through-out; indistinct, smooth boundary,
BC	7-28	slightly moist; 50% dark red (10 YR 3/6), 25% grey (5 YR 6/1) 25% reddish-brown (5 YR 4/3) clay loam; weakly developed coarse blocky structure breaking to single grain; slightly sticky; slightly plastic; friable; few, faint, reddish-brown (5 YR 4/3) clay/organic costings; common, fine and medium roots; many, distinct yellowish-red (5 YR 4/8) concretions (goethite); strongly weathered in situ rock; indistinct smooth boundary,
C	28-128	slightly moist; 50% dark red (10R 3/6) and 50% grey (5 YR 6/1) silty clay loam (variable because of intact weathered boulders); massive; non-sticky; non-plastic; firm; few, distinct reddish-brown (5 YR 4/4) clay/organic coatings; common, prominent manganese coatings; few, medium roots; strongly weathered in situ rock.

Pedon Drasa 3B

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	4.6	3.4	0.80	0.06	13	29	<1	60	28.9	29.1
30-35	4.5	3.4	2.56	0.17	15	15	<1	68	30.6	28.1
50-60	4.5	3.6	0.06	0.02	3	48	<1	49	21.1	11.1

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-10	16.1	3.8	24	1.8	1.8	<0.1	0.2	10.0	17	36	47
30-35	17.8	3.0	17	1.8	1.2	<0.1	<0.1	9.6	39	26	35
50-60	11.5	1.9	17	0.5	1.1	<0.1	0.3	5.9	54	30	16

Profile 3B

Classification:		Typic Ustorthent, loamy-skeletal, mixed, isohyperthermic
Au	0-8 cm	slightly moist; dark reddish-brown (5 YR 3/3) clay loam; weak to moderately developed, fine, nut structure; slightly sticky; non-plastic; friable; abundant fine and medium roots; indistinct, smooth boundary,
AB	8-36	slightly moist; 75% dark red (10R 3/6) and grey (5 YR 6/1), 25% dark reddish-brown (5 YR 3/4) silty clay loam (variable); weakly developed, fine and medium nut structure with single grain; slightly sticky; non-plastic; friable; many, fine and medium roots; sharp wavy boundary (paralithic contact),
C1	36-81	dry; 85% brownish-yellow (10 YR 6/8) and 15% (as bands) white (2.5Y 8/2) very fine sand; massive; non-sticky; non-plastic; extremely firm; few, very fine roots (down cracks); horizon comprises one large moderately weathered boulder, sharp wavy boundary,
C2	81-131	dry; 50% dark red (10R 3/6) and 50% grey (5 YR 6/1) silty clay loam (variable); massive; non-sticky; non-plastic; firm; stiff penetration; common, distinct black (5 YR 2/1) manganese coatings; common yellowish-red (5 YR 4/8) concretions (goethite); upper 3-5 cm (immediately below boulder), reddish brown, blocky structured layer.

Pedon Drasa 3C

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	3.9	3.4	0.69	0.07	10	34	<1	65	28.9	28.3
25-32	5.1	3.8	1.93	0.11	17	28	<1	62	32.5	31.2
35-45	4.8	4.3	0.15	0.04	4	24	<1	81	47.3	37.6
70-80	3.6	3.4	0.06	0.02	3	21	<1	74	43.5	38.4
120-125	3.9	3.5	0.04	0.02	2	29	<1	78	54.4	40.5

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-10	13.5	2.8	21	1.6	1.0	<0.1	0.2	9.3	26	26	48
25-32	26.9	6.5	24	1.1	3.1	0.3	2.0	6.4	32	36	32
35-45	19.0	2.1	11	0.5	1.5	<0.1	0.1	10.3	20	35	45
70-80	21.9	3.3	15	1.1	2.0	0.1	0.1	14.1	27	32	41
120-125	21.5	2.0	9	0.5	1.4	<0.1	0.1	12.6	44	22	34

Profile 3C

Classification:		Typic Ustorthent, clayey, mixed, isohyperthermic
Au	0-19 cm	slightly moist; dusky red (2.5 YR 3/4) clay loam; white flecks of parent material; weakly developed fine nut structure with single grain; slightly sticky; non-plastic; friable; abundant, fine and medium roots; indistinct smooth boundary,
Ab	19-39	slightly moist; dark reddish-brown (5 YR 3/3) silty clay loam; moderately developed fine and medium nut structure; slightly sticky; non-plastic; friable; many, fine and medium roots; few moderately weathered subangular gravels (bottom 7 cm only); indistinct, smooth boundary,
Bt	39-62	slightly moist; dark red (2.5 YR 3/6) with 25% dark reddish-brown (5 YR 3/3) clay loam; weakly developed coarse blocky structure; sticky; slightly plastic; friable; few, faint reddish-brown (2.5 YR 4/4) clay coatings; common, very fine roots; distinct, wavy boundary,
C1	62-83	slightly moist; 50% dark red (10R 3/6) and 50% grey (5 YR 6/1) silty clay loam (variable); massive; non-sticky; non-plastic; very firm; common, distinct, light olive brown (2.5Y 5/4) clay coatings; strongly weathered <u>in situ</u> rock; indistinct, smooth boundary,
C2	83-133	dry; 50% dark red (10R 3/6) and 50% grey (5 YR 6/1) silty clay loam (variable); massive; non-sticky; non-plastic; very firm; common, distinct, red (2.5 YR 4/6) clay coatings; strongly weathered <u>in situ</u> rock.

Pedon Drasa 4

Sample Depth (cm)	pH H_2O	pH KCl	C %	N %	C:N	MAF	P(ppm) Olsen	P Retention %	15 Bar Moisture Retention % Field Moist	15 Bar Moisture Retention % Air Dry
0-10	5.4	4.0	2.59	0.15	17	14	<1	56	25.9	24.8
25-35	5.3	4.3	0.49	0.04	12	50	<1	64	33.1	30.3
50-60	5.1	4.1	0.23	0.05	5	16	3	55	28.4	30.1
80-90	4.8	3.9	0.22	0.04	6	13	<1	51	30.0	30.1
120-125	4.6	3.8	0.15	0.03	5	12	<1	56	30.1	28.1

Sample Depth (cm)	CEC (pH 7.0)	Σ Bases	% BS	Ca	Mg	K	Na	Exch.Al	Sand %	Silt %	Clay %
0-10	14.3	3.7	26	1.3	1.8	<0.1	0.6	2.4	20	38	42
25-35	11.0	1.6	15	0.3	0.8	<0.1	<0.1	1.4	24	29	47
50-60	3.9	1.1	28	0.7	0.4	<0.1	<0.1	1.9	16	30	54
80-90	6.4	2.2	34	1.2	0.8	<0.1	0.2	2.3	29	26	45
120-125	8.2	1.1	13	0.4	0.5	<0.1	0.2	2.8	30	28	42

Pedon Drasa 4

Classification:	Oxic Haplustult, clayey, kaolinitic, isohyperthermic
Location:	Drasa, near Lautoka, Viti Levu, Fiji
Physiographic Position:	plateau surface; planar crest; altitude 30 a a.m.s.l.
Topography:	slope 2° facing N; flat microrelief
Drainage:	well drained
Vegetation:	talasiga vegetation
Parent Material:	some colluvium over strongly weathered in situ rock; ground surface 75% covered with small stones (lag gravel following erosion)
Au 0-10 cm	dry; 75% dark reddish brown (5 YR 3/4) and 25% yellowish red (5 YR 4/6) clay loam; moderately developed fine and medium nut structure; sticky; slightly plastic; very friable; common, fine and medium roots; distinct, smooth boundary,
Bt1 10-42	dry; yellowish red (5 YR 4/8) clay loam; few, fine, faint,red (2.5 YR 4/6) motties or parent material; few, fine, subangular, crystalline dusky red (5R 3/4) particles; moderate to strongly developed fine nut structure; sticky; slightly plastic; friable; few, faint, reddish brown (5 YR 4/4) clay/organic coatings; few, fine roots; diffuse, smooth boundary,
Bt2 42-73	dry; red (2.5 YR 4/6) clay loam; few, fine, faint red (2.5 YR 4/8) mottles or parent material; few, fine subangular, crystalline red (5R 3/4) particles; weak to moderately developed fine blocky structure with single grain; slightly sticky; non-plastic; friable to firm; few, faint yellowish red (5 YR 4/8) clay coatings; diffuse, smooth boundary,
Bt3 73-107	dry; red (2.5 YR 4/6) to yellowish red (5 YR 4/6) silty clay loam; few, fine, faint red (2.5 YR 4/8) mottles or parent material; few, fine subangular, crystalline red (5R 3/4) particles; weak to moderately developed, very fine blocky structure; slightly sticky; non-plastic; firm; few, faint yellowish red (5 YR 4/6) clay coatings, diffuse, smooth boundary,
Bs 107-132	dry, yellowish red (5 YR 4/6) clay loam; few, fine, faint red (2.5 YR 4/6) mottles or parent material; few, fine, subangular, crystalline red (5R 3/4) particles; weak to moderately developed medium blocky structure; slightly sticky; non-plastic; firm; common, distinct yellowish red (5 YR 5/8) clay coatings.

APPENDIX 4

BIBLIOGRAPHY OF SOILS INFORMATION FROM THE SOUTH PACIFIC REGION

This Bibliography has been compiled using information obtained from a literature survey carried out using the computer facilities of the Australian National University Library and from participants attending the Forum. While a substantial amount of information has been compiled, it is certain that some reports are not listed. The Institute of Natural Resources would appreciate receiving details of any missing reports and any future reports on soils of the Region. In this way it is hoped that an updated bibliography can be published from time to time.

The information is listed by country, with the reports for each country listed chronologically.

GENERAL
COOK ISLANDS
FIJI
FRENCH POLYNESIA
MICRONESIA
NEW CALEDONIA
NIUE
PAPUA NEW GUINEA
SOLOMON ISLANDS
TONGA
VANUATU
WESTERN SAMOA
OTHERS

Please forward information on any missing/future reports to:

Regional Soils Bibliography Coordinator
Institute of Natural Resources
University of the South Pacific
P O Box 1168
Suva FIJI

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